International Colloquium on Latest Trends and Innovations on

- Power Transformers & Reactors
- Overhead Lines; and
- Materials and Emerging Test Techniques

(Under the aegis of CIGRE SC A2 on Transformers; B2 on Overhead Lines and D1 on Materials)

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International Colloquium on Latest Trends and Innovations on Overhead Lines (CIGRE Study Committee B2)
Design of Towers for EHV/UHV Transmission Lines for Specific Site Requirements

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Power Grid Corporation of India Limited, India

ABSTRACT

A number of transmission lines have been constructed across India from north to south and east to west to evacuate power from different parts of the country in the last few years. Transmission line system with voltages ranging from 66kV to 1200kV have been designed and constructed in the last few years. There have been a number of occasions where high voltage line such as 765 kV D/C line has to cross another high voltage line and to make crossing arrangements availability of space to erect tower sometimes is not adequate. This situation possesses a big challenge and demands to design and develop a special kind of tower with a narrower base width and a taller height required for crossing along with the special design considerations. These kind of high voltage towers are then easily accommodated in the narrow space and are tall enough to cross the intercepting line. These transmission lines also pass through some major rivers which are having width ranging from 1-1.5 km. India is blessed with huge network of rivers, mainly carrying water from mountains and is mostly perennial in nature. Most of the times the water flows throughout the year in the rivers and it becomes difficult to spot any tower with deep foundation in the mid-stream. Further, as most of the rivers are navigable, therefore to maintain adequate electrical clearances and to account for long span and huge sag, the height of tower goes up to 170-180 m. Accordingly special considerations are then followed for the design of such long slender towers. Furthermore, there have been numerous occasions when lines are to be terminated at substations with very limited available corridor/severe space crunch as already many existing lines are terminating at the substation. These lines occupy most of the corridor and there is hardly any space left to accommodate any new line. In one of the case, a line was required to be terminated in the substation with no any corridor as available space between the two existing line was already occupied by another tower which was to be used to cross the existing lines at the same place. Due to the severe space crunch near substation, a special kind of tower has to be designed. The paper covers in detail, salient design aspects and other special design features of narrow base towers 765 kV D/C DDN+55 & 800 kV DDN+60, 765 KV D/C river crossing towers and special Power line crossing tower designed for site specific requirement.

Keywords: Narrow Base, River Crossing, Power line crossing.

1. INTRODUCTION

Transmission line is an integrated system consisting of conductor subsystem, ground wire subsystem and one subsystem for each category of support structure. Mechanical supports of transmission line represent a significant portion of the cost of the line and they play an important role in the reliable power transmission. They are designed and constructed in wide variety of shapes, types, sizes, configurations and materials. The supports of EHV transmission lines are normally steel lattice towers. Consequently, transmission line lattice towers are designed for structural and electrical requirements for a safe design. These transmission line tower are to be placed in variety of site conditions and constraints. Sometimes these towers has to transverse across existing power line, wide rivers, limited ROW width available, etc. which needs to be addressed by adopting special site specific tower designs. POWERGRID over the years have designed towers addressing the above issue which shall be discussed in the upcoming sections.

2. TOWER DESIGN

Tower design involves following steps:

1. Selection of tower Geometry based on electrical clearances.
2. Calculation of loads on towers based on wind pressure, ice loading, wind/weight spans, Reliability Levels, terrain category size & weights of components (e.g. conductor, earth wire diameter, insulator etc.).
3. Analysis using software for indeterminate structural design and development of structural drawings subsequently
4. Full scale tower testing to verify the design.

3. POWER LINE CROSSINGS

Power line crossing involved in the route of transmission line under construction are also very important. Adequate clearance is required to be maintained between bottom conductors of the line going above from top most conductor/earth wire of the line going below under maximum temperature conditions as given hereinafter. For better optimization of the system, line having higher voltage should pass above the line having lower voltage. In case the voltages of two lines are same then the line being constructed afterwards has to cross the existing transmission line by providing necessary extensions +18/25 m to normal towers so as to achieve necessary electrical clearances as illustrated above. The power line crossing is to be done at such a place where maximum clearance is obtained at the crossing point between the two lines. POWERGRID in its projects often encounters these crossings which are successfully executed using suitable extensions namely +18/25 m. As no. of 765 kV D/C lines has been constructed in areas where new 765 kV D/C line has to cross another 765 kV D/C /800 kV HVDC and vice-versa, in such cases the required height (55-60 m) of bottom x-arm level for crossing exceeds the available height of extensions available. This situation possesses a big challenge and demands to design and develop a special kind of tower with a narrower base width (To restrict very large base width at such high extensions). and a taller height required for crossing along with the special design considerations. These kind of high voltage towers are then easily accommodated in the narrow space and are tall enough to cross the intercepting line.

The following towers were designed as narrow based with higher extensions.

• 765 kV D/C DDN+55
• 800 kV HVDC DDN+60

3.1 765 kV D/C Wardha-Hyderabad Power line Crossing with DDN+55 Meters Extension

In the construction of POWERGRID’s 765 kV D/C Wardha-Hyderabad line, several power line crossings were encountered near Deoli town to terminate in Hyderabad bay in Wardha substation. It was to cross 765 kV D/C Wardha-Aurangabad Tr. Line and 1200 kV S/C Wardha-Aurangabad Tr. Line. The following alternatives were proposed but didn’t work out:

• Crossing with DD+25 towers for 765 kV D/C lines is not possible as required clearances are on negative side (nearly -19 meters).
• Undercrossing of 1200 kV line is not possible as truncated towers were used and required clearances are not achieved.
• Under crossing of 765 kV D/C Wardha-Aurangabad Tr. Line also not possible as the maximum height of the tower is corresponding to DB+6 up to 10km from the S/S.

It was therefore proposed to cross both 765 kV D/C and 1200 kV S/C Tr. Lines with overhead crossing using a special tower with sufficient height. After looking into the required clearances, a tower of minimum extension height of 55 meter was required to be designed with narrow base width( To restrict very large base width at +55 m Ext.), which was designed and constructed in the scheduled timeline.

Fig. 1 : 765 kV D/C Wardha-Hyderabad Power line crossing with DDN+55 meters extension
3.2 800 kV HVDC Raigarh-Pugalur Power Line Crossing with DN+36/48/60 Meters Extension

In the endeavour to construct the iconic 800 kV HVDC Raigarh-Pugalur Transmission line, time was a big constraint. Along with other construction and engineering activities, 800 kV HVDC power line crossing with 765 kV D/C at ten locations was a big challenge in such a tight schedule. 765 kV D/C Kurnool-Tiruvalam had to be crossed over by 800 kV HVDC transmission line. It was therefore proposed to cross using a special tower with sufficient height. After looking into the required clearances, a tower of minimum extension height of 48 meter was required to be designed with narrow base width (To restrict very large base width at +48m Ext.), which was designed and constructed in the scheduled timeline.

Some design features for the above towers are given in the table below:

<table>
<thead>
<tr>
<th>S No.</th>
<th>Description</th>
<th>765 KV D/C DD</th>
<th>765 KV D/C DDN+55</th>
<th>800 KV HVDC D</th>
<th>800 KV HVDC DN+36/48/60</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Design Wind Span (m)</td>
<td>400</td>
<td>400</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>2</td>
<td>Reliability Level</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Wind Zone</td>
<td>4 (47m/s)</td>
<td>4 (47m/s)</td>
<td>4 (47m/s)</td>
<td>4 (47m/s)</td>
</tr>
<tr>
<td>4</td>
<td>Total Height (m)</td>
<td>78.30</td>
<td>115.30</td>
<td>57.00</td>
<td>108.00</td>
</tr>
<tr>
<td>5</td>
<td>Base Width (m)</td>
<td>28.9</td>
<td>30</td>
<td>25.156</td>
<td>34.732</td>
</tr>
<tr>
<td>6</td>
<td>Total Weight (MT)</td>
<td>137</td>
<td>220.7 0</td>
<td>81.514</td>
<td>257.30</td>
</tr>
<tr>
<td>7</td>
<td>Foundation Depth(m)*</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>Steel Used</td>
<td>HT &amp; MS</td>
<td>HT &amp; MS</td>
<td>HT &amp; MS</td>
<td>HT &amp; MS</td>
</tr>
<tr>
<td>9</td>
<td>Cost compared to Standard Tower</td>
<td>+24.5%</td>
<td></td>
<td></td>
<td>+10.85%</td>
</tr>
</tbody>
</table>

*Due very high foundation loads foundation depth has been kept as 5 m as compared to standard 3 m.

4. RIVER CROSSING

These transmission lines pass through some major rivers which are having width ranging from 1-1.5 km. Most of the times the water flows throughout the year in the rivers and sometime it becomes difficult to spot towers with deep foundation in the mid-stream as HFL and RL has a large difference so pile foundation required. As most of the rivers are navigable, therefore during river crossing, adequate electrical clearances is maintained and to account for long span and huge sag, the height of tower goes up to 150-160 m. These towers can be truncated for a spotting done on reduced span than design span. Further, River Crossing involved in any Transmission line is most important link of the line. The height and weight of the towers vary considerably depending on the span, minimum clearance above water, ice and wind loads, number of unbroken conductors, etc. Usually the governing specification requires that towers employed for crossing of navigable water ways be designed for heavy loading conditions and utilise larger minimum size members than the remainder of the line. In addition to these structural requirements, it is often necessary to limit the height of tall crossing towers because of the hazard they present to aircraft. It has to be safe & sound from design considerations to take care of field conditions, vagaries of nature such as cyclones/storms, whirl winds, flood & change of course of rivers etc. The major River crossings should be done on Suspension Type Towers, suitably designed for all wind conditions i.e. for transverse load incorporating wind load depending upon the height of the tower and upon the height of clamping point of Conductor and Earth wire, Vertical load, and longitudinal load including the effect of
diagonal wind (at 45°) load conditions. The ‘Anchor Towers’ designed for Dead-end conditions should be provided on both the sides of crossing. POWERGRID in its many 765 kV D/C and 400kV D/C Tr. Lines has developed the design of the following River crossing towers.

4.1 765 kV D/C River Crossing (RC)

POWERGRID has developed the design for 765 kV D/C River Crossing tower for 765 kV S/C Silwar – Satna part of Sasan –Satna Trans. Line associated with Sasan Ultra Mega Power Project. The tower was required to cross Son and Banas rivers having a width of about 1km at some places. Hence tower is designed for 1000m span. Due to the very large sag value of 88m the tower height was increased many fold.

4.2 400 kV D/C River Crossing (RC)

In the construction of 400 kV D/C Raipur-Wardha Transmission line, river crossing location was spotted in Wain Ganga river. The tower design was developed for the same. The span between the RC towers was around 920meters. Due to spotting of tower near to river flow, scouring was anticipated. Hence pile foundation was proposed. Anchor towers were also installed at a distance of 300m from RC towers to anchor the RC towers. Some salient features for the above towers are given below.

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### Table: Design Specifications

<table>
<thead>
<tr>
<th>S No.</th>
<th>Description</th>
<th>765 kV D/C River Crossing</th>
<th>400 kV D/C River Crossing</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Design Wind Span (m)</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>2</td>
<td>Wind Zone</td>
<td>4 (47m/s)</td>
<td>4 (47m/s)</td>
</tr>
<tr>
<td>3</td>
<td>Total Height (m)</td>
<td>162.5</td>
<td>139.5</td>
</tr>
<tr>
<td>4</td>
<td>Base Width (m)</td>
<td>31</td>
<td>26.5</td>
</tr>
<tr>
<td>5</td>
<td>Total Weight (MT)</td>
<td>378</td>
<td>342</td>
</tr>
<tr>
<td>6</td>
<td>Foundation Depth(m)*</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>Steel Used</td>
<td>HT &amp; MS</td>
<td>HT &amp; MS</td>
</tr>
</tbody>
</table>

*Due very high foundation loads foundation depth has been kept as 5 m as compared to standard 3 m.
5. INTERSECTION TOWER

POWERGRID has used a unique arrangement of a multi-circuit tower with two circuits perpendicular to other two circuits near Kota Sub-station (NR-I). There are two existing 400 kV D/C lines of POWERGRID namely Kota-Merta and RAPP-Kota line terminating at 400/220 kV Kota sub-station. Entire area just behind the sub-station is a forest. POWERGRID has been constructing a new 400 kV D/C RAPP 7 & 8 – Kota line and bays at Kota S/s were allocated in between the existing 400 kV lines. Forest clearance for the new line was already obtained. A 220 kV D/C KTPS-Kota line of RVPN was over-crossing our both the existing 400 kV lines and a tower was placed in between our existing lines. This tower was blocking the take-off of the new line. The options available were - Change the alignment of existing 220 kV line of RVPN or replace a portion of the new line with 400 kV cable.

Both the options were taking lots of time due to involvement of forest and delay in approval of alignment change of the existing line. Hence, a new engineering solution has been introduced to provide a multi-circuit tower with two circuits perpendicular to other 2 circuits in the alignment of our new line and close to the RVPN tower which was blocking corridor of the new line.

The M/C tower has also been modified to suit the site conditions. Normally, all four circuits on a M/C tower are parallel to each other. Technical analysis for the same was done and tower drawings were modified. Presently, upper two circuits of M/C tower are being used for 220 kV line of RVPN and bottom one have been utilized for newly commissioned 400 kV D/C RAPP 7 & 8 - Kota line.

Fig. 5 : Schematic plan for the transmission lines terminating at PGCIL's Kota substation

Fig 6. : Multi circuit tower (Intersection tower) at Kota Substation providing smart transmission solution
6. CONCLUSION

India already has a huge transmission line network and to accommodate further transmission lines, many constraints such as ROW, Power line/River crossings and corridor space crunch are needed to be addressed. In the endeavour to address the above constraints special transmission line towers are designed for specific site requirement. Narrow base and River crossing towers are often used in the transmission lines of POWERGRID due many river intersections. But it is the first time in POWERGRID that such an unique arrangement for intersection of lines has been made for by developing an intersection tower. POWERGRID in its future endeavour will continue to design special towers pertaining to constraints possessed by site condition and will remain a trendsetter.

BIBLIOGRAPHY

2. IS: 802 (Part 1/ Sec 1) – Indian Standard - Use of Structural Steel in Overhead Transmission Line Tower
Overhead Line Design for Extreme Weather Conditions in Austria

KLEMENS REICH AND HERBERT LUGSCHITZ

Austrian Power Grid – APG, Austria

ABSTRACT

Austria is a country in the middle of Europe with a big part of mountainous regions. Overhead lines (OHL) have been planned and erected in these regions since decades, considering appropriate loading assumptions, among them for ice, snow, wind, temperatures, avalanches, and landslides. The Austrian standards for OHL have been adopted to consider these assumptions, leading to a reliable and successful set of regulations for design, construction and erection. In the 1990ies, the European Standardisation Institute CENELEC started the work on a standard valid for all CENELEC countries (the countries of the European Union and affiliates). The design method changed from a former deterministic to a semi-probabilistic approach. National practices and climatic conditions are considered in this standard in the form of National Annexes.

The contribution gives an overview about the challenges and solutions for OHL design in the Austrian regions with extreme weather conditions and presents the development of the Austrian standards from 1913 till today. Examples will be given and explained. This concerns loadings from ice and wind, considerations for powdery avalanches and high speed winds. Further risk assumptions of existing structures and exchange of information with other relevant national and international bodies is given.

Keywords: Overhead Lines, OHL, extreme weather, avalanches, downdrafts, downbursts, risk

THE TRANSMISSION GRID IN AUSTRIA

Austrian Power Grid owns and operates the Austrian transmission grid, mainly with voltage level of 220 and 380 kV, see figure 1. APG must adapt the grid to the new framework conditions resulting from the expansion of renewable energies. These are above all a better connection between the pumped storage power plants in the Alps (in the western part of the country) and the wind generation sites (in the north-eastern part of the country).

At the same time, the climatic conditions in the Alps are changing significantly, necessitating a new assessment of avalanches, heavy precipitation and also drought situations.
DEVELOPMENT OF STANDARDS FOR OVERHEAD LINES IN AUSTRIA AND ON EUROPEAN LEVEL

When an OHL has been finished, only the technical structures can be seen. Before that, a big number of other aspects are crucial, like optimization of the route, environmental aspects, authorisation procedures, technical design and standards for the design of OHL. Technical facilities must be safe, and standards guarantee that they are. OHL are in the open environment and are accessible for everybody. Standards guarantee safety for the general public as well as the utility’s staff and guarantee security for the technical facility they refer to. The actual version of the European standard EN 50314:2012 expresses these principles very clearly in chapter 3.2.1 “Basic requirements”:

An overhead electrical line shall be designed and constructed in such a way that during its intended life:

- it shall perform its purpose under a defined set of conditions, with acceptable levels of reliability and in an economic manner. This refers to aspects of reliability requirements;
- it shall be designed to avoid a progressive collapse (cascading) if a failure is triggered in a defined component. This refers to aspects of security requirements;
- it shall be designed to avoid human injuries or loss of life during construction and maintenance. This refers to aspects of safety requirements.

An overhead line shall also be designed, constructed, and maintained in such a way that due regard is given to safety of the public, durability, robustness, maintainability, environmental considerations and appearance. The above requirements shall be met by appropriate design and detailing, by the choice of suitable materials and by specifying control procedures for design, manufacturing and construction relevant to the particular project. The selected design scenarios, represented by differing load cases, shall be sufficiently severe and varied as to encompass all conditions, which can reasonably be foreseen to occur during the construction and the design working life of the overhead line.

AUSTRIAN NATIONAL STANDARDISATION

The Austrian standardisation for OHL began in 1913 with the publication of “Normalien for Overhead Lines” (Standard for OHL). This document defined mechanical requirements for conductors (till 310 mm²), joints, minimum ice loads on conductors in grams per meter conductor (190 + 50 x d) where d is the conductor diameter in mm, static and dynamic requirements for towers made of wood or steel, tower spotting and erections of towers, foundations, insulators, mechanical safety margins, protection of birds, wind loads on towers and reduction factors for conductors as well as methods for electrical tests of OHL till 50kV. Minimum clearances have been defined for conductors at +40°C and at -5°C and ice. OHL in certain defined areas must be constructed considering “enhanced safety” (e.g. when crossing living areas, roads, business areas), which means more severe design conditions. It can be stated that these “Normalien” have been developed on base of experience and present a well balanced standard for the design of OHL. All following standards in Austria are based on this document and are calibrated and improved in an empirical approach. Updates were published in 1929, 1943, 1950, 1956, 1967, 1979.

EUROPEAN CENELEC STANDARDISATION

CENELEC is the European Committee for Electrotechnical Standardization. It issues electrotechnical standards. CENELEC members are bound to comply with the CENELEC Internal Regulations which stipulate the conditions for giving an European Standard the status of a national standard without any alteration.

In 2002 the first European CENELEC standard for OHL, EN 50341:2002, was issued. It presented two possibilities for the design, a) the empirical deterministic approach or b) the probabilistic approach. The National Standardisation Organisations had to decide which approach shall be followed in their respective country. In 2012 the revised standard EN 50341:2012 was issued, which supports an semiprobabilistic approach.

Each version of the EN 50341 consists of a “Main Body” which includes clauses common to all CENELEC countries and is compulsory. The Main Body is available in English, French and German. The National Standardisation Organisations can define National Normative Annexes NNA in which additional regional or national conditions may be defined, e.g. those due to climatic conditions, earth resistivity, etc. An NNA for a country is normative in that country and informative in other countries. NNA generally include A-deviations, special national conditions and national complements.

Fig. 2 : European Standard for overhead lines EN 50341:2012, principles of main body and NNAs
The establishment of NNAs can be a rather complicated and time consuming work for the National Standardisation Organisations, as they in many case follow a new terrain of standardisation. The volume of NNAs reach from 9 to 97 pages and depends e.g. on the differences between traditional deterministic empirical approaches and new probabilistic approaches in the countries.

**EXAMPLES FOR THE APPLICATION OF CLIMATIC DATA FOR THE OHL DESIGN**

**Ice Loads**

A standard gives only minimum requirements. Under other preconditions as assumed in the standard, e.g. more severe climatic conditions, these other requirements need to be considered. An example from APG’s practice is the following for ice loads. During the empirical approach we had two kind of ice loads, the Regular Ice Load (depending on the conductor diameter) and the Exceptional Ice load (depending on the voltage). The semiprobabilistic approach defines only one ice load (Extreme Ice Load), which for HV lines >45 kV depends on the conductor diameter only.

**Table 1 :** Ice loads (minimum values) on conductors for Austrian NNAs 2002 and 2012 (loads in N per meter conductor/subconductor; conductor diameter in mm)

<table>
<thead>
<tr>
<th>Voltage level</th>
<th>1 kV – 45 kV</th>
<th>&gt;45 kV-110 kV</th>
<th>150 kV-220 kV</th>
<th>380 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empirical approach AT-NNA 2001</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Regular Ice Load</td>
<td>4 + 0,2 d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exceptional Ice Load</td>
<td>25</td>
<td>35</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Semi-probabalistic approach AT-NNA 2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extreme Ice Load</td>
<td>( I_{50} = 10 + 0,2 \times d )</td>
<td>( I_{50} = 20 + 0,4 \times d )</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The values from table T1 are minimum values. The need to be increased for higher altitudes or when the line crosses extremely prone areas. In such cases APG considers additional ice zones, starting with zone A for the minimum level and ending with Zone D - exceeding zone C.

**Table 2 :** Ice loads on conductors depending on ice zones from APG´s projects (loads in N per meter conductor/subconductor; conductor diameter d in mm).

<table>
<thead>
<tr>
<th>Ice Zone</th>
<th>Zone A</th>
<th>Zone B</th>
<th>Zone C</th>
<th>Zone D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular Ice Load</td>
<td>4 + 0,2 x d</td>
<td>2,5</td>
<td>5</td>
<td>exceeding C</td>
</tr>
<tr>
<td>Exceptional Ice Load</td>
<td>50</td>
<td>75</td>
<td>100</td>
<td>exceeding C</td>
</tr>
</tbody>
</table>

**Fig. 3 :** 380 kV and 220 kV transmission grid of APG and related ice zones. Black = Zone D, Red = Zone C, Blue = Zone B, everything else is Zone A
Wind Loads
The empirical Austrian standards defined the minimum wind speed as 120 km/h for all regions in Austria and gave additional values when exceeding certain heights above ground. The new semiprobabilistic approach refers to the European standard Eurocode 1 and its Austrian NNAs, which defines windloads for all Austrian regions depending on the specific topography. The new windloads are mostly higher, in a few cases lower than before. For exposed sections of a line, separate values need to be considered. Combined load cases have been introduced for simultaneous wind and ice loads, but with reduced values. This must be considered when comparing new and old values for wind.

Loads from Powdery Avalanches
OHL in the Alps sometimes have to cross areas, which are prone to avalanches. Of the most dangerous avalanches are powdery avalanches. Such avalanches need to be considered during the routing and design of the line. The tower spotting shall prevent locations with spreading areas of such avalanches, but the conductors can be designed to withstand such forces. An example for such an OHL design is given here. This is a single circuit 220 kV line which has been erected in the High Alps and is in service since 45 years. A few powdery avalanches occurred in the area, but no failures occurred on the line so far.

Powdery avalanches consist of a mixture of powdery snow and air and have an enormous destructive power. The density of this mixture is rather small and mostly does not exceed 110 kg/m³, but they can reach speeds up to 100 m/sec (360 km/h). They can be deviated easily by obstacles as formations of rocks, hilltops, or even by transversely acting wind. This makes the prediction of the direction of powdery avalanches difficult and uncertain. Powdery avalanches can cut off trees on the opposite slopes easily. The height of the snow/air mixture can reach 15m and the unit action may exceed 50 kN/m², which is 10 to 100 times the normal wind load assumptions for OHL towers. In reality no element of an OHL will be able to withstand when directly affected by a powdery avalanche – unless extremely expensive and technically challenging installed. It is therefore more practical to find locations for towers which are not exposed to a direct crash with these avalanches. This is also valid for lines on the opposite slope of expected powdery avalanches. The use of only dead end towers has been proven successfully according to experience.

A powdery avalanche can be deflected by various obstacles, even by the ground. This needs to be considered for the development of the tower configuration and conductor arrangement. In the case of the mentioned 220 kV line this results in the configuration in Figure 4. Powdery avalanches did not harm this OHL so far.

For ground wires and conductors a speed of the airmasses of 90 m/sec (unit action 5 kN/m²) acting transversely along the total length of a span at a coincident temperature of -20°C has been considered.

Under such conditions ice accretion has not been considered. For insulators and fittings only dead end equipment was chosen. Towers and foundations have to withstand a unit action of 5 kN/m² simultaneously acting on all groundwires and conductors of both adjacent spans and the tower itself. The extreme deviation of the conductors will lead to additionally acting transverse loads. In the loading assumptions it was considered that all groundwires and conductors ruptured on one side of the tower, while the tension from all other groundwires and conductors on the other side of the tower should be equal to the breaking strength of these conductors. In addition other torsional effects have been considered.

Downdrafts (downbursts)
Downbursts are downward winds with high velocity within a thunderstorm concerning a relative small area. They occur seldom but can have severe effects and are responsible for various local damages on buildings, forests and infrastructure as e.g. overhead lines. The Cigre reports 350 and 410 deal with localized high intensity winds. They state that “…more research is needed to study the interaction of localized winds with supports…”

The question arose if the terrain triggered wind speed-up effects. Another question was which wind forces and directions occurred during these events. To investigate the influences of high wind speeds on damaged overhead lines, a pilot study was carried out. Three dimensional wind fields where computed and analyzed regarding to speed-up effects. This paper presents the investigations, climatological aspects as well as CFD case studies (Computational Fluid Dynamics) and shows the amplification factors for the wind speed.
Damages on Overhead Lines by Cyclone Emma

From February 29th to March 2nd in 2008 the extratropical cyclone Emma crossed North and Eastern Europe and caused serious damage especially in Germany, Switzerland, Austria, Czech Republic, Hungary and Slovakia. In very local areas thunderstorms with downbursts led to severe damages on houses, forests, all kind of facilities and to collapses of overhead lines. In APG’s grid in Austria towers of a 110 kV and a 220 kV line failed in a very small area of app one km in diameter, whilst another 110 kV line 600m apart remained more or less unaffected.

In the Cigre publication 350 a downburst is defined as “…a strong convective down-draft inducing an outward flow of damaging winds when reaching the ground. The downdraft makes contact with the ground and then spreads outwards, causing severe winds at low altitudes. These events are often associated with thunderstorms”. It is there also mentioned: “Downdrafts can sometimes be larger than tornadoes in extent, i.e. more than one span can be affected by an event.”

During the cyclon Emma seven suspension towers at the 220 kV line and five suspension towers at the 110 kV line collapsed. No foundations failed. There was no indication for poor material quality, neither for the steel angles nor for the bolts. No indication for brittle fracture could be found. Conductors and towers were not covered by ice. Due to the high content of steel (single conductor aluminium/steel 340/110 mm²), the conductors did not brake. The lines were built 1958 and 1979. Both lines were designed for loads exceeding the minimum values given in the relevant Austrian standards (see chapter above). The design ice loads were of 60–70 N per meter conductor and ground wire. The material quality of all components was in order and was not the reason for the collapses.

Eyewitnesses of Emma reported heavy rain and hail during the disastrous wind, which lasted only a few minutes. Nobody was hurt, no property was damaged from broken towers. In Hungary and in the Czech Republic Emma created similar damages on lines from 110 kV to 380 kV. Damages on buildings, forests and other facilities were enormous. The situations were reported as natural catastrophes. In APG’s grid with 12,000 towers the collapses caused by storm Emma were the only ones from effects of heavy wind so far. The region of St. Peter am Hart in Austria was hit by windstorms, which caused severe damage, twice within 19 years.

Research Program and Methodology

The meteorological analysis took into account observational information from all meteorological sites in Austria as well as sophisticated interpolation algorithms. Nevertheless the area of the affected overhead lines does not agree with
the areas of the highest analysed gust speeds. This fact suggested the hypothesis that very local effects, such as downbursts, were responsible for the collapse of the towers. According to radar-echoes and the character of damages on lines and other buildings and facilities, it was concluded that a downburst occurred with most likely wind speeds of 210-220 km/h, in the level of standard measuring height 10 m above ground level.

In view of the observed wind storms a model-based climatological investigation has been carried out to assess the spatial pattern and temporal distribution of strong wind events. This synthetic climatology covers the time period 1974 to 2008 and is based on atmospheric reanalysis-data downscaled to 1x1 km using a chain of numerical weather prediction models.

Further investigations had to be carried out, to answer the following hypotheses: Either the local terrain is able to trigger the wind speed-up as e.g. explained in Cigre 410, or downbursts associated with severe thunderstorms are responsible for the collapse of the towers.

MODELLING THE WIND FIELD BY CFD SIMULATION AND RESULTS

To investigate the influences of terrain and/or downbursts on the overhead lines, a high resolution Computational Fluid Dynamics (CFD) model was adapted to this task. Magnitude and direction of the ambient winds were taken from the climatology explained above. What was calculated by the model were the modifications of the provided flow by the terrain (dark gray in Figure 9) and other features like buildings and forests (light gray and green in Figure 9, respectively).

Figures 9 and 10 show the results of one scenario (thunderstorm within cyclone Emma with downburst) from two viewpoints. The backward trajectories illustrate the path of the air that reaches the OHLs (red circles). The legend in the figures shows amplification factors with respect to the downburst wind speed: factors greater than 1,0 mean amplification of wind speed, factors less than 1,0 mean deceleration.

The location of the downburst is annotated with arrow “D” and has a wind speed at the inlet of 104 km/h. The mean flow preceding the downburst is about 30 km/h (annotated with arrow “M” in Figure 10).
The maximum amplification of the downburst air can be seen in the vertical cut in Figure 9 (orange colours). The OHLs lead directly into that maximum which is caused when the air hits the ground and is deflected upward again. The other viewpoint in Figure 10 reveals how the accelerated air reaches the towers at a top factor of 2.0 (corresponds to a top speed of 208 km/h).

Another nice feature is the horizontal mean flow which is whirled aloft by the downburst and deflected downwards (left hand side in figure 10). The vertical cut in Figure 9 shows the amplification of the wind speed and an upward deflection of the air after it has reached the ground.

CONCLUSIONS DOWNDRAFTS

The investigation showed clearly that amplifications factors appear in downdraft due to the accelerating effect when reaching ground. This can lead to windspeeds exceeding 200 km/h.

New lines in this area have been calculated for much higher design wind speeds than before. In combination with load cases “wind and ice” such OHL should withstand events like downdrafts in thunderstorm Emma.

The method which was developed in the project can be used for any other region to simulate tendencies of wind speed-up, regardless if they come from downbursts or not. It helps to a better understanding of the reason for wind induced failures.

RISK ASSUMPTION OF EXISTING STRUCTURES

APG had a risk assumption for natural hazards carried out for each of its 12,000 overhead towers and for the substations. This assumption is being updated periodically. It covers risks from the structure’s environment, e.g. landslides, avalanches, high waters, changes of the surrounding vegetation (cut down woods in the vicinity), storms. On base of this assumption, measures can be taken in time to prevent damages and outages respective to reduce them.

The collection of actual data is as simple as possible to allow fast progress. In addition, APG evaluates the risks of natural hazards to the grid on a yearly basis.

In addition, APG plans to carry out an overall evaluation covering three areas:

- Impact on technical components of OHL (e.g. towers, foundations, conductors)
- Effects on the route of line (ground distances, earthing conditions), also taking into account increased requirements from operation and normative protection goals
- Update of the above mentioned natural hazards on the route using state-of-the-art simulations, e.g. of avalanches.

INFORMATION EXCHANGE WITH OTHER RELEVANT BODIES

Influences from climatic events are theme for several companies, which erect or run technical facilities in the environment. This concerns not only electric utilities, but also antenna towers for telecommunication and broadcast, motorways, airports, railway companies. APG has a continuous exchange of information and experiences with these companies about climatic loads and their probability. Such an exchange is also held two times a year with other Austrian utilities, which run OHL, and with utilities from Switzerland and Germany. The goal is to calibrate the own practice on the practice of the others, and vice versa.

BIBLIOGRAPHY

H. SCHAUER, “Effect of powdery avalanches on the design and behaviour of overhead transmission lines in Austria”, Cigre Stockholm 1981, S22-81, 115-05


Fig. 11: Access road to tower partially collapsed due to avalanche, winter 2018/2019
Examples of How Dynamic Ratings is Considered in Grid Expansion Planning

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Ampacimon, Belgium & India

ABSTRACT

Dynamic Line Rating (DLR) uses real-time measurements and/or forecasted weather parameters like wind speed, ambient temperature and solar irradiance to calculate the ampacity of an overhead transmission line. The ampacity value used by grid operator may be a static value which never changes, varies between seasons, or a dynamic value which changes on an hourly basis according to the DLR. The use of DLR for grid operation is starting to gain popularity as a reliable means to exercise flexibility during maintenance outages or to better integrate distributed energy resources. The value of DLR for grid expansion planning exists where the extra capacity gain enables grid reinforcement to be postponed or avoided all together. Methodologies on how to integrate the DLR potential into grid expansion planning are not yet well established. In this paper, three examples are presented where this is either already considered in formal grid expansion plans, or methodologies are being explored by grid operators. It is expected that these methodologies will undergo further review and enhancement in terms of compatibility to integrate them into current practices of grid expansion planning.

Keywords: Dynamic line rating, Grid Expansion Planning, Transmission Capacity, Grid design optimization

INTRODUCTION

It is known that prevailing weather conditions like ambient air temperature and wind speed affect the actual thermal capacity of overhead transmission lines. The practice to operate the power grid using such dynamic line rating (DLR) is becoming more commonplace and is expected to become the norm in the future.

Grid planning studies that guide investment in line upgrades and new lines, typically are based on power flow calculations using static ratings as the line load limit. However, in Germany and France, some methodologies have been developed how to consider the value of efficiently operating the grid using DLR, to optimize also the grid planning process.

In this paper, three methods are presented. The two cases in Germany are: the method applied in the National Grid Development Plan[1], and a method developed by the Grid Planning department at 50Hertz[2]. These use historical weather data to identify geographical regions that are suitable for DLR. The case in France is a method to estimate the CAPEX savings by considering DLR operational characteristics in the initial line design.

Case I: Consideration of Dynamic Line Rating in the German National Grid Development Plan

The method applied in the German National Grid Development Plan is described in[3]. It divides the country into zones with high, middle and low winds (roughly corresponding to north, middle and south of the country) (Figure 1). The static rating used as the loading limit for the power flow calculations are then altered depending on the zone in which the line is situated, and the wind power infeed level of the snapshot studied.

For each region, the highest ambient temperature and the lowest wind speed is taken into account and the ampacity gain is then calculated. The result is elaborated in a grid form in (Figure 2). This calculation is done on an hourly basis such that there exists one ampacity value for each region per hour which can then be applied to all the lines in that region.

In (Figure 2), the 100% ampacity value is for the conductor with the environmental conditions of 35 ambient temperature, 0.6 m/s wind speed and global irradiation of 900 W/m² according to DIN 50341[3]. It can also be seen in Figure 2, that in order to maintain a conservative estimation of DLR values, the considered wind speeds are less than the measured ones. The figure also shows that for high wind speeds and low ambient temperatures an ampacity gain of 150% is available.
When N-1 power flows are calculated for 8760 hours of the target year, if it results in an overload at a particular instant on a particular line, the corresponding wind speed is checked, and the corresponding gain is checked (Figure 2). If the overload is within the rating considering this gain, then it is no longer considered an N-1 critical flow.

**Case II: Framework to consider the potential of Dynamic Line Rating in new line routing**

The method developed by the Grid Planning department at 50 Hertz, uses the same set of historical weather data as that for the German National Grid Development Plan, but creates a more detailed mapping of the DLR potential, precisely per weather data point (7 km x 7 km). In this way, the potential weak sections (due to unfavorable weather conditions for DLR) of a line can also be highlighted. This information can be used when deciding the routing of new lines, so that the line routing avoids potential weak areas.

In this method the DLR ampacities for each weather point were calculated on an hourly basis for the whole year. Then, the difference between these values and a typical static rating of 2520 A was calculated. This delta was summed for the whole year and averaged to get one average DLR gain value for each weather point. These points were divided into seven groups based on their average ampacity gains and are represented in (Figure 3).

From the figure, it can be seen that there are different regions in the country with different average ampacity gains. It shows that the northern coastal areas offer an average ampacity of 145% more than the static rating of 2520 A whereas the southern most regions still offer 46%. This effect is coherent with that showed in the German National Grid Development Plan in case I where the northern regions of the country offer higher ampacity gains than the south. However, this heat map of (Figure 3) offers more detail than (Figure 2) since the ampacity gain information is now available on a higher resolution.

For the planning of new lines, this serves as a new input to the route planning. It indicates the naturally good and bad weather areas for ampacity gains. Using this information, the new lines could be routed such that those areas could be avoided where there is no benefit from DLR and as well more lines could be routed through the areas with better DLR effects. Another advantage of this new route planning would be that the lines are not only naturally better cooled, but their loadings will also have high probability of being synchronized with DLR. This in turn reduces the overall need for redispatch especially for the northern areas with abundance of wind infeed.

**Case III: Evaluation of cost saving effects to construct new lines by considering the gains of Dynamic Line Rating**

The method developed for a new line location in France, uses the information about the DLR potential based on the proposed line route. In comparison to the conductor size
recommended by assuming a static rating, considering the DLR potential, a smaller conductor size can be used. Smaller conductor size leads to savings also on tower size, foundation, civil works, etc resulting in cost savings. This method presents a way to trade the cost savings with the risks that would have to be managed by operation using DLR.

To illustrate the method and magnitude of cost savings, two lines were evaluated, one 90 kV line and another 225 kV line. By conventional design, the expected power flow would result in a line conductor sizing as below.

- The 90 kV line would be a double-circuit ASTER366 line, 14 km long, includes 49 pylons (20 anchors and 29 suspensions), and steel lattice towers. The reference static rating of this line is 765A. Reference cost of 4.9 m EUR.
- The 225 kV line would be an AZALEE 666 line, 10 km long, with 10 km of single-circuit and 3.7 km of double-circuit sections. It consists of steel lattice towers, and the reference static rating is 1090A. Reference cost of 7.7 mEUR.

The use of forecast DLR that makes it possible to know the transit capacity for the next hours could be used to reduce the conductive section of the conductors. Even more so in the case of connection of wind farms, the climatic conditions ensuring good site production (presence of significant winds) are also conditions that promote the cooling of the conductors of overhead lines, which in turn, ensures a transport capacity often much higher than the static ampacity.

Table 1 and Table 2 list the alternative options of conductors that could be considered by operating them with DLR. The smaller the conductor size, the smaller the current carrying capacity and therefore static rating. The required DLR gain to obtain the same static rating as the line by conventional design, is shown in the last row of each table.

By using smaller conductors, it is possible also to downsize the pylons and their foundations, since the dimensioning of pylons is essentially dictated by the size of the conductors. Logically, this results in lower costs. Figure 4 and Figure 5 show the financial savings due to downsizing each component for different conductor sizes. Obviously, the higher the potential for DLR, the higher the effect.

### Table 1: Alternative conductors considered for the 90 kV line

<table>
<thead>
<tr>
<th></th>
<th>ASTER 366</th>
<th>ASTER 329</th>
<th>ASTER 288</th>
<th>ASTER 256</th>
<th>ASTER 228</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section (mm²)</td>
<td>366</td>
<td>329</td>
<td>288</td>
<td>256</td>
<td>228</td>
</tr>
<tr>
<td>Diam. Ext Cond (mm)</td>
<td>24,85</td>
<td>23,56</td>
<td>22,05</td>
<td>20,79</td>
<td>19,60</td>
</tr>
<tr>
<td>Rdc (Ω/km)</td>
<td>0,0905</td>
<td>0,100</td>
<td>0,115</td>
<td>0,127</td>
<td>0,146</td>
</tr>
<tr>
<td>Static Rating (A)</td>
<td>765</td>
<td>720</td>
<td>660</td>
<td>620</td>
<td>570</td>
</tr>
<tr>
<td>Static rating variation (%)</td>
<td>100</td>
<td>94,1</td>
<td>86,3</td>
<td>81,0</td>
<td>74,5</td>
</tr>
<tr>
<td>Required DLR gain</td>
<td>N/A</td>
<td>6%</td>
<td>16%</td>
<td>23%</td>
<td>34%</td>
</tr>
</tbody>
</table>

### Table 2: Alternative conductors considered for the 225 kV line

<table>
<thead>
<tr>
<th></th>
<th>AZALEE 666</th>
<th>AZALEE 599</th>
<th>AZALEE 533</th>
<th>AZALEE 455</th>
<th>AZALEE 400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section (mm²)</td>
<td>666</td>
<td>599</td>
<td>533</td>
<td>455</td>
<td>400</td>
</tr>
<tr>
<td>Diam. Ext Cond (mm)</td>
<td>31,5</td>
<td>29,9</td>
<td>28,2</td>
<td>26,1</td>
<td>24,5</td>
</tr>
<tr>
<td>Rdc (Ω/km)</td>
<td>0,0504</td>
<td>0,0560</td>
<td>0,0630</td>
<td>0,0738</td>
<td>0,0839</td>
</tr>
<tr>
<td>Steady-State Ampacity 1 (A)</td>
<td>1090</td>
<td>1020</td>
<td>945</td>
<td>860</td>
<td>790</td>
</tr>
<tr>
<td>Steady-State Ampacity variation(%)</td>
<td>100</td>
<td>93,5</td>
<td>86,7</td>
<td>78,9</td>
<td>72,5</td>
</tr>
<tr>
<td>Required DLR gain</td>
<td>N/A</td>
<td>6%</td>
<td>16%</td>
<td>23%</td>
<td>34%</td>
</tr>
</tbody>
</table>
The results show that, for example, if the line is in a location where 16% gain above the static rating could be expected using DLR, an ASTER 288 could be used instead of an ASTER366 for the 90 kV line, and an AZALEE666 could be used instead of an AZALEE666 for the 225 kV line. Against the reference cost, this would enable 12% savings for the 90 kV line and 7% savings for the 225 kV line.

The way to balance this cost saving and risk, lies in the analysis of potential gains by DLR of a specific line. For example, if the line showed gain characteristics like that in Figure 6, more than 99% of the time the gain is larger than 6%, 97.5% of the time larger than 16%, 93% of the time larger than 23% and 68% of the time larger than 34%.

This means that, there is some probability that the undersized conductor does not reach the reference static rating. However, if this probability is less than 1% of the time, so long as this incident can be predicted with forecast DLR, the safety could be managed by other means, like curtailment of wind infed. It is up to the grid operator to decide on a threshold for balancing this risk of constrained capacity against the savings in CAPEX. The value that forecast DLR safety could be managed by other means, like curtailment of wind infeed. It is up to the grid operator to decide on a threshold for balancing this risk of constrained capacity against the savings in CAPEX. The value that forecast DLR brings in this case is the clear visibility of risk ahead of time, so that the grid operator can take suitable actions, and a means to trade-off these activities with CAPEX savings.

BIBLIOGRAPHY
ABSTRACT

Utilities in almost all parts of the world face a common obstacle in the construction of new overhead transmission line - obtaining land for their clearway (ROW). Moreover, due to the ever increasing power demand and pressing needs of integrating renewable energy sources into the grid, increasing the power transfer capacity of existing transmission line, seems to be one of the viable solution. The present condition of the existing transmission corridor may be completely different from the one designed years ago. Hence, the selection of suitable HTLS conductor technology considering ruling span and existing tower loadings may not meet the ground clearance requirements. So, evaluating with respect to present conditions like actual ground clearance of the complete transmission corridor, current tower loadings, spotting and weather conditions is more important and would bring cost effective and reliable solution. This paper elaborates the advantages of selecting technology, considering the present conditions of the transmission corridor over the ruling span methodology, in one such case in Nepal (Baneshwar S/S to Bhaktapur S/S). The surveyed data of the existing line has been used in PLS CADD for the selection of suitable HTLS conductor technology to double the power evacuation capacity considering optimum cost and reliability.

Keywords: Reconductoring, Upgrading, transmission line, High Temperature Low Sag (HTLS) Conductor, ground clearance.

1. INTRODUCTION

In many countries of the world, new power lines have not been built from many years as obtaining right of way is difficult. Nevertheless, over the same period of the time, the world experienced an increase in power consumption. But most of the transmission lines are strung with conventional conductors like ACSR, AAC, AAAC, ACAR etc., and by using the same lines it is difficult to draw more power. It has thus become necessary to uprate the thermal power transfer capacity. Upgrading of overhead line is possible by increasing current carrying capacity of transmission line, but that may lead to increase in sag value by considering ruling span with same towers/poles, which may not meet the ground clearance of existing line. So, evacuating more power with present conditions such as existing ground clearance and towers/poles, there is an optimal technique for Upgrading the transmission line with high temperature low sag conductors (HTLS).

HTLS has been used across the world to upgrade the existing transmission line. The investigation of different techniques to improve the transmission system capacity in power network shows that HTLS conductor was useful in upgrading by increasing current rating. More than double increase in power capacity was obtained by replacing conventional conductor with HTLS Conductor, which was evaluated to be the best solution from both technical and economic aspects. This paper elaborates the advantages of selecting suitable HTLS technology, with respect to the existing tower, weather and ground clearance conditions of the transmission corridor over the ruling span methodology, in one such case in Nepal to enhance the power transfer capacity.

2. HIGH TEMPERATURE LOW SAG CONDUCTORS

“High Temperature Conductor” is defined as a conductor that is designed for applications where continuous operating temperature is higher than the traditional conductors which is about 75°C to 85°C.

“Low Sag” is defined on the basis of at that particular operating temperature sag should matches with ‘traditional conductors’ sag value.

HTLS Conductors are made by thermal-resistance aluminium/super thermal-resistance aluminium/annealed aluminium layers stranded around a core of material with low coefficient of thermal expansion.

Note: The maximum permissible duration of emergency operating temperature of HTLS Conductor shouldn’t be more than 400 hours for total life of the conductor.
2.1 Conductive Layer – Aluminium

Generally, the conventional aluminium and its alloy has limitation of operating temperature from 75°C to 100°C throughout its life span. The conventional aluminium and aluminium alloy (1350, 1370, 6201, 6101, Al59, 1120, etc) will lose its strength at higher temperature because of annealing.

The challenge of increasing the operating temperature of the aluminium and its alloy without loss of its electrical conductivity was addressed with the following high temperature electrical conductivity aluminium and its alloy:

a) High temperature EC grade – 1350 – Annealed Aluminium
b) Thermal resistant aluminium alloy – Al-Zr alloy (Aluminium-Zirconium)

<table>
<thead>
<tr>
<th>Properties</th>
<th>ACSR (Hard drawn 1350 Al)</th>
<th>Annealed Aluminium – 1350</th>
<th>TAL (Thermal Alloy Al Zr)</th>
<th>STAL (Super Thermal Alloy Al Zr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength in MPa</td>
<td>160</td>
<td>60</td>
<td>160</td>
<td>160</td>
</tr>
<tr>
<td>Conductivity %IACS</td>
<td>61</td>
<td>63</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Continuous Operating Temperature</td>
<td>85</td>
<td>250</td>
<td>150</td>
<td>210</td>
</tr>
</tbody>
</table>

2.2. Core – Strength Member

Aluminium has good electrical conductivity and lesser density but the challenge is tensile strength and endurance limit. So ACSR uses steel core as strength member for reinforcement. Steel has higher strength, lower linear expansion than aluminium but the constraint is lower electrical conductivity and higher density.

The core material for HTLS conductors should have:

- High strength
- Less density
- Less linear expansion
- Good modulus of elasticity

In the past, development in core materials were made to increase the strength of steel or to reduce the linear expansion with alloy steel etc. But in the year 2002, composite materials were introduced. The composite materials have higher tensile strength, less density, less linear expansion but the challenges are compressive strength, modulus of elasticity.

Commercially available core materials are listed below
TABLE: 2 The list of commercially available HTLS technologies are as follows:

<table>
<thead>
<tr>
<th>Technology</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACSS</td>
<td>Aluminium Conductor Steel Supported</td>
</tr>
<tr>
<td>TACSR</td>
<td>Thermal Resistant Aluminium Alloy Conductor Steel Reinforced</td>
</tr>
<tr>
<td>GTACSR / GZTACSR</td>
<td>Gap Type Ultra Thermal Resistant Aluminium Alloy Conductor Steel Reinforced</td>
</tr>
<tr>
<td>STACIR</td>
<td>Super Thermal Aluminium Alloy Conductor Invar Reinforced</td>
</tr>
<tr>
<td>ACCC</td>
<td>Aluminium Conductor Composite Core</td>
</tr>
<tr>
<td>ACFR</td>
<td>Aluminium Conductor Faber Reinforced</td>
</tr>
<tr>
<td>ACCR</td>
<td>Aluminium Conductor Composite Reinforced</td>
</tr>
</tbody>
</table>
3. NEPAL 66 KV LINE TECHNICAL CONSEQUENCES

3.1 Scope of the Project:

The overhead transmission lines, having voltage level of 66 kv are mostly equipped with ACSR 150 mm2 & ACSR 120 mm2 conductors.

To enhance the power transfer capacity, the first solution considered, was to install new overhead line. For the new transmission lines increasing power transfer capacity is easy, as it can be performed by increasing portion of aluminium or by increasing the number of conductors in bundle.

However, this solution has several inconveniencies. First, land saturation that generates difficulty to get right of way to install a new overhead line. Also, the period of time when the need of a new line is identified, until the line is finally installed can be a decade or longer. Another problem is that a new overhead line produces an increment of visual and environmental impact. These factors make a sector of the society refuse the installation of new overhead lines.

Taking into account the difficulties to install new line, second solution is to improve the current rating of existing line by replacing traditional conductor with HTLS Conductor. Reconductoring the line with HTLS conductors without any tower reinforcements with short time execution and a reasonable cost. With two times the current carrying capacity, HTLS Conductors maintaining the existing ground clearances.

3.2 Existing Tower Loadings:

Tower loading is the most vital input for designing any transmission line. The existing towers in the 66 KV transmission line has been designed with various types of loads. In the load calculation, wind plays a major role.

In this case the existing component of tower like insulator string, ground wire will remain the same but the existing conductor will be replaced with new HTLS conductor. So, the only change in component is overhead conductor.

The existing tower was designed with ruling span and wind conditions depending on the weather condition of the corridors. So, the proposed HTLS conductor should have equal or lesser loading conditions of the existing ACSR conductor under the designed conditions of tower. So, the data of existing tower design plays a vital role in designing a suitable HTLS conductor.

The conductor loading condition:

1) Transverse Load
   Wind load on conductor
   Mechanical tension of conductor

2) Vertical load
   Loads due to weight of conductor

3) Longitudinal Load
   Unbalanced horizontal load due to mechanical tension of conductor
4. OUR APPROACH FOR RECONDUCTORING OF EXISTING LINE WITH SUITABLE HTLS TECHNOLOGY

Survey the existing line with respect to tower spotting, every 50 meters ground elevation of existing corridor and existing sag/ground clearance → Feed the survey data into PLS CADD → Create tower profile similar to the existing tower heights

String the existing conductor with respect to the existing ground clearance ← Creating existing conductor wir file ← Tower spotting with respect to the existing tower locations

Design different HTLS conductor technology to match the existing ground clearance → Finalize the suitable HTLS technology or any other technology solutions to meet the need of the customer → Conclude the technology with respect to terrain conditions and need of the customer

5. TECHNICAL ANALYSIS

To maintain the line’s safety in operation, for example to conserve the towers and the insulating strings when using HTLS conductors, the following restrictions have to be fulfilled:

TABLE: 3
The HTLS conductor shall meet the following minimum requirements:

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall diameter of complete</td>
<td>mm</td>
<td>Not exceeding 14.28</td>
</tr>
<tr>
<td>Conductor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approx. mass of complete</td>
<td>Kg/km</td>
<td>Less than or equal to 435</td>
</tr>
<tr>
<td>conductor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direction of lay of outer layer</td>
<td>-</td>
<td>Right Hand</td>
</tr>
</tbody>
</table>

For maintaining the ground clearance of existing line, the HTLS Conductor should meet the following sag tension requirements as specified in table: 4
**TABLE: 4**  
Sag - Tension Requirements

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension at everyday condition (28 deg C, no wind)</td>
<td>Not exceeding 25% of UTS of proposed conductor</td>
</tr>
<tr>
<td>Tension at 20 deg C, full wind (53 kg/m²)</td>
<td>not exceeding 50% of UTS of proposed conductor</td>
</tr>
<tr>
<td>Tension at minimum temperature -5 deg C, 37.7% of full wind (20 kg/ m²)</td>
<td>not exceeding 50% of UTS of proposed conductor</td>
</tr>
<tr>
<td>Maximum working stress allowed for conductor</td>
<td>1110 Kg</td>
</tr>
</tbody>
</table>

Table: 5 shows the comparison of technical characteristics that will have an impact on the existing tower while replacing with different HTLS technologies.

**TABLE: 5**  
ACSR vs HTLS reconductoring Comparison Considering Ruling Span 298 meters

<table>
<thead>
<tr>
<th>Description</th>
<th>ACSR</th>
<th>ACSS</th>
<th>STACIR</th>
<th>ACCC</th>
<th>ACFR</th>
<th>ACCR</th>
<th>GAP</th>
<th>TACSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC resistance at 20 deg C</td>
<td>Ohm/km</td>
<td>0.2816</td>
<td>0.2969</td>
<td>0.32526</td>
<td>0.2286</td>
<td>0.2203</td>
<td>0.27482</td>
<td>0.2633</td>
</tr>
<tr>
<td>Min UTS of conductor</td>
<td>KN</td>
<td>43.5</td>
<td>45.6</td>
<td>43.9</td>
<td>67.3</td>
<td>44.1</td>
<td>39.46</td>
<td>40.71</td>
</tr>
<tr>
<td>Weight</td>
<td>Kg/km</td>
<td>435</td>
<td>432</td>
<td>435</td>
<td>394</td>
<td>378</td>
<td>341</td>
<td>434</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>Kg/sq.mm</td>
<td>7338</td>
<td>8140</td>
<td>8162</td>
<td>6943</td>
<td>6426</td>
<td>8996</td>
<td>7520</td>
</tr>
<tr>
<td>Co-efficient of linear expansion</td>
<td>X 10^-6 °/C</td>
<td>18.44</td>
<td>17.86</td>
<td>14.40</td>
<td>16.48</td>
<td>17.94</td>
<td>15.94</td>
<td>19.55</td>
</tr>
<tr>
<td>Maximum allowable continuous operating temperature</td>
<td>Deg C</td>
<td>75</td>
<td>250</td>
<td>210</td>
<td>180</td>
<td>180</td>
<td>210</td>
<td>210</td>
</tr>
<tr>
<td>Emergency operating temperature</td>
<td>Deg C</td>
<td>100</td>
<td>280</td>
<td>240</td>
<td>200</td>
<td>200</td>
<td>240</td>
<td>240</td>
</tr>
<tr>
<td>Temperature at 264 Amps</td>
<td>Deg C</td>
<td>75</td>
<td>76.63</td>
<td>79.43</td>
<td>70.43</td>
<td>69.73</td>
<td>74.55</td>
<td>73.73</td>
</tr>
<tr>
<td>DC resistance at 264 Amps</td>
<td>Ohm/km</td>
<td>0.34365</td>
<td>0.36537</td>
<td>0.40385</td>
<td>0.27532</td>
<td>0.26428</td>
<td>0.33488</td>
<td>0.32098</td>
</tr>
<tr>
<td>Sag at 264 Amps</td>
<td>Meters</td>
<td>9.55</td>
<td>8.70</td>
<td>8.90</td>
<td>7.46</td>
<td>7.65</td>
<td>8.42</td>
<td>8.70</td>
</tr>
<tr>
<td>Maximum ampacity that can pump per conductor without exceeding the ACSR Sag</td>
<td>A</td>
<td>N/A</td>
<td>434</td>
<td>547</td>
<td>623</td>
<td>635</td>
<td>583</td>
<td>463</td>
</tr>
<tr>
<td>Temperature at above ampacity</td>
<td>Deg C</td>
<td>N/A</td>
<td>127</td>
<td>200</td>
<td>180</td>
<td>180</td>
<td>190</td>
<td>128</td>
</tr>
<tr>
<td>Enhancement of double the Ampacity</td>
<td>A</td>
<td>N/A</td>
<td>530</td>
<td>530</td>
<td>530</td>
<td>530</td>
<td>530</td>
<td>530</td>
</tr>
<tr>
<td>Temperature at above ampacity</td>
<td>Deg C</td>
<td>N/A</td>
<td>172.83</td>
<td>189.07</td>
<td>138.70</td>
<td>135.01</td>
<td>161.35</td>
<td>157.11</td>
</tr>
<tr>
<td>Sag at double Ampacity</td>
<td>Meters</td>
<td>N/A</td>
<td>10.30</td>
<td>9.49</td>
<td>7.62</td>
<td>8.22</td>
<td>9.28</td>
<td>9.99</td>
</tr>
<tr>
<td>AC Resistance at double Ampacity</td>
<td>Ohm/km</td>
<td>N/A</td>
<td>0.47995</td>
<td>0.54691</td>
<td>0.33783</td>
<td>0.32177</td>
<td>0.43028</td>
<td>0.40903</td>
</tr>
<tr>
<td>Ampacity at Max operating temperature</td>
<td>A</td>
<td>264</td>
<td>648</td>
<td>561</td>
<td>623</td>
<td>635</td>
<td>616</td>
<td>626</td>
</tr>
<tr>
<td>Sag at Max operating temperature</td>
<td>Meters</td>
<td>9.55</td>
<td>11.50</td>
<td>9.60</td>
<td>7.72</td>
<td>8.28</td>
<td>9.75</td>
<td>10.78</td>
</tr>
<tr>
<td>AC Resistance at Max operating temperature</td>
<td>Ohm/km</td>
<td>0.34365</td>
<td>0.57187</td>
<td>0.57422</td>
<td>0.3761</td>
<td>0.3614</td>
<td>0.4849</td>
<td>0.46489</td>
</tr>
<tr>
<td>Description</td>
<td>Unit</td>
<td>ACSR</td>
<td>ACSS</td>
<td>STACIR</td>
<td>ACCC</td>
<td>ACFR</td>
<td>ACCR</td>
<td>GAP</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>--------</td>
<td>------</td>
<td>------</td>
<td>------</td>
<td>-----</td>
</tr>
<tr>
<td>Ampacity at emergency operating temperature</td>
<td>A</td>
<td>370</td>
<td>687</td>
<td>603</td>
<td>661</td>
<td>673</td>
<td>661</td>
<td>672</td>
</tr>
<tr>
<td>Sag at emergency operating temperature</td>
<td>Meters</td>
<td>9.94</td>
<td>11.94</td>
<td>9.76</td>
<td>7.76</td>
<td>8.30</td>
<td>10.03</td>
<td>11.22</td>
</tr>
<tr>
<td>AC Resistance at emergency operating temperature</td>
<td>Ohm/km</td>
<td>0.3718</td>
<td>0.60761</td>
<td>0.61336</td>
<td>0.3944</td>
<td>0.37902</td>
<td>0.5189</td>
<td>0.49657</td>
</tr>
<tr>
<td>Ruling span</td>
<td>Meters</td>
<td>298</td>
<td>298</td>
<td>298</td>
<td>298</td>
<td>298</td>
<td>298</td>
<td>298</td>
</tr>
<tr>
<td>Tension 28 Deg C, no wind</td>
<td>Kg &amp; %</td>
<td>594 &amp; 13</td>
<td>647 &amp; 14</td>
<td>626 &amp; 14</td>
<td>609 &amp; 9</td>
<td>682 &amp; 15</td>
<td>516 &amp; 13</td>
<td>611 &amp; 15</td>
</tr>
<tr>
<td>Tension at 20 Deg C, Full wind pressure (53 Kg/sq.mm)</td>
<td>Kg &amp; %</td>
<td>1102 &amp; 25</td>
<td>1088 &amp; 23</td>
<td>1102 &amp; 25</td>
<td>1102 &amp; 16</td>
<td>1075 &amp; 24</td>
<td>1102 &amp; 28</td>
<td>1095 &amp; 26</td>
</tr>
<tr>
<td>Tension at -5 Deg C, 37.74% of wind pressure (20 Kg/sq.mm)</td>
<td>Kg &amp; %</td>
<td>817 &amp; 18</td>
<td>817 &amp; 18</td>
<td>812 &amp; 18</td>
<td>806 &amp; 12</td>
<td>817 &amp; 18</td>
<td>757 &amp; 19</td>
<td>817 &amp; 20</td>
</tr>
<tr>
<td>Losses at 264A per CKM (Loss load factor 0.53, circuit - single, Route Length - 1 Km)</td>
<td>Kw</td>
<td>38.08</td>
<td>40.49</td>
<td>44.75</td>
<td>30.51</td>
<td>29.29</td>
<td>37.11</td>
<td>35.57</td>
</tr>
</tbody>
</table>

The calculations of steady-state thermal rating, given a maximum allowable conductor temperature, weather conditions, and conductor characteristics were performed by the computer using PLS CADD based on the IEEE Std 738 - 2006. For steady – state thermal rating, the following parameters were adopted:

- Wind speed: 0.56 m/s;
- The angle between wind and conductors: 90°;
- Emissivity: 0.45;
- Solar absorptivity: 0.8;
- Air temperature: 40°C
- Solar radiation: 1045 watt/sq.m;
- Elevation above sea level: 1300 meters;

**Current carrying capacity comparison graph at 75 Deg C for Different Conductors**

![Current carrying capacity comparison graph at 75 Deg C for Different Conductors](image-url)
**HTLS Conductors Sag comparison at ≥ double current carrying capacity**

![Graphical representation of HTLS Conductors Sag comparison](image)

**Graphical representation is based on below assumptions**

- Ruling span: 298 meters
- Everyday temperature: 28 deg C
- Operating temperature at double current capacity of each HTLS conductor

*The above graphical representation showing the results of sag value for different type of HTLS technology at after creep condition.

**Conclusion:**

The replacement of existing conductor should improve the mechanical reliability of the line conductor. To uprate the 66 KV line in Nepal by using high temperature conductors is considered as a feasible desideratum from the technical point of view. All the selected conductors can be strung to accomplish equal or smaller sag than the initial one, but at higher temperature.

Finally, from techno – commercial point of view, the detailed analysis of the suitable conductor technology can be considered on the basis of techno commercial evaluation of different HTLS technology by the customer. From the detailed technical analysis considering maximum power transfer capacity without violating the ground clearance of existing line, the most attractive solutions are Invar & Composite core technologies. The utility can reconductoring the line either with Invar or composite core conductors if cost will be accepted.

**REFERENCES**


Working Group SC 22-12 Cigre (Chairman R. Stephen). “The thermal behaviour of overhead conductors Section 1 and 2 Mathematical model for evaluation of conductor temperature in the steady state and the application there of” (Electra number 144 October 1992 pages 107-125).

LFE_CIGRE High Performance Conductors An International viewpoint

**Standards:**

POLE & JOINT TYPES

- CONSTRUCTIONAL FEATURES
  - DIRECT EMBEDDED TYPE POLE
  - BASE PLATED TYPE POLE
  - GUED POLES
  - DUAL POLE STRUCTURE/H-FRAME STRUCTURE
  - TRIPLE / MULTI POLE STRUCTURE
  - A-FRAME STRUCTURE
  - X-FRAME STRUCTURE

- JOINT TYPES

STEEL POLE ASSEMBLY & INSTALLATION

- HORIZONTAL / GROUND ASSEMBLY
- VERTICAL / SECTION BY SECTION METHOD
- VERTICAL BY HELICOPTER METHOD
- POLE INSTALLATION BY HYDRAULIC JACKS / HOIST
SAFETY, NIL/LESS MAINTENANCE AND REPAIRS

- Engineered product
- Effective corrosion protection (Zinc coating thickness 80 to 100 μm)
- Controlled Fabrication Process
- Structural Integrity maintained through service life

MULTI POLE STRUCTURES

- Monopole
- Dual Pole
- Triple Pole
- Four Pole
Selection of Optimised Overhead Conductor in a New Transmission Line – Reduce the Transmission Tariff

UJJAL DAS
Sleepwalkers, India

ABSTRACT

In recent years, private investment on transmission line has impacted the transmission tariff. This further can be reduced by selecting optimised component that meets all the requirements of the power system. This paper looks into how the optimal selection of conductor can reduce the tariff of utilities, as the conductor is the major portion of the power transmission project cost (around 30 to 40 per cent of the overall cost). In one such case for a South American transmission system need, we have evaluated a solution to cope up with the desired future requirements without disturbing transfer capacities of distribution systems as well as of transmission systems. Our solution, a monolithic conductor design, facilitates minimal tariff. With an overview, we can conclude how an appropriate selection of conductor for the project can optimise the overall project cost.

Keywords: ACSR, 1120 AAAC, Power transmission line, SW conductor, corrosion, tariff, sag-tension, ruling span, structures.

INTRODUCTION

In the race of power industries, since past 40 years thought-out the globe there has been a trend of using aluminium conductor steel reinforced (ACSR) type conductor rather than the use of only 1350 H19 hard drawn aluminium strands in the conductor for any power transmission line. Also, the composite conductor like aluminium conductor steel reinforced (ACSR) conductor was introduced in the transmission line projects to maintain mechanical strength. The power transmission line consists of series and parallel combinations of conductor along with electrical equipment, subjected to mechanical, electrical, and thermal stresses. And the collective purpose is to transmit power with safety and reliably under wide varying operational situations.

This paper emphasizes, to assist the utilities for better understanding and tailoring out the solutions for enhancing its engineering goals. Our knowledge is illustrated by describing a new EHV above 230 kV overhead transmission line projects which are in use of the South American Utility, that include all discussions where significantly saving has been documented in our investigating effort, line outages, and construction cost for ACSR, and 1120 (AAAC) conductor, the critical infrastructural and of all our reasons. The standardised approach is suggested in this paper as an optional approach with SW conductor, for similar type of EHV above 230 kV overhead transmission line projects, which would be the best approach with the elevated global energy demand as well the highlighting interest of the utilities in evaluating the best solution. This paper presents an overview for how the sag-tension of SW conductor will head place 1120 (AAAC) conductor and ACSR conductor, and how the overall conductor design will influence to reduce the tariff for the end-customers by the electric utilities.

OBJECTIVES FOR THE FUTURE, IN IMPLEMENTING THIS PROJECT

(i) Improving the response to environment concerns.
(ii) Reduce the lifetime costs of overhead transmission line.
(iii) Reduce the overall initial cost of the overhead transmission line.
(iv) Better property and performance for the components of overhead transmission line.

SELECTION OF CONDUCTOR BASED ON THE CASE STUDY

In this study of energy network, the technical requirements are to be link up with different time zones, seasons, and load patterns and due to the uneven distribution of energy resources across the globe, the assumptions are considered to provide and support the results for one of the South American utility. The temperature of the conductor to the reference current may be rounded up, so as to be compatible with usual values for the project as the below assumptions varies depending upon the short or long-term requirement as mentioned in the table i.e. Table 1, during day or night, for different seasons as mentioned in the table i.e. Table 2. As the transmission line may pass through different regions of different climates, where the capacity for each season may correspond to the different weather conditions.
Table 1. Ampacity requirement of transmission line

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Voltage Level (kV)</th>
<th>Long term duration</th>
<th>Short term duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>500</td>
<td>3005</td>
<td>4000</td>
</tr>
<tr>
<td>2.</td>
<td>500</td>
<td>3005</td>
<td>4000</td>
</tr>
<tr>
<td>3.</td>
<td>230</td>
<td>940</td>
<td>1185</td>
</tr>
<tr>
<td>4.</td>
<td>230</td>
<td>1485</td>
<td>1875</td>
</tr>
<tr>
<td>5.</td>
<td>230</td>
<td>1450</td>
<td>1825</td>
</tr>
<tr>
<td>6.</td>
<td>500</td>
<td>2956</td>
<td>3725</td>
</tr>
</tbody>
</table>

Beside usual calculations for everyday condition, or the calculations supporting for daily summer and winter season conditions, there are also results of calculations based on season conditions, where these results are supposed by the meteorological conditions for day and night in summer as well in winter season. For summer and winter night the time between 19:00 p.m. and 07:00 a.m. is considered for calculation. For summer night, adopted value for air temperature parameter is 25 degrees C, and the same condition is a varying for the winter condition as 5 degrees C. The night conditions values are based on the largest average values approximation for corresponding season, according to approximation for corresponding season and situations, according to the available literature [3].

Table 2. Seasonal ampacity during long term and short term.

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Voltage level[a] (kV)</th>
<th>Long term duration[b]</th>
<th>Short term duration[b]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sd</td>
<td>Sn</td>
</tr>
<tr>
<td>1</td>
<td>500 - A</td>
<td>3005</td>
<td>3940</td>
</tr>
<tr>
<td>2</td>
<td>500 - B</td>
<td>3005</td>
<td>3957</td>
</tr>
<tr>
<td>3</td>
<td>230 - A</td>
<td>940</td>
<td>1259</td>
</tr>
<tr>
<td>4</td>
<td>230 - B</td>
<td>1485</td>
<td>1924</td>
</tr>
<tr>
<td>5</td>
<td>230 - C</td>
<td>1450</td>
<td>1946</td>
</tr>
<tr>
<td>6</td>
<td>500 - C</td>
<td>2956</td>
<td>3192</td>
</tr>
</tbody>
</table>

Note [a]: A, B, and C are the different transmission lines for one particular Lot of this project.
Note [b]: Sd – Summer day, Sn – Summer Night, Wd – Winter day and Wn – Winter Night.

Generally, for high capacity power transfer over the long EHV AC transmission lines uses high voltage above 230 kV which are necessary as these high voltage transmission lines gives lesser current, lesser transmission losses, and high-power transfer. In this EHV transmission line to reduce the corona effects and increasing the transmission line capacity, bundled conductors are used. In this paper providing a best solution for conductor design, maintaining conductor and sub-configuration, spacing between the conductors, bundle spacing, diameter of conductor, and number of sub-conductors per phase, which will reduce the inductance and...
increase the value of the surge impedance loading as the depending factors are optimized to maintain the seasonal capacity.

Table 3. Suitable ACSR conductor for 230 kV, 345 kV and 500 kV overhead transmission lines.

<table>
<thead>
<tr>
<th>Code name</th>
<th>Area Al/St (mm²)</th>
<th>Complete conductor</th>
<th>Ultimate Tensile Strength (kN)</th>
<th>Weight (kg/km)</th>
<th>20°C DC resistance (ῼ/km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardinal</td>
<td>484.5/62.8</td>
<td>547.3 30.42 54/3.38 7/3.38</td>
<td>151.46</td>
<td>1833</td>
<td>0.05969</td>
</tr>
<tr>
<td>Rail</td>
<td>483.8/33.5</td>
<td>517.3 29.61 45/3.70 7/2.47</td>
<td>116.10</td>
<td>1604</td>
<td>0.0597</td>
</tr>
<tr>
<td>Drake</td>
<td>402.6/65.4</td>
<td>468.0 28.11 26/4.44 7/3.45</td>
<td>139.7</td>
<td>1627</td>
<td>0.0717</td>
</tr>
</tbody>
</table>

Over the Aluminium Conductor Steel Reinforced (ACSR) type of conductors the All-Aluminium Alloy Conductors have produced benefits with regards to both the cost of installation and lifetime costs. The clamps and all current carrying joints are made onto homogeneous metal, which avoids the mechanism of aging. The all-aluminium alloy type conductors itself has no galvanised steel core like ACSR, which has been the cause of most cases of rapid conductor corrosion. Also, the resistance of the conductor starts increasing with ageing in the ACSR conductor.

The bare overhead transmission lines are affected by the wind blowing over sub-conductors, causing damages due to the generation of oscillation and vibrations within the conductor. Therefore, the factors need to be satisfied along with our requirements. Additionally, suffering from galvanic corrosion due to the presence of dissimilar metals in composite type conductor and pollution in the atmosphere are the other factors, which are also to be taken care of as above factors. The life service of the conductors ranging from 11-80 years, while on average it is 30-43 years for ACSR conductor, 45 years for 1120 (AAAC) conductor, and also for the SW conductor it is 45 years life service i.e. Table 4 [1].

Table 4. Service Life of conductors.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Conductor</th>
<th>Range</th>
<th>Average[c]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ACSR</td>
<td>11 to 80</td>
<td>30-43</td>
</tr>
<tr>
<td>2</td>
<td>1120 (AAAC)</td>
<td>11 to 80</td>
<td>45</td>
</tr>
<tr>
<td>3</td>
<td>SW Conductor</td>
<td>11 to 80</td>
<td>45</td>
</tr>
</tbody>
</table>

Note: [c] Depending on the loading, corrosive environment and quality product.

VALIDATION OF THE APPROACH FOR SELECTION OF THE CONDUCTOR.

The chosen conductor needs to perform the requirements under all seasonal duration i.e. Figure c, maintaining less power losses, which creates need for the provision of additional capacity to be installed over and above that required amount of power requirement to satisfy the demand. The SW conductor is having more strength than the 1350 H19 hard drawn Aluminium or 1120
Aluminium alloy type conductor. In particular, it has (10-15)% increase in strength over 1120 (AAAC) Conductor, and can be strung higher than the 1120 (AAAC) conductor. So, sag may be lesser than 1120 which may lead to either increase in the span length or reduction in tower height. This may reduce the capex cost for the transmission line.

![Seasonal Capacity Diagram]

**Figure c.** Seasonal ampacity during long term and short term.

The conductor can be conveniently manufactured than 1120 (AAAC) ensuring lower losses, which adds benefit in production cost and product quality. It has better strength to weight ratio. The combination of the class of material used for conductor design has been precisely selected on the application requirement of the case study.

![Seasonal Current Carrying Graphs]

**Figure d.** Seasonal current carrying 1120 conductor at a temperature of 85°C for 500 kV [5].

**Figure e.** Seasonal current carrying SW conductor at a temperature of 85°C for 500 kV [5].
Table 5. Joules loss in conductor.

<table>
<thead>
<tr>
<th>SL No.</th>
<th>Voltage Level (kV)</th>
<th>Reference Temperature (°C)</th>
<th>Requirement for meeting the positive sequence resistance of transmission line (Ω/km)</th>
<th>1120 (AAAC) conductor</th>
<th>SW conductor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>500</td>
<td>50</td>
<td>0.0174</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2.</td>
<td>500</td>
<td>50</td>
<td>0.0174</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>3.</td>
<td>230</td>
<td>50</td>
<td>0.0687</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>4.</td>
<td>230</td>
<td>50</td>
<td>0.0348</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>5.</td>
<td>230</td>
<td>50</td>
<td>0.0348</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>6.</td>
<td>500</td>
<td>50</td>
<td>0.0174</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The best way to evaluate the suitable conductor could be done by comparing the SW conductor with the 1120 conductors (AAAC).

Table 6. Technical Particulars of conductors [4,6,7,8].

<table>
<thead>
<tr>
<th>SL No.</th>
<th>Conductor Parameters</th>
<th>Units</th>
<th>Conductor constructional data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Conductor type</td>
<td></td>
<td>ACSR</td>
</tr>
<tr>
<td>2</td>
<td>Number of wires</td>
<td>No./mm</td>
<td>45 (Al) 1120 (AAAC) 61 (Al) SW</td>
</tr>
<tr>
<td>3</td>
<td>Total area of conductor</td>
<td>mm²</td>
<td>517.30 553.83 53.26</td>
</tr>
<tr>
<td>4</td>
<td>Overall Conductor diameter</td>
<td>mm</td>
<td>29.61 30.6 30.06</td>
</tr>
<tr>
<td>5</td>
<td>Weight</td>
<td>kg/km</td>
<td>1604 1511 (Al) 1472 (Al)</td>
</tr>
<tr>
<td>6</td>
<td>Ultimate strength</td>
<td>kN</td>
<td>116.1 119.6 139.5</td>
</tr>
</tbody>
</table>

**SAG-TENSION AND SPAN**

For the ACSR conductor the material used is a combination of both aluminium and steel. The weight of the steel is 2.8 times more compare to the aluminium, which makes a big difference in choosing between the Aluminium Conductor Steel Reinforced and All Aluminium Alloy Conductor. The sag tension simulation is done for both the conductors SW and 1120 (AAAC) conductor, and are to found as less sag in SW conductor, which describes the better performance of the conductors. This makes a difference in considering weight of the conductor, which reflects its effect in use of number of towers thought-out the transmission line route. By providing the better sag-tension, we can reduce the spans or weight of the tower used in the transmission line route, which will reduce the overall capex cost of towers in the route. Additionally, the cost of installation, maintenance, and hardware usage will be also less. As the conductor material starts elongating with time, (i.e. creep) thus the calculated sag with minimum clearance increases, as the maximum tension decreases [2]. The elongation of the conductor again depends on the temperature and type of conductor material used.
SURGE IMPEDANCE LOADING

In the transmission line the reactive power is generated, which is absorbed by the transmission line itself. The voltage level (kV) is proportional to the surge impedance loading of the line. When the transmission line is over loaded above the limits of the surge impedance loading (SIL), it absorbs the reactive power from the system, and when it is loaded below the surge impedance loading, it supplies the reactive power to the system. At the surge impedance loading the natural reactive power balance is occurring. The transmission line capacity can be improved by either by reducing the self-inductance of the transmission line or by increasing the mutual inductance of the transmission line. The conductor spacing and the sizing is again depending on the optimized conductor design with the same requirement of performance with improved power transfer capacity. The bundle conductors are configured to enhance the power transfer and utilize the potential of a transmission line.

SHORT CIRCUIT CURRENT

To provide an optimise solution in increasing the power transfer capabilities and maintaining the compact tower design, minimum safe electrical clearance needs to be made, by maintaining the same performance and by simultaneously reducing the transmission cost for the same power transfer too. This criteria of maintaining safe electrical clearance, the conductor stability limits would ensure at least the original performance of the transmission line and should not be damaged or under-perform after short-circuit occurred in the transmission line. As the stability limits are the function of line length and surge impedance loading. And with the better conductor stability limits, the conductor design permits a reasonable degree of compaction in the tower and obtaining higher power transfer capabilities. For the ACSR and 1120 (AAAC) conductor the short-circuit current performance is evaluated in the following Figures, i.e. Figure: f and Figure: g.

Figure: f. Short Circuit Current performance of the SW conductor for 500 kV. Figure: g. Short Circuit Current performance of the 1120 (AAAC) conductor for 500 kV.
The requirement for the safe performance of the transmission line are provided along with the short circuit current performance of SW conductor and 1120 (AAAC) conductor as mentioned in the following table, Table: 7 [9]. Further, the SW conductor ensures for its robustness thought-out the transmission line.

Table: 7. Sizing of the conductors for short-circuit current.

<table>
<thead>
<tr>
<th>Reference voltage level (kV)</th>
<th>Required of Short-Circuit Current value (kA)</th>
<th>Short-Circuit Current performance of the 1120 (AAAC) conductor</th>
<th>Short-Circuit Current performance of the SW conductor</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>40 - 50</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>345</td>
<td>40 - 50</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>230</td>
<td>40 - 50</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

TOWER AND CONDUCTOR BASIC COST

The approach to consider the transmission tower design along with the additional equipped conductors with its accessories majorly depends on the conductor design. The towers are designed and calculated with a return period of 50 years. The height above the ground of the transmission towers are adjusted to the wind velocities, which quote appropriate formulae and meteorological conditions to determine conductor sags and swings at the mid-span to associate with the corresponding internal electrical clearances. Our probabilistic approach represents an additional significant improvement in the design of tower. Also, for the conductor by maintaining a range of safe short-circuit current for the conductor, along with the fewer burdens on the transmission towers. The compact towers used in one of the South American utility for 230 kV and above transmission line use will permit to increase the surge impedance loading, thus representing a significant economic gain.

Table: 8. Sag characteristic.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Conductors</th>
<th>Route Length (km)</th>
<th>Sag (m)</th>
<th>Span (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SW</td>
<td>150</td>
<td>11.36</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>SW</td>
<td>100</td>
<td>11.36</td>
<td>400</td>
</tr>
<tr>
<td>2</td>
<td>1120-AAAC</td>
<td>150</td>
<td>13.85</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td>1120-AAAC</td>
<td>100</td>
<td>13.85</td>
<td>400</td>
</tr>
</tbody>
</table>

Conclusion

This paper summarises obtaining results, suggestions and recommendations for important future work, by providing an optimized solution where the significantly saving is observed in one of the transmission line project situated in South American. Since, the conductor design here determines the tower, hardware, and all the other component design in the transmission line (30-40) % of the total project cost. So, by the optimum selection of (SW conductor) conductor design
considering the need with respect to the electrical and mechanical parameters, that are easy to manufacture, easy to maintain, and easy install, which will further impact in reduction of capex of the entire transmission line project. Thus, the monolithic conductor (SW conductor) design will drive the entire project cost, which determines the tariff, and the bidders can facilitate with minimal transmission tariff.

BIBLIOGRAPHY


Non-Destructive Condition Monitoring of Transmission Line Towers & Foundation

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ABSTRACT
With the reforms in power sectors in India, the availability of Transmission line becomes very important. Condition monitoring of the line is one of the better ways to assure reliability and higher percentage of availability of the lines. The non-destructive testing and inspection of foundation and super structures is quicker and better method of condition monitoring. The paper below presents ways and means to carry out condition monitoring using non-destructive methods and a case studies thereof.

Keywords: Non-Destructive Test, Ultrasonic Pulse Velocity, Rebound Hammer Test, Zinc Coating, Verticality Test

1.0 INTRODUCTION
1.1 Condition monitoring can be done on existing lines in service. With the line getting older, it becomes more significant.
1.2 Non-destructive testing can be done on the line under construction or even just before commissioning of the line.
1.3 The non-destructive testing of the line, includes ultra-pulse velocity (UPV), rebound hammer test measurement of verticality of the towers and galvanizing test at site. Core cutting of concrete slabs of foundation can also be done for ascertaining the quality of concrete work done

2.0 ULTRASONIC PULSE VELOCITY (IS 13311 PART I: 1992):
2.1 The ultrasonic pulse velocity measurement technique involves determination of velocity of ultrasonic pulse through solid material. The velocity of these pulses depends upon the density and elastic properties of the material.
The pulse velocity is determined by the equation:

\[ \text{Pulse Velocity} = \frac{\text{Pathlength}}{\text{Transit time}} \]
The path length and transit time are measured to determine the pulse velocity.
2.2 The velocity of longitudinal pulse in elastic solids.
The velocity \( V \), of pulse of longitudinal ultrasonic vibration traveling in an elastic solid is given by an equation:

\[ V^2 = \frac{E}{p \cdot (1+\mu)} \cdot \frac{1}{(1-2\mu)} \]  

(B.S. 1881 Part 203 - 1986)

Where, 

- \( E \) is the dynamic elasticity modulus,
- \( p \) is the density,
- \( \mu \) is the Poisson’s ratio.
The instrument indicates the time taken for the earliest part of the pulse to reach the receiving transducer measured from the time it leaves from a suitable point on the surface of the material. The relative values indicative of quality of concrete with reference to UPV are given in the table below.

**(As per IS 13311 (Part I) 1992)**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>U.P.V. (kM/sec)</th>
<th>Quality of Concrete for Direct Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Above 4.5</td>
<td>Excellent</td>
</tr>
<tr>
<td>2</td>
<td>3.5 to 4.5</td>
<td>Good</td>
</tr>
<tr>
<td>3</td>
<td>3.0 to 3.5</td>
<td>Medium</td>
</tr>
<tr>
<td>4</td>
<td>Below 3km/sec.</td>
<td>Doubtful</td>
</tr>
</tbody>
</table>

Readings of semi direct & indirect methods are generally less than direct method by 1km/sec

2.3 Pulses are not transmitted through large air voids in a material and if such a void lies directly in the pulse path, the instrument will indicate the time taken by the pulse, which followed quickest route. It is thus possible to detect large voids when grid of pulse velocity measurement is made over a region in which voids are located.

The measurement of pulse velocity may be used to determine the following

(a) The homogeneity of the concrete.
(b) The presence of void, cracks or other imperfections.
(c) Changes in the condition of concrete, which may occur with time or through the action of fire, frost or chemical attack or any other reason.
(d) The quality of concrete in relation to specified standard requirement, which generally refer to its strength.
(e) Detection of large voids or cavities in the concrete.
(f) Estimating the depth of the cracks.
(g) Monitoring the change in the concrete structure with the time.

2.4 As per BS 1881, Section 203, 1986 (3), UPV method may be used for applications like evaluation of strength of concrete, uniformity of concrete, quality control during construction, investigations and survey for pre-stressed structure, estimation of damages due to fire or due to environmental impacts, deterioration of concrete due to chemical attack due or due to chloride ingress near sea shore etc.

2.5 The windows-based software can be used for waveform visualization and analysis.
### Table Natural Frequency of Transducers for Different Path Length

<table>
<thead>
<tr>
<th>Path Length (mm)</th>
<th>Natural Frequency of Transducer (kHz)</th>
<th>Minimum Transverse Dimensions of Members (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 500</td>
<td>150</td>
<td>25</td>
</tr>
<tr>
<td>500-700</td>
<td>≥ 60</td>
<td>70</td>
</tr>
<tr>
<td>700-1500</td>
<td>≥ 40</td>
<td>150</td>
</tr>
<tr>
<td>Above 1500</td>
<td>≥ 20</td>
<td>300</td>
</tr>
</tbody>
</table>

2.6 The pulse velocity may be higher by 2% in case of concrete with moisture. The pulse velocity is not affected for the temperature of concrete between 5° & 30°C. Elevated temperatures reduce pulse velocity by about 5% & reduced temperature including sub-zero temperatures increase the velocity about 7.5%.

**The surface of the concrete to be subjected to UPV, shall be made smooth.**

### 3.0 REBOUND HAMMER TEST (IS 13311 PART II: 1992):

3.1 Rebound Hammer Tests is carried out in accordance with I.S. 13311 (Part II) –1992 for assessing THE FOLLOWING

(a) Assessing the likely compressive strength of concrete.

(b) Assessing the uniformity of concrete and

(c) Assessing the Quality of concrete with respect to standard requirements.

The apparatus used for this test consists of a spring-controlled mass that slides on a plunger within a tubular housing. The impact energy required for rebound hammers is 2.25 Nm. For this test smooth, clean & dry surface shall be selected.

For taking a measurement, the rebound hammer is held at right angles to the surface of the concrete member. The test can thus be conducted horizontally on vertical surfaces or vertically on horizontal surfaces. If the situation demands, the rebound hammer can be held at intermediate angles also, but in each case, the rebound number will be different for the same concrete.

3.2 The probable accuracy of prediction of concrete strength in a structure is ±25 % (tolerance). Thus, the Rebound Hammer test is not an absolute test of quality of concrete but is very good for random inspection of concrete work at any time.

The representation of results of Rebound Hammer Test in colour is given here under **LEGEND FOR REBOUND HAMMER RESULTS**

<table>
<thead>
<tr>
<th>Rebound Number Range</th>
<th>Colour</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 20</td>
<td>Blue</td>
<td>Poor</td>
</tr>
<tr>
<td>20 to 40</td>
<td>Green</td>
<td>Doubtful</td>
</tr>
<tr>
<td>40 to 60</td>
<td>Orange</td>
<td>Good</td>
</tr>
<tr>
<td>60 to 80</td>
<td>Yellow</td>
<td>Very Good</td>
</tr>
<tr>
<td>80 to 100</td>
<td>Gray</td>
<td>Excellently</td>
</tr>
</tbody>
</table>
4.0 TEST FOR ZINC COATING OF STEEL TOWER PARTS:
4.1 Proper galvanizing of the tower members prevents corrosion of tower members. Minimum specified value of zinc coating for hot dip galvanized tower material is 85 microns. The test was carried out with the help of a special mobile handheld device known as ELCOMETER.
4.2 The image of typical Elcometer is given below:

![Digital Elcometer](image.jpg)

This portion to firmly touch the galvanized surface.

Digital Elcometer.

4.3 Elcometer is an instrument which shows the thickness of coating of galvanizing, paint etc. on a plane surface. One end of the chord (Transducer) is connected to device and the other end of chord (Receiver) is connected to the tower part. The receiver is required to remain firmly touched to the surface in such a way that there is no gap between the round surface of receiver and the tower part.

5.0 VERTICALITY TEST
5.1 While the tower is being erected, the crew members generally ensure that the tower is truly vertical. The permissible deviation in verticality is 1 in 300. This deviation is in transverse and longitudinal directions. This is indicated below.

![Transverse and Longitudinal Faces](image.jpg)

Transverse Face Longitudinal Face

5.2 The loss of verticality is due to improper stub setting, erection & stringing.
5.3 The total station, which is normally used for survey work, is also deployed to measure the verticality of the tower. For the measurement of actual deflection of tower in transverse
direction, the total station is positioned below the line in the centre. For the measurement of verticality in longitudinal direction, the total station is positioned parallel to longitudinal face.

5.4 If the tower is inclined beyond limit and likely to suffer from damage, the rectification need to be done by de-stringing and restringing. There are various ways and means to accomplish this: They may include
(a) balancing tension on the tower
(b) retrofitting some members
(c) tightening of Bolts-nuts.

6.0 CONCRETE CORE CUTTING
6.1 The Ultra Pulse Velocity (UPV) and Rebound Hammer (RH) tests give fair idea about the soundness of concrete, homogeneity and density. However, the quality of concrete in terms of mix proportion and compressive strength cannot be determined. The core cutting and subsequent testing gives much better reflection of the strength of the concrete, voids, cracks, depth of carbonation of concrete, chemical composition etc.
6.2 The concrete core cutter have a rotary Dimond cutting bits. It can be operated manually, hydraulically or through electric power, depending upon the diameter of core and depth of cutting.

6.3 Core cutting can be done in slabs, Beams or columns. The core cutting machine has to be positioned accordingly. The strength of the concrete core test specimen depends upon its shape, proportions and size. As the core is cut in a cylindrical shape, the test result will
depend upon Height to Diameter (H/D) ratio of the sample. The most preferred H/D ratio is around 2.0. The diameter of core shall be more than 3 times the size/diameter or aggregate used in the concrete, for better results. If the cutter of particular size is not available, correction factor may be required.

6.4 Presence of steel in the core across the cross-section causes 5% to 15% reduction in the compressive strength of the concrete. Presence of steel along the length of the core is not desirable.

7.0 CASE STUDY ON A FEED WATER PUMP LINE OF THERMAL POWER STATION

The above line was constructed more than 15 years ago. Due to various failures, it became necessary to carry out non-destructive testing on foundation and tower body. The details of the NDT carried out are given hereunder. This includes, UPV Test, Rebound Hammer Test, Verticality Test and the Zinc Coating Test.

7.1 CASE STUDY OF UPV AND REBOUND HAMMER TEST

7.1.1 UPV was performed to find out the condition of concrete work. The typical photograph of work of UPV being done are given below

7.1.2 Similarly, a rebound hammer test was carried out on the concrete work of the same line. The typical photo of work under process is given below
Tower No. 5

7.1.3 The tabulation of measurement of UPV and Rebound Hammer test on some locations is as given under

**UPV TEST:** – UPV readings obtained at various locations of transmission line tower are as under

<table>
<thead>
<tr>
<th>Location</th>
<th>Type</th>
<th>Transit time (µs)</th>
<th>Path length (mm)</th>
<th>Pulse Velocity (km/s)</th>
<th>Corrected Pulse Velocity (km/s)</th>
<th>Quality of concrete as per IS 13311 (part I) 1992</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHIMNEY-P1</td>
<td>1</td>
<td>101</td>
<td>500</td>
<td>4.930</td>
<td>4.930</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>102</td>
<td>501</td>
<td>4.920</td>
<td>4.920</td>
<td>Excellent</td>
</tr>
<tr>
<td>CHIMNEY-P2</td>
<td>1</td>
<td>95</td>
<td>502</td>
<td>5.309</td>
<td>5.309</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>96</td>
<td>503</td>
<td>5.229</td>
<td>5.229</td>
<td>Excellent</td>
</tr>
<tr>
<td>CHIMNEY-P3</td>
<td>1</td>
<td>100</td>
<td>504</td>
<td>5.053</td>
<td>5.053</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>98</td>
<td>505</td>
<td>5.132</td>
<td>5.132</td>
<td>Excellent</td>
</tr>
<tr>
<td>CHIMNEY-P4</td>
<td>1</td>
<td>99</td>
<td>506</td>
<td>5.112</td>
<td>5.112</td>
<td>Excellent</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>102</td>
<td>507</td>
<td>4.995</td>
<td>4.995</td>
<td>Excellent</td>
</tr>
</tbody>
</table>

Note: The concrete work is very good

**REBOUND HAMMER TEST**

Rebound hammer testing was conducted at the same locations where UPV readings were taken. Six readings of Rebound number were taken at each location. The rebound numbers obtained at each location are presented below.

<table>
<thead>
<tr>
<th>Location</th>
<th>Rebound hammer numbers</th>
<th>Average RH Number</th>
<th>Compressive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHIMNEY-P1</td>
<td>1</td>
<td>59 51.5 48 39</td>
<td>46 42.5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>56 53.5 43.5</td>
<td>62.5 59 48</td>
</tr>
<tr>
<td>CHIMNEY-P2</td>
<td>1</td>
<td>60 49.5 39 57</td>
<td>52 49.5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>50 56 48</td>
<td>44.5 31.5 29</td>
</tr>
<tr>
<td>CHIMNEY-P3</td>
<td>1</td>
<td>49 56 51</td>
<td>57.5 39 42.5</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>55 54.5 48</td>
<td>60 69 59.5</td>
</tr>
<tr>
<td>CHIMNEY-P4</td>
<td>1</td>
<td>50.5 52 51.5</td>
<td>53 57 48</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>58 49 48.5</td>
<td>54 49.5 51.5</td>
</tr>
</tbody>
</table>

Note: Higher rebound number suggest possibility of carbonation in concrete.

CC: Carbonated Concrete. However, no rectification is required immediately.
Tower No. 7

**UPV TEST:** – UPV readings obtained at various locations of transmission line tower are as under

<table>
<thead>
<tr>
<th>Location</th>
<th>Type</th>
<th>Transit time (µs)</th>
<th>Path length (mm)</th>
<th>Pulse Velocity (km/s)</th>
<th>Corrected Pulse Velocity (km/s)</th>
<th>Quality of concrete as per IS 13311 (part I) 1992</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHIMNEY -P1</td>
<td>1</td>
<td>275</td>
<td>500</td>
<td>1.820</td>
<td>1.820</td>
<td>Doubtful</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>479</td>
<td>501</td>
<td>1.046</td>
<td>1.046</td>
<td>Doubtful</td>
</tr>
<tr>
<td>CHIMNEY -P2</td>
<td>1</td>
<td>122</td>
<td>502</td>
<td>4.115</td>
<td>4.115</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>135</td>
<td>503</td>
<td>3.716</td>
<td>3.716</td>
<td>Good</td>
</tr>
<tr>
<td>CHIMNEY -P3</td>
<td>1</td>
<td>614</td>
<td>504</td>
<td>0.821</td>
<td>0.821</td>
<td>Doubtful</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>300</td>
<td>505</td>
<td>1.685</td>
<td>1.685</td>
<td>Doubtful</td>
</tr>
<tr>
<td>CHIMNEY -P4</td>
<td>1</td>
<td>155</td>
<td>506</td>
<td>3.261</td>
<td>3.261</td>
<td>Medium</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>150</td>
<td>507</td>
<td>3.374</td>
<td>3.374</td>
<td>Medium</td>
</tr>
</tbody>
</table>

Note: Some concrete portion is showing poor results. Repairing is required.

**REBOUND HAMMER TEST**

Rebound hammer testing was conducted at the same locations where UPV readings were taken. Six readings of Rebound number were taken at each location. The rebound numbers obtained at each location are presented below.

<table>
<thead>
<tr>
<th>Location</th>
<th>Rebound hammer numbers</th>
<th>Average RH Number</th>
<th>Compressive Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHIMNEY -P1</td>
<td>1 25.5 35 32.5 25 26 28.5</td>
<td>29</td>
<td>10.8</td>
</tr>
<tr>
<td></td>
<td>2 22 29 27 29.5 25 23.5</td>
<td>26</td>
<td>9.8</td>
</tr>
<tr>
<td>CHIMNEY -P2</td>
<td>1 34 40.5 39 34.5 36 38</td>
<td>37</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>2 35 40.5 39 34.5 36 38</td>
<td>37</td>
<td>17</td>
</tr>
<tr>
<td>CHIMNEY -P3</td>
<td>1 30.5 29 23 25 22.5 29</td>
<td>27</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>2 20 21.5 25.5 28 32.5 31</td>
<td>26</td>
<td>9.8</td>
</tr>
<tr>
<td>CHIMNEY -P4</td>
<td>1 36 33 29.5 35.5 34 38.5</td>
<td>34</td>
<td>14.2</td>
</tr>
<tr>
<td></td>
<td>2 31 32 26.5 38 37.5 28</td>
<td>32</td>
<td>13</td>
</tr>
</tbody>
</table>

Note: Higher rebound number suggest possibility of carbonation in concrete.

CC: Carbonated Concrete
The average compressive strength of concrete for tower 7 as per Rebound Hammer test was found 12.70 MPa. The grade of concrete shown in construction drawing was m–20. This suggest poor quality of concrete work.

7.2 CASE STUDY OF VERTICALITY MEASUREMENT OF TOWERS

7.2.1 Verticality measurement of tower is done with the help of Total Stations and Prism as already indicated earlier. The verticality measurement done on certain tower locations are indicated below

<table>
<thead>
<tr>
<th>Tower Type &amp; Location No.</th>
<th>Tower Height (Mtr.)</th>
<th>Actual Deflection in Transverse (+/-) X Direction (mm)</th>
<th>Permissible Deflection in Transverse (+/-) X Direction (mm)</th>
<th>Actual Deflection in Longitudinal (+/-) Y Direction (mm)</th>
<th>Permissible Deflection in Longitudinal (+/-) Y Direction (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (T)</td>
<td>26</td>
<td>0</td>
<td>86.67</td>
<td>(+) 190</td>
<td>86.67</td>
</tr>
</tbody>
</table>

Recommendation / Suggestion: The Longitudinal deflection is towards Location Number 2. Links/ “D” shackles shall be added on the tension strings. Verticality should be checked again. Once it is found to be within the permissible limit, further addition of links/ “D” shackles should be stopped. If the verticality do not improve after addition of links/ “D” shackles, it indicates improper stub setting and or forced fitting of members during erection. If this is the situation, we may have to de-string the tower, and rectify the defects in the tower and re-string it.

However, it appears that there is no immediate danger to the tower and if rectification is to be done, it can wait till plant shutdown is available.

<table>
<thead>
<tr>
<th>Tower Type &amp; Location No.</th>
<th>Tower Height (Mtr.)</th>
<th>Actual Deflection in Transverse (+/-) X Direction (mm)</th>
<th>Permissible Deflection in Transverse (+/-) X Direction (mm)</th>
<th>Actual Deflection in Longitudinal (+/-) Y Direction (mm)</th>
<th>Permissible Deflection in Longitudinal (+/-) Y Direction (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 (T)</td>
<td>38.3</td>
<td>(-) 160</td>
<td>127.67</td>
<td>(+) 30</td>
<td>127.67</td>
</tr>
</tbody>
</table>

Recommendation / Suggestion: Deflection in only transverse direction is marginally high. No rectification is required. However, the verticality should be monitored by taking readings at an interval of 5 years or less.
Non-Destructive Condition Monitoring of Transmission Line Towers & Foundation

<table>
<thead>
<tr>
<th>Tower Type &amp; Location No.</th>
<th>Tower Height (Mtr.)</th>
<th>Actual Deflection in Transverse (+/-) X Direction (mm)</th>
<th>Permissible Deflection in (+/-) X Direction (mm)</th>
<th>Actual Deflection in Longitudinal (+/-) Y Direction (mm)</th>
<th>Permissible Deflection in Longitudinal (+/-) Y Direction (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 (S)</td>
<td>26.5</td>
<td>0</td>
<td>88.33</td>
<td>(+) 120</td>
<td>88.33</td>
</tr>
</tbody>
</table>

**Recommendation / Suggestion:** Deflection in only longitudinal direction is marginally high. This may be due to improper stub setting or forcible fitting of members during tower erection. No rectification is required. However, the verticality should be monitored by taking readings at an interval of 5 years or less.

7.3 **CASE STUDY OF MEASUREMENT OF ZINC COATING ON STEEL TOWER PARTS**

7.3.1 The Zinc coating on steel tower parts was measured by handheld Elcometer. The equipment has already been described here before.

7.3.2 The details of measurement done on some towers is given here under.

<table>
<thead>
<tr>
<th>TOWER LOC. N0.</th>
<th>SPAN (Mtr.)</th>
<th>Average Galvanizing Value (in micron)-Leg 1</th>
<th>Average Galvanizing Value (in micron)-Leg 2</th>
<th>Average Galvanizing Value (in micron)-Leg 3</th>
<th>Average Galvanizing Value (in micron)-Leg 4</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>260</td>
<td>90.2</td>
<td>97.6</td>
<td>93.2</td>
<td>98.9</td>
<td>All Values are found to be well above the prescribed limit of 85 microns, hence safe. No</td>
</tr>
<tr>
<td>02</td>
<td>240</td>
<td>104.1</td>
<td>112.5</td>
<td>111.8</td>
<td>98.8</td>
<td></td>
</tr>
<tr>
<td>03</td>
<td>250</td>
<td>105.8</td>
<td>98.5</td>
<td>112.8</td>
<td>100.3</td>
<td></td>
</tr>
<tr>
<td>04</td>
<td>217</td>
<td>115.8</td>
<td>110.5</td>
<td>104.8</td>
<td>116.8</td>
<td></td>
</tr>
<tr>
<td>05</td>
<td>161</td>
<td>97.6</td>
<td>125.1</td>
<td>94.5</td>
<td>99.7</td>
<td></td>
</tr>
<tr>
<td>06</td>
<td>290</td>
<td>119.3</td>
<td>132.3</td>
<td>114.3</td>
<td>99.6</td>
<td></td>
</tr>
<tr>
<td>07</td>
<td>220</td>
<td>99.5</td>
<td>95.8</td>
<td>110.4</td>
<td>96.7</td>
<td></td>
</tr>
<tr>
<td>08</td>
<td>251</td>
<td>97.0</td>
<td>100.1</td>
<td>107.0</td>
<td>103.0</td>
<td></td>
</tr>
<tr>
<td>09</td>
<td>202</td>
<td>84.7</td>
<td>99.0</td>
<td>86.9</td>
<td>99.2</td>
<td></td>
</tr>
</tbody>
</table>
7.3.3 All the measured values are within the permissible limit of 85 micron. This indicates that all the tower structures are having good galvanizing after a passage of more than 15 years.

8.0 CASE STUDY OF CORE CUTTING AND TEST ON THEM

8.1 In yet another line, there was a doubt regarding the quality of concrete used in the tower foundation work. The chimney and footing of randomly selected towers were subjected to core cutting and the testing of the cores in the laboratory.

8.2 The following photographs show the process and equipment for core cutting and the results of the analysis.

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>202</td>
<td>101.9</td>
<td>105.2</td>
<td>100.4</td>
<td>102.6</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>195</td>
<td>96.6</td>
<td>89.3</td>
<td>106.4</td>
<td>106.4</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>226</td>
<td>114.7</td>
<td>287.9</td>
<td>97.8</td>
<td>90.3</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>231</td>
<td>97.9</td>
<td>97.8</td>
<td>104.6</td>
<td>95.3</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>231</td>
<td>95.0</td>
<td>112.4</td>
<td>109.5</td>
<td>106.8</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>232</td>
<td>94.8</td>
<td>99.4</td>
<td>117.9</td>
<td>114.8</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>225</td>
<td>110.3</td>
<td>107.1</td>
<td>97.1</td>
<td>149.8</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>159</td>
<td>113.9</td>
<td>118.4</td>
<td>107.0</td>
<td>126.3</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>740</td>
<td>111.0</td>
<td>107.1</td>
<td>108.2</td>
<td>121.0</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>152</td>
<td>115.4</td>
<td>115.0</td>
<td>131.3</td>
<td>116.0</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>205</td>
<td>86.0</td>
<td>82.1</td>
<td>89.9</td>
<td>106.0</td>
<td></td>
</tr>
</tbody>
</table>

8.3 The samples of core retrieved from the foundation are shown below. It can be seen that the concrete work from where the below core were retrieved, is quite good. The test result indicated that it was more than M20.
8.4 The following photographs clearly show that the concrete work is not up to the mark. Some of the cores are subjected to laboratory testing and it was found that the concrete mix ranged from 7mpa to 12 mpa. This is much lower and can be termed as poor concrete.

8.5 One of the footing from where the samples of core cutting were retrieved, is shown below. It can be seen that concrete work is not at all up to the mark.

9.0 CONVENTIONAL METHOD OF REPAIRS:

9.1 Whenever, the results of UPV and Rebound Hammer Test are found to be not favorable, it is required to carry out rectification work. The, conventional method of repairs is given hereunder:

(a) The foundation shall be opened by excavating one leg in a clockwise manner (from Left to right while traveling from source station to user sub–station).
(b) This will be done by chipping of the concrete (by using concrete breaker or manually) and exposing the re-bars and then providing same no of bars in the cap with stirrups.
The additional capping re-bars shall be placed at a distance of minimum of 100mm from the existing bars.

(c) The cover to the new set of re-bars shall be 75mm minimum. The eccentricity observed in the chimney should be made good by adjusting the re-bars and shuttering. If during the concrete breaker operations, excess honeycombing is found, pressure grouting shall be resorted to. This will help in covering the damaged concrete portion.

(d) If the footing and the lower portion of chimney is also found not to be giving metallic sound while striking the hammer (giving a dull sound), the re-bars of footing and chimney shall be exposed as indicated above. We can use rebound hammer and compare various sections of the concrete and concentrate upon the weaker portions of the concrete work.

(e) The footing shall be excavated from sides to the tune of around 450 mm to facilitate placement of shuttering and re-bars for the purpose of capping. After the capping work is over, backfilling shall be done by using slurry made out of soil/fly ash, fine sand and cement in the proportion of 1:4:8 (respectively cement, sand and soil/fly ash). The slurry shall be stiff enough for pouring and should not be in a liquid form. This will be done to a minimum height of 30% from the bottom of the footing taking into account the depth of the footing from ground level. Rest of the pit shall be backfilled with the excavated soil.

(f) Proper compaction shall be done at every 150mm layer of backfill using water.

(g) Curing shall be done for a minimum period of 10 days.

9.2 Whenever, the results of verticality test are not favorable rectification can be done in following manner.

(a) If the verticality in the transverse direction is not within the allowable limit, there may be reasons like improper stub setting or inadequate tightening of bolts – nuts. Sometimes forcible fitting of members also results into loss of verticality. Improper bifurcation of angle of deviation may also cause excess deflection.

(b) We may have to destring such towers and retrofit the same so as to bring the verticality within permissible limit.

(c) If the verticality in the longitudinal direction is found more than permissible, the reasons for the same may be not following the sag and tension values indicated in the stringing charts for the earth-wire and conductors, causing imbalance of tension in the normal condition of tower. The defect can be rectified by destringing the tower location and adjust the sag and tension by providing links on any one side of the tension location. For this purpose, we may have to de-clip the suspension clamps and transfer the conductor on rollers. After carrying out the rectification work, and re-stringing, the verticality may be checked again.

(d) In any case the loss of verticality in transverse and longitudinal direction not amounting to a heavy deflection is not much serious in normal condition. However, it can pose a threat to tower under broken wire condition.
Re-Baring Provided At Chimney Section Sectional View [Existing Re-Bars To Be Exposed By Chipping/Concrete] Figure – 1

Re-Baring Provided At Footing And Chimney Section Sectional View [Existing Re-Bars To Be Exposed By Chipping/Concrete Breaking] Figure – 2

Re-Bar Provided At Footing And Chimney Section Sectional View [Existing Re-Bars To Be Exposed By Chipping/Concrete Breaking] Figure – 3
10.0 NDT DURING CONSTRUCTION

10.1 It is said that “prevention is better than cure”. If the NDT as indicated as above, is carried out during Foundation work, Erection of tower and the stringing work, we can save lot of embarrassment during the operation & maintenance of the line.

10.2 These days large number of 400kV & 765kV lines are being constructed on PPP (BOOM) model where the SPV is required to Build the transmission line at its own cost and maintain it for 35 years with an availability of 98.5% or more. There are penalties on default on availability and incentive on stretching availability beyond the guaranteed benchmark of 98.5%.

10.3 Use of advance NDT equipment can ensure good quality of foundation, tower erection and stringing work.

11.0 CONCLUSION

11.1 The UPV test, rebound hammer test, Zinc coating test and verticality test on the existing line loads to the present condition of transmission line.

11.2 N.D.T. can also be done on the line under construction.

11.3 Repairing & corrective action can ensure better life of the transmission line.
Hyperspectral Detection Method for Pollution Degree of Overhead Line Insulators

GUANGNING WU, WENFU WEI, YUJUN GUO, KAI LIU AND YAN QIU
Southwest Jiaotong University, China

ABSTRACT
Pollution flashover can easily cause the system to lose stability leading to large-scale outages. With the rapid development of industry and agriculture, severe weather conditions such as fog-haze and salt-fog happen more frequently. As the insulator of overhead lines is exposed to the atmospheric environment for a long time, pollution problem is more serious. Meanwhile, with the construction of UHV overhead lines, once pollution flashover accident occurs, it will cause greater damage. The on-line detection of insulator pollution degree of overhead lines is important to the prevention and control of flashover. This paper proposed a non-contact detection method of insulator pollution degree based on hyperspectral technique. Firstly, hyperspectral images of the samples with different pollution degrees were obtained by hyper-spectrometer. Secondly, after original hyperspectral images were corrected by black-and-white correction, hyperspectral curves from the region of interest (ROI) of corrected images were obtained. Finally, a multiclassification model of extreme learning machine (ELM) was built to realize the pollution degree classification of test samples. The results show that with same kind of pollution on the surface of silicone rubber, there are no differences on the absorption peak, the position of reflection peak, amplitude and the change trend of the hyperspectral curves, but the amplitude obviously changes; and the ELM-classification model established by the whole-band data can accurately and rapidly classify the pollution degrees, with the pollution degree classification accuracy of NaCl-CaSO4 reaching 95%; and the ELM model based on hyperspectral curves data of the artificial pollution samples can classify the surface of insulator umbrellas with different pollution degrees, and the classification accuracy of sample NaCl-CaSO4 is 90.0%. Therefore, this method can provide a technical reference for on-line measurement of insulator pollution degree. In order to make hyperspectral technique better applied to the on-the-spot detection of insulator pollution, the identification of principal components and the classification of pollution degrees of natural pollution based on the hyperspectral features should be further studied. Consequently, the results of this study prove that hyperspectral technique has considerable potential for the non-contact detection of insulator pollution degree.

Keywords: Hyperspectral technique; insulator; pollution degree; black-and-white correction; extreme learning machine.

1. INTRODUCTION
The flashover of overhead line insulator is the key problem to be solved for the safe and stable operation of electrical power system. Moreover, the loss caused by pollution flashover to the power system is nearly 10 times of the loss caused by lightning flashover[1], pollution flashover can easily cause the system to lose stability leading to large-scale outages. With the rapid development of industry and agriculture, severe weather conditions such as fog-haze and salt-fog happen more frequently. As the insulator of overhead line is exposed to the atmospheric environment for a long time, pollution problem is more serious. Meanwhile, with the construction of UHV overhead lines, once pollution flashover accident occurs, it will cause greater damage[2-3].
In order to prevent pollution flashover, a variety of insulator pollution detection methods have been applied in laboratory and field. Measurement methods commonly used in insulator pollution degree include equivalent salt deposit density (ESDD), leakage current (LC), surface pollution layer conductivity (SPLC) [4-6]. These traditional measurement methods have certain limitations. The ESDD method requires operators to climb up the overhead towers to remove insulators, and the cleaning and measurement process is tedious, which is not suitable for on-line detection. LC measurement will be affected by the voltage polarity of power supply, ambient humidity, temperature, etc., so that it is difficult to establish a direct relationship with pollution degree. The measurement of SPLC should be carried out under the condition of saturated and damp pollution layer, and need complex measurement equipment, and it is difficult to control the damp condition of the insulators, which is not convenient for field measurement. Spectral analysis technology such as infrared imaging [7], ultraviolet imaging [8] have been widely used in insulator pollution flashover prevention because of the advantage of non-contact detection, but these two methods’ spectral resolution is relatively low, and spectrum is narrow (imaging in a particular band). Infrared imaging only reflects the characteristics of insulators’ heating, while ultraviolet imaging only reflects the characteristics of insulators’ discharge, both of them lacking the complete reflection of insulator pollution state.

Hyperspectral technique is the new technology which combines image and data based on imaging spectroscopy technology, with some advantages such as multiband (up to hundreds of wavebands), high resolution, rich information collected by hyperspectral images and large amounts of data description models, etc. [9-10]. Hyperspectral technique is mainly used in food detection, agriculture monitoring, resource exploration, archaeological investigation and so on. S. Shrestha captured hyperspectral images of four tomato varieties and analyzed the data by principal component analysis (PCA) and partial least squares-discriminant analysis (PLS-DA), and the results showed the application prospects of using hyperspectral imaging in varietal identification studies of tomato seeds [11]. X. D. Zhang presented an automatic soil texture classification system using hyperspectral soil signatures and wavelet-based statistical models, and the results showed that the methods are both reliable and robust [12]. O. Daikos made use of hyperspectral imaging for in-line monitoring of thickness and conversion of white pigmented UV-cured acrylate coatings, proving that hyperspectral imaging has considerable potential for in-line process and quality control [13]. Hyperspectral technique also shows good application potential in insulator detection of overhead lines, but there is a lack of relevant research in the field.

This paper aims to study the pollution degree detection method of insulators based on hyperspectral technique. Through obtaining hyperspectral images of artificial samples with different pollution degrees, the full-band hyperspectral curves of the regions of interest in label sample images are extracted after pretreatment to build an ELM multiclassification model. The full-band data of label samples are taken as training data to classify the pollution degree of artificial samples to be tested. This method is a way of non-contact detection, which can realize undamaged and on-line detection of the pollution degree. The results show that this method has considerable potential for the non-contact detection of insulator pollution degree with high classification accuracy.

2. The principle of the pollution degree detection based on hyperspectral technique

With the wide application of hyperspectral technique in various fields, great changes have taken place in the theory, technology and applications. The imaging spectrometer mounted in hyperspectral sensors of different spatial platforms can get hyperspectral data, and simultaneously image the target in ultraviolet, visible, near-infrared and mid-infrared regions of the electromagnetic spectrum in tens to hundreds of continuous spectral bands, as shown in Fig.1. Hyperspectral image not only improves the richness of information, but also analyzes and processes the spectral data more reasonably and efficiently.
The spectral characteristics of substance are closely related to its inherent physicochemical characteristics, and the absorption and reflection of photons at different wavelengths within the substance are selectively due to the differences in composition and structure. Therefore, the reflectance spectrum of the substance has a “fingerprint” effect, which can distinguish different substance information according to the principle that different substances have different spectra and the same substance has the same spectrum. A complete and continuous spectral curve can better reflect the intrinsic microscopic differences between different substance, which is the physical basis of hyperspectral imaging for fine substance detection.

3. Experiment method

3.1. Hyperspectral test platform

The hyperspectral test platform is composed of the hyperspectral imaging system (GaiaField-F-V10 hyper-spectrometer, computer, etc.), the symmetrical double light sources, and a standard white board with reflectance nearly about 100%. The system can be used to obtain hyperspectral images of experimental samples. In the experiment, the hyper-spectrometer was mounted on a tripod with a distance of 120 cm from lens to the sample and a downward angle of 45°. As shown in Fig.2, the light sources were symmetrically placed on both sides of the samples. The samples were placed in the imaging area for hyperspectral acquisition, and the data were transmitted to the computer via the USB line of the hyper-spectrometer. The experiment was carried out under the conditions of temperature 18-25 ℃ and humidity 30%-80%.
3.2. Sample preparation

The experimental samples were divided into three groups, and samples were prepared according to the standards IEC standard 61245 [14] and IEC standard 60815-1 [15], and the silicone rubber insulation sheet (5 cm × 5 cm) was used as base material. Since the pollution of insulator often contains NaCl, CaSO\(_4\) and other components, NaCl is generally 10% to 30% and CaSO\(_4\) accounts for 20% to 60%. Although CaSO\(_4\) is a slightly soluble substance, it has a significant effect on the flashover voltage [16-17]. Therefore, we selects NaCl and CaSO\(_4\) as the leaching solute to prepare the mixed artificial effluent of different solute and kaolin.

According to the solid layer method recommended in the standard [14], samples of four pollution degrees were prepared f. As shown in Fig.3, sample P were labelled as tag sample P 1-4, and test sample P 5-8. The ESDD corresponding to the samples with different pollution degrees were 0.06 mg/cm\(^2\), 0.10 mg/cm\(^2\), 0.20 mg/cm\(^2\), 0.35 mg/cm\(^2\), and the NSDD was 0.10 mg/cm\(^2\). The samples were naturally dried for 24 hours.

![Fig. 3. Artificial pollution Sample NaCl-CaSO\(_4\) made by solid layer method](image)

3.3. Sample spectrum acquisition

Images of each group of samples were collected separately in the laboratory via the GaiaField-F-V10 hyper-spectrometer. The pixel reflectance of samples with different pollution degrees was extracted from the hyperspectral image of artificial pollution samples, and the wavelength was taken as the abscissa and the reflectance was taken as the ordinate. Among them, 10 sets of data were extracted from each tag sample as training data, and same process of test data.

The hyperspectral image reflectance obtained by the hyper-spectrometer forms a continuous spectral curve in the wavelength range of 400-1000 nm, and the samples with different pollution degrees correspond one-to-one with the spectral curves. The curves can be further analysed by algorithms.

4. Results and analysis

4.1. Black-and-white correction

In order to overcome the influence of image noise and dark current in the band with weak light distribution, when collecting the sample hyperspectral image, the standard white board was scanned at the same time to collect the white calibration image with reflectance nearly about 100%, and then the black calibration image with the reflectance of 0 was collected under the lens cover. The hyperspectral data correction can be realized by using black-and-white correction. Correction algorithm is as follows:

\[
R_{ci} = \frac{Sample_{ci} - dark_{ci}}{White_{ci} - dark_{ci}}
\]  

Where \(Sample_{ci}\) is original spectral image data; \(Dark_{ci}\) is black calibrated image data; \(White_{ci}\) is white calibration image data; \(R_{ci}\) is black-and-white corrected image data. As shown in Fig.4, the burr of spectral curves relatively decreased, and the curves were smoother after black-and-white correction.
4.2. Classification of pollution degrees based on the ELM model

ELM is a kind of machine learning algorithm based on feed-forward neuron network. Its main characteristic is that parameters of hidden layer nodes can be randomly or artificially given without adjustment, and the learning process only needs to calculate the output weight. Therefore, ELM has the advantages of high learning efficiency and strong generalization ability [18-19]. This paper adopted the ELM theory [20-21] into the problem of insulator pollution degrees classification. Considering that this is a multiclassification problem, we designed an ELM multiclassification model.

In this paper, the classification objectives were four pollution degrees. As the spectral curves had obvious characteristics in the entire band reflectance, the reflectance values of 256 bands were taken as the input, and the output was the classification result of test sample data, as shown in Fig.5.

In Fig.5, the ordinate represents the pollution degree I, II, III and IV, and the abscissa represents the number of test sample data. The true pollution degree of sample 1-10 are I; sample 11-20 are II; sample 21-30 are III, and sample 31-40 are IV. The results show that there are errors in the classification of sample 6 and 23, so that the accuracy is 95%. Therefore, it is proved that the ELM classification model can accurately classify substances with different pollution degrees.

4.3. Model verification

In this paper, insulator FQJG2-30/16-400-M was used as an example to verify the model. Through artificial pollution test [18], pollution was deposited on composite insulator umbrella, as shown in Fig.6. In Fig.6, pollution on insulator was NaCl, CaSO₄ and kaolin. Because the size of insulator's umbrella was
different from that of silicone rubber insulation sheet, only cleaned the fan-shaped area of insulator's umbrella which had same size with silicone rubber insulation sheet (5 cm × 5 cm) with distilled. As shown in Fig.6, the ESDD of insulator umbrella 1 was 0.05 mg/cm², and the NSDD was 0.09 mg/cm², corresponding to pollution degree I. The ESDD of umbrella 2 was 0.07 mg/cm² and the NSDD was 0.15 mg/cm², corresponding to pollution degree II. The ESDD of insulator umbrella 3 was 0.21 mg/cm², and the NSDD was 0.13 mg/cm², corresponding to pollution degree III. The ESDD of umbrella 4 was 0.35 mg/cm² and the NSDD was 0.18 mg/cm², corresponding to pollution degree IV.

Fig. 6. Pollution distribution of artificially polluted composite insulator

After pollution accumulated on the insulator, its hyperspectral image was collected, and then black-and-white correction were applied to get hyperspectral curves of umbrella 1-4, each group had 10 spectral curves data as the test data of the ELM classification model established in section 4.2, classification results as shown in Fig.7. Among them, sample 1-10 were taken from umbrella 1 with true pollution degree I. Sample 11-20 were taken from umbrella 2 with true pollution degree II. Sample 21-30 were taken from umbrella 3 with true pollution degree III. Sample 31-40 were taken from umbrella 4 with true pollution degree IV. The classification results in Fig.7 indicated that the classification of sample 13, 15, 23and 26 is wrong, with an accuracy rate of 90.0%. This is because the pollution distribution of artificially polluted insulator was uneven. Hyperspectral data was taken from local area, reflecting the pollution degree of local area, but the pollution degree measured of the fan-shaped area was the average for the area. Therefore, the pollution degree measured might be a little different with that expressed by hyperspectral data, resulting deviations in part of the predicted results.

Fig. 7. The degree classification results of artificially polluted composite insulator

5. Conclusion

This paper studied the detection method of insulator pollution degrees based on hyperspectral technique. The following conclusions can be drawn.

1) with same kind of pollution on the surface of silicone rubber, there are no differences on the absorption peak, the position of reflection peak, amplitude and the change trend of the hyperspectral curves, but the amplitude obviously changes
2) The ELM-classification model established by the whole-band data can accurately and rapidly classify the pollution degrees, with the pollution degree classification accuracy of NaCl-CaSO₄ reaching 95%.

3) The ELM model based on hyperspectral curves data of the artificial pollution samples can classify the surface of insulator umbrellas with different pollution degrees, and the classification accuracy of sample NaCl-CaSO₄ is 90.0%. Therefore, this method can provide a technical reference for on-line measurement of insulator pollution degree.

4) In order to make hyperspectral technique better applied to the on-the-spot detection of insulator pollution, the identification of principal components and the classification of pollution degrees of natural pollution based on the hyperspectral features should be further studied.

6. Acknowledgment

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Improving Transmission Network Resilience Based on DLR Grid Management System

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ABSTRACT

Since the changes in the energy sector in the last few years, it can be stated that the electricity systems will play a particularly important role in the future of the sustainable energy systems. The increasing demand for electricity on the consumer side and the growing number of renewable energy sources on the producer side are encouraging the increase in transmission capacity.

Dynamic Line Rating (hereinafter referred to as DLR) is a novel, cost-effective grid management method that can increase power lines ampacity without serious network development. While the use of DLR has many benefits, there are also some challenges that system operators have to cope with for the implementation at system level. Real-time monitoring of the power lines requires several special sensors and weather stations installed on the conductor and the high voltage towers, which are currently being developed. DLR calculation algorithms are also being developed. There are several realization options for system implementation, such as soft-computing methods, probability based and physical models or the use of overhead line monitoring systems. The purpose of this article is to give a comprehensive view of the DLR method and the existing DLR models. Another major aim is to present the BME white box model developed from the CIGRE and IEEE model and the soft computing method based on BME DLR black box model. To compare the results of the two models, a case study was carried out, which could give a more accurate picture of the operation of the models and their application limits.

As a result of a complete DLR grid management system the transmission capacity of overhead lines could be raised without compromising safety and security issues. In this way, the transmission grid becomes more resilient and flexible.

Keywords: dynamic line rating, DLR, renewable energy sources, resource management, system resilience, transmission line, soft computing, neural network
INTRODUCTION OF PROJECT FLEXITRANSTORE

21.7 M Euro project »Flexitranstore« has begun on the 1st of November 2017 and will last for 4 years. 27 project partners with 8 demonstrations in 6 countries will provide new results in several topics including Dynamic Line Rating (DLR).

The project itself aims to contribute to the evolution towards a pan-European transmission network with high flexibility and high interconnection levels. This will facilitate the transformation of the current energy production mix by hosting an increasing share of renewable energy sources. Novel smart grid technologies, control and storage methods and new market approaches will be developed, installed, demonstrated and tested introducing flexibility to the European power system [1].

Increasing the reliability of both the distribution and the transmission grid is essential, especially in cases of unpredictable or even extreme weather conditions. During the project, a novel Dynamic Line Rating (DLR) model is going to be developed and tested. DLR enables existing power lines to be used in the same way as lines with higher rated temperature of the conductors. A de-icing algorithm to be developed will integrate the advantages of several already established DLR systems with some additional parameters in an effort to increase accuracy. Given a more precise DLR algorithm the state of the conductors during the de-icing process can be followed online. During normal operational conditions DLR constitutes an effective way to increase the transfer capabilities of a power line. In case of extreme weather conditions de-icing can prevent serious failures. The main objectives are to demonstrate sensor technology for power system operators to effectively handle and prevent sudden and often fatal failures, especially during icing weather conditions, to increase system security and reliability by reducing icing phenomena and to facilitate cross-border power exchanges by the implementation of the described systems [2].

INCREASING TRANSMISSION CAPABILITIES – DYNAMIC LINE RATING

Today's energy consumption and energy demand is increasing. That is particularly true in case of electric power consumption. Although the transmission lines should operate at their designed voltage and ampacity, due to the increased demands, some of the lines are already operating on elevated temperatures. To resolve that issue, the capacity of the transmission network should be increased. Dynamic Line Rating is one of the most cost effective way to increase the transmission capacity of the already existing network. DLR is an operating method, which makes it possible to utilise better the network, based on real-time data and calculations.

The DLR system is based on different types of sensors, weather stations and weather forecast which provide the essential data for the system. Line monitoring sensors are complex electrical equipment which has to function reliably and properly on the conductor or near to the conductor. Therefore, these sensors have to be tested and fitted to operate in high voltage environment [3].

Having higher ampacity rates over a power line due to DLR, increased thermal stress occurs not only on the conductors, but on insulators, and on other pieces of equipment as well. Increased ampacity resulting in increased temperature of conductors brings about an increase in sag, thus electrical clearance might be violated with higher probability [4].
During DLR system implementation the first step is critical span analysis. In this phase of work all of the spans of the selected transmission line shall be examined by different aspects through calculations and simulations. Therefore, critical spans can be identified which firstly violate the regulations related to clearance, especially when the conductor operates near the designed maximal temperature or exceed this temperature even for a short period of time.

The longitudinal section of the whole overhead line has to be investigated, and critical spans shall be selected by the following criteria:

- Highest level differences between towers,
- Longest spans,
- Obstacles and terrain under the span.

The length of the span is a critical factor, because longer spans have higher sag in case of elevated temperatures. Level difference of the towers is also crucial, because in case of larger level differences the permitted sag is smaller than in case of smaller ones. Furthermore, obstacles and terrain under the span shall also be inspected.

These objects may violate clearance, because they may change after the construction of the line, too. As the result, design documentation may not take these effects into consideration (e.g. the growth of the vegetation or terrain changes due to landscaping). Figure 1 shows a part of an elevation profile of a transmission line, which is based on the above-mentioned three criteria.

![Elevation profile of a transmission line](image)

**Figure 1 – Elevation profile of a transmission line (example)**

To ensure that clearance regulations are not violated, critical spans shall be locally examined, and the sag of the line shall be calculated for higher temperatures than the designed to know which the thermal limit is, when the sag reach the clearance limit. In case of DLR, operating temperature might exceed the designed temperature for short time – e.g. during the use of short-time emergency rating – and the clearance regulations should be comply under all
operating conditions. The transmission line sag calculations are usually carried out by modelling the sag as a parabola as it is shown in Figure 2.

**BME'S WHITE-BOX AND BLACK-BOX MODELS FOR CALCULATION**

**Preliminary studies of wind**

As several studies have shown in the past, the main cooling factor is the wind during the DLR calculations (both speed and direction).

It is common that a given direction characterizes the behaviour of the wind. This direction correlates with the strength of the wind, so the higher the wind speed is, the direction becomes closer to the dominant wind direction. Most of the studies agree that the wind speed above 5 m/s is worth to calculate with.

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Figure 2 – Sag simulations for different conductor temperatures

Figure 3 – Windrose (example)
Figure 4 and Figure 5 shows the windroses based on real meteorological data between 2013 and 2014. The diagrams justify the claim, that there is no characteristic win direction in case of low wind speeds – while wind speed ≤ 5m/s – thus the direction of the wind is fully stochastic. In case of higher wind speeds – while wind speed > 5 m/s – there is major direction which was south-southeast and north-northeast in this study. This study showed the wind direction cannot be accurately predicted in case of low wind speeds.

BME’s extended white box model

In case of so-called »white-box« models, results of the calculations are based on equations taking the inputs as variables into consideration. An extended white box model was developed in the Budapest University of Technology and Economics (BME) based on the experiences gained during the analysis of archive weather data and the physical equations of the calculation methods. BME’s extended white box model unites the international standards with the following new approaches:
- Considers the cooling effect of the precipitation
- Considering wind effect in different OHL sections
- Improved weather forecast processing

The extended physical model takes into consideration the cooling effect of the precipitation on the line, which grants higher transmission capacity in case of rainy weather conditions. The stochastic behavior of the wind was corrected with the consideration of the wind in different OHL sections, thus the local thermal overloads of the conductor were eliminated. The improved weather forecast processing module increases the time resolution of the weather forecast with various interpolation methods.

**BME’s black box model**
Currently there are two well-known algorithms to determine the ampacity of a given power line by the white-box model: CIGRE [5] and IEEE [6] methods. In general, CIGRE model takes more environmental factors into account than IEEE. In terms of »black-box« models, no equations are used. In the algorithm of BME, a novel approach has been developed and introduced based on the use of soft-computing methods (neural networks). Figure 6 shows the applicability of the neural network for DLR calculations:

The DLR model of the CIGRE and IEEE standards are empirical ones which means that there are some simplifications (cooling effect of the precipitation) in both of them. Moreover, there are special circumstances when these models provide different limit values for the current (e.g. when the wind speed is above 5 m/s). Due to this fact, it may be worthwhile investing new models based on different approaches. The examinations of the soft computing methods have shown that the use of neural network could be promising, because these kinds of networks are able to learn and handle complex data-sets. In BME’s model, there are 2 main steps for the determination of the maximum current value: the calculation of the temperature of the line and the determination of the DLR value itself.

For the calculation of the temperature of the conductor, a neural network is applied. There are 4 inputs of the network, such as ambient temperature, wind speed, solar radiation, and the real-time current, while the output of the model is the temperature of the conductor. Running the simulations have shown, that a 4-layer, forward cascade neural network has the lowest error, where the number of the neurons are 4 in the input, 32 in the hidden and 1 in the output layer as it shown in Figure 7. Figure 8 illustrates the validation of the used neural network.
The average error of the network is about 2-3 °C, which is shown in Figure 9. This error is acceptable, because the average deviation of most sensors is ±2°C.

As the line temperature is available, the DLR value can be calculated from a heat equation by determining the extra heat gained from the increased current of the grid as it shown in Figure 10. By using this calculation method, it is important to not exceed the temperature limit of the conductor.
The biggest advantage of the black box model is that temperature sensor for the validation of the results is installed on the line, while all the environmental parameters can be taken into account.

CONCLUSION

The application of DLR can significantly increase the transfer capacity of power lines without reducing availability and security requirements. However, the existing models in the literature are neglected and due to this they need to be further developed and refined. BME's extended white box model is a further development of the CIGRE model, which includes, among others, the cooling effect of the precipitation. Contrary, BME's black box model uses a neural network to calculate the temperature of the conductor, from which dynamic transfer capacity of the line can be determined. To compare how these different models work, a case study was carried out within the FLEXITRANSTORE project framework. Based on the simulations on a 110 kV power line, the results of the different models are in the same range. The different approaches have different advantages also, and the presented results are good basis to refine both models in the future.

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Need for Integrating Dynamic Line Rating to the Overhead Transmission Lines

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ABSTRACT

Dynamic line rating (DLR) is an overhead transmission line real-time monitoring system for monitoring and rating of existing and new overhead transmission lines. DLR sensors are becoming popular with utilities for optimal use of line capacity. DLR provides real-time monitoring of conductor temperature, sag, load, and weather conditions. Additionally, it provides predictive load model to enhance the efficiency and optimise the line ampacity. The software provided can be used for maximizing the line loading.

The actual current, thermal rating of the line and sag are easily measured using DLR. The sag measurement helps in reviewing ground clearance of the overhead lines in cities, crossings over roads, railroads, other overhead lines, etc. Additionally, measured data like angle (sag) is implemented to the software application to detect ice overloads or fallen trees. Sag cannot be correlated in two similar overhead lines due to various external factors. Higher sag is observed in the older lines.

INTRODUCTION

The existing transmission lines should ensure safe, reliable and assured power delivery. In India, renewable energy sources are being added rapidly and there is a simultaneous increase in load demand. This calls for additional capacity of the existing lines. In such cases, to deliver assured power, utilities look for new line or uprating of the existing lines.

Today all such measurements are based on Static line rating (SLR). Traditionally, industry relies on the worst-case weather conditions for calculating SLR. This simplifies equipment specification while providing significant safety margin. But it would be wrong to assume the real rating is always greater than the SLR. The maximum utilization of the transmission line is only possible if the operators have accurate data about the actual ground clearance, crossed lines, vegetation, instantaneous conductor temperature, sag and current.

Adding renewable energy sources can cause dynamic current changes on the lines, including direction of power flow changes. Therefor some lines are overloaded and others under loaded. The electricity demands stable and reliable operation in this new condition with the support of smart-grid elements like DLR for real time measurement and data analysis.

If the real conditions of the line are continuously measured in place of SLR, then, more appropriate rating can be considered. This is called in power transmission as Dynamic Line Rating (DLR). The devices used in DLR measure true current, more accurate conductor thermal limits, weather conditions and line sag which is a critical safety need. It has been reported around the world that, the utilities have got benefited by using DLR devices in their network operationally and financially. This is mainly because, utilities can unlock unused transmission capacity, potentially unforeseen impact of contingencies, un-necessary curtailment during forced outages, or not detecting N-1 bottleneck conditions like during wind ramps or even to measure ice loading or tree falling.

Understanding real time changing energy flow, weather conditions in transmission lines is really demanding and complex.
**DLR TECHNOLOGY**

There are always two different possibilities to increase the ampacity level of the transmission lines. Building new transmission lines or uprate the existing infrastructure. Upgrading with DLR on exiting lines provide realistic data for augmenting the capacity. On the new lines helps in unlocking the additional capacity and helps in taking decision in balancing the network.

DLR technologies have been in service in world utilities since 1977. The products use a variety of physical properties and sensors for both the transmission line and the environment to help define a real time limit which is more appropriate than the commonly used Static Line Rating (SLR). Whereas, traditionally, industry relies on the worst-case weather conditions for calculating SLR.

The assumption underlying SLR is that, the conductor temperature and line sag are deterministically correlated. However, in the field there will be some deviations based on load, age of the line and various site conditions like ambient temperature, wind speed, wind direction etc and hence actual behaviour of the transmission line and capacities must be well established based on dynamic line rating.

The heat transfer of overhead conductor is important to understand to appreciate the fact that DLR is important compared to present day SLR per the below equation;

**Relationship between heating and cooling**:  
\[ PJ + PM + PS + Pi = PC + Pr + Pw \]

- **PJ**: the Joule heating  
- **PM**: the magnetic heating  
- **PS**: the solar heating  
- **Pi**: the corona heating  
- **PC**: the convective cooling  
- **Pr**: the radiative cooling  
- **Pw**: the evaporative cooling

**Selecting the right DLR technology and devices**

Direct and indirect measurement devices are available for DLR.

The right technology to be selected should be based on physical measurements and not based on mathematical calculations. The most important measurements are current, temperature and sag.

The accuracy of current, temperature, sag, type of alarms is critical while selecting the right sensors. Interlinkage with the SCADA and maintenance of software need to be well understood along with hardware and sensors calibration. The software must be intuitive and open to add different measurements for past and future analysis.

The number of sensors needed depends upon the line length, landscape, critical spans like road crossing or railway crossing or settlement areas etc. If the line is straight and having no change in landscape, then even one device at the lowest clearance from the ground may serve the purpose. Generally, with a line survey, or tower schedule report, it will be easy to suggest the minimum number of sensors needed per line. These devices are easy to install and re-deployable.

The DLR in India, is the most needed on 66kV to 220kV transmission lines due to the rapid increase in load and with the rapid addition of renewable energy sources. These devices are available for higher than 220 kV also.

**Kerala Pilot Project Case Study**

Sterlite has installed DLR at Cheruthponi dam, Idukki district on VZTP-NDKM-KTPL line at 2300 feet height above sea level. This is a 66kV line and about 40 years old. This line is having different conductors for different sections. The problem statement from KSEB was to review the possible capacity of the line, to connect renewable power generation on this line.
KSEB had done the line survey to identify the longest span on the line with higher sag. The section identified is with ACSR Dog with 680m span. The current on this line today is about 93A -132A and the conductor can be safely loaded up to 324A. One section of the line is having ACSR Mink and hence, the line has got maximum setting for 200A. If this section is uprated, then, the capacity of line may be increased to 300A.

The DLR device was installed in the month of May 2019 and the line is being monitored from then.

The implementation of the DLR sensor has passed through severe rain, thunderstorm, and varying weather conditions and proved to be rugged.

In this case, study is done to see the possible ampacity increase on an existing 40 years old line to utilize the existing assets fully, with additional renewable power connected. The data indicates that the average amperage of the line is 93A. We observed that between 13.00 – 14.00 hours current is about 160A. The recordings are taken for every 10 minutes; hence, it is clear from the graph the current exceeding 150A for a short duration and is not frequently. If the line current goes as high as 160A, the total ampacity on the line that is possible is about 370A from the DLR data.

That means 370-160 = 210A is the additional ampacity available. This should be always read with weather and wind conditions. The total ampacity can be higher or lower depending upon wind speed, direction and solar irradiation etc.

This data along with complete line survey (e.g. hotspot survey) if done then actual ampacity and capacity is possible to predict. The graph clearly indicates that if a section of Mink is reconductored then, line capacity can be enhanced. Hence, connecting renewable energy source to the same line may be a possibility.

**Advantages of Using DLR Device**

DLR usage has got many advantages like; congestion relief before CAPEX is approved for uprating, Improved grid reliability, capacity curtailment, faster integration of renewable, after reconductoring to help review the enhanced capacity and savings in CAPEX and OPEX, understanding the capacity and planning needs.

The implementation challenges

There is a need to promote such devices by the utilities with good regulatory environment. This unlocks additional capacity on the existing asset or helps in network planning on the new line.
CONCLUSION
Transmission line capacity can be fully utilised, and reliability can be increased by using DLR devices across the lines. The DLR is a simple device, easy to install and reusable.

Understanding the transmission line real time data brings in intelligence and helps in faster decision making. It is good to consider DLR as part of the CAPEX.

Digitisations of the lines using DLR helps in CAPEX and OPEX optimisation. Before submission for CAPEX approval for any line, the real time data, study and recommendations based on that will support to take the right decision. The same when installed on the new lines, help in understanding the additional available capacity and planning.

Acknowledgement
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Need of Protective Coating to Enhance the Life of the Overhead Transmission Lines Towers

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ABSTRACT
There is an increasing pressure to provide the substantial power uprating/upgrading of existing ac transmission line using existing infrastructure in the same right-of-way, especially in the urban areas. Countries having more population and more industries are experiencing increasing difficulty in finding suitable corridors for new overhead transmission lines. In such cases, towers are generally 10+ years old. Enhancing the life of the towers with uprate and upgrade of the lines become essential to provide desired new service life. In the old towers the major problems include corrosion, missing members and hardware. This paper talks about reviving the life of the tower by arresting/controlling surface deterioration using protective coating.

INTRODUCTION
Destruction of steel metal by chemical and/or electrochemical reaction with their environment is called corrosion. Continued corrosion deteriorates the tower resulting in tower failure and consequently disruption in the power supply. When the galvanized structure loses its zinc coating the deterioration of the structure rapidly enhances due to exposed surface to the atmosphere. The life of such structure is unpredictable. Failures in such transmission line structures causes disruption in the power transmission. Additionally, any fatality associated with such failure can be very disturbing to the public. In order to avoid tower failures due to aging or corrosion, regular maintenance of the towers is necessary. This type of failure aggravates and reduces the life of the metallic towers in aggressive atmospheric or polluted environments. Hence, the protective coating discussion is important for the structures in service.

TYPICAL GALVANIZED STRUCTURES LIFE CYCLE
Good galvanized steel structure in a normal atmospheric condition is expected to have life as stated below. However, the life depends on many factors like galvanizing condition, process of galvanizing and impurities during the process. This is in addition to the atmospheric conditions which acts as accelerators to deteriorate the surface condition of the steel.

The hot dip galvanized (HDG) reaction and life as explained below;

- Brand New HDG: Five layers with a surface layer of 100% zinc. Spangled and shiny zinc metal colour.
- Second Stage HDG: Pure zinc layer reacts with atmospheric oxygen (O2) and forms a zinc oxide (OH2) layer. This second stage is unstable, as is the first stage, and will normally occur in the first 48 hours.
- Third Stage HDG: The zinc oxide layer reacts with moisture in the atmosphere and forms zinc hydroxide, which is also an unstable form of HDG. This third stage of HDG can take from 48 hours to six months to occur.
- Fourth Stage HDG: Zinc hydroxide reacts with carbon dioxide in the atmosphere to form zinc carbonate, which is the first stage of "weathered galvanized" in that it is a stable form of zinc. This stage can take from six months to two years to occur.
- Fifth Stage HDG (2nd stage of aged galvanized): This stage can take a short time to many years to occur. It can be described as fully weathered galvanized HDG steel that has not yet begun to corrode or has very little zinc/iron alloy layer showing with little to no staining from exposed layers of zinc/iron alloy exposure.
- Sixth Stage HDG (3rd stage of weathering): <10% of the surface area showing signs of corrosion and/or zinc/iron alloy staining.
- Seventh Stage HDG (4th stage of weathering): 10-50% of the surface area showing signs of corrosion and/or zinc/iron alloy staining.
• Eighth Stage HDG (5th stage of weathering): 50-90% of the surface area showing signs of corrosion and/or zinc/iron alloy staining, and some pitting corrosion as well.
• Ninth Stage HDG (6th stage of weathering): 100% of the surface area corroded, and little to zero galvanized remaining. Condition is closer to pitted corroded carbon steel, as no galvanized remains.

These nine stages may happen rapidly in transmission lines running close to coastal area which are attacked by chlorides & salts, also the towers in the vicinity of chemical, cement, fertilizer and other industries. Because of the extreme climate conditions prevailing in these certain areas, transmission line tower stubs/coping/muffing concrete deteriorate severely and results in corrosion.

CORROSION PROCESS
Anode, cathode, electrolyte, and metallic pathway are the four essential ingredients of a corrosion cell; and oxygen plays a role also. If anyone is missing; the corrosion cell (circuit) cannot be complete; and electrochemical corrosion may slow down or stop. In case of steel and galvanizing: An electrochemical reaction with the environment, that produces a deterioration of the metal.

DEGREE/RANKING OF CORROSION

<table>
<thead>
<tr>
<th>Condition</th>
<th>Rating</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nondeteriorated</td>
<td>R - 1</td>
<td>0 to 0.1% rust; coating almost intact; red rust covers less than 0.1% of all surfaces; reevaluate in 6 to 12 years.</td>
</tr>
<tr>
<td>Slightly to Moderately Deteriorated</td>
<td>R - 2</td>
<td>0.1 to 1% rust; coating somewhat weathered, may show slight staining or blistering; after stains are wiped off, less than 1% of surface area shows rust, blistering, loose mill scale, or loose paint film; reevaluate in 3 to 5 years.</td>
</tr>
<tr>
<td>Deteriorated</td>
<td>R - 3</td>
<td>1 to 10% rust; coating thoroughly weathered, blistered, or stained, up to 10% of surface area is covered with rust, rust blisters, hard scale or loose paint film; very little pitting visible; needs attention in 1 to 3 years.</td>
</tr>
<tr>
<td>Severely Deteriorated</td>
<td>R - 4</td>
<td>10 to 50% rust; large portion of surface is covered with rust, pits, nodules, and nonadherent paint; pitting is visible; needs attention within 1 year.</td>
</tr>
<tr>
<td>Totally Deteriorated</td>
<td>R - 5</td>
<td>Over 50% rust; needs immediate attention.</td>
</tr>
</tbody>
</table>

CORROSION CONTROL
The old HDG structure above 10 years need a check on available galvanizing thickness. Above the ground and stubs below the ground both need attention and maintenance. Generally, structures losing galvanization need preventive maintenance by providing protective coating. The applicable standards for that are;


Sterlite Power Solutions evaluated various protective coatings options to enhance the life of the structure along with upgrade/uprate of the existing infrastructure. This is essential as the conductor is getting changed and enhancing the line capacity. This means supporting infrastructure too must have enhanced life. However, in the present-day scenario bidding documents focus on only line rating enhancement. This does not provide full proof uprating and upgrading as the main element of support that is tower is ignored.

Chemical composition of several coatings available for structural need is studied. The test report in such cases can not be considered to predict the true life of the structure of coating. Generally, selection of such coating shall be based on prior long-lasting experience in the field. This is the only good way to identify the strength of the coating protecting the surface of the steel from weather conditions. Here it should be noted that the accelerated life tests may not provide clear idea on field performance. The other qualification criteria include higher solid content, good wetting property suitable for both galvanized and ungalvanized surfaces, film-build to edge retention property.

CASE STUDY

The structure of 220kV tower was selected from Delhi Transco Ltd. i.e. 109th tower of Mehrowli- Bomnawli transmission line. This recently reconducted with HTLS conductor. This line is about 40+ years old in a very dusty atmosphere. This tower was selected to demonstrate application of protective coating. In this tower R-4 rusting was observed up to 18meter height. This portion was fully corroded without any galvanized protection left. Hence, both below grade and above grade coating decision was taken.

BELOW GRADE

In this tower, it is observed that stubs/coping/muffing concrete have been severely deteriorated and stub angle were corroded very much. Initially, thorough cleaning of the surface was done till left over galvanizing was visible. It is important to observe the kind galvanize protection left over. The picture indicates that galvanization had rust spots. This is a bad condition of the surface. In some parts of the foot loose rust flakes observed. The protective coating when provided bottom surface closer to ground must be non-hydroscopic in nature. The best selection for such application is moisture cured, urethane coal tar with pigments that repel moisture. This protective coat dries and cure rapidly even at low temperature. Surface preparation is a crucial part for this process. Before the application, all concrete surfaces shall be made free of voids, cracks and other imperfections. Surface preparation shall be as per ICRI 310.2 to achieve surface profile to meet a CSP 3-4. Urethane coal tar is a high build and high solids coating. Wet film thickness is easily and quickly achievable. This can also be applied on surrounding concrete to resist water ingress.

ABOVE GRADE

While selecting the above grade coating the selection of the primer and over coat need a thorough study based on weather and climate. The coating selected shall have maximum wetting and penetration properties like modified linseed oil. This has been used in tower coatings, with great success, due to the excellent “wetting” of the substrate, especially tight rust, and the edges of old coatings remaining on the substrate. The primer used is free of lead, mercury, chromates, and other toxic pigments and hence green solution is provided.

Overcoating is with high solids, high-build, self-priming for weathered galvanized and previously painted structures. This is a modified linseed oil, metallic and ceramic pigmented coating designed for maximum corrosion protection over minimal surface
preparation. The picture indicates fully coated top member. The tower portion which is coated is hard to avoid peel off due to abrasion. The coating takes about a month fully cure. This is essential for full penetration of the coating on the surface.

CONCLUSION

The study indicates that it is essential to manage the condition of the towers. Temporary solution of air spray-based coatings or high solvent content coatings do not last long. This kind of solutions may look good initially but within a year the structure surface will be exposed. Application of the coating on HDG surface need not be at the end of the life. This type of coating can be applied when galvanization is remaining on steel. In such cases the life enhancement will be better, and quantity of coating needed will be lower.

We recommend the right green eco-friendly coating as suggested as part of the process of uprating or upgrading of the existing lines. This way utility can be assured of longer working life of the infrastructure with enhancement of the power carrying capacity with very low investment.
Experimental Investigations on Glass Fibre Reinforced Polymer Composite Pultruded Sections and Transmission Line Towers Modules

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ABSTRACT

The mechanical and environmental properties of Glass Fibre Reinforced Polymer (GFRP) composite pultruded members of angle, channel and box section with crush % under compression have been compared. Performance of various connections in GFRP composite pultruded members using adhesive, bolt and hybrid joints including crush % under compression have been evaluated. Fabrication of 3D tower module using different GFRP composite pultruded members have been done and tested for compression and investigation of connection behavior including crush % have been carried out. Based on the investigations conducted, the performances of GFRP pultruded sections under different loading conditions and performance of various types of connections in GFRP composite pultruded sections have been discussed. The outcomes of 3D GFRP tower module made up of various sections have been presented and the best performing combination have been identified. A 110 kV Transmission Line Tower (TLT) model out of GFRP composite pultruded angle section have been fabricated for conducts load test.

Keywords: Adhesive connection, Hybrid connection, Butt joint, Crush %, GFRP Pultruded Sections, Lap Joint, TLT

INTRODUCTION

In our country, attempts to develop Transmission Line Tower using Fibre Reinforced Plastics pultruded sections are very few. To ensure the electric power transmission in the urban and rural areas, there is a need to technically develop compact 66 kV, 110/132 kV and 220/230 kV TLT structures and various factors like minimization of the tower footprint, its visual impact, utilization of restricted ROW and reduced land requirement along the TL route have to be ensured.

Under such circumstance in our country, need for conducting research in this vital area can't be ignored and hence an attempt has been made in the present research to

• Review the Literatures published which are dealing with the issues and challenges in construction of FRP based TLTs.
• Outline the need for investigating the mechanical and environmental properties of GFRP pultruded sections and connections.
• Suggest the step by step procedure for carrying out a comprehensive research in individual members, TLT modules and TLT models.
Literature Review

In order to identify the issues and challenges in construction GFRP based TLTs, published articles have been reviewed and the points identified are presented here under.

Selvaraj.M et al\textsuperscript{[1]} have performed for technical, aesthetic and economic reasons, our next generation overhead transmission lines will be built with new materials and new design concepts in order to reduce the dimensions of the support structures. Selvaraj.et al\textsuperscript{[2]} have conducted experimental studies on a X braced panel of TLT made from FRP pultruded sections and have indicated that building of TLT with FRP pultruded structural sections with suitable joining techniques is feasible. They have also performed an experimental analysis of a full scale 66 kV FRP tower under mechanical loading and demonstrated successful use of FRP sections.

Hernandez-corona et al\textsuperscript{[3]} have checked the polymeric composite members, simulation of stresses along the TL were performed using COMSOL Multiphysics. Polyzois et al\textsuperscript{[4]} have studied the structural behavior of a composite filament wound latticed tower under static and dynamic load conditions. The tower sections were fabricated without the use of fasteners, thus eliminating the labour-intensive and fatigue prone bolted connections used in steel towers.

Prasad Rao. N et al\textsuperscript{[5]} have studied the importance of design assumptions and connections detailing the overall performance of towers and highlighted the system behavior and prediction of failure pattern and ultimate load by Nonlinear finite-element analysis. Raghunathan M.D et al\textsuperscript{[6]} have discussed the development of the polymer composite known as Glass Fiber Reinforced Polymer (GFRP) material application in the civil/structural infrastructure.

The international council on large electrical system (CIGRE) has come up with a technical brochure on Transmission Line structures with FRP Composite under working group B2.61. It has elaborately discussed on various aspects of FRP material development, FRP structures manufacturing methods, FRP applications of lattice structures, FRP construction methods, Testing of FRP materials and structural components including FRP research and development needs in relation to overhead line components.

Need for the Present Research:

From the Literature review carried out, it is observed that the investigation on the behaviour of GFRP pultruded section of different shapes and connections are very scarce and limited. Hence there is a need for investigating the behaviour of GFRP pultruded sections in a systematic way as outlined below.

1. Various shapes of GFRP pultruded members
2. Various joints and connections in the GFRP pultruded members
3. Development of GFRP TLT module and model
4. Experimental Investigation under load test.

Step by Step procedure for carrying out a comprehensive research:

The step by step procedure followed for comprehensive research on this vital area is as below:

1. Visual inspection of FRP profiles
2. Testing for Mechanical and Environmental Properties
3. Testing for various connection
4. Fabrication and Testing of GFRP materials
1) Visual Inspection of FRP profiles

The common surface defects are identified as per the ASTM 4385-13 Standards. As of the present GFRP pultruded profiles are concerned following are the major defects noticed and such specimens were discarded.

Table 1 Defect Identified in GFRP Specimens

<table>
<thead>
<tr>
<th>S.No</th>
<th>Common Defects</th>
<th>Photos</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Blister</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Blooming, Undercure</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Chips</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Delamination</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Fiber Bridging</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Fiber Prominence</td>
<td></td>
</tr>
</tbody>
</table>

2) Testing for Mechanical and Environmental Properties:

In order to examine the mechanical and environmental properties of GFRP pultruded section, 3 no of sample specimen have been prepared and various tests have been conducted as per ASTM standards and the tests is furnished in Table 2

Table 2 Various Property Tests with ASTM code

<table>
<thead>
<tr>
<th>S.No</th>
<th>Test</th>
<th>ASTM</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Compression test</td>
<td>D695</td>
<td>Mechanical</td>
</tr>
<tr>
<td>2</td>
<td>Tensile test</td>
<td>D3039</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Flexural Test</td>
<td>D790</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Abrasion test</td>
<td>D4060</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Moisture Absorption test</td>
<td>D570</td>
<td>Environment</td>
</tr>
<tr>
<td>6</td>
<td>Fire test</td>
<td>D635-14</td>
<td></td>
</tr>
</tbody>
</table>

The comparative results of maximum compressive strength and crush percentage, maximum tensile strength and tensile extension percentage, maximum flexural strength and deformation percentage and abrasion weight loss in percentage of various GFRP pultruded sections are furnished in the table 3 below.
Table 3 Comparison of Mechanical properties test results

<table>
<thead>
<tr>
<th>S. No</th>
<th>Specimen</th>
<th>Compression</th>
<th>Tensile</th>
<th>Flexural</th>
<th>Abrasion (Max Wt Loss %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Max. Crush %</td>
<td>Max. Strength (MPa)</td>
<td>Max. Ext. %</td>
<td>Max. Force (kN)</td>
</tr>
<tr>
<td>1</td>
<td>GFRP Channel</td>
<td>78.32</td>
<td>395.27</td>
<td>1.1</td>
<td>16.3</td>
</tr>
<tr>
<td>2</td>
<td>GFRP Angle</td>
<td>50.10</td>
<td>449.76</td>
<td>2.5</td>
<td>38.2</td>
</tr>
<tr>
<td>3</td>
<td>GFRP Box</td>
<td>81.63</td>
<td>1202.5</td>
<td>2.5</td>
<td>38.2</td>
</tr>
</tbody>
</table>

- It is observed that GFRP pultruded box section withstanding 5% more crushing ability when compared to GFRP pultruded channel section and 30% more crushing ability when compared to GFRP pultruded angle section.
- It is observed that GFRP pultruded box section exhibits compressive strength 3 times higher than the GFRP pultruded channel section and 2.5 times higher than the GFRP pultruded angle section.
- While considering the tensile elongation, flexural deformation and abrasion loss, GFRP pultruded box section is in advantageous side. But GFRP pultruded angle section is more effective in the fabrication and connection when compared to box sections.
- From the abrasion test results, the observation of the channel specimen has been abraded more than angle and box specimen.

Table 4 Comparison of Environmental Properties test results

<table>
<thead>
<tr>
<th>S.No</th>
<th>Specimen</th>
<th>Moisture Absorption Test (Weight Gain %)</th>
<th>Fire Test (Ignition time in seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GFRP Channel</td>
<td>1.75</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>GFRP Angle</td>
<td>2.50</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>GFRP Box</td>
<td>2.50</td>
<td>9</td>
</tr>
</tbody>
</table>

- It is noted that in the moisture absorption test, GFRP pultruded angle & box sections weight gain of 43% higher than GFRP Channel section.
- It is noted that the GFRP pultruded channel sections withstands only 7 seconds for ignite which is 22 % lesser than GFRP angle and box sections.

3) Testing for Various Connections:

Experimental Setup:
In order to verify the efficiency of connection in the GFRP pultruded member for TLT fabrication is carried out may test have been conducted and the table 5 furnished the details.

Table 5 Details of Various Connection and Joints of GFRP Pultruded Member
### Experimental Investigation on Glass Fibre Reinforced Polymer Composite Pultruded Sections and Transmission Line Tower modules

<table>
<thead>
<tr>
<th>S No</th>
<th>Joint</th>
<th>Member</th>
<th>No of Specimens</th>
<th>ASTM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bolt (Butt &amp; Lap Joint)</td>
<td>4 bolted Connection</td>
<td>3 No’s (50mm x 5mm x 6mm)</td>
<td>D695</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 bolted Connection</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8 bolted Connection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Adhesive</td>
<td>Butt &amp; Lap Joint</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Combined (Butt &amp; Lap Joint)</td>
<td>4 bolted Connection &amp; Adhesive</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 bolted Connection &amp; Adhesive</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>8 bolted Connection &amp; Adhesive</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Result and Discussions:

**Fig 1 Comparison of Compression Test on Various Connection Joints of GFRP pultruded members**

<table>
<thead>
<tr>
<th></th>
<th>4 bolted (MPa)</th>
<th>6 bolted (MPa)</th>
<th>8 bolted (MPa)</th>
<th>Adhesive (MPa)</th>
<th>Hybrid (4Bolt+Adhesive) (MPa)</th>
<th>Hybrid (6Bolt+Adhesive) (MPa)</th>
<th>Hybrid (8Bolt+Adhesive) (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle Lap Joint</td>
<td>297</td>
<td>483</td>
<td>0</td>
<td>37.4</td>
<td>556</td>
<td>516</td>
<td>0</td>
</tr>
<tr>
<td>Angle Butt Joint</td>
<td>381</td>
<td>556</td>
<td>298</td>
<td>604</td>
<td>585</td>
<td>615</td>
<td>411</td>
</tr>
<tr>
<td>Channel Lap Joint</td>
<td>26.9</td>
<td>102</td>
<td>78.7</td>
<td>30.53</td>
<td>148</td>
<td>99</td>
<td>75.3</td>
</tr>
<tr>
<td>Channel Butt Joint</td>
<td>96.9</td>
<td>44.2</td>
<td>38.4</td>
<td>42.06</td>
<td>300</td>
<td>278</td>
<td>38.5</td>
</tr>
</tbody>
</table>
While considering the joints, butt joint exhibits better performance when compared to all other joints.

As of connection investigations are concerned, the results are compared in the figure 11 and it is observed that 6 bolted with adhesives butt joint possess higher compressive strength value when compared to all other joint types.

4) Fabrication and Testing of GFRP materials:

Experimental Setup:

In the next step a comprehensive arrangements have been made for evaluating the performance of TLT module fabricated out of various GFRP pultruded profiles. Table 6 shows the details of the TLT modules and dimensions.

<table>
<thead>
<tr>
<th>S.No</th>
<th>TLT Modules</th>
<th>Description</th>
<th>No of Specimens</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Channel (C)</td>
<td>Vertical member: Channel and Bracing: Channel</td>
<td>1</td>
<td>40 cm x 40 cm x 50 cm</td>
</tr>
<tr>
<td>2</td>
<td>Angle (B)</td>
<td>Vertical member: Angle and Bracing: Angle</td>
<td>1</td>
<td>40 cm x 40 cm x 50 cm</td>
</tr>
<tr>
<td>3</td>
<td>Box (A)</td>
<td>Vertical member: Box and Bracing: Angle</td>
<td>1</td>
<td>40 cm x 40 cm x 50 cm</td>
</tr>
</tbody>
</table>

(a) GFRP TLT Channel  (b) GFRP TLT Angle  (c) GFRP TLT Box

Fig 2 GFRP TLT Modules Test setup

In order to investigate the behaviour of various shapes of GFRP pultruded modules such as channel, angle and box sections against the maximum load, the test have been conducted in the universal testing machine as shown in Fig 2.
Result and Discussions:

A comparison on compression behaviour of GFRP pultruded TLT module is furnished in the figure 3 and it is noted that TLT module A category shows more compressive strength when compared to C module which is nearly 4 times the compressive strength and compared to B module which is 1.7 times the compressive strength.

Conclusion:

In the experimental investigation, the following studies have been concluded:

- Visual inspection of FRP profiles have been carried out and discarded.
- Testing for Mechanical and Environmental Properties have been carried out and the behavior of GFRP profiles have been investigated.
- Testing for various connection have been carried out identified the best connection and joints suitable for TLT
- Fabrication and test of GFRP modules have been carried out and compared the ultimate load carrying capacity of compression.

Future Work:

- A 110 kV Transmission Line Tower (TLT) model out of GFRP composite pultruded angle section have been fabricated for conducts load test.
- GFRP Transmission Line Tower (TLT) model will be analysed by software.

BIBLIOGRAPHY


4) **Polyzois et al. (2013)** “The structural behavior of a composite filament wound latticed tower under static and dynamic load conditions”.


8) **IS 5613 Part2/Sec1:1985** “Code of practice for design, installation and maintenance of overhead power lines”.

9) **CIGRE Technical Brochure WG B2.61** on the topic of “Transmission line structures with Fibre Reinforced Plastics (FRP) Composite”.


13) **ASTM D4060** - Standard Test Method for Abrasion Resistance of Organic Coatings by the Taber Abraser

14) **ASTM D570** - Standard Test Method for Water Absorption of Plastics

15) **ASTM D635-14** - Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position
Smart Energy Conductor
ACMR/TW (Aluminum Conductor M Steel Reinforced/ Trapezoidal Wire)
ACMR/TW HS (Aluminum Conductor Steel Reinforced/ Trapezoidal Wire High Strength)

JAE KWAN KU
Metal Link Inc.

DONG IL LEE
KEPCO

Smart Energy Conductor – ACMR/AW

- High Current Capacity
- Long term reliability
- Optimized HTLS Conductor
- Economics
- Installation
- Conductor cost
- Labor cost
- low line cost
- Easy and rapid installation
- Compatible to existing installation method

Characteristics of ACMR/AW

ACSR / Drake Equivalent

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>ACMR Drake / 410mm²</th>
<th>TECHNICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strand</td>
<td>#/mm</td>
<td>12/TW 1350-O</td>
<td>Trapezoidal wires</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8/TW 1350-O</td>
<td>O-Tempered Al Conductor</td>
</tr>
<tr>
<td>Core</td>
<td>#/mm</td>
<td>7/3.45</td>
<td>New Materials Core</td>
</tr>
<tr>
<td>Area</td>
<td>mm²</td>
<td>413.4</td>
<td></td>
</tr>
<tr>
<td>Continuous Current</td>
<td>A</td>
<td>1,672</td>
<td>Higher than Invar conductor</td>
</tr>
<tr>
<td>Sag</td>
<td>m</td>
<td>13.77</td>
<td>Lower than Invar conductor</td>
</tr>
<tr>
<td>Continuous Current Temp.</td>
<td>°C</td>
<td>210</td>
<td></td>
</tr>
</tbody>
</table>

Co-Research with KEPCO
This Conductor is now used in KEPCO Transmission Line

B2 - 87
New Smart Energy Conductor

Development of New Conductor

- **New HTLS Conductor**

- **ACSR Conductor**
  - Aluminum Conductor
  - Steel Core
  - Round

- **The direction for New Conductor**
  - Trapezoidal wires:
    - increase the aluminium profile;
    - increases conductivity.

- **Core**:
  - Increases strength: lighter & stronger
  - Virtually eliminates line Sag

- **Economic Effects**:
  - Resistance 2% Decrease → 6Billion Won/year Reduction

- **New Materials Core**
  - O-Tempered Al Conductor
  - Annealed Aluminum Conductor : Resistance 2% ↓
  - TW Type Conductor → Resistance 20% ↓(Same Diameter)
    - Diameter 8% ↓(Same Area)
  - High Strength & Light material Core
Conductor Properties

- **ACMR/TW Conductor**
  - Aluminum is fully annealed (O Temper aluminum)
    - High Conductivity: 63%IACS grade
  - Core is high strength & Anti-corrosion
    - TS: 170–200kgf/mm² grade
    - Salt spray test: 10,000hr
  - Conductor is Available in trapezoidal (TW) strands
    - High Anti-Creep & Vibration
    - Excellent properties in Heavy snow
    - Easy installation
    - Reduce of installation cost
    - Low of conductor cost

---

**Sag [tested by KEPCO]**

<table>
<thead>
<tr>
<th>Calculation Sag(m)</th>
<th>Measured Sag(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.5</td>
<td>11.5</td>
</tr>
<tr>
<td>11.7</td>
<td>11.7</td>
</tr>
<tr>
<td>11.9</td>
<td>11.9</td>
</tr>
<tr>
<td>12.1</td>
<td>12.1</td>
</tr>
<tr>
<td>12.3</td>
<td>12.3</td>
</tr>
<tr>
<td>12.5</td>
<td>12.5</td>
</tr>
<tr>
<td>12.7</td>
<td>12.7</td>
</tr>
<tr>
<td>12.9</td>
<td>12.9</td>
</tr>
</tbody>
</table>

Span: 350m

---

Conductor Properties

- **ACMR/TW Conductor**
  - Aluminum is fully annealed (O Temper aluminum)
    - High Conductivity: 63%IACS grade
  - Core is high strength & Zn or Galfan Coated steel
    - TS: 200kgf/mm² grade
    - Anti corrosion effect (3 times excellent than Zn coated steel)
  - Ampacity Upgrading: x 2 ACSR
  - No limitation for application area:
    - Heavy wind & snow, galloping area
  - No Modification & Reinforcement on Existing Tower
  - Easy Installation with Same Method & Equipment as ACSR’s
  - Reduced Design Time and Cost
Comparison between other Conductors

<table>
<thead>
<tr>
<th>ITEM</th>
<th>UNIT</th>
<th>ACMR</th>
<th>Carbon Composite Conductor</th>
<th>Invar Conductor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code</td>
<td>Drake</td>
<td>![ACMR Diagram]</td>
<td>![Composite Conductor Diagram]</td>
<td>![Invar Conductor Diagram]</td>
</tr>
<tr>
<td>Current</td>
<td>A</td>
<td>1672</td>
<td>1787</td>
<td>1689</td>
</tr>
<tr>
<td>Dip</td>
<td>m</td>
<td>13.77</td>
<td>8.48</td>
<td>15.27</td>
</tr>
<tr>
<td>Temperature</td>
<td>ºC</td>
<td>210</td>
<td>180</td>
<td>210</td>
</tr>
<tr>
<td>Accessories</td>
<td></td>
<td>Simple</td>
<td>Complicate</td>
<td>Simple</td>
</tr>
<tr>
<td>Installment</td>
<td></td>
<td>Easy</td>
<td>Difficulty</td>
<td>Easy</td>
</tr>
<tr>
<td>Price</td>
<td></td>
<td>x 1</td>
<td>x 2.5</td>
<td>x 2</td>
</tr>
</tbody>
</table>

Sample of KEPCO Installation Commercial T/L

154kV 원흥-수색T/L by KEPCO in KOREA
ACMR/TW 330SQ  May 29th, 2019  11,292m,7D/M(393m*1,1814m*3,1819m*3)
Merit of ACMR / TW

Compression Deadend Assembly for Conductor

- Deadend Assembly of ACSR & ACMR/TW Conductor Series is similar type

Compression Dead-End Assembly

Easy Installation

Installation Comparison for Conductor

- Installation method for ACMR/TW Series Conductor is identical to the conventional method for ACSR Conductor.

<table>
<thead>
<tr>
<th>Installation Factors</th>
<th>ACSR</th>
<th>ACMR/TW Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bull Wheels</td>
<td>40× diameter</td>
<td>40 × diameter</td>
</tr>
<tr>
<td>Sheaves Wheels</td>
<td>20× diameter</td>
<td>20 × diameter</td>
</tr>
<tr>
<td>Pulling Angles</td>
<td>Unlimited</td>
<td>Unlimited</td>
</tr>
<tr>
<td>Extremer Angle Alternative</td>
<td>Double blocks</td>
<td>Double blocks</td>
</tr>
<tr>
<td>Pre-Stress (Sagging)</td>
<td>None</td>
<td>Recommended</td>
</tr>
</tbody>
</table>
Field test by KEPCO

- **Field Test by KEPCO**
  - Period: 2013.~ 2015
  - Test Conductor: ACCC, ACMR/TW, HVCRC, GAP

- Passed Conductor
  - ACCC, ACMR/TW

Installation for Commercial Test Line
Test Results for Commercial Line

**KEPCO Decision for HTLS Conductor**

- ACMR/TW
  - Excellent: Installation & Maintenance, Economics(Conductor & Assembly), Responsibility
  - Good: Sag

**Future Police of KEPCO**

- Conductor choice by region
  - Normal Regions: ACMR/TW and ACCC
  - Snowing Regions & Mountainous area: ACMR/TW
  - More than 400meter span: ACMR/TW

*Metal Link Inc. & KEPCO are ready to provide our customers with best products and Solutions*

*Thank You!*
Experience in Monitoring of Icing and Prevention Against Icing on Overhead Power Lines

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C&G d.o.o. Ljubljana, Slovenia

N. GUBELJAK
University of Maribor, Faculty of Mechanical Engineering, Slovenia

B. NÉMETH AND G. GÖCSEI
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ABSTRACT
The development of technology has spurred after the catastrophic icing event when large numbers of low, medium and high voltage overhead power lines (OHL) collapsed particularly in Slovenia in the beginning of 2014. Development and financial incentives for the construction of the DEMO were obtained from European development funds, the Horizon 2020 project called "FLEXITRANSTORE". The DEMO was constructed on OHL 110 kV Kleče - Logatec single circuit overhead line equipped with ACSR 240/40 mm² conductors. On the OHL two devices OTLM (On-line transmission line monitoring) SMART and one weather station were installed on two towers. The OTLM SMART software was updated with inclination measurement and with new software features for determining additional mechanical load of conductors due to ice or wet snow. Additional mechanical load is determined based on the difference between measured angle and mathematically determined angle by model. The combination and synchronization between algorithms, weather service and measuring equipment is the key of successful operation. EU H2020 financed project "FLEXITRANSTORE" was launched by the end of 2017 to develop a cross-country co-operation, with objective to improve anti-icing and de-icing solutions. A test equipment was installed to demonstrate the capabilities of this new technologies on the DSO grid of Electro Ljubljana (ELJ). This paper will present the positive experience and results from BME and C&G, partners of DEMO, after the first winter 2018/2019 after polygon was established.

1. INTRODUCTION OF PROJECT FLEXITRANSTORE
Project HORIZON 2020 FLEXITRANSTORE (21.7 M Euro) has begun on the 1st of November 2017 and will last for 4 years. 27 project partners with 8 demonstrations in 6 countries will provide new results in several topics including Dynamic Line Rating (DLR). The main objectives are to demonstrate sensor technology for power system operators to effectively handle and prevent sudden and often fatal failures, especially during icing weather conditions, to increase system security and reliability by reducing icing phenomena and to facilitate cross-border power exchanges by the implementation of the described systems.

2. CATASTROPHIC ICE STORM IN SLOVENIA IN 2014
After the catastrophic icing event in Slovenia at the beginning of 2014, when large numbers of low, medium and high voltage overhead power lines (OHL) collapsed particularly in the western part of Slovenia, a sophisticated development was initiated regarding advanced ice monitoring. Several hundred thousand of customers in this area of Slovenia have been out of electrical power supply for
several days. The complete reconstruction of the damaged OHL network lasted several months. Distribution System Operators (DSOs) and Transmission System Operator (TSO) were forced to use provisional solutions at all levels of tension. The single important high voltage OHL has been successfully put into service using Emergency Restoration Systems (ERS). In the last thirty years, in the Slovenian transmission and high voltage distribution, there were more than forty breakdowns on different transmission lines from 110 kV to 400 kV [3,4]. Especially disastrous were the consequences on the line between the transformers in the vicinity of Ljubljana and Divača, where 220 kV and 400 kV transmission lines were destroyed. The additional load of the ice also broke the towers and tore the wires [3,4]. The ice storm of February 2014 paralysed Slovenia, with damage to overhead lines of all voltages, including voltage (LV), medium voltage (MV) and high voltage (HV). The consequences were catastrophic, and more than 250,000 people were left without electricity for several days. Whole cities were without electricity. After a few days of complete darkness, aggregates were turned on, and the restoration of LV and MV lines as well as some 110 kV OHLs started, with the help of emergency restoration towers [3,4]. On Fig. 1 is detail of glaze ice on a conductor on the OHL 110 kV Cerkno – Idrija (TSO, ELES).

Fig. 1 Glaze ice on a conductor on the OHL 110 kV Cerkno – Idrija (TSO, ELES) [3].

Around midday Friday, January 31st, the snow turned to rain in most parts of Slovenia. It was snowing in the north-western part of the country. On Saturday, February 1st, the weather conditions worsened in most parts of Slovenia, where the temperatures were around -3°C. Slovenia was covered in ice. At around 5.30 p.m., the OHL 220 kV Klčev–Divača failed, and an hour later the so did the OHL 400 kV Beričev–Divača (Fig. 2) [3].

Fig. 2 Typical image of a 400 kV OHL tower after catastrophic icing storm (TSO, ELES) [3].
3. ICE DETECTION SYSTEM OF OTLM SMART

As technology advances, we will be able to collect, analyse and predict very large databases in the field of meteorology and electrical engineering. The ability of processing mentioned data, combined with know-how results in the capacity to operate power lines at their thermal limits during different ambient parameters. This technology, called Dynamic Line Rating (DLR) – is not only a great way to increase the transmission capacity of a certain OHL, but can also be effectively used to prevent, or even solve icing-related issues. Higher currents result in higher Joule-heats, that consequently heat the conductors. If limits can be reached or approached, icing can be prevented. If prevention is not possible, the detection and removal of the ice layer is necessary. The proper handling of this icing issues requires advanced algorithms (expert systems) and reliable measuring equipment. In order to determine the available capacity of electrical high voltage transmission lines, the distributor needs results about safety clearance and temperature of conductors. Therefore, the OTLM SMART software unit was updated with inclination angle measurement “inclinometer” and with new software features for determination of additional mechanical load of conductors due to ice or wet snow. Determination of additional mechanical load based on difference between measured angle and mathematically determined angle by model. Since angle of conductor is usually small (less than 10°) the measurement of conductor angle is challenging. In order to overcome the problem of accurate angle measurement the new expert system has been developed. The newly developed expert system is based on the statistical analysis of collected data of on-line measurement in the long time period with a specific time interval of 10 min. The set of data at each temperature of the conductor includes the air temperature, humidity, current (A) and the conductor angle at the attachment point of the OTLM SMART device. All measurements of the conductor’s angles are statistically analysed at belonging temperature of the conductor in order to determine the mean value and statistical range at 99.97 % of probability. This is statistical relevant parameters, without any additional mechanical load of the conductor, are considered as initial statistical data. From the current set measurement, the expert system calculates new statistic parameters. Each new measured value of the angle is considered as a new added value in statistical analysis. The Expert system compares both set, initial statistical data and new statistical data with additional value. The range of probability distribution overlapping provides the probability of ice on the conductor. The statistical analysis contributes to a better quality of compared values and provides higher reliability to measured values. The combination and synchronization between algorithms, weather service and measuring equipment is the key to the successful operation.

3.1 Development of OTLM SMART line monitoring sensor

The severe ice storm was observed in Slovenia in 2014, indicates the demand for new safety measures during overhead lines operations. For this purpose, one of the additional safety precautions was to inspect the overhead lines when received information from national weather service that ice storm is possible in the given region. Based on this forecast information the TSO should check if ice storm is affected by the overhead line or not. Unfortunately, some overhead lines are located high in the hills and approach is nearly impossible in case of snowy winter time. These facts encourage the manufacturer to build a camera into OTLM SMART line monitoring sensor (Fig. 4), which can be used for monitoring overhead lines and to check the ice status on overhead line conductors [5].
3.2 OTLM SMART’s ice detection function

The thermal monitoring of OHL in a transmission grid is possible with various technologies on different power levels. The choice depends on the requests given by the transmission system operators. The sag and the conductor temperature are two key parameters which define the ampacity of the OHL. The conductor temperature is defined by thermodynamic equilibrium where the heat input equals heat losses. The conductor is heated by the solar radiation and by the heating effect of flowing current ($I^2R$). The technical brochures CIGRE are of great help with the development of the application for determining ice formation on conductors [6-15]. At the time of development and understanding thermal rating calculations of overhead lines we used excellent literature CIGRE [10-15]. The conductor temperature can be measured in one spot or continuously all over the length of the line. The spot method is cheaper but the device has to be carefully placed on the OHL. It should be mounted on the bottom conductor, on the part of the line which passes through the area where the landscape changes sharply and a line is shielded from the wind by various natural or manmade barriers. In complex terrain, the number of measurement points should be greater than in flat woodless areas. The ampacity was calculated by using the newest CIGRE formula (TB 601) [15]. Considering conductor temperature and ambient weather conditions the real-time sag and safety height are calculated by using a mathematical model [15]. A mathematical model has been developed for sag and horizontal force calculation. The model was developed as a computer application. The model includes installation conditions and conductor characteristics and determines the interdependence between conductor sag and horizontal force for actual conductor temperatures. The computer application is an integral part of OTLM SMART software. The developed mathematical model includes mechanical and physical characteristics of the conductor, conductor weight and sag size for the calculation of internal forces. Combining measurements of conductor geometry and sag at several conductor temperatures with software is using for calibration of the sag and angle function. Ensuring conformity is crucial for the implementation of the function ICE-ALARM since a continued growth of discrepancy between the measured and calculated angle in ambient conditions is a sign of glaze ice on the conductor [16-19]. The paper presents the concept of the application and the relation between the geometry and load parameters on the catenary curve when ice or heavy snow builds up and the estimated effect of the current increase on the melting of ice as a tool for the prevention of tower collapse. A conductor is a quasi-statically loaded self-supporting element, where a tensile force changes depending on the oscillating temperatures and mechanical loading. Due to the complex design of the conductor, it is necessary to determine the behaviour of the conductor during the cyclic tensile loading and the stable elastic constant, which is applied to determine a change in the force depending on the elongation. The parameters of the catenary curve at the temperature of the freezing rain represent the initial state of the activation of the ICE-ALARM computer algorithm. If favourable conditions for the formation of ice appear during the continuous monitoring of the conductor condition and condition on the route in the surroundings of the meteorological station then it is possible to estimate the amount of additional loading and the ice
thickness on the basis of the change in the angle of inclination and by knowing the tension-deformation behaviour of the conductor at increased loading.

Fig. 5 shows the change in the angle in accordance with the model and the angle measured by the inclinometer. White circles present actual average angles as a function of average temperature of conductor measured in the time interval of 30 s. Red circles present the expected behaviour of the conductor and/or a change in the angle due to the build-up of the ice on the conductor. The continuous red line represents the angle of inclination depending on temperature according to the mathematical model. If an angle significantly increases in the meteorologically favourable ice conditions and the temperature inversion and if the calculated angle significantly differs from the angle measured by inclinometer, the application informs the operator that ice has built up on the conductor.

4. BME’S ICE PREDICTION MODEL

Besides the geometry of the conductor, local environmental conditions, such as rainfall, ambient temperature, humidity, wind speed and direction, also play an important role in the formation of ice layer on the surface of the conductors. These parameters determine the structural properties of the resulting ice layer and thus its properties. Based on these environmental factors, three types of ice can be distinguished, which can cause high mechanical extra load to the conductors through high-adhesion and density. These three ice types are wet snow, glaze and hard rime. BME’s ice type determining system is established to predict the expected ice type based on environmental parameters, on which based the ice layer diameter and extent of extra mechanical load can be calculated according to the actual ice type. The algorithm takes into account the ambient temperature, precipitation type and intensity, relative humidity and also the temperature of the conductors in order to determine the expected ice type. The results of the system can be the following: wet snow, mixture of wet snow and glaze, glaze, mixture of glaze and hard rime, hard rime or ice formation is not expected. Ice can only shape when conductor temperature below 2 °C, but due to the uncertainty of the conductor temperature calculation model and the deviation of line monitoring devices, this threshold value was set to 3 °C in the model, which appears as a safety factor while it can be also increase the number of false alarms.
The structure of the ice layer deposited on the overhead line conductors largely depends on the type of precipitation, which through several parameters - water droplet / snowflake velocity and mass concentration, collision efficiency, adhesion factor, deposition factor - influences the forming ice layer. In this way, the ice layer will be accreted differently for different types of ice, so the calculation of the thickness of the resulting ice sleeve and the consideration of the extra mechanical load caused by it should be calculated in different ways depending on the type of ice. BME’s ice determining system uses Lacavalla et al. model [21], [22] for wet snow calculation, Pytlak et al. model [23] for glaze computation and Shao et al. model [24] for hard rime estimation.

5. CASE STUDIES

To illustrate the operation of the two-level icing model, some case studies are presented here. Although, there was a “green winter”, which means there was no considerable icing, only some snowing events occurred, nevertheless the operation of the model can be showed through these snowing events. Case studies were made for Kleče - Logatec 110 kV single circuit transmission line equipped with 240/40 mm2 ACSR conductors [25].

5.1 20 November 2018

BME’s model predicted wet snow and glaze ice types based on weather forecast for different grid points. The expected ice thickness was 5 to 6 mm for glaze and 10 to 14 mm for wet snow. Fig. 6 shows the accretion of glaze ice depending on precipitation intensity. On the other hand, as Fig. 7 shows the image captured by OTLM device, there is a slight ice layer can be seen on the bottom of the wire [25].

![Glaze accretion according BME’s model](image1)

![Real state of a phase conductor](image2)

5.2 18 January 2019

A mixed type of ice from wet snow and glaze was anticipated according to BME’s ice prediction model with a thickness between 9 to 12 mm for the different forecast grid points. The expected ice formation is shown in Fig. 8. The real field conditions are shown in Fig. 9, where a huge snow deposit can be seen front of the camera, and a layer of ice on the tower [25].
5.3 Summary of case studies

The operation of the model was investigated in 2018-19 winter time, when only slight ice formed on the conductors mostly form wet snow. BME’s ice prediction model forecasted properly the ice formation, while the quantitative estimation should be fine-tuned, when significant ice sleeves will occur. On the other hand, OTLM device offers an appropriate solution for real-time monitoring of the conductors, which can be the basis to the intervention for system operators [25].

6. CONCLUSIONS

According to FLEXITRANSTORE’s project this paper presented the development of a two-level ice prediction and detection model for high voltage overhead lines. The first level is a weather-based system, which aims to predict the possibility of different ice types – wet snow, glaze, hard rime – accretion on conductors. The model is able to calculate the radius of the ice sleeve and its mechanical extra load based on the accreting ice layer’s type. On the second level a computer algorithm was developed for re-calculation of the sag and tensile strains in the conductor. It takes into account the actually measured form of the catenary curve of the conductor on the presented span at the conductor temperature measured by OTLM. Based on the knowledge about the change in the sag of the catenary curve and the tensile forces dependence on the temperature of the conductor and monitored weather conditions, it is possible to determine the moment of activation the ICE-ALARM application. Furthermore, OTLM sensor is able to monitor the actual state of the conductors with its camera. The essence of the two-level system is the prediction opportunity combined with the real-time monitoring function. System operators get a forecast of the seriousness of the icing event in this way, while the intervention can be made according to the danger factor, therefore the number of unnecessary interventions can be reduced.

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Effects of Resonance Frequency Error on the Self-damping Measurements and Fatigue Testing of Conductor

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ABSTRACT

When executing conductor self-damping measurements and conductor/suspension clamp fatigue testing on laboratory spans, multiple parameters need to be controlled within allowed error margins. The standards and guidelines for these kinds of tests state that they should be executed at one of the resonant frequencies of the conductor. However, even if the parameters of tension and temperature are within the error margins, the natural frequency tends to change gradually during the testing period with the warming of the conductor. This paper shows the influence of an excitation frequency which is not exactly equal to the natural frequency on the self-damping measurements following two different measurement techniques and on the conductor/clamp fatigue testing.

To do so, a Bersfort conductor (ACSR 48/7) was excited on a 63.5 meters laboratory span at two subsequent tunable harmonics and then at intermediate frequency values. This procedure was repeated for different modes and different antinode amplitudes to observe its effects.

Regarding the modal shape, it was observed that the wavelength varies gradually with the variation of frequency but remains constant throughout the span for every frequency step, except for the last loop length where the electrodynamic shaker is located.

About the conductor self-damping measurement, it is observed that the variation is higher when using the power method compared to the inverse standing wave ratio method. This variation was much more important for lower frequencies.

Finally, when studying the relative displacement of the conductor at the clamp opposite to the shaker, no significant difference was observed between the different frequencies for a constant fYmax parameter. This confirms that even though the resonance frequency varies during a fatigue test on a laboratory span, the result would still be valid because the end curvature where the suspension clamp is located would remain the same. The fatigue severity is equivalent if the relative displacement amplitude measured at 89 mm is the same.

Keywords: Conductor, vibration, self-damping, cable, fatigue, laboratory span, resonance, power method, inverse standing wave ratio
INTRODUCTION

In the field of cable dynamics, the numerical simulation and the theoretical models are not accurate enough yet in order to determine some dynamic and mechanical properties of transmission line conductors. Therefore, experimental tests are still required to characterize the performance of new conductors. Fatigue tests for a new combination of conductor and suspension clamp and self-damping measurements of conductors are part of these tests. They are both part of the necessary information required for the determination of an adequate damping system when designing a new overhead transmission line in order to prevent vibration amplitudes that would lead to fatigue failures of the conductor.

Those two tests are carried out on a laboratory span where the conductor is excited using typically an electrodynamic shaker. The self-damping measurements consist of a conductor excited successively at multiple amplitude levels, vibration modes and mechanical tension levels. To measure the damping property of the conductor, three methods are generally used: the power method, the inverse standing wave ratio method and the decay method.

Regarding fatigue testing, normally a minimum of 12 tests are performed to determine the endurance limit of a conductor/clamp system. Three of these tests shall be at an amplitude that produces no wire failure up to 500 million cycles of vibration. The vibration amplitude of the other tests shall be determined in order to distribute, as evenly as possible, the wire failures between 0.8 and 500 million cycles [3].

Standards were published in order to guide the experimental practice for those tests [1], [2] and [3]. For the fatigue tests, IEC 62568 [3] specifies that the frequency must remain constant within a ±5% margin during the test while for the measure of conductor self-damping, IEC 62567 [2] specifies that the frequency shall be controllable to an accuracy of ±2% and that it shall be stable within 0.001 Hz. In IEEE 563 [1], it is recommended that the frequency variations must be kept below 0.1% to measure conductor self-damping. However, in practice it is sometimes difficult to ensure that some of the parameters remain constant throughout the test. Especially for a fatigue test, the temperature may vary in a spacious laboratory during the test period, which lasts up to four months, and the conductor mechanical tension may slightly decrease due to creep. For these reasons, it is sometimes difficult to remain on the resonance frequency throughout the test as recommended in the standards. This paper presents the effect of an error of the resonance frequency on fatigue and self-damping measurements in order to decide if it is better to excite at a constant frequency throughout the test or adjust the excitation frequency regularly to make sure that it corresponds to the resonant frequency.

EXPERIMENTAL SETUP

The tests were carried out at Hydro-Québec’s research institute, on a 63.5 meters laboratory span where the conductor is tensioned and clamped on rock anchored concrete blocks at each end of the free span in order to minimize span-end energy losses (Figure 1). The conductor is excited with an electrodynamic shaker and the vibration amplitude is controlled by means of a displacement sensor located at a central antinode. Other required amplitude measurements are done by scanning specific locations of the span at really low speed (1 mm/s) with a displacement sensor mounted on a millimetric motorized drive screw as shown in the right side picture of Figure 2.

The conductor tested was a Bersfort (ACSR 48/7) strung at a tension of 37 kN (20.5% RTS). Its characteristics are presented in Table 1.
In order to quantify the resonance frequency error effect on the bending amplitude and self-damping of the conductor, the conductor was excited at two of its consecutive vibration modes and then at three intermediate frequencies between those two. At every frequency step, every node position on the span was measured and the conductor displacement at the end span opposed to the electrodynamic shaker was measured with the scanning sensor. The power method and the inverse standing wave ratio method were then used to calculate the conductor self-damping for every frequency. Additional frequency steps were done for the power method to have a better resolution on the behaviour observed.

This procedure was repeated for three pairs of subsequent vibration modes and at two different values of the \( f_{Y_{\text{max}}} \) parameter for modes 27 and 28 as presented in Table 2, where the \( f_{Y_{\text{max}}} \) parameter corresponds to the excitation frequency multiplied by the peak antinode amplitude.
The node positions measured along the span for every frequency step are illustrated in Figure 3 for modes 13 and 14. Since the wave propagation velocity is constant, the length of the loops (half wavelengths) decreases gradually as the frequency increases except for the last wavelength where the shaker is located. These results are presented differently in Figure 4 by showing the length of every loop along the span. It is indeed possible to observe that for the two vibration modes, every half wavelengths are approximately equal except for the first and the last one that are slightly longer due to the near field effect. However, for the three intermediate frequencies, the last half wavelength is shorter when an additional vibration node appears and increases until the next resonant frequency is reached.

It is to be noted that this behaviour observed for modes 13 and 14 presented here is representative of the results obtained for every other pairs of successive modes tested.

**Table 2: Test frequencies for every pair of modes**

<table>
<thead>
<tr>
<th>Ωy</th>
<th>Modes 13-14</th>
<th>Modes 19-20</th>
<th>Modes 27-28</th>
<th>Modes 27-28</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 mm/s</td>
<td>13.500 Hz</td>
<td>19.070 Hz</td>
<td>29.240 Hz</td>
<td>29.570 Hz</td>
</tr>
<tr>
<td>50 mm/s</td>
<td>13.770 Hz</td>
<td>19.340 Hz</td>
<td>29.545 Hz</td>
<td>29.752 Hz</td>
</tr>
<tr>
<td>50 mm/s</td>
<td>14.040 Hz</td>
<td>19.610 Hz</td>
<td>29.850 Hz</td>
<td>30.175 Hz</td>
</tr>
<tr>
<td>50 mm/s</td>
<td>14.310 Hz</td>
<td>19.880 Hz</td>
<td>30.155 Hz</td>
<td>30.478 Hz</td>
</tr>
<tr>
<td>50 mm/s</td>
<td>14.580 Hz</td>
<td>20.150 Hz</td>
<td>30.460 Hz</td>
<td>30.780 Hz</td>
</tr>
</tbody>
</table>

**DEFORMED SHAPE**

The node positions measured along the span for every frequency step are illustrated in Figure 3 for modes 13 and 14. Since the wave propagation velocity is constant, the length of the loops (half wavelengths) decreases gradually as the frequency increases except for the last wavelength where the shaker is located. These results are presented differently in Figure 4 by showing the length of every loop along the span. It is indeed possible to observe that for the two vibration modes, every half wavelengths are approximately equal except for the first and the last one that are slightly longer due to the near field effect. However, for the three intermediate frequencies, the last half wavelength is shorter when an additional vibration node appears and increases until the next resonant frequency is reached.

It is to be noted that this behaviour observed for modes 13 and 14 presented here is representative of the results obtained for every other pairs of successive modes tested.

**Figure 3: Spatial distribution of the vibration nodes at multiple frequency steps from mode 13 to 14**

**Figure 4: Half wavelengths along the span**
The fact that the length of the first loop of the span (opposite side from the shaker) is inversely proportional to the frequency when the conductor is excited at frequencies between vibration modes would lead to the conclusion that the vibration severity remains the same and has no impact on fatigue tests even if the conductor is not excited at a resonant frequency. As described in the experimental setup section, this assumption was verified by scanning the conductor at the exit of the span-end support. The result is shown in Figure 5 where it is possible to see indeed that the bending amplitude at the exit of the span-end remains fairly constant throughout the range of frequency tested.

![Figure 5: Vibration displacement (peak-to-peak) at the exit of the clamp opposed to the shaker](image)

Using those scans of the conductor, it was possible to extract the relative displacement ($Y_b$) at 89 mm as a function of the frequency excited. These results are shown in Table 3 with another serie of $fY_{\text{max}}$ and $Y_b$ obtained with a fixed sensor at 89 mm. However, the displacements obtained with the fixed transducer and the one scanning the conductor were not performed simultaneously. Therefore, they cannot be compared directly. It is to be noted that it was more difficult to control adequately the $fY_{\text{max}}$ parameter in order for it to remain constant when the excitation frequency was in the middle of two vibration modes. This could explain the higher variation of the results for these frequencies.

<table>
<thead>
<tr>
<th>Excitation frequency (Hz)</th>
<th>$fY_{\text{max}}$ (mm/s)</th>
<th>Relative displacement (mm p-p)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Transducer</td>
<td>Sweep</td>
</tr>
<tr>
<td>18.890 Hz</td>
<td>49.87</td>
<td>0.0764</td>
</tr>
<tr>
<td>19.165 Hz</td>
<td>50.03</td>
<td>0.0818</td>
</tr>
<tr>
<td>19.440 Hz</td>
<td>49.96</td>
<td>0.0782</td>
</tr>
<tr>
<td>19.715 Hz</td>
<td>50.06</td>
<td>0.0791</td>
</tr>
<tr>
<td>19.990 Hz</td>
<td>50.17</td>
<td>0.0742</td>
</tr>
<tr>
<td>29.380 Hz</td>
<td>49.95</td>
<td>0.0793</td>
</tr>
<tr>
<td>29.675 Hz</td>
<td>49.85</td>
<td>0.0804</td>
</tr>
<tr>
<td>29.970 Hz</td>
<td>47.34</td>
<td>0.0703</td>
</tr>
<tr>
<td>30.265 Hz</td>
<td>49.93</td>
<td>0.0694</td>
</tr>
<tr>
<td>30.560 Hz</td>
<td>50.12</td>
<td>0.0734</td>
</tr>
</tbody>
</table>
SELF-DAMPING MEASUREMENTS

Regarding the effect on the self-damping calculation, the power method and the Inverse Standing Wave Ratio method (ISWR) were applied at each of the five frequencies for comparison purposes. Additional frequency steps were done with the power method to have a better resolution on the error observed and because this method requires less time.

The power method consists of calculating the self-damping capacity of the conductor by assuming that the energy dissipated by the conductor is equal to the energy introduced by the shaker. The dissipated power and the corresponding damping ratio are obtained with the following equations, where \( F \) is the single amplitude exciting force, \( A \) the forcing point transverse acceleration, single amplitude, \( \theta_a \) the phase angle between force and acceleration, \( m \) the conductor mass per unit of length, \( L \) the free length of the test span, \( \omega \) the circular frequency and \( Y_o \) the vibration single amplitude at antinode.

\[
P_{diss} = \frac{1}{4\pi f} FA \sin \theta_a \quad \xi = \frac{P_{diss}}{\pi fmL\omega^2 Y_o^2}
\]

The inverse standing wave ratio method (ISWR) is based on the principle that a wave is generated by the electrodynamic shaker and that it is reflected at the end-span to be superimposed to the incident wave but with an energy lower than the latter because of the power dissipation all along the conductor due to its internal damping. This results in a small shift that generates a measurable amplitude at the vibration nodes. The difference of amplitude at two distinct vibration nodes is proportional to the energy dissipated by the conductor between those two nodes. Thus, the power dissipation corresponds to the ratio between the node amplitude and the antinode amplitude which is called the inverse standing wave ratio \( S_n \). The power dissipated between two nodes and the corresponding damping ratio are obtained with the following equations where \( d \) is the distance of the nodes, \( T \) the conductor mechanical tension, \( m \) the conductor mass per unit of length, \( V_n \) the vibration velocity at the \( n^{th} \) antinode, \( a_n \) the vibration amplitude at the \( n^{th} \) node, \( Y_n \) the corresponding antinode amplitude and \( n_{kj} \) the number of loops between loop \( k \) and loop \( j \).

\[
P_c = \frac{P_k - P_j}{d_k - d_j} \quad \text{with} \quad P_n = \sqrt{Tm} \frac{V_n^2}{2} \left( \frac{a_n}{V_n} \right) \quad \xi = \frac{S_k - S_j}{\pi n_{kj}} \quad \text{with} \quad S_n = \frac{a_n}{V_n}
\]

The results obtained using both the power method and the inverse standing wave ratio method (ISWR) for every frequency range tested are presented in Figure 6.

It is possible to observe in the following graphs that even if there are some small discrepancies among the results obtained with the inverse standing wave ratio method, the error in the excitation frequency does not seem to have a significant effect on the resulting damping ratio. This is in accordance with the previous conclusion that every loop length on the span, except for the last one, is constant along the span and decreases gradually with the excitation frequency. Therefore, the measured damping ratio is not affected if the last node located close to the shaker is not used in the calculations. As demonstrated in [4], the conductor damping varies proportionally with \( f^{5.63} \). Therefore, a fitted curve with this power was used to calculate the variation of the results. The maximum variation observed was 22%.

For the power method, it is possible to observe a significant effect of the resonance frequency error for lower frequencies. However, this effect decreases as the frequency increases. The damping ratio obtained with the power method tends to vary with a sinusoidal behaviour throughout the frequency range. This phenomenon appears to be much more significant for lower frequencies of excitation with an error on the damping ratio that goes up to an order of magnitude. It does not seem to vary however with the \( f Y_{max} \)
parameter as we can see in the two bottom graphs. With these excitation frequencies, the error in the measurement of the self-damping is similar to the variation in the results of the standing wave ratio method. The error on the calculated damping ratio for the modes 13-14 corresponding to the error margins on the frequency recommended in the three standards are presented in Table 4. It is possible to observe that it increases significantly.

![Graphs showing comparison of power method and ISWR method at different frequencies between two vibration modes.](image)

*Figure 6: Comparison of the power method and the ISWR method at different frequencies between two vibration modes*

*Table 4: Error on damping ratio related to recommended error margins from standards*

<table>
<thead>
<tr>
<th>Frequency Error</th>
<th>Frequency (Hz)</th>
<th>Damping Ratio Error</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>±0.1%</td>
<td>13.500</td>
<td>2.15E-04</td>
<td></td>
</tr>
<tr>
<td>±2%</td>
<td>13.514</td>
<td>2.02E-04</td>
<td>-6%</td>
</tr>
<tr>
<td>±5%</td>
<td>13.770</td>
<td>2.27E-04</td>
<td>18%</td>
</tr>
<tr>
<td>±0.1%</td>
<td>14.580</td>
<td>1.93E-04</td>
<td></td>
</tr>
<tr>
<td>±2%</td>
<td>14.565</td>
<td>2.27E-04</td>
<td>18%</td>
</tr>
<tr>
<td>±5%</td>
<td>14.288</td>
<td>6.27E-04</td>
<td>192%</td>
</tr>
<tr>
<td>±0.1%</td>
<td>13.514</td>
<td>2.02E-04</td>
<td>-6%</td>
</tr>
<tr>
<td>±2%</td>
<td>14.565</td>
<td>2.27E-04</td>
<td>18%</td>
</tr>
<tr>
<td>±5%</td>
<td>13.851</td>
<td>2.35E-04</td>
<td>424%</td>
</tr>
</tbody>
</table>

To have a better understanding of the behaviour observed for the power method in Figure 6, every component of the calculation of the dissipated power was illustrated individually at Figure 7. It is possible to observe that the force and acceleration peak at different frequencies and that the phase crosses 90 degrees two times around the resonant frequency. This can generate confusion when looking for the resonant frequency because in the standard [2] it is recommended to determine the resonant frequency by finding the frequency where the phase between force and acceleration is 90 degrees. Furthermore, as it was observed in Figure 6, such an error on the resonant frequency can lead to a considerable error in the damping ratio calculated.
CONCLUSION

This paper presented experimental tests that were done on a laboratory span at Hydro-Québec’s research institute (IREQ). They aimed to quantify the effect of a resonance frequency error on conductor self-damping measurements and conductor/suspension clamp fatigue testing.

It was shown that the only impact of not being exactly on the vibration mode on the conductor deformed shape tends to be located in the last half wavelength where the electrodynamic shaker is located. The other wavelengths decrease gradually when excited from one vibration mode to the subsequent so that the wave propagation velocity remains constant as expected. The relative displacement of the conductor at the clamp located on the opposite side of the shaker on the span also shows that there is no significant difference of the deformed shape at this location. This implies that there would be no problem to realise fatigue tests at a frequency that is not precisely on the resonance frequency for a constant $f_{Y_{\text{max}}}$ parameter.

Regarding the conductor self-damping measurement, the results obtained showed that the error increases significantly with an error on the resonance frequency when using the power method. This error tends to be as important as 700% for the lower tested frequencies. For the inverse standing wave ratio however, the gap between the exciting frequency and the resonance frequency does not seem to have a significant effect on the dissipated energy calculated, although a maximum variation of 22% throughout the results is still present.

The previous observations lead to the conclusion that the required error margins recommended on the excitation frequency in the three published standards [1], [2] and [3] may need to be revised. For the fatigue testing, the excitation frequency does not need to be a resonant frequency. Regarding the self-damping measurements, the precision on the resonant frequency is not very important when using the inverse standing wave ratio method but shall be precise when using the power method. In order to have a variation similar to inverse standing wave ratio (22%), the error on resonant frequency shall not exceed 0.12% based on our measurements. This error would be even higher at lower frequencies of the self-damping measurement range of frequencies tested as recommended in the standard [2].

BIBLIOGRAPHY

Design & Construction of India’s First Multi-Pole
+-320 kV HVDC Transmission Line

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Power Grid Corporation of India Ltd., India

ABSTRACT

The First VSC based +-320 kV HVDC transmission system of the country is being constructed by POWERGRID CORPORATION OF INDIA LTD. (POWERGRID), the Central Transmission Utility of India, between Pugalur, Tamil Nadu and North Trichur, Kerala. The VSC based +-320 kV HVDC transmission system consisting of two symmetric monopoles shall deliver 2000MW of power through a narrow corridor. Due to severe ROW constraints in the area, special consideration in deciding configuration & dimensions of transmission line towers for +-320 kV HVDC line was necessitated. For minimizing land use of transmission lines, all four poles of the +- 320 kV HVDC transmission system have been accommodated on the same structure, thereby developing the 1st Multi-pole HVDC overhead line of the country. Also for further reduction in corridor requirement for the multi-pole overhead line, special narrow base towers with sleek body have been developed. It may be mentioned that for transmission of 2000-2500MW power, conventionally +-500kV HVDC or 765kV S/C lines having ROW requirement of atleast 52 m and 64 m are built. By accommodating all four pole conductors on narrow-base multi-pole towers having base width of approx. 6 m, ROW requirement of +-320 kV HVDC line has been reduced to mere 44 m which is even less than that of 400 kV D/C lines having power transfer capability in the range of 1000-1500 MW.

Design and development of the 1st Multi-pole HVDC overhead line has been carried out based on intelligible and methodical studies for assessment of air-gap/clearance requirements, conductor bundle selection and finalizing optimum positioning/placement of pole conductors so as to meet the electric field & interference level requirements stipulated by International guidelines within a narrow corridor. Special considerations have also been given to design of insulator strings so as to nullify the effect of increased insulator length (for meeting creepage distance requirements corresponding to very–heavy pollution level) on Right-of-Way requirements.

The paper describes in details, the studies carried out for accommodating all the four poles on the same structure for India’s 1st Multi-Pole 320kV HVDC transmission line.

Keywords: Multi-pole, +-320 kV, HVDC, Optimization, Space Charge, Surface Gradient, Electric Field, Right-of-the-way, Narrow-base
1.0 INTRODUCTION
The VSC based +/-320kV HVDC link between Pugalur in Tamil Nadu and North Trichur in Kerala, in Southern region of India, is a part of the +/-800kV HVDC Raigarh-Pugalur system for transfer of 6000 MW of power from Western region to Southern Region of India. Out of the 6000 MW power received at Pugalur, 4000 MW is envisaged for utilization in the state of Tamil Nadu itself through 400kV AC transmission line links. Balance 2000 MW is to be transferred to the state of Kerala through VSC based +/-320kV HVDC link. While major portion of the transmission line is being constructed as overhead line; in view of Right-of-the-Way (ROW) constraints, a small portion is being constructed using underground cable. In order to minimize ROW requirement of overhead portion, both the symmetrical monopoles have been accommodated on the same tower, thereby making this line as India’s first Multi-pole +/-320kV HVDC line. Further reduction in ROW requirement of the overhead line has been achieved by use of narrow base towers.

2.0 TRANSMISSION LINE CHARACTERISTICS

2.1 Electrical Parameters of +/-320 kV HVDC transmission line

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Nominal Line Voltage</td>
</tr>
<tr>
<td>2.</td>
<td>Maximum Line voltage</td>
</tr>
<tr>
<td>3.</td>
<td>Temporary Overvoltage</td>
</tr>
<tr>
<td>4.</td>
<td>Switching Impulse Withstand Level</td>
</tr>
<tr>
<td>5.</td>
<td>Lightning Impulse Withstand Level</td>
</tr>
<tr>
<td>6.</td>
<td>Power Flow (Normal Condition)</td>
</tr>
<tr>
<td>7.</td>
<td>Power Flow (Overload Condition)</td>
</tr>
</tbody>
</table>

2.2 Structural Parameters of +/-320 kV HVDC transmission line

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Reliability Level</td>
</tr>
<tr>
<td>2.</td>
<td>Wind Zone</td>
</tr>
<tr>
<td>3.</td>
<td>Terrain Category</td>
</tr>
</tbody>
</table>
2.3 Air Gap Clearances

The Live-Metal clearances between pole conductor and tower structure has been calculated for nominal voltage and for overvoltages indicated at 2.1 above. Like EHV & UHVAC lines, maximum Live-metal clearance for +/-320kV HVDC line is based on switching impulse withstand level and is equal to 3 metres.

3.0 DESIGN & OPTIMIZATION STUDIES

Based on the system voltage & ampacity requirements, following studies have been carried out for selection of appropriate size of conductor bundle:-

3.1 Identification of Conductor bundle alternatives:

Based on the current carrying requirements and past experience of EHV & UHV DC transmission systems, following conductor bundle alternatives were identified for carrying out Optimization studies:-

1. Twin ACSR Bersimis (2 X 35.05 mm diameter)
2. Twin ACSR Lapwing (2 X 38.2 mm diameter)
3. Triple ACSR Zebra (3x 28.62 mm diameter)
4. Triple ACSR Canary (3 x 29.52 mm diameter)
5. Triple ACSR Snowbird (3 x 30.4 mm diameter)

3.2 Development of Preliminary Tower Geometry:

Based on the live-metal clearances, mechanical strength requirements during Everyday & Ultimate Loading Conditions and creepage distance requirements corresponding to Specific Creepage of 55 mm/kV, following insulator string configuration were identified:-

<table>
<thead>
<tr>
<th>Conductor Bundle</th>
<th>Suspension Insulator string</th>
<th>Tension Insulator String</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twin ACSR Bersimis</td>
<td>Single V String; 2 X 120 kN</td>
<td>Double Tension String; 2 X 160 kN</td>
</tr>
<tr>
<td>Twin ACSR Lapwing</td>
<td>Single V String; 2 X 160 kN</td>
<td>Double Tension String; 2 X 210 kN</td>
</tr>
<tr>
<td>Triple ACSR Zebra</td>
<td>Single V String; 2 X 160 kN</td>
<td>Double Tension String; 2 X 210 kN</td>
</tr>
<tr>
<td>Triple ACSR Canary</td>
<td>Single V String; 2 X 160 kN</td>
<td>Double Tension String; 2 X 210 kN</td>
</tr>
<tr>
<td>Triple ACSR Snowbird</td>
<td>Single V String; 2 X 160 kN</td>
<td>Double Tension String; 2 X 210 kN</td>
</tr>
</tbody>
</table>
Accordingly, preliminary tower geometry was developed with following salient dimensions:

- Pole-to-pole spacing (Horizontal): 12 m
- Pole-to-pole spacing (Vertical): 8 m

### 3.3 Surface Gradient & Corona Onset Gradient

Maximum surface gradient at average conductor height for above conductor bundle alternatives have been calculated. Further, comparison with Corona Onset Gradient of the conductor bundle alternatives has been done. Salient results of Surface Gradient studies are indicated in the following Table:

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Max. Surface Gradient (kV/cm)</th>
<th>Corona Onset Gradient (kV/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Twin Bersimis</td>
<td>22.96</td>
<td>21.69</td>
</tr>
<tr>
<td>Twin Lapwing</td>
<td>21.41</td>
<td>21.50</td>
</tr>
<tr>
<td>Triple Zebra</td>
<td>21.75</td>
<td>22.18</td>
</tr>
<tr>
<td>Triple Canary</td>
<td>21.21</td>
<td>22.09</td>
</tr>
<tr>
<td>Triple Snowbird</td>
<td>20.69</td>
<td>22.03</td>
</tr>
</tbody>
</table>

Since, the maximum surface gradient at average conductor height for the above conductor bundle alternatives except Twin Bersimis configuration is less than their respective corona onset gradients, further studies have been carried out considering all the above conductor bundle alternatives except Twin Bersimis.
3.4 Ground Clearance

The minimum required ground clearance in the preliminary design for +/- 320 HVDC line has been calculated as 8.5 m on the basis of statutory requirement stipulated in CEA (Measures relating to Safety and Electric Supply) Regulations.

Further, Space Charge-free Electric Field has also been calculated considering following three pole configurations:

**CONFIGURATION-1**

**Monopole-1**

+320kV  -320kV

**Monopole-2**

+320kV  -320kV

**CONFIGURATION-2**

**Monopole-1**

+320kV  -320kV

**Monopole-2**

+320kV  -320kV

**CONFIGURATION-3**

**Monopole-1**

+320kV  -320kV

**Monopole-2**

-320kV  +320kV

From the electric field studies, it is observed that for Pole Configuration-3 with one symmetrical monopole set in right hand side and another in left hand side but with opposite polarity in one horizontal plane, the Electric field works out to be the lowest. Therefore, this configuration was selected and further analysis for all conductor bundle alternatives were carried out for ground clearance of 8.5 metres.

Space Charge-free Electric Field at ground level has been studied for following two conditions:

i) When both symmetric monopoles are working

ii) When one symmetric monopole is working
Salient results are as follows:-

<table>
<thead>
<tr>
<th>Conductor Bundle Alternatives</th>
<th>Maximum Electric Field (kV/m)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>When both symmetric monopoles are working</td>
<td>When only one symmetric monopole is working</td>
</tr>
<tr>
<td>Twin Lapwing</td>
<td>8.87</td>
<td>9.94</td>
</tr>
<tr>
<td>Triple Zebra</td>
<td>9.92</td>
<td>11.12</td>
</tr>
<tr>
<td>Triple Canary</td>
<td>9.95</td>
<td>11.15</td>
</tr>
<tr>
<td>Triple Snowbird</td>
<td>9.97</td>
<td>11.18</td>
</tr>
</tbody>
</table>

From the above table, it is seen that with Twin Lapwing conductor, the Ground level Electric field, under both the two conditions mentioned above, is within the stipulated maximum limit of 10kV/m.

Accordingly, Twin Lapwing conductor was selected for the +/-320 kV HVDC Transmission line with two symmetrical monopoles.

3.5 Right-of-the-way

Right-of-the-way requirement for +/-320kV HVDC line with Twin ACSR Lapwing conductor has been calculated as 44 m, generally, on the basis of CEA (Measures relating to Safety and Electric Supply) Regulations.

Further, based on the Interference studies, it is observed that the values of Charge-free Electric field, Radio Interference and Audible Noise at edge of Right-of-way are within the stipulated limits.

4.0 SALIENT PARAMETERS OF +/-320kV HVDC NARROW BASE TOWERS

Keeping in view ROW constraints, overhead transmission line portion is being constructed using narrow base towers and raft foundations. Salient particulars of the towers are as follows:-
Total four types of Multi-pole Narrow-base towers for +/-320 kV HVDC line (one Suspension tower i.e. DA type and three Tension towers i.e. DB, DC & DD type) have been successfully tested and the transmission line is presently under construction.

5.0 CONCLUSION

With the ambitious power development program in the country and enhanced focus on sustainable development of power transmission infrastructure, it has become even more pertinent to maximize the power transfer per metre of right of way. Use of Multi-pole HVDC transmission lines for transfer of bulk power through narrow corridor showcases POWERGRID’s sincere efforts towards sustainable development of power transmission system in the country.

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Recent Improvements in Design Criterion and Specifications of New Technology HTLS Conductors
– Utility Perspective

MAHENDRA KR. CHAURASIA, RAKESH KR., CHANDRA KANT, 
SUBHASH C. TANEJA, ANISH ANAND AND R.N. SINGH 
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ABSTRACT

Indian transmission network has grown by leaps & bounds over the past decade, marked by a whopping 5-fold rise in the inter-regional transmission capacity during the 11th & 12th five year plans. This spectacular growth of transmission network couldn’t have been accomplished without due consideration to right-of-the-way (ROW) conservation and minimization of land use of transmission lines. One of the most effective ways towards conservation of ROW and achieving sustainable development of transmission network is uprating of existing line using New Technology conductors so as to utilise the existing corridor for wheeling higher quantum of power. Even construction of new high capacity corridors using high temperature low sag (HTLS) conductors, reduces requirement of additional parallel transmission corridors in near future.

Various HTLS conductor technologies have proven their worth for re-conductoring & new line operation purpose in different parts of the world. Each type of HTLS Conductor has its own merits & demerits and selection of the right solution involves detailed techno-economic analysis and precise calculations through latest software tools to ensure compliance of the conductor to myriad electrical & mechanical design considerations & limits.

POWERGRID has a vast experience, of more than 15 years, in use of HTLS conductors of various technologies including INVAR, GAP, ACSS and Composite core type. The company has adopted a no-technology-bias selection policy for its Transmission assets and prior to finalization, carries out detailed techno-economic analysis amongst all the participating proven HTLS conductor technologies. POWERGRID’s procedure for comparative evaluation of losses amongst the different HTLS conductor solutions is a landmark in the industry.

The paper gives an insight to the step-by-step procedure for selection of the appropriate HTLS conductor technology & evaluation of its performance and elaborates the ingenious methodologies of POWERGRID in this regard.

Keywords: Right of Way (ROW) – Uprating - High Temperature Log Sag (HTLS) conductors - INVAR - GAP - ACSS–Composite core conductors - Sag Tension – Loss evaluation

1. INTRODUCTION

Meteoric rise in the transmission infrastructure in the steeply growing developing economies has been accompanied with a ubiquitous opposition to the land use of transmission lines. As such the transmission utilities have been striving hard to maximize power transfer through the existing or new corridors. Conventionally, this has been achieved via EHV & UHV transmission systems, multi-circuit transmission lines, etc. Lately utilities have also harnessed the benefits of compact tower designs, pole structures, narrow base towers, etc. With the advent of new conductor technologies, utilities have started constructing new transmission lines as well as uprating the existing transmission lines with high temperature low sag (HTLS) conductors for more effective utilization of transmission corridors.

As HTLS conductors are able to carry two to four times power without any increase in sag vis-à-vis ACSR conductors, their application in uprating of existing lines significantly enhances power transmission capacity of existing corridor; thereby eliminating any requirement of new transmission corridors. For uprating of transmission lines, HTLS conductor should not only have higher ampacity as per the new system requirements but also its overall diameter, weight, sag-tension
characteristics, etc. should be within the design limits of existing towers/structures. Also, as multiple HTLS conductor technologies are available, it is imperative to adopt standard practices & tools for evaluation of conductor and due consideration to operating losses so as to ensure level playing field for different participating conductor technologies.

2. HTLS CONDUCTOR

High Temperature Low Sag conductors (HTLS) are capable of being operated continuously at temperatures of at least 150°C without any appreciable increase in sag at elevated temperatures. Above a certain temperature called 'knee point temperature', all the stress of the conductor is borne by the core, which has low thermal coefficient of expansion and high modulus of elasticity, resulting in relatively low sag increase when operated at high temperature. Usage of thermal resistant aluminium alloy (TAL) or fully annealed aluminium (1350-O) in such conductors enable high temperature operation without loss of strength.

Commonly used HTLS conductor technologies include GAP conductor, INVAR conductor, Aluminium Conductor Steel Supported (ACSS) conductor and composite core conductor.

3. DESIGN CONSIDERATIONS FOR SELECTION OF HTLS CONDUCTOR

Various Design considerations adopted for selection of HTLS Conductor are elaborated below:

I. Current Carrying Capacity or Ampacity

HTLS conductor must be capable of continuously carrying the specified current (as per the power flow requirements of the new system) within its operating temperature range, without affecting its electrical, mechanical & metallurgical properties. Ampacity and continuous operating temperature under specified ambient conditions can be determined on the basis of Heat Balance equation as per IEEE-738. Reduction in AC current carrying capacity of conductor due to Core Magnetization Effect (in case of steel core and odd layers of aluminium) and Skin Effect should also be taken into account.

Generally, maximum operating temperature of the conductor is limited by the operating temperature of outer Aluminium/Aluminium alloy layers. For instance, maximum operating temperature of Thermal resistant aluminium alloy is 150°C (for TAL) & 210°C (for ZTAL) and of annealed aluminium is 200-250°C. However, in certain cases such as in composite core conductors and cores with galvanized coating, maximum temperature endurance capability of core determines the maximum operating temperature of HTLS conductor.

The latest version of IEEE-738 also stipulates due consideration to higher core temperatures in determining the maximum operating temperature of conductor.

II. Physical Properties

The size of the conductor and its weight are critical from the point of view of design loads of existing towers and structures. Therefore, it is necessary to limit the size and weight of the new conductor to that of the existing conductor. At times, small conductor diameter tends to meet high ampacity requirements of the new system and also have better sag-tension characteristics due to reduced weight and wind loads. This is advantageous, specially, in case of new transmission lines where design of towers and foundations can be accordingly optimized.

However, drastic reduction in conductor diameter enhances the surface gradient on conductors and deteriorates its corona performance. As such, for selection of HTLS conductor, due consideration should also be given to minimum permissible conductor diameter.

III. Sag & Tension Characteristics

The tension of HTLS conductor under various tower design conditions such as in case of full wind conditions, should not exceed the design tension of tower & structures. Similarly, maximum sag of the conductor should be within the limits of sag of the existing towers & structures. Utilities may also consider limiting sag under minimum temperature and nil wind so as to prevent infringement of mid span clearance with the shield wire.

India's CEA Regulations also stipulate limiting everyday conductor tension to 25% of conductor UTS and maximum conductor tension to 70% of conductor UTS. Since, in such conductors, knee point condition may be experienced during everyday conditions and entire conductor tension is borne by the core only, it is necessary to limit the tension
under knee-point condition to certain percentage of the core UTS. In POWERGRID, this tension is limited to 40% of the core UTS.

Further, as there is reduction in the mechanical properties of materials at high temperatures, it should be ensured that conductor tension under maximum operating temperature should not exceed 25% of conductor UTS at that temperature. Also, conductor tension at maximum operating temperature and full wind conditions should not exceed 70% of conductor UTS at that temperature. Some limit should also be specified for permissible reduction in the conductor UTS at high temperature. In POWERGRID, this is limited to 70% of the conductor UTS at room temperature.

For uniformity in sag-tension calculations for various HTLS conductor technologies, standard softwares such as PLS CADD are adopted. The stress-strain and creep behaviour are also generally modelled based on that of standard sizes available in public domain. Sometimes, reliable data from tests done in past can also be considered.

4. ECONOMIC ANALYSIS

Selection of appropriate HTLS conductor size involves holistic comparison of capital cost including cost of conductor, associated fittings & accessories, cost of stringing & installation, etc. as well as cost of losses during normal operating conditions. Such economic analysis is also generally carried out for deciding techno-economic feasibility of twin HTLS conductor in place of Triple or Quad ACSR conductor.

Sometimes, when comparative evaluation of ohmic losses amongst different HTLS conductor alternatives is difficult, the resistance of HTLS conductor can be restricted based on resistance of equivalent ACSR conductor.

5. TESTS FOR VALIDATING CONDUCTOR DESIGN

In addition to theoretical calculations, HTLS conductor design should be validated through appropriate design tests. Myriad International/ National standards and Guidelines such as CIGRE Technical Brochure 426 stipulate various design and sample tests to be carried out on HTLS conductor and its individual strands. These tests can be generally classified into Basic Characteristics tests, Installation tests and In-service tests.

Basic characteristics tests determine the characteristics of conductors for use in line design. For example breaking strength test, stress-strain, electrical resistance, creep test, etc. Technology specific modifications in test set up can also be allowed such as in case of resistance test of GAP conductor for enabling steel core to also participate in the test. Based on the offered technology, some additional tests may also be required to be stipulated such as heat resistance test in case of aluminium alloy strands and glass transition temperature test on composite core.

Installation tests relate to conditions that conductor may experience during installation. For instance, Sheaves test, Radial Crush and Torsional Ductility tests.

In-service tests relate to mechanical, electrical and environmental stresses imposed on the conductor during in-service conditions. For example, Aeolian vibration test, Temperature Cycle tests, corona extinction voltage test, corrosion tests, etc.

6. CONCLUSION

HTLS conductors, in general, offer good solution for uprating of existing lines for use of existing transmission corridor, minimization of land use & environmental impact of transmission networks. However, its use should be preceded by intelligible review & evaluation of conductor design and techno-economic analysis on case-to-case basis. Since, some of the HTLS conductor technologies involve use of unconventional clamps and fittings and unique stringing/ installation methodologies, the HTLS conductor manufacturer/ core technology provider should also be associated at all stages of site handling & conductor installation.

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Testing of RTV Coated Disc Insulators and their Use in the Indian Power Sector for Enhancing Network Performance

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NEELESH ARORA
Epsilon Asia Group, India

ABSTRACT
The Indian power sector has undergone a gigantic leap in terms of capacity addition of the transmission network over the past decade, the Indian electrical grid is one of the widest spanning synchronous grids in the world enabling congestion-free power transfer that requires transmission system performance to be highly reliable while also being highly price sensitive. One of the most crucial components of a transmission line are Insulators and the selection of the same. Suboptimal performance under heavy pollution conditions has resulted in contamination flash-overs on a transnational basis despite design creepage being increased from 25 mm/kV to 31 mm/kV. Though India has seen an adoption of Silicone Rubber Insulators (SRIs) in the recent past, performance and life are often negatively impacted by the quality of the material supplied.

Porcelain Disc insulators are still most widely used across the transmission lines and substations. However, Pollution levels have risen manifold and the performance of ceramic insulators have sometime failed to deliver. As part of various technological innovations to enhance the performance of Porcelain Disc insulators under heavy pollution conditions, various permutations and combinations of Room Temperature Vulcanizing (RTV) coated insulators have been widely experimented. This paper examines the laboratory testing on multiple ‘full’ and ‘bottom-only’ coated porcelain disc insulator strings that are coated with a quartz-filled RTV coating at 300μ and 500μ Dry Film Thickness. The ‘full’ and ‘bottom-only’ coated insulator of 400 KV strings have passed three 60-minute test cycles at a salinity level of 224 kg/m³.

The “bottom-only” coated Porcelain Disc string could be an economically viable method to obtain desired pollution performance compared to fully coated insulators, due to savings in terms of less material requirement, reduced package redesign requirements, easier transportation, handling and field use.

Keywords: Pollution performance, rtv coated insulators, artificial pollution test, partially coated insulators.

INTRODUCTION
The Indian power sector has undergone a gigantic leap in terms of capacity addition, particularly with respect to generation and transmission from renewable energy sources which is expected to reach 175 GW by 2022. A total of 413,407 circuit km of transmission lines (220 kV and above) were in operation in March 2019 with peak load touching 176.7 GW. With an unprecedented augmentation of the transmission network over the past decade, the Indian electrical grid is one of the widest spanning synchronous grids in the world enabling congestion-free power transfer from generation to load centres across the length and breadth of the country. As our society has become increasingly dependent on a continuous supply of electrical energy, which is the necessity, more attention has been given to reliable and cost effective power system, including the insulation of power lines and substations. The integrity of outdoor insulation is crucial to maintain the reliability and cost-effectiveness of modern power systems. In addition to this, India is working towards an ‘affordable-power-for-all' national policy, the statutory regulatory mechanism in place for purchase of power from the exchange, requires transmission system performance to be highly reliable while also being highly price sensitive! Life expectancy of a transmission line has been deemed to be a minimum 40 years and being a passive element, its operation may continue for longer than anticipated.
One of the most crucial components of a transmission line are insulators and the selection of the same. Suboptimal performance under heavy pollution conditions has resulted in contamination flash-overs on a transnational basis despite design creepage being increased from 25 mm/kV to 31 mm/kV. Though India has seen an adoption of Silicone Rubber insulators (SRIs) in the recent past, performance and life are often negatively impacted by the quality of the material supplied. The pollution performance is therefore, one component of the overall insulation coordination design and the final solution will be chosen by taking due consideration of all the aspects of insulator performance.

Historically, the majority of HV & EHV transmission lines in India use porcelain disc insulators due to the long-term electro-mechanical properties and proven low life-cycle costs. They are in operation for many years on Indian power transmission network as being an inorganic material, which provides advantage of long lasting surface properties and primarily add value on transmission lines. These Inorganic materials are inert and not vulnerable to breakdown by combination of UV radiations, pollution, moisture and other stresses, that means they have the potential to remain in Service for many decades, with little, to no change, in composition & characteristics.

SRIs are organic material and comparatively quite recent in India. SRIs also have some of the inherent advantages, such as being lighter in weight, performing well in very highly polluted zones and in the coastal regions. They have greater resistant to stone throwing vandalism, although bullet piercing the housing remains a threat, as it could cause catastrophic line drops. SRIs require proper storage, handing and installation that may not be as rigorously implemented in the field as ideally desired or required. SRIs damaged before installation, especially when the damage is not visible remain a considerable threat to the stability of the line. SRIs are susceptible to UV rays degradation, which creates stickiness in the polymeric properties, attracting dust particles (majorly in the desert region) which challenges the so called hydrophobic properties as it create path for the leakage current & as such these insulators cannot undergo hot washing which will further result erosion of the surface of the shed. There are still a number of performance problems that need to be resolved- some of them on urgent basis, like brittle fracture, decay-like fracture, localized temperature rise, and quality of interface. Other problems which also need to be looked into are natural ageing, decrease in hydrophobicity and bird pecking & shed tearing[1-3].

To overcome such operational issues, R&D activities have been taken up globally and utilities are experimenting with various options. After analysis of experimental and empirical data, it has been found that RTV-coated insulators are a most viable option for utilities internationally due to:

1. Consistently reliable performance in polluted (H-VH) conditions
2. Excellent resistance to UV, chemicals, thermal degradation and corona discharge
3. Excellent sustained hydrophobicity over the life of the insulator
4. Good Resistance to Development of Leakage Currents, Tracking & Erosion
5. Flexibility Application Techniques: Spraying, Dipping and automated processes
6. Robustness in deployment on equipment up to 800 kV HVDC and 1200 kV

In India, it is estimated that RTV coated equipment is performing satisfactorily for many years in highly polluted locations at over 100 locations, including at about 45 substations/locations of Power Grid, (35 stations of 765 kV, 2 stations of 800 kV HVDC, Bina 1200 kV test station, 500 kV HVDC stations and several 400 kV stations).

Recent research[4] examining the development of leakage current on horizontal strings of RTV coated porcelain insulators in a salt-fog chamber over a 1,000-hour test period has demonstrated that quartz-filled RTV Coatings can delay the onset leakage current for up to eight times longer than what ATH-filled coatings were capable of. The hydrophobicity performance of the quartz-filled RTV coating was found to be superior to the ATH-filled coating when horizontally orientated. Hence, in this work, we have taken anti-fog cap and pin type 160 kN Porcelain Disc insulator with a diameter of 305 mm, Creepage Distance of 475 mm and spacing of 170 mm (conforming to IS 731) for quartz-filled RTV coating with varying coating thickness & type and subsequently studying the artificial pollution performance after coating. Figure 1 shows the schematic drawing of this disc insulator.

**RTV COATING PROCEDURE**

Epsilon quartz-filled RTV Coating was applied on all porcelain disc insulators. The coating thickness maintained was in the range of 300 μ ± 10% Dry Film thickness (DFT) and 500 μ ± 10% DFT. In order to improve coating efficiency, (a) multiple Wet Film Thickness (WFT) readings were taken during coating without having to wait for a full cure, and (b) to be able to make corrections in coating thickness before cure. DFT was arrived at by a simple calculation formula based on percentage of solvent in the coating. The existing international practice[5] makes no preference to either the wet film gauge or the dry film gauge, so either is acceptable. The extrapolated DFT method proved to be an effective
and quick method for deployment and continues to serve the owner well without any signs of peeling or adhesion problems even after six years in operation[6]. Two sets of insulators coated for 'full' and 'bottom-only' were subjected for artificial pollution performance test in the high voltage laboratory of Central Power Research Institute, as per IEC 60507[7]. Salt-fog and solid layer are the two methods that are generally used for artificial pollution test on insulators. In the present study, the highest salinity withstand level of the insulator string was obtained by conducting salt-fog test. The test was conducted on 400 kV single suspension string consisting of 1X23 numbers with hardware fittings suitable for twin ACSR moose conductor. Figure 2 shows the String of insulators after artificial pollution test.

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**Fig. 1**: Drawing of 160 kN AF Porcelain Disc Insulator conforming to IS 731

**Fig. 2**: String of Disc Insulators after RTV Coating (A) ‘full’ (B) ‘bottom-only’ coated
TEST RESULT

Table 1: Artificial pollution by salt-fog test result

<table>
<thead>
<tr>
<th>S. No.</th>
<th>RTV Coating Type</th>
<th>RTV Coating Thickness (μ DFT)</th>
<th>Salinity (Kg/m³)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>‘full’</td>
<td>300</td>
<td>160</td>
<td>Withstood</td>
</tr>
<tr>
<td>2</td>
<td>‘full’</td>
<td>300</td>
<td>224</td>
<td>Withstood</td>
</tr>
<tr>
<td>3</td>
<td>‘full’</td>
<td>500</td>
<td>160</td>
<td>Withstood</td>
</tr>
<tr>
<td>4</td>
<td>‘full’</td>
<td>500</td>
<td>224</td>
<td>Withstood</td>
</tr>
<tr>
<td>5</td>
<td>‘bottom-only’</td>
<td>300</td>
<td>160</td>
<td>Withstood</td>
</tr>
<tr>
<td>6</td>
<td>‘bottom-only’</td>
<td>300</td>
<td>224</td>
<td>Withstood</td>
</tr>
<tr>
<td>7</td>
<td>‘bottom-only’</td>
<td>500</td>
<td>160</td>
<td>Withstood</td>
</tr>
<tr>
<td>8</td>
<td>‘bottom-only’</td>
<td>500</td>
<td>224</td>
<td>Withstood</td>
</tr>
</tbody>
</table>

It is evident from Table 1 that all the RTV coated strings were passed three 60-minute test cycles at a maximum salinity level of 224 kg/m³ at the highest system voltage of 243 kV (420kV/√3). The 300μ DFT of ‘bottom-only’ coating could be an economically viable method to obtain the highest pollution performance compared to fully coated insulators due to savings in terms of less material usage. If the ‘bottom-only’ RTV coating is done at factory, it will be further economical in terms of reduced package redesign requirements, easier transportation, handling and field use.

In addition to better pollution performance, the RTV coating are highly stable under UV conditions due to the high bonding energy of the silicon to oxygen [444 kJ/mol] being higher than the energy of 300 nm sunlight [398 kJ/mol]. Neither do controlled UV tests in laboratories nor harsh climatic conditions significantly impact or degrade quality silicone coatings. Furthermore, with bottom-only coated disc insulators that are largely shaded from the sunlight, UV would play an even lesser role as a material degrading factor.

CONCLUSIONS

1. It is possible to control the coating thickness while applying the RTV coating of commercially available Epsilon quartz-filled RTV on 160 kN anti-fog porcelain cap and pin type disc insulators.
2. It is possible to achieve a maximum salinity withstand level of 224 kg/m³ in artificial pollution by salt-fog test with a coating thickness of 300μ DFT. This is much higher than 160 kg/m³ of Silicone Rubber insulators.
3. The ‘bottom-only’ coating with a coating thickness of 300μ DFT is the most economically viable method to obtain the highest pollution performance.
4. If the coating is done at factory, it will reduce package redesign requirements, easier for transportation, handling and field use.
5. Considering the historically proven electromechanical advantages of porcelain disc insulators and accumulated field experience, the ‘bottom-only’ RTV coated disc insulators could be the most economically viable solution for all new EHV/UHV transmission lines where very heavy pollution exists or is expected for next 35 to 40 years.

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Salient Aspects of Use of Composite Insulators in EHV & UHV Transmission Lines – Indian Experience

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ABSTRACT
With rapid growth in urbanisation and industrialization across the globe, pollution has also increased considerably. The increased levels of pollution have resulted in accumulation of dust & carbon particles on surface of insulators of overhead transmission & distribution lines. During foggy/ moist weather conditions, operational performance of transmission lines is badly affected due to pollution related flashovers on conventional insulators. As such, utilities around the world have taken up several measures for mitigation of the problems associated with increased pollution levels such as use of anti-fog insulators of higher creepage distance, regular cleaning/ washing of insulators, use of Composite Insulators and RTV coating of insulators.

Silicone rubber Composite Insulators, consisting of an inner Fibre-reinforced plastic (FRP) rod moulded with silicone rubber outside, are the most commonly used types of Composite Insulators. As insulators are a vital part of overhead lines and are crucial for their reliable performance, it is imperative to design Composite Insulators for not only withstanding the continuous tensile loads and electrical stresses but also to avert any deterioration during their service life. As these insulators are prone to damage due to improper handling, detailed guidelines are required to be followed to ward off such instances during site handling, erection and stringing.

Power Grid Corporation of India Ltd. (POWERGRID), the Central Transmission utility of the country, has been using silicone rubber Composite Insulators for more than 20 years and as such has streamlined procedures & practices for design, selection and handling of these insulators. POWERGRID has also engendered specific type test procedures, acceptance tests, routine tests and tests during manufacture, based on International standards, for weeding out manufacturing defects and ensuring long term performance of Composite Insulators. POWERGRID has also established prudent practices for transportation, storage and installation of Composite Insulators.

This paper highlights these efforts of POWERGRID in details and gives an insight into the vital aspects of design and selection of Composite Insulators for EHV and UHV level transmission lines.

Keywords: Composite Insulators – pollution – creepage distance – electric field – FRP -Shed profile
1.0 INTRODUCTION

Indian Power System has made rapid strides in the past two decades and is poised for phenomenal growth in coming years to make pace with the economic resurgence in the country. However, growth in urbanization and industrialization has thrown challenges for the planners and developers of power systems to deal with the constraints posed by pollution. Due to large number of high capacity corridors consisting of 765kV and +/-800kV HVDC transmission lines in India where higher reliability levels are desired, pollution performance has become even more relevant today.

Power Grid Corporation of India Ltd. (POWERGRID) in its endeavor for sustainable development of transmission network in the country has taken various initiatives involving new technologies/ innovative solutions in this regard. POWERGRID has been using Silicone rubber Composite Insulators in polluted stretches of transmission lines for addressing issues pertaining to pollution related tripping of transmission lines. Silicone rubber is hydrophobic in nature and as such it inhibits formation of continuous water layer on the surface, thereby reducing leakage currents and the likelihood of flashovers. Because of good performance in contaminated environment, light weight, easy handling, lesser maintenance and considerably low cost, these insulators are being used in transmission/ distribution lines on large scale.

However, in the past, incidents due to improper handling or incorrect installation have been reported in some countries. Therefore, apart from the review of design through short term & long term tests, it is necessary to also take up requisite measures to avoid slippages during site handling and installation of these insulators. Based on the past experience, POWERGRID has taken up several ingenuous measures in this respect.


2.0 COMPOSITE INSULATORS

Conventional Porcelain/ Glass insulators are being used in EHV/ UHV transmission lines. These insulators are however more prone to flashovers in polluted stretches during foggy/ moist weather conditions, thereby resulting in tripping of transmission lines. On the other hand, owing to their hydrophobic nature, silicone rubber Composite Insulators are performing better in such areas. The low surface tension of silicone rubber surface causes water to form into beads and continuous water layer is not developed. As a result, leakage current remains small and probability of dry band arcing as well as flashover is drastically reduced. The silicone molecules being light in weight also tend to gather on the surface of pollutants thereby retaining the hydrophobicity of silicone rubber despite dust deposition. This is referred to Transfer of Hydrophobicity. Further, in the event of local loss of hydrophobicity due to arcing etc., silicone rubber tends to recover its hydrophobicity in 24 to 48 hours, thereby retaining its performance over a long time.

These insulators consist of fibre-reinforced plastic (FRP) rod on which silicone rubber materials is molded or assembled through extrusion process to form sheath and shed. Metal fittings are attached to the rod by means of a controlled compression technique for transmitting mechanical load to the core.

Salient parts of Composite Insulators are briefly described below:-

i. **Core:** The core of Composite Insulators is made up of glass-fiber reinforced (FRP) rod. The rod is manufactured through pultrusion process using epoxy resin and Electrical grade Corrosion resistant (ECR) glass fibers. For resistance to brittle fracture, the rods should be essentially boron free. Further, for good electrical performance, the rods should be devoid of air bubbles and should be of low seed category.

ii. **Housing & Weather Sheds:** FRP rod is covered by a sheath of silicone rubber compound, generally, of 3 mm thickness in AC applications and 5 mm thickness for HVDC applications. Typically, housing & weather sheds have minimum 30% silicon content (by weight). The shed profile is based on International guidelines such as IEC-60815. Open aerodynamic profile without any under ribs is mostly used for good self-cleaning of these insulators. The specific creepage distance is based on the pollution level specified in IEC 60815.
iii. **End fittings:** Metal fittings are connected to the ends of FRP rod through crimping process or controlled compression technique. The system of attachment of end fitting to the rod should provide superior sealing performance between housing and metal connection to prevent any ingress of moisture etc. For this purpose, over-moulding technique is most common.

iv. **Grading Rings:** Grading rings are used in Composite Insulators for transmission lines for minimizing the voltage gradient on and within the insulator. These rings also reduce electric field levels inside the core and on the surface of insulator so as to minimize the possibility of dielectric breakdown of air bubbles, if any, inside the FRP and possibility of corona in water droplets on insulator surface.

### 3.0 RECENT IMPROVEMENTS- POWERGRID EXPERIENCE

Based on its vast experience of use of Composite Insulators for various voltage levels, POWERGRID has taken up various design improvements and numerous measures to avoid damages due to improper handling during manufacturing, installation, storage etc. so as to ensure better performance over the lifespan

I. **Improvements in Design**

a. In order to ensure that the electric field is restricted to desirable limits, apart from type tests, POWERGRID stipulates Electric Field modeling studies for finalization of placement of grading rings for different insulator string configurations. Also, for restricting electric field levels, one grading ring (on live end) is being used for 132kV & 220 kV insulators and grading rings on both ends (on tower as well as live end) are being used for 400 kV & higher voltage insulators.

b. Keeping in view the adverse effects of bird excreta on performance of Composite Insulators, Covered grading rings are being used on the tower side of suspension insulators strings to prevent deposition of bird excreta. These grading rings have sloping surface to facilitate natural cleaning/ removal of any deposition on its surface.

c. Further, to allow removal & installation of grading rings after hoisting insulator strings, while spacing/ gap is provided in open type grading rings, the covered type grading rings are supplied in two halves.
d. POWERGRID specifies use of High-strength extruded aluminium alloy such as Grade 6063 or 6061 (as per EN 573) for open type grading rings, to avoid any damage due to accidental impacts at the time of stringing/ installation.

e. Use of stainless steel bolts and higher galvanizing thickness for ferrous parts has been specified for insulators envisaged for marine/ coastal areas.

f. POWERGRID has standardized the size of grading rings amongst Composite Insulators of various makes, so as to facilitate interchangeability. This has reduced problems during construction and has also significantly minimized inventory requirements for line maintenance.

g. Other design modifications, to avoid possibility of incorrect installation and loosening/ opening of grading ring during service are as follows:-

- Use of Holder-keeper arrangement for grading rings so that the rings are supplied with factory fitted holder and only keeper is bolted onto the holder at the time of installation at site, thereby minimizing the number of loose parts.
- Use of additional locking measures viz. Lock nut/ bolt patch/ locking washer etc.
- Marking of slots on grading ring and corresponding projection on the holder/ keeper so as to avoid possibility of wrong placement of grading rings.

II. Improvements in Testing

a. Apart from the tests specified in the IEC 61109 & 62217, POWERGRID also specifies additional tests such as Torsion test to ensure integrity of FRP in case of accidental twists during transportation, hoisting or site handling.

b. As a Manufacturing process improvement measure, POWERGRID has mandated use of acoustic emission sensors for detection of cracks/ fissures at the time of crimping and carrying out Non-destructive test (N.D.T.) on all insulators for ensuring proper jointing amongst housing interface and core.
III. Improvements in Storage, Handling & Installation

a. In order to reduce plastic waste due to discarded PVC/plastic packings at the time of line construction, POWERGRID is accepting insulators in water resistant cardboard tubes and only small quantity of insulators (meant for O&M requirement) are accepted in PVC/plastic tubes.

b. Suitable cushioning, protective padding, dunnage/spacers are being provided to prevent damage or deformation during transit and handling.

c. In bird prone stretches, to prevent birds from pecking the insulators installed on transmission lines before charging, removable plastic/polyethylene/polypropylene covers are being provided.

d. For easy movement of workers on insulators strings and to avoid any damage to insulators during stringing/installation, POWERGRID has mandated use of ladders with suitable hooks and attachment arrangement.

4.0 CONCLUSION

Performance of Composite Insulators in polluted stretches is quite satisfactory during foggy/moist weather conditions. Considering the increasing pollution levels due to rapid industrialization & urbanization, new lines in polluted areas are being constructed with Composite Insulators. With the above mentioned improvements in design, manufacturing, installation, storage & site handling, these insulators are expected to perform as per the intended system and environmental requirements.

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