Re-Conductoring scenario & Payback Calculations of ACSR Moose and its Equivalents Conductors for 400 kV Transmission line [Thermal Uprating]

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Abstract: Now a day’s increase in demand for electricity is a big issue of the day in many countries. Installation of new power lines is very costly and not enough time to build new lines. It is difficult to acquire tower sites and right-of-way. So the best solution is Re-Conductoring of existing transmission lines with Techno graded High Temperature & Low Sag (HTLS) Conductors.

Keywords: Techno-Economical solution in EHV transmission lines, Electrical parameters, Payback calculations, Application of New Generation HTLS Conductor in INDIAN power sector.

1. INTRODUCTION

1.1 Basic Comparison of HTLS Conductor with ACSR Conductor:
An attractive method of increasing transmission line thermal rating (up rating) involves replacing the original (typically) steel-reinforced aluminum conductor (ACSR) with a high-temperature, low-sag (HTLS) conductor with approximately the same diameter as the original conductor. The increase in thermal rating of existing lines recondored with one of these HTLS conductors varies from 20% to 80% depending on whether the replacement HTLS conductor is able to reach its maximum operating temperature within electrical clearance limits.

Most existing overhead transmission lines use steel reinforced aluminum conductors (ACSR). On a continuous basis, ACSR may be operated at temperatures up to 100°C and, for limited time emergencies, at temperatures as high as 125°C without any significant change in the conductor’s physical properties. These temperature limits constrain the maximum current density of ACSR to the range of 1 to 2 amps/kcmil (2 to 4 amps/mm²). This in turn limits the thermal rating of a typical 230 kV line with a single 795 kcmil ACSR conductor per phase to about 400 MVA. In order to increase the thermal rating of existing lines, one method involves replacing its ACSR conductors with special “high-temperature low-sag” (HTLS) conductors having approximately the same diameter as the original ACSR but being capable of operation at temperatures as high as 200°C with less thermal elongation than ACSR. Ideally, these special HTLS conductors can be installed and operated without the need for extensive modification of the existing structures and foundations. As with ACSR, HTLS conductors typically consist of aluminum wires helically stranded over a reinforcing core. Most of the electrical current flows in the high conductivity, low density, aluminum strand layers. Most of the tension load is in the reinforcing core at high temperature and under high loads. The comparative performance of the HTLS conductors depends on the degree to which the aluminum strand and reinforcing core’s physical properties are stable at high temperature and on the elastic, plastic and thermal elongation of the combined HTLS conductor.

1.2 Some of HTLS conductors:
- ACSS and ACSS/TW [Aluminum Conductor Steel Supported] – Annealed aluminum
- Strands over a conventional steel stranded core. Operation to 200°C.
- Z/TACIR [Zirconium alloy Aluminum Conductor Invar steel Reinforced] – High Temperature aluminum strands over a low-thermal elongation steel core. Operation to 150°C (Tal) and 210°C (ZTA1).
- GTACSR [“Gapped” TAL alloy Aluminum Conductor Steel Reinforced] – High temperature
- Aluminum grease-filled gap between core and inner layer. Operates to 150°C.
- ACCR [Aluminum Conductor Composite Reinforced] – High-temperature alloy aluminum over a composite core made from Alumina fibers embedded in a matrix of pure aluminum. Operation to 210°C.
- CRAC [Composite Reinforced Aluminum Conductor] – Annealed aluminum over Fiberglass/thermoplastic composite segmented core. Probable operation to 150°C.
- ACCCFR [Aluminum Conductor Composite Carbon Fiber Reinforced] – Annealed or High-temperature aluminum alloy over a core of strands with carbon fiber material in a matrix of aluminum. Probable operation to 210°C.

1.3 Comparative Cost Analysis (Operation Period: 30 Years):
<table>
<thead>
<tr>
<th>Build Period</th>
<th>Based on 30 km route.</th>
<th>18 Months</th>
<th>6 Months (Short Period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preliminary work</td>
<td>Required</td>
<td>Not Required</td>
<td></td>
</tr>
<tr>
<td>Cost of right of way (ROW)</td>
<td>High Cost</td>
<td>Low Cost</td>
<td></td>
</tr>
<tr>
<td>Tower Foundation</td>
<td>Required</td>
<td>Not Required</td>
<td></td>
</tr>
<tr>
<td>Conductor &amp; Ground wire:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Conductor Furnishing</td>
<td>Low price</td>
<td>High price</td>
<td></td>
</tr>
<tr>
<td>2. Stringing</td>
<td>Required</td>
<td>Required</td>
<td></td>
</tr>
<tr>
<td>3. Ground-wire Furnishing</td>
<td>Required</td>
<td>Not Required</td>
<td></td>
</tr>
<tr>
<td>4. Ground-wire Stringing</td>
<td>Required</td>
<td>Not Required</td>
<td></td>
</tr>
<tr>
<td>Line Accessories</td>
<td>Required</td>
<td>Partially Required</td>
<td></td>
</tr>
<tr>
<td>Grounding</td>
<td>Required</td>
<td>Not Required</td>
<td></td>
</tr>
<tr>
<td>kWh Loss</td>
<td>Low</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Cost due to Difference of Construction Period</td>
<td>High</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Small</td>
<td>Small Cost (same as ACSR)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1.4 Advantages of HTLSC over ACSR Conductor:
- High conductivity
- High Ampacity transfer capacity at max. temperature
- Low Sag-Tension properties
- High ratio of tensile strength to weight
- Retention of tensile strength at high temperature
- Low plastic elongation
- High mechanical self-damping
- Low ratio of outside diameter to cross sectional area
- Easy fabrication into wire
- Weather ability (unaffected by humidity, sun, rain)

1.5 Issues Related With Power Transmission:
The power sector in India is undergoing tremendous growth due to statutory changes. The new electricity act 2003 & open access under the same, have paved a way for speedy development of transmission sector. Large numbers of private players have entered into the business. The existing state & central power utilities have to mend their ways to optimize the power transmission capability. The following issues are related to the power transmission sector of this country.
- The state utilities which came into existence after independence have large number of transmission lines of 33 kV/66 kV/132 kV etc. These lines are very old and are not able to carry more power. Up rating of such transmission line to carry more power at the same voltage, is important for state utilities. Many of such lines which were once upon a time outside the urban boundaries are now appearing dotted on the main thorough fares
of the extended urban boundaries. Changing the tower and or foundation is almost impossible in such crowded streets. The use of high ampacity conductor is therefore inevitable.

- Due to rapid urbanization, sometimes it becomes necessary to up rate the existing line to next higher voltage. In such a situation, the utility would like to transmit higher quantum of power using the same right of way (ROW).
- The bus bars in the existing substation have to be augmented for higher ampacity. Use of higher size or multiple bundle conductors may need change in the existing bus bar gantry structures (Beams & Columns) and foundations for columns. This will need a long shut down of the bus. This may not be possible if the sub-station is heavily loaded. Alternative would be to use new generation conductor with identical mechanical parameters compared to the existing conductor but having very high current carrying capacity (say 150 to 200%).
- Due to increase in urban load, the utility may have construct new substation by acquiring small piece of land in the urban area. Bringing in new transmission line with high ampacity may be a problem. The compact towers with small spans and high conductivity conductors can come to the rescue of the utility.
- Due to oceanic & or industrial pollution, the existing conductors of the line show sizable degradation. It may be necessary to replace such conductors by new generation conductors, which may be resistant to such vagaries and simultaneously can carry higher current.
- ROW is becoming difficult day by day. The cost of ROW is escalating exponentially. The government utilities & private players may like to transmit large block of power using the same ROW with higher voltage, with higher ampacity or both. The conventional conductors cannot be loaded beyond a thermal rating of 85 deg. C.
- For long river crossing spans, the valleys & major high way crossings and in ravines, the conventional conductor will sag more & result into excess height of tower & cost of foundation. If new generation low sag conductors are used, situation can be addressed.
- While constructing a new line, it now becomes absolutely essential to optimize the tower spotting, the power transfer capability & ultimately the cost of towers & foundations. This can be done by selecting the most appropriate conductor.

1.6 Effect on Transmission Line Components due to Change in Conductor:

Change in conductor is required if the existing transmission line is to be up-rated or up-graded. Up-rating means increasing ampacity without change in voltage. Up-gradation means increasing the voltage level of transmission line with or without increase in ampacity.

**Up-rating** of the transmission line by changing the conductor with higher size has the following consequences:

- The clamps /connectors and insulator hardware requires change
- The conductor accessories require change
- The ground clearance may reduce which may increase the tower weight and the foundation quantity.
- If the same towers are to be used, the span may have to be decreased resulting into more number of structures per Kilometre.
- Increase in Sag will vary the insulation coordination and earth wire may have to be re-strung to maintain the shield angle in the mid span.
- The load due to wind on wire and load due to deviation will increase. This will also add to the tower weight.
- If the UTS of the proposed conductor is not higher, the insulators may have to be changed.

**Up-gradation** of the transmission line with/without changing the conductor with higher size has the following consequences:

- If the conductor is changed, all the consequences listed above will have to, be faced by the utility.
- Insulator string will have to be changed for higher voltage. This will mean increase in height of the tower to maintain tower body clearances and phase to phase clearances.
- The statutory ground clearance will have to be increased which will again add to the tower weight in the foundation quantity.
- If the line is passing through the populated area or through forest, the width of right of way will have to be increased. This may create social and environmental hurdles.

1.7 Higher Ampacity Conductors– Usage and application in Indian Power Systems:

The growth of power system in India is causing a great burden on the power transmission system. The most important item of transmission network expansion is the right of way. Due to urbanization and conservation of Forest Act, acquisition of right of way is becoming extremely difficult. The open access being granted to private players has added one more dimension to this problem.

The utility and the private players are now looking forward to an avenue to transmit large blocks of power using minimum R.O.W. This has resulted into a race for designing super conductor or otherwise the conductors which can operate at very high temperature without causing any break down or hazard the power system. The pros
& cons of the temperature elevations in conductor are as follows:

- The use of alloy conductor makes it possible to increase the conductor temperature and transmit more power. However, such conductors are vulnerable to continuous high in velocity (as there is no steel core).
- Operating the conductor with high temperature also means that there is an increase in the line resistance. This increase in resistance also leads to increase in line losses and voltage drop.
- The increase in temperature is also resisted by environmentalists on the plea that the birds who line up on conductor may suffer from the burn injury. The line passing through the forest may also cause fire.
- The high temperature conductors are most suitable for metropolitan cities where the density of consumers is very high & is the distance of transmission line is minimum.
- The use of bundle conductors is becoming very popular for transfer of power in large block with the same R.O.W. However, this is possible only for the lines which are being planned.
- If the existing line is to be operated with bundle conductors, it will be difficult to use the same tower. However, if the R.O.W. is secured and if it is possible to lay tower in between, in will be the best alternative.
- Raising the transmission voltage beyond 400kV is yet another alternative for transmitting large block of power over long distance. However, such lines are required to be designed for a very high reliability level. This has a cost in terms of money and R.O.W. Besides, the cost of substation equipment is enormous for such extra high voltage.
- The various alloy conductors, TW conductors, Air-gap conductors

1.8 Selection of Conductor:

The selection of conductor for overhead EHV transmission Line is a very precise job and calls for accurate calculations. In the total construction cost of EHV Transmission Line, the conductor has a lion’s share. Therefore any over estimation will result into cost escalation. On the other hand under estimation may result into inadequate power transfer capability of the line.

There are various basic considerations while selecting the conductor. The same are prescribed below,

1. Selection based on Voltage
2. Selection based on Current
3. Selection based on Strength
4. Selection Base on Environment
5. Selection Based on the span
6. Selection Base on the Production and Availability

2.1 White paper (Base paper) for Techno-economical comparison of conventional (ACSR) with HTLS conductors

For techno-economical comparison, we have consider HTLS conductors such as STACIR, ACSS Curlew, ACCC Budapest TACSR, ACCR against conventional conductor (ACSR Moose) having same mechanical properties as that of conventional.

Vertical weight (Kg/Km) of
STACIR is 0.5489 % less than conventional.
ACSS Curlew is 1.1477 % less than conventional.
ACCC Budapest is 0.0698 % less than conventional.
TACSR is 8.6327 % less than conventional.
ACCR is 17.4151 % less than conventional.
DC Resistance (ohms/Km) of
STACIR is 3.5567 % less than conventional.
ACSS Curlew is 2.3413 % less than conventional.
ACCC Budapest is 24.2180 % less than conventional.
TACSR is 8.5075 % higher than conventional.
ACCR is 4.5576 % less than conventional.

2.1.1 CASE-1:- The purpose of this case is to mark the difference in line losses when same current (i.e. 350Amp) is passes through all the conductors,

STACIR is 3.4468 % less than conventional.
ACSS Curlew is 2.2708 % less than conventional.
ACCC Budapest is 23.4387 % less than conventional.
TACSR is 1.3130 % higher than conventional.
ACCR is 4.4606% less than conventional.

2.1.2 CASE-2:- This case shows the maximum continuous operating capacity of individual proposed conductor.

2.2 Graphical representation of SAG-Power for HTML conductors:-

<table>
<thead>
<tr>
<th>Case 1 : Maintaining 400 MW power to be catered in all the power conductors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrical Properties</strong></td>
</tr>
<tr>
<td>The following calculations are carried out at temp stated besides:</td>
</tr>
<tr>
<td>Current to be maintained:</td>
</tr>
<tr>
<td>AC Resistance (ohms/km)</td>
</tr>
<tr>
<td>Line losses in kW/ckt</td>
</tr>
<tr>
<td>Power Factor</td>
</tr>
<tr>
<td>Power Transferred in MW/ckt</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Case-2 : Maximum power to be catered from all the power conductors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrical Properties</strong></td>
</tr>
<tr>
<td>The following calculations are carried out at temp stated besides:</td>
</tr>
<tr>
<td>Current to be maintained:</td>
</tr>
<tr>
<td>AC Resistance (ohms/km)</td>
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<tr>
<td>Line losses in kW/ckt</td>
</tr>
<tr>
<td>Power Factor</td>
</tr>
</tbody>
</table>
2.2.1 Graphical representation of Temperature-Power for HTML conductors

2.2.2 Graphical Representation of Temperature-AC Resistance for HTML Conductors

2.2.3 Graphical representation of Temperature-Current for HTML Conductors

2.2.4 Graphical Representation of Temperature-Sag for HTML conductors
2.3 Payback for Re-conductoring Scenario

Power conductor, conductor accessories, Insulator hardware, Destripping of conventional power conductor & Re-straining of HTLS conductors & Re-conductoring design engineer charges are to be considered. Availability factor of 80% of the year for 400 MW, 15% of the year for 800 MW and 5% of the year for 1200 MW is considered for payback calculations.

<table>
<thead>
<tr>
<th>Description</th>
<th>Qty per</th>
<th>Unit</th>
<th>Unit Rate per kM in INR</th>
<th>Single ACSR Moose Line Cost in INR per kM</th>
<th>Single ACSR Moose Line Cost in INR for Complete 50 kM length</th>
<th>Single STACIR Line Cost in INR per kM</th>
<th>Single STACIR Line Cost in INR for Complete 50 kM length</th>
<th>Single AGSS CURLEW Line Cost in INR per kM</th>
<th>Single AGSS CURLEW Line Cost in INR for Complete 50 kM length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Towers</td>
<td>37 MT</td>
<td>70,000</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Conductor</td>
<td>6.6 km</td>
<td>0.09</td>
<td>15000</td>
<td>798000</td>
<td>6851770</td>
<td>342688500</td>
<td>2709630</td>
<td>153481500</td>
<td>984000</td>
</tr>
<tr>
<td>Insulation of JAR</td>
<td>210 Nos</td>
<td>800 per Connections</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>Tower Accessories</td>
<td>Approx</td>
<td>15000</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Conductor Accessories</td>
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<td>800000</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Insulator Hardware</td>
<td>Approx</td>
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<td>115000</td>
<td>575000</td>
<td>138000</td>
<td>690000</td>
<td>126500</td>
<td>632500</td>
<td>492000</td>
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<tr>
<td>Earth Wires</td>
<td>2.2 km</td>
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<td>0</td>
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<td>0</td>
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<tr>
<td>Earth Wire Accessories</td>
<td>Approx</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>Foundation</td>
<td>3 Nos</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Erection of Tower</td>
<td>27 MT</td>
<td>15000</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Stringing (conductor+ Est)</td>
<td>1 km</td>
<td>110000</td>
<td>110000</td>
<td>575000</td>
<td>138000</td>
<td>690000</td>
<td>126500</td>
<td>632500</td>
<td>492000</td>
</tr>
<tr>
<td>R.O.W</td>
<td>1 km</td>
<td>100000</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Design Engg. &amp; Misc.</td>
<td>1.5</td>
<td>100000</td>
<td>100000</td>
<td>100000</td>
<td>300000</td>
<td>300000</td>
<td>300000</td>
<td>300000</td>
<td>300000</td>
</tr>
</tbody>
</table>

Estimated Cost of New 400 kV D/C line with Twin conductor 2939399 9619500 7537770 362188500 3161090 153351500

Saving in Initial Cost 265933500 57156100

Additional Revenue Generated as compared to ACSR for 1 253593722 283322444

Additional Revenue generated as compared to ACSR for 1 286970048 92121944

Ultimate Saving at the end of years mentioned besides 340937222 340288944

Pay Back Period (YsAID) 0.167 0.302

Pay Back Period (YsAID) 342.05 73.730

Notes:
(1) The Total length of the line is assumed to be 50 kM. Actual span is considered as 400 M. Numbers of Towers comes out to be 325, out of which 75 Towers are assumed to be Suspension and rest are assumed Tension.
(2) Cost of 1 MT of Steel is considered as Rs. 70.00.
(3) The Price of 1 KM ACSR Moose conductor is considered as Rs. 24/1500, while that of STACIR, AGSS CURLEW, ACC BUDAPEST, TSCAR, AGC Conductors are 4.3, 1.7, 2.6. 1.3, 3.8% higher respectively as compared to ACSR Moose Conductor.
3. CONCLUSION

After Re-conductoring design of HTLS conductors we conclude that ACCC Budapest conductor is best suited for the purpose as it provides, 23.4387% reduction in line losses, 0.0698% reduction in weight, 24.2180% reduction in DC resistance thus boosting up the power in the range of 4-4.5 times to that of conventional ACSR conductor & providing 1m less sag as compare to ACSR moose conductor.

4. REFERENCES

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