Enhancement of Power Transfer Capability of Existing 400kV Transmission Lines

Rajiv Gandhi, Anish Anand, Y. K. Sehgal, M. Krishnakumar and Anand Mohan

Abstract—The Indian Power sector has ambitious plan to add about 100,000 MW generating capacity in the next 10-12 years. A great proportion of this would be generation confined to coal pitheads in Eastern Region and hydro generation in North Eastern region and Northern region. To meet the power evacuation needs of such large generation expansion; a judicious decision considering optimum utilisation of right of Way and existing transmission infrastructure is of great significance. Enhancing capacity of existing transmission lines, therefore, is considered as one of the alternatives. The paper presents salient studies conducted by in this regard and examines various possibilities.

Index Terms—Series Compensation, Uprating, Weather Predicted Thermal rating systems

I. INTRODUCTION

The power transfer capability of an AC transmission line is influenced by:

(a) Stability limit: This limit depends on voltage class, line length and power system network configuration.

(b) Thermal limit: This limit depends on the type of conductor, its sag-tension characteristics, maximum permissible conductor temperature, ambient temperature and other environmental factors.

For the Indian 400 kV transmission lines having lengths more than 200 kms, stability limit has been the factor determining safe power carrying capability. For lower voltage class lines having lower lengths however, the power flow capacity generally is dependent on its thermal limits. The power transfer capability of existing transmission system can be enhanced through (i) improvement of stability limits and (ii) current uprating.

Increasing thermal limits of the existing facilities along with improved stability limits achieved by introduction of FACTs, series compensation etc can yield encouraging solutions for optimising Right of way and new investments. Various alternatives possible in this direction have been examined and discussed in this paper.

II. NEW TECHNOLOGIES FOR IMPROVEMENT OF STABILITY LIMITS AND OTHER CONSIDERATIONS

While enhancing the thermal limit of the existing lines or choosing high thermal capacity conductor or multiple conductor line, various aspects like voltage instability and/or angular instability need to be examined. These two aspects are related with the line length, hence line reactance, strength of the parallel/underlying transmission network and the strength of the termination points. Therefore, before making any effort to enhance the capacity of the line, there is a need to analyse these aspects in detail. Generally, to take care of angular stability problem as well as voltage instability issue, application of series compensation on long lines, Static Var Compensators (SVC) and other type of FACTS devices like TCSC, Controlled Shunt Reactor (CSR) etc are nowadays in use in the transmission network. These power electronic devices facilitate enhancement of power transfer capacity of EHV lines by providing adequate reactive power support as well as reduction in line reactance.

While enhancing the power transfer capacity of line, another important aspect need to be considered is transmission losses at different power order at 400KV level and compare it with next higher voltage level like 765kV. As such with the increase in loading (current, I), transmission losses increase in proportion to the square of the current (I^2 R). Therefore, economic benefit of increase in line rating along with the increase of line loss need to be compared with the cost of higher voltage level line.

III. ENHANCEMENT OF THERMAL RATING OF TRANSMISSION LINES

A. Weather Predicted Thermal Rating Systems

Thermal rating of a transmission line is influenced by factors such as ambient temperature, maximum permissible conductor temperature for the type of conductor used, wind velocity, solar radiation, solar absorption & emissivity coefficients etc. Since all these variable conditions / parameters do not usually attain their peaks simultaneously, their exists scope of possible increase in thermal capacity of the lines if realistic / justifiable parameters are identified. In various countries, power utilities have now started use of weather predicted thermal-rating systems instead of using...
conventional static or book ratings based on conservative assumptions used earlier. It has been found that increase in power flow capacity by around 10% is generally possible though not 100% of the time by adopting weather predicted systems.

As per Planning Criteria [2] presently in force, the following factors are considered for calculation of current carrying capacity / thermal rating of transmission lines:

- Solar radiation 1045 watts/sqm
- Solar Absorption coeff. 0.8
- Emmissivity coeff. 0.45
- Wind velocity 2 kms/hr
- Ambient temperature 45 degC

However, these parameters considerably vary with time of the day, days and seasons in a year. Analysis of variations in thermal rating of 400 kV line w.r.t. variations in influencing parameters (i.e. ambient temp., solar radiation, wind velocity, solar absorption coeff., emmissivity coeff., maxm. conductor temp.) have been conducted using in-house developed software and salient results are indicated in Fig. 1 to 5.

From the results, it is observed that ambient temperature has a major impact on current carrying capacity of the line. As this can be predicted to a good degree of accuracy based on actual measurements (for operation) and past climatological data (for planning), this can be effectively utilized to identify thermal rating of lines in different time of a year. Similarly, variations in solar radiations due to time of day, month/season etc. can also be utilized as peak load hours do not necessarily coincide with time of maximum solar radiation.
Fig. 4. Current carrying capacity: Variation w.r.t Absorption coefficient

Fig. 5. Current carrying capacity: Variation w.r.t emissitivity coefficient

B. Enhancement Of Maximum Permissible Conductor Temperature Limit

During the initial development of 400kV transmission system in India where the line lengths were more than 200 kms and the network was in developing stage, stability limit was the determining factor for the safe power carrying capacity of transmission lines for operational as well as planning purposes. As such the thermal limit has not been a constraint. In late 70’s, the maximum permissible ACSR conductor temperature was fixed at 65 deg.C (17/20 deg. C more than the maximum ambient temperature of 48/45 deg.C). In mid 80’s this temperature was increased to 75 T degrees with the development of system network and this practice has been followed till recently for planning & design of EHV transmission lines in the country.

The stability limits of lines are now being enhanced by means of series compensation, FACTs etc. It is advantageous to increase the thermal limits of lines also where such devices are installed so that the power transfer capacity in those transmission corridors can be enhanced to maximum possible limits in an economical manner. Enhancing maximum operating temperature limit is one of the feasible solutions.

Salient observations and results of the study conducted [8] in this direction for 400 kV lines are presented in Fig. 6 and Table I & II.

Fig. 6. Current carrying capacity: Variation w.r.t max permissible conductor temperature

Table-I

<table>
<thead>
<tr>
<th>Conductor Temperature (Deg C)</th>
<th>Conductor Current carrying capacity of Conductor (Amp)</th>
<th>Thermal rating (MVA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>614</td>
<td>851 (Base)</td>
</tr>
<tr>
<td>85</td>
<td>787</td>
<td>1090 (128%)</td>
</tr>
<tr>
<td>95</td>
<td>923</td>
<td>1280 (150%)</td>
</tr>
</tbody>
</table>

Table - II

<table>
<thead>
<tr>
<th>Conductor Temperature (Deg C)</th>
<th>Conductor sag for 400 m span (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>12.87 (Base)</td>
</tr>
<tr>
<td>85</td>
<td>13.26(+0.39 m, 3%)</td>
</tr>
<tr>
<td>95</td>
<td>13.65 (+0.78 m, 6.1%)</td>
</tr>
</tbody>
</table>

The increase in thermal rating is 28 % & 50 % respectively for 85 & 95 degree C maximum operating temperature for ACSR MOOSE used for 400 kV lines and the sag increase is also nominal and this can be catered to either by reducing the span or increasing the tower height nominally for new lines. The cost impact on account of this is also of the order of 1% & 2 %
respectively for 85 & 95 degree C conductor temperature. Considering the advantages, POWERGRID has decided to adopt 85 deg C as the conductor temperature limit for all its under construction/future 400 kV transmission lines. The adoption of 95 deg C is proposed to be taken up on case-to-case basis based on power flow requirement estimated at planning stage.

The possibility of increasing the permissible maximum operating conductor temperature for the existing 400 kV lines is also being examined by POWERGRID on case-to-case basis. This involves detailed study of existing ground profiles and tower spotting to assess whether additional margins in ground clearance are physically available. Utilisation of ground clearance margins physically available and also by adopting methods like re-tensioning or re-conductoring with alternate low sag conductor in critical spans can prove to be an economical solution to improve thermal rating of the lines.

C. Uprating Of Existing Lines

ACSR is the most common type of conductor used for EHV transmission lines in India as well as other countries. It is a relatively low technology item and its performance has been quite satisfactory in Indian transmission system. However these have limitations in operating at temperatures beyond 95 deg C and also the sag varies at a relatively higher proportion with temperature. Therefore such conductors cannot be adopted for current capacities beyond certain limits.

Uprating of existing transmission lines to enhance thermal limits can be accomplished by re-conductoring the existing line with conductor types having high current carrying capacity, high temperature endurance, compatible sag–tension characteristics etc. Custom made conductors to suit specific applications can be selected. Various new technology conductor types used by other World utilities have been subjected to detailed study and possibility of adoption for uprating of existing lines have been examined.

The conductor types thus examined were:

i. AAAC

AAAC is a stranded conductor of good conductivity, high tensile strength and corrosion resistant Aluminium alloy. The AAAC offer improved strength to weight ratio resulting in lower sag, lower electrical losses owing to lower ac resistance and superior corrosion resistance.

ii. COMPACT CONDUCTORS

Compact Conductor is an ACSR conductor with Aluminium wires/strands shaped in the form of a trapezoid. Due to greater compactness of trapezoid wires, more Aluminium is present in the conductor compared to same diameter ACSR conductor. This reduces electrical resistance of the conductor and also results in increasing the current carrying capacity.

iii. ACSS & GAP CONDUCTORS

ACSS is Aluminium conductor steel supported. The construction is similar to standard ACSR except that the Aluminium strands are fully annealed. Under typical operating conditions, ACSS allows the entire mechanical load to be carried by the steel core. Some of the major advantages of ACSS are improved conductivity and better self-damping characteristics. Since the Aluminium strands do not take any mechanical load, the conductor may be operated at temperatures in excess of 200 deg .C without loss of strength.

The technology of GAP conductor is similar to ACSS conductor, the only difference being that a small gap is maintained between the steel and Aluminium layer and the conductor is strung by tensioning the steel core only. Hence under all operating conditions, the mechanical load is carried by steel core only and conductor may be operated at temperatures in excess of 200 deg. C.

iv. INVAR CONDUCTORS

INVAR Conductor consists of core of alloy of iron and nickel which has an extremely low co-efficient of thermal expansion of about 1/3rd that of conventional steel wire. The outer aluminium alloy layers of INVAR conductors are thermally annealed. As such INVAR conductors can operate at temperatures in excess of 200 deg. C. Above certain transition temperature all mechanical load is transferred to INVAR core and hence at temperature above this transition temperature INVAR conductors have less sag compared to ACSR conductors. Typical temp v/s sag curve of INVAR conductors are exhibited in Fig- 7.

![Fig. 7. Sag vs Temp of various INVAR conductors](image-url)
i. Mechanical loading with alternate conductors does not exceed the design loads of existing tower structures.

ii. Sag of the conductor should be less than or equal to the existing conductor sag.

iii. Techno economic evaluation should be carried out for each case.

A wide range of alternative types & sizes of conductors (having different stranding ratios, diameter etc) are required to be analyzed for current carrying capacities, sag-tension characteristics, mechanical loading on structures, operating temperature limits, line losses etc to arrive at a techno economically suitable selection satisfying the above mentioned requirements.

Salient results of studies carried out for conductor selection for uprating of 400 kV transmission lines are presented in Table - III

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Operating temperature w.r.t permissible Sag (deg. C)</th>
<th>Thermal rating in MVA after uprating</th>
<th>Cost of re-conductoring in Rs lacs/km</th>
<th>Cost per MVA in Rs lacs for 100kms line</th>
<th>Avg line loss in MW for 100kms line (loss factor-0.5215)</th>
<th>Additional cost of re-conductoring as a % of standard line cost</th>
<th>Ratio of enhanced capacity to Additional cost</th>
<th>% Increase in power flow over standard line</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACSR Moose</td>
<td>75</td>
<td>1702</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avocet/TW (Compact)</td>
<td>100</td>
<td>2768</td>
<td>27.3</td>
<td>2.6</td>
<td>43.7</td>
<td>52.2</td>
<td>1.2</td>
<td>62.6</td>
</tr>
<tr>
<td>AAAC Moose</td>
<td>95</td>
<td>2800</td>
<td>16.3</td>
<td>1.5</td>
<td>9.5</td>
<td>31.1</td>
<td>2.1</td>
<td>64.5</td>
</tr>
<tr>
<td>ACS-Cardinal</td>
<td>125</td>
<td>3312</td>
<td>48.6</td>
<td>3.0</td>
<td>75.1</td>
<td>92.8</td>
<td>1.0</td>
<td>94.6</td>
</tr>
<tr>
<td>60 ZTACEIR</td>
<td>165</td>
<td>3534</td>
<td>69.9</td>
<td>3.8</td>
<td>117.1</td>
<td>133.5</td>
<td>0.8</td>
<td>107.6</td>
</tr>
</tbody>
</table>

IV. CONCLUSIONS

To take care of power transfer requirement of any transmission corridor, power flow under normal condition as well as under contingencies as stipulated in the CEA’s manual on transmission planning criteria must be within the capacity of the line. As discussed in the paper, power transfer capacity is limited due to thermal, angular stability and voltage stability considerations. There are various new technology options available now to enhance thermal limits of existing transmission lines and adoption of such options would facilitate conservation of right of way, reduced environmental impact and reduction in construction time. While adopting any such means to update the thermal capacity of the line, detail studies for angular and voltage instability need to be carried out for each specific transmission corridor. To take care effect of line reactance alternate devices to give static and dynamic reactive power support or change in static and dynamic line reactance may be required through FACTS. In addition increase in power flow would be associated with increase in transmission losses. Therefore, before taking decision, various aspects like cost-benefit, conservation of Right-of-Way etc. need to be considered.

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