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A Case Study: Innovations in Building High Capacity Power Transmission Corridors

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Abstract

This paper addresses the critical issues pertaining to the construction of high capacity power transmission corridors through the reduced Right of Way (ROW). Upon analyzing the techno -commercial aspects of various tower configurations with conventional or upgraded conductors and Insulators, a combination of 400kV/220kV Multi-circuit Multi-voltage Tower configuration with newly proposed ACSS conductor and polymeric insulators in V string arrangement are found to be more viable for the construction of a 2000MW power corridor which utilizes the existing 35m RoW. The implementation of the above proposal is now reached to final stage in Kerala under Kerala State Electricity Board Ltd. aiming to evacuate power from HVDC Station, Thrissur to Northern Region of Kerala state.

Keywords: HTLS Conductors, MCMV Towers, Transmission Corridors

1. Introduction

The National policy and the Electricity Act 2003 have put emphasis on the development of transmission sector through adequate and timely investments by preparing an efficient and coordinated action plan to develop a robust and integrated power system.

This case study is about establishing a 400kV 2000MW link between North Thrissur and Kozhikode in Kerala state and keeping the existing intermittent 220kV substation without any interruption, wherein many times the acquisition of new RoW even at the level of 33kV remains only a dream. A special team was constituted for accomplishing this specific task. The team is assigned with the task of establishing the link without making much disturbance to the public. Already the bitter experience from the 400kV Quad Moose link from Edamon to Kochi was a illustrative sample and it is evident that the work was delayed inordinately due to the RoW issues. Government of Kerala was bound to pay special compensation package to the Rubber Plantations for resuming the project even though the project was under taken by the central transmission utility (PGCIL). The work is still not completed and the project cost is escalated above expectations. Kerala State Electricity Board Ltd has employed a special team for that project only for resolving the RoW issues.

The power transfer capacity of the corridor between Thrissur and Kozhikkode was fixed at 2000MW in 400kV one circuit full redundancy, considering the interstate and intrastate power flow requirement in the upcoming years.

2. High Capacity Power Transmission

The transmission system is expected to be capable of meeting the demand at any part of the network without any overloading / constraints in a secure, reliable, efficient and economic manner even under contingency conditions. Kerala state is highly dependent on power from outside comprising of central sector sources and

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Long term and Medium / Short term tie-ups for the purchase of power from various other sources. Based on the above and the generation additions expected inside the State, it is estimated that an additional import capability of around 2000MW by year 2018 and 4000MW by year 2022 increasing to about 8000MW by 2032 will become quite essential for meeting the above forecasted demand. Taking into account the above facts along with the importance of the transmission planning, a long term transmission plans up to 2023 horizon year was prepared to streamline the investment and activities of KSEBL. A major thrust with a focused effort was adopted in planning and developing a transmission network to meet the challenges in transferring power to Northern region and for evacuating power from the proposed high capacity ISTS project (Pugalur – Thrissur). Kerala state is highly inhabited and the entire state has to be treated as an extended metro city for all purposes of transmission planning. Considering the severe RoW issues that can permeate in future due to this demographical nature of the state, it was proposed that all new lines on important corridors needs to be planned with higher capacity conductors on multi circuit towers (narrow based) taking into consideration the expected load growth in the concerned areas.

3. Right of Way

The width of Right of Way (RoW) for a transmission line is based on the consideration for safety clearances as per CEA regulations 2010, Electromagnetic field exposure limits and design considerations for tower structure. The required RoW for 400kV AC Double Circuit Vertical configuration is 46metre and for 220kV AC Double circuit is 35metre (IS 5603 and CBIP Manual).

The note inserted as per the Amendment on IS 5603, section 5.3.2 says that “Lower values of Right of Way may be adopted by power utilities by use of V-strings or using lower spans” and CBIP manual note to section on Right of Way says that “Due to Right of way constraints usually monopole / compact tower and Tall tower can be adopted and the corridor requirement can be calculated separately.

The constraint in getting the required RoW for construction of overhead transmission line is a matter of serious concern for all utilities. Reduction in RoW is essential, particularly in urban areas / populated areas and forest areas. Adoption of various technical measures is required, particularly in forest areas, and urban / populated areas, as availability of transmission corridor has become extremely difficult. Utilities are forced to consider various technological options for optimization and optimum utilisation of RoW.

Various technological options available for optimisation and optimum utilization of RoW including urban / forest areas are as follows:

- Reduction in Span length
- Reduction in foot print of tower base [i.e use of Steel pole structure, Narrow based lattice structure]
- Use of V- type insulator strings for suspension towers and use of tension towers
- Use of multi-circuit and multi-circuit and multi-voltage towers
- Use of lattice / Steel pole structure with one side stringing
- Exclusively used for high power transmission and where multi cable per phase is required.
- Use of compact towers with insulated cross arm
- Use of covered conductors upto 66kV level
- Upgrading of the existing line to higher voltage AC / converting to HVDC or uprating with high Ampacity conductor [High Temperature (HT) / High Temperature Low Sag (HTLS)] in the existing corridor
- Use of multi-circuit / multi-voltage with raised tower height to save trees (without cutting of trees) maintaining required safety clearance over the trees [e.g. multi-circuit andmulti voltage tower used in Jaldapara Reserve forest area executed by PGCIL]
- Exploring the possibility of use of Voltage Source Converter (VSC) based HVDC transmission on over-head line or underground cable.

Thus the Right of Way requirement for transmission line depends on the following factors:

1. Configuration of tower
2. Span Length
3. Sag of conductor which depends on the type of conductor used, maximum operating temperature of the conductor and span length
4. Wind velocity and angle of swing
5. Projection of cross arms.
6. Minimum horizontal and vertical clearance.
7. Insulator configuration
8. Electric field limits below the bottom of the conductor at the edge of RoW

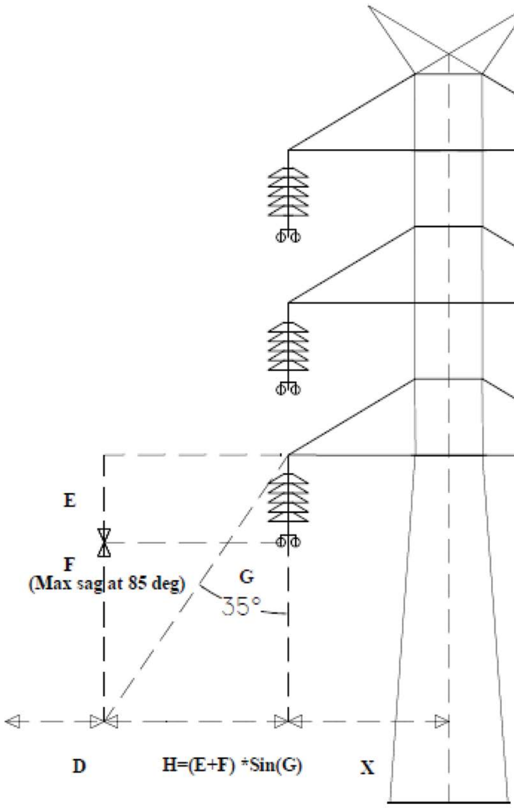

Figure 1. I String Insulator Arrangement.

4. Background Case

All the above factors were considered while proceeding with design of Madakkathara - Areekode High Power Corridor and it was decided to use the existing 220kV Single Circuit Corridor from Thrissur to Areacode (Kozhikode) for constructing the 400kV link.

The existing 220kV SC Transmission Line from Thissur to Areacode (Kozhikode) is occupying 35M RoW with Horizontal configuration of Conductors. This 220kV Circuit was feeding one 220kV S/S (Malaparamaba) in between Thrissur and Areacode. This 220kV S/S is not having another 220kV source. Hence this 220kV link has to be maintained while establishing the 400kV link making the situation more complex. Also the team explored the possibility of 220kV LILO arrangement by constructing new 220kV line from a nearby point to Malaparamba S/S which again will invite RoW issues because the area in particular is highly vegetated and populated. Finally, it was decided to construct a 400/220kV Multi Circuit Multi Voltage (MCMV) line in the existing RoW with power transfer capacity of 2000MW in 400kV one circuit and 500MW in 220kV one circuit with full redundancy.

Various possibilities of using modern high capacity conductors were explored for optimising the design of the MCMV configuration through open Tenders invited for the same including the design fabrication and testing of Towers and conductors with the following requirements.

1. Line capacity shall be 2000MW under N-1 condition
2. RoW for the Line shall be limited to 35mtrs generally.
3. The Towers shall be suitable for Double Moose and Single Kundah Combination also.
4. Towers must be located in the existing RoW and same locations as far as possible.

M/s.Trucon, Nagpur has taken up the Challenge of meeting the above constraints and taken up the design and type testing job from KSEBL.

5. Innovations in Technology

5.1 Conductors

The advancement in current technology has generated many new types of conductors like ACCR (Aluminium Conductor Composite Reinforced), ACCC (Aluminium Conductor Composite Core), TACSR (Thermal Resistant Aluminium Alloy Conductor, Steel Reinforced), ACSS (Aluminium Conductor Steel Supported), STACIR (Super Thermal Resistant Alloy Conductor, Inver Reinforced), GZTACSR (Gap Type Thermal Resistant Aluminium Alloy Conductor) etc.; out of which the following types of conductors have been explored for subject EHV MCMV line:

ACSS – Aluminium Conductor Steel Supported – This conductor has been designed for use as a replacement conductor in up-rating existing transmission and distribution lines with minimum capital outlay. The concept of design is higher conductor operating temperature without the detrimental annealing of the aluminium as in standard ACSR causing a loss of strength in aluminium. ACSS conductor uses 1350 – O (fully annealed) aluminium strands with 63% conductivity rather than the traditional 1350-H19 hard drawn aluminium used in ACSR which possess 61.2% IACS conductivity. The steel core may be made of conventional or extra high strength steel wire. Compared to an equal size ACSR, ACSS has a lower resistance, higher breaking strength, lower creep elongation and lower elastic module.

ACSS can be operated at higher temperatures, as high as 250 0C without loss of strength at higher unloaded percentage tension, because of good self-damping.

ACCC – Aluminium Conductor Composite Core – This conductor has a core consisting of polymer bound carbon fibres encased in a fibre glass tube. ACCC is typically constructed using fully annealed 1350 –O aluminium wires over a single rod composite core. Very low value of coefficient of linear expansion (*of the core*) results in low value of sag at very high temperature; which presents prominent advantage of utility of this conductor to reduce the height of the supporting structure in comparison to any other conductor; which reduces the overall cost of the EHV line.

5.2 Towers

The original basis of designing the subject transmission line tower structures was to consider it as a light structure; but due to enormous requirement of power transmission for the subject link, the tower structures have to carry huge loads and therefore it has obviously become a heavy structure. Introduction of new quality of conductors are providing sufficient support to reduce the number of conductors with reduction in sag value of conductor, which really reduces the loads and heights of the structures and their foundations. It was proposed to put the foundations of new towers in the existing tower locations and near to the same location wherever possible. It was also proposed to limit the new tower footprint within the existing tower base as far as possible and to restrict the RoW to 35M. Different options in tower design were explored with variation of conventional and up-graded conductors, have considered with normal and most popular steel angle frame structure (HT/MS), of vertical formation with square base, as a Multi-Circuit Tower (providing support to 400KV circuit as an upper circuit and 220KV circuit as a lower circuit) with respective alterations of tower loads and tower heights.

Major design complexity was with the tower design. Especially the tower geometry to address the required constraints:

1. RoW limited to 35M.
2. Tower Footprint limited to the existing footprint (6-12metre).

Various geometries of lattice towers were explored and finally most suited vertical arrangement is chosen with minimum height and base width. It was not at all possible to limit the footprint to the existing tower base because of huge momentum of taller towers. Moreover, with reduced base the cost of foundations will be very high and the line will not be economical. Hence an economical configuration between Broad Base and Narrow base design is selected with minimum base width starting 9meters for normal suspension tower with height of 60metres. The detailed discussion of the various options is given under section IV (Options Considered).

5.3 Earth Wire

Two numbers of ground wires were proposed in these multi circuit towers, to provide proper shielding to all the phase conductors of 400kV and 220kV circuits of the transmission line. One is GSW 7/3.66mm and the other is 24 Fibre OPGW equivalent to the GSW.

5.4 Insulators

As the RoW of the subject transmission line, limited to the available RoW of the existing line, i.e 35 m only; I-string insulators cannot be used for suspension towers due to violation of RoW limit. Therefore, V-string insulators

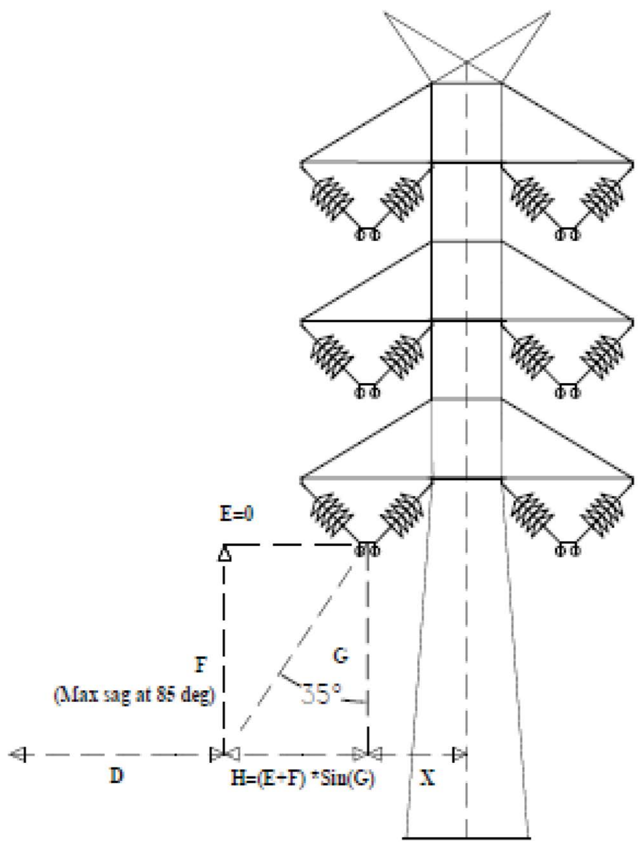

Figure 2. V String Insulator Arrangement.

need to be used for suspension tower for controlling the swing angle of suspension insulators. Long rod polymeric insulators have been proposed for the new line.

6. Options Considered

Various options/combinations were analyzed for arriving at an optimal solution. The following factors limiting the design concepts were incorporated in all options:

1. Tower base width
2. RoW limited to 35M
3. Tower Height
4. Tower foundations to be isolated footing for ease of execution.
5. Suitability for future lines with ACSR MOOSE/ KUNDAH combination.

It was not at all possible to reduce the tower base width below 9m for because of huge foundation design for extremely narrow based Multi Circuit Towers. Hence as an optimization the tower base width limited to the starting value of 9m for normal suspension tower. Arriving at the most suitable tower height was a challenging task. The base height was fixed at about 60m for suspension tower. The major hurdle was the inter-circuit clearance between upper 400kV and lower 220kV circuit for different conductor options. There no flexibility for selection of economic span for the subject line as the line is proposed in the existing 220kV RoW with tower locations restricted to the existing locations. Similar was the case for weight span limits. Standard values were not applicable to the subject line. Further there were locations where even the existing tower foot print was encroached by the public making it impossible to install normal based towers and unfortunately these locations were angle locations making the task more complex.

Option 1

Use of Conventional Lattice Tower with Quad ACSR Moose for 400kV (Two Circuits) and Twin ACSR Moose for 220kV (Two circuits) by expansion of the ROW wherever possible, and New/Special towers for areas where there are RoW issues and at least one OPGW ground wire.

Option 2

Use of conventional Lattice Tower with ACSS(HTLS) –Twin Curlew (Quad Moose equivalent conductor in ampere capacity) for 400kV (Two Circuits) and ACSS(HTLS)-Drake (Twin Moose equivalent conductor in ampere capacity) for 220kV (Two circuits) without expanding the RoW and New/Special design lattice Towers for areas with RoW issues and at least one OPGW ground wire.

Option 3

Use of conventional lattice type towers suitable for CCC(HTLS)-Twin Drake (Quad Moose equivalent conductor in ampere capacity) for 400kV (Two Circuits) and CCC(HTLS) – TW Drake (Twin Moose equivalent conductor in ampere capacity) for 220kV (Two circuits) without expanding RoW at all, but even reducing the RoW if possible at places with RoW issues and at least one OPGW ground wire.

Option 4

Use of conventional lattice type towers suitable for ACSS- (HTLS) Twin Curlew (Quad Moose equivalent conductor in ampere capacity) for 400kV (Two Circuits) and ACCC(HTLS) TW Drake (Twin Moose equivalent conductor in ampere capacity) for 220kV (Two circuits) without expanding RoW at all, but even reducing the RoW if possible at places with RoW issues and at least one OPGW ground wire.

Option 5

Use of conventional lattice type towers suitable for ACSS- (HTLS) Twin Great Hornbill (Quad Moose equivalent conductor in ampere capacity) for 400kV (Two Circuits) and CCC(HTLS) TW Drake (Twin Moose equivalent conductor in ampere capacity) for 220kV (Two circuits) without expanding RoW at all, but even reducing the RoW if possible at places with RoW issues and at least one OPGW ground wire.

The team has verified the technical and financial parameters related to various options based on the Overall cost and implementation feasibility without increasing the RoW and avoiding felling of trees. The most challenging task was to optimise the tower height and inter-circuit clearance for different options. In case of MCMV towers the difference in Hot Sag @Nil wind of Top circuit conductor and Cold sag @ EDT is compared to decide the optimum tower height for the entire transmission line.

Option 1 was not feasible due to the RoW and Tower footing/foundation issues as the towers will occupy comparably wide footprint than the normal Quad Moose Double Circuit Broad Based towers and the tower weight will be also on the higher side. Due to the corridor constraint and power handling capacity, the option with ACSR conductor is eliminated in the preliminary stage.

Option 3 was feasible but having high capital cost of CCC conductors and OandM cost as the CCC hardware costs are very high compared to the other High temperature conductors and hence not considered.

Option 2 and Option 4 are feasible and compared. Even though the Option 2 is economically cheaper it may not be possible to take care of lesser RoW due to increased sag and hence the Tower height will be more than compared to the normal.

The Techno Commercial comparison is also carried out for all the options. Option 1 and 3 are found more expensive compared to Option 2, 4 and 5 in terms of cost of project, time required to complete the project and overall material requirement. Option 1 is not suitable due to impracticability for the present line with limited RoW, land required for wide foundation and non-utility in future lines (Twin ACSR for 400kV and single ACSR for 220kV) as weights and Volume increase by 35-40% which will be an extra expense for future line. Hence option 2, 3, 4 and 5 are being assessed for techno commercial viability. Option 2 and Option 4 are not suitable for longer span due to higher sag of the top circuit conductor; the top circuit conductor crosses the bottom circuit conductor due to increase in span. Option 3 and 5 are suitable for longer span (up to 800m).

Thus the team has decided to go ahead with the Option 5 of the design with the following design and application criteria:

1. The upper 400 kV circuits will be utilising the Twin ACSS conductor which matches the sag/ mechanical properties of ACSR moose, but carry 2000MW around 200 degree centigrade when twin bundled conductors are used. The ACSS conductor was specially designed to suit the sag requirement of the subject line for maintaining the inter-circuit clearance. The leading manufactures shared their expertise in finalising the conductor design. The newly proposed conductor was named as "ACSS Great Hornbill" with ampacity 1654A.
2. The lines will be using polymeric insulators in V-Configuration so as to reduce the RoW requirement thus arresting the horizontal movement of insulators.
3. The 220kV circuits will be utilising the Single Carbon Composite Core (CCC) conductors with lesser losses matching the Drake ACSR conductor in mechanical properties and can carry 500MW of power @175 degree centigrade (1540A).
4. The lines will carry 2000/500MW of power in its maximum operating temperature in 400/220kV circuits respectively.
5. The ground clearances and statutory clearance are maintained in the present line and future lines.
6. Inter circuit clearances, Live metal clearances and Mid-span clearances were maintained as per the standard requirements in Indian Standards/CBIP (Central Board of Irrigation and Power) manual. Mid-span clearance of 6.1m maintained between maximum sag of 400kV circuit ACSS conductor and sag at EDT without wind of 220kV circuit conductor.
7. Inclined sag clearances at full wind conditions also examined and found satisfactory.
8. Detailed engineering and type testing to be carried out as per the design evolved based on the basic considerations mentioned.
9. Suitability of these towers for using in 400/220kV lines using conventional ACSR Moose/Kundah is also studied and found satisfactory.
10. The HTLS conductors proposed for this project have also to be undergone the type test for its GTP from an accredited lab.

The outline diagram of these Towers are verified with minimum statutory requirement and found that the tower height could be reduced by more than 5 meters than the conventional design of Towers with conventional conductors.

The detailed design and successful type testing can lead to the patenting of the said design as it is first of its kind in India. Very special narrow based MCMV tower was also designed for the extremely congested locations with hardly 5m base width.

Since the proposed line is a Multi circuit Multi Voltage (MCMV) it will be equivalent to saving Row for three more lines in the same Right of way of existing 220kV single circuit line.

7. Final Selection and its Features

After analyzing all the options on the basis of following criteria:

1. Technical parameters/Power transfer capacity
2. Total Line Cost
3. Line Losses
4. Suitability for future line (Twin Moose + Single Kundah)
5. Essential requirement of longer span in the existing line.

Option 5 is best suited option for the particular line.

8. Limitations of the Design

The inter-circuit clearance is within limits only up to 800m span. Above this span the clearance will reduce and hence the lower circuit tension to be reduced to maintain the clearance.

As the line is utilizing the existing RoW and tower locations, the optimization in tower design is minimized. The design parameters of the towers were based on the existing spans.

Another important point for limitation in design is in the case of O and M of 400/220kV circuits on either side. Maintenance of 400kV or 220kV circuit on either side will automatically affect the operation of 220kV or 400kV and vice versa. The inter circuit clearance is fixed at 7.5m at the cross level still it may not suffice the safety working clearance at mid-span. Obviously this limitation is common in the case of Multi Circuit towers.

9. Conclusion

Kerala State Electricity Board Ltd has already commenced the construction of the subject line and the construction is almost halfway completed. The erected towers on the field are now seen as trademark aesthetic eco-friendly design and we call it as “Green Power Corridor” by virtue of its reduced carbon footprint. The project is funded by Power System Development Fund (PSDF) considering the technological innovations and use of High capacity conductors.

10. Way Forward

With the experience in successful designing and testing of 400/220kV MCMV line for 35M RoW, Kerala State Electricity Board Ltd has also developed Narrow/Broad based 220/110kV MCMV towers with RoW limited to almost 22M and these 220/110kV towers were already type tested at CPRI and installed and commissioned. 400/220kV towers were named as MLA, MLB, MLC, MLD and MLS. The 220/110kV Narrow/Broad based towers were named as KLA/GLA, KLB/GLB, KLC/GLC and KLD/GLD. Huge savings in RoW compensation expected by suing these newly designed towers for the existing corridor.

Thus the trends in conventional transmission line technology have taken a new turn to have smaller RoW with lesser height and higher ampacity. Author is sure of the future trends in Power Transmission in reduced RoW and High Temperate conductors or High Performance Conductors with the advent of better outputs from the researches in conductor, Insulation and Tower technologies.

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