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Frugal and Technological Innovations for Sustainability in Power Transmission Sector

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Abstract

This paper attempts to address the various concerns prevailing in Power transmission sector Viz: Right of Way (RoW) issues in drawing new power lines, insufficient capacity of existing transmission lines, lack of space for constructing new transmission lines etc., so as to match the Transmission Capacity requirement as per the increase in demand of power. Rightly addressing the above issues, those create effective corridors for transmitting power between power-starving and power-surplus regions at national level would be the need of the hour. Government of India (GOI) is taking various measures to address these issues, which are mostly through innovations that can be applied in up-rating and upgrading of the existing transmission lines and using bipolar DC Transmission links between the regions. Use of DC power transmission, distributed generation, concept of energy producing customer (Prosumer) etc. are few other modern trends in the field of Power. Any innovations that can address the power crisis and that is taking care of the environment will be ensuring the sustainability in power transmission sector, rather than finding out short term solutions. Use of innovations in material science is an emerging technology in High Capacity Conductor (HPC) manufacturing and hence the country is marching towards the sustainable development in power transmission sector also. Government of Kerala (GOK) is also taking several measures to address the various issues as mentioned above, especially it being a state having large population density, thick vegetation and forest coverage. It would be very wise for Kerala to adopt innovative and technological solutions to keep its environmental richness and the sustainability of so called "God's Own Country".

Keywords: Gas Insulated Lines (GIL), HTLS Conductors, MC Towers

1. Introduction

Electricity being the key to growth in any sector, whether it is Industry, Agriculture, Commerce, Research and Development, service sector etc, and its availability abundantly ensures the required contribution to the overall development of the country. The per capita consumption of electricity is recognized as an index of advancement of the country and standard of living of the people. The per capita consumption is around 1000 units in India while in developed countries it is more than 3000 units. The per capita consumption in Kerala is still lower than the national average, which nearly 700 units.

The reports of World Energy Council (WEC) states that the energy sector has to depend on conventional fuel based power generation also, even with the addition of Non-conventional energy sources in large quantum in forthcoming decades. While considering the growth in GDP of various countries and development indexes projected the world energy demand is expected to raise up to 35000 Trillion Units from the availability of energy of around 22000 Trillion Units. The above assessment

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considers the innovations that may take place for enhancing the efficiency of the existing power plants and increasing capacity of existing transmission lines also. In next three to four decades 40-70% of the investment in power sector would be in the renewable energy sector and by the year 2050 the total production from Solar is expected to exceed the production from fossil fuels as per a report of WEC. However, the need of having high capacity transmission system is imperative to have a flexible power flow between generation nodes and load centres.

It is quiet astonishing fact that about 1200 million people are not having electricity today and even in the year 2050 it may remain at 500 million and in India this number will be around 60 Million. In the total 3,10,000 MW installed capacity in India only 50000MW is from the non-conventional energy sources. Also India may need to add around 100,000MW by the year 2040 as per the power survey reports. India is expecting add non-conventional energy to 47% of its installed capacity by 2050, the share of energy from renewable sources will be around 25% of total energy demand at that time. In Kerala the share will be again less due to the issues of land availability for solar power plants and limited wind potential in Kerala. The above facts also pointing towards, the need of high power transmission corridors from generation centres to load centres.

As we all know the power plants from conventional fuels are a major source of Greenhouse gases especially Carbon dioxide. However, the total CO2 emission by India is only around 3% of world average and per capita emission is only one third of the world average. Kerala is expecting to add 50MW wind and 500MW solar to its grid up to 2030 considering the various issues mentioned above related to renewable energy plants and hence Kerala needs to depend heavily upon the thermal energy imported in addition to its hydel generating stations. As per 18th power survey Kerala needs to add nearly 450MW every year to meet its demand[6]. The interstate and intra state transmission corridors are mandatory to bring power from other power surplus regions in India.

Power sector in India is divided in to five regions and each region load and generation is monitored and controlled by regional load dispatch centres. There are unbalances in generation and usage of electricity in each region and proper energy balance will happen when there are enough power corridors available across for free flow of power at any time. For this to happen we need to draw large capacity transmission lines for long distances in which the Extra High Voltage DC Transmission lines using high capacity conductors are the emerging solutions.

KSEB is a public sector utility under the Government of Kerala that generates, transmits and distributes the electricity supply in the state. KSEB Ltd has 23 hydro-electric projects, two diesel power plants and one Wind Farm. Also it can be seen that the growth of the power sector in Kerala has been very lopsided. The grid of Kerala power system is connected to the Southern Region Transmission system through two 400 kV double circuit lines. Perhaps Kerala would be the state with full of green energy, as all in-house power plants are hydro based power plants without pollution and renewable in nature. But the energy deficit is met from the thermal power stations outside the state which needs to be brought in to Kerala through large number of EHV transmission lines.

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. 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.

In April 2016 the peak demand of Kerala system has risen up to 4004MW and the daily energy consumption has increased to 80.44MU which are first time in the history of the state of Kerala. Such increase in demand can be expected in future also by which the need of having good EHT network is inevitable.

Thus additional transmission lines need to be drawn in to and across the state to have a seamless flow of power within the state. Hence the efficient and sustainable solution to the EHV transmission lines demands innovations in technology and the application of frugal engineering concepts.

2. Issues Related to Transmission System in Kerala Power Sector

Despite the encouraging growth trajectory in the energy space over the last few years, the Kerala Power sector has still not been able to induce and sustain the required capacity addition in transmission sector matching the ever growing power demand of the state due to some challenges. They include:-

- Popular feeling against construction of high voltage overhead lines in urban and suburban areas.
- Interstate transmission corridor not sufficient.
- Skewed demand and very heavy demand during morning and evening.
- Opposition from public in putting up new transmission lines.
- Existing transmission lines are not meeting the N-1 planning criteria
- The system is not capable taking care of seasonal variations and load growth.
- Higher Aggregate Technical and Commercial (AT&C) losses due to old and outdated sub-transmission and distribution infrastructure.
- Difficulty in obtaining new RoW
- High cost to install new power lines
- Time involved in constructing new power line
- Provision or contingencies for shutdown
- Increased population density
- Environmental Issues
- Increased cost of conductors

Hence the various options that utility can resort to for strengthening the transmission network are as follows:

- Addition of new Transmission lines and substations to avoid over loading of existing system (wherever three or more circuits of the same voltage class are envisaged between two sub-stations) the next higher transmission voltage, especially new substations at load centres.
- Upgradation of the existing transmission lines and substations such as raising height of conductor supports and / or switch over to insulated cross-arms to facilitate change over to higher voltage, if the tower designs so permit and upgrading the substation to higher voltage to attain higher power handling capacity.
- Re-conductoring of the existing transmission line with higher size of conductors/high performance conductors and renewal of the substation equipments with higher capacity.

The choice for the above shall be based on cost, reliability, right of way requirements, energy losses, down time, etc.

3. Use of Innovative Technology in Transmission

Besides, for optimizing power transfer per unit ROW, the Ampacity of conductors used in the transmission lines can be raised by use of technological advancement.

This calls for new generation conductors, which can deliver large quantum of power without any change in the existing tower/foundation designs or minor modifications therein.

In this scenario, one possible solution is to upgrade the transmission capacity, so that higher power Transfer capacity could be established from the central generating stations and neighbouring states. The transmission capacity can be increased by laying new towers and structures parallel to the existing structures also. But it often requires high initial cost and obtaining the necessary right of way for laying structures. Many times drawing parallel lines for increasing capacity causes objections from public. Moreover, the high population density, environmental concerns and high population growth causes hindrance to the necessary right of way very difficult in the state of Kerala. Many projects were scrapped in its drawing board due to this reason alone.

Thus a viable alternative is to rewire the existing Aluminium Conductor Steel Reinforced (ACSR) conductor by High Temperature Low Sag (HTLS) conductors. For the same mechanical load, HTLS conductors can withstand more heat thus making it possible to transmit higher current that too with lower sag.

Use of specialised design for Towers, insulators and accessories can also act as a catalyst for resolving the issue of RoW to some extend and to arrive at an optimum solution.

4. High Temperature Low Sag (HTLS) Conductors

Traditionally, overhead high voltage transmission lines have been using the "Aluminium Conductor Steel Reinforced" (ACSR) design. ACSR conductors are characterized by strands of aluminium wrapped around steel wires. The outer aluminium strands conduct electricity, while the steel core provides tensile strength to the ACSR cable. Aluminium is ductile, it can deform under tensile stress. The steel core, in turn, prevents aluminium strands from stretching out extensively and sagging lower than the permissible levels. Although ACSR transmission lines are relatively cheap and have been used over a hundred years for high voltage transmission, they are disadvantaged by their high coefficient of thermal expansion, which causes the cables to expand and sag. Also these conductors generate more resistance with increasing load, causing the lines to overheat or the knee point for plastic expansion is less. Transmission lines cannot sag beyond this knee point limit, after which they pose a threat to public safety. Additionally, greater resistance with temperature means greater transmission losses on ACSR lines as grid operators needs to push more power across the system. Because the use of ACSR transmission lines is restricted by these technical inadequacies, they cannot reliably transmit power in excess of their line ratings (under assumed weather conditions) to meet increased demand.

Technologies that can increase the capacity of the transmission network by making lines more capable of carrying higher volumes of power without overheating or sagging can significantly reduce this loss and increase the efficiency of the installed transmission infrastructure. So how can the transmission capacity of the power network be increased without acquiring new Right of Way?

One option is to replace ACSR with "High Temperature Low Sag" (HTLS) conductors in transmission lines using the existing towers and right of way (ROW). The use of HTLS Conductors is an attractive method of increasing transmission line thermal rating. The conventional ACSR Conductors are able to withstand a continuous temperature of 75 deg C to 85 deg C. In case of emergency, for a short duration the conductors can work up to 105 deg C without any sign of deformation. Special HTLS conductors having approximately the same diameter as the original ACSR are capable of operation at temperatures as high as 250 deg 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 also typically consist of aluminium wires helically stranded, but annealed to withstand high temperatures, wound over a reinforcing core of lesser thermal expansion coefficient. Most of the electrical current flows in the high conductivity, low-density aluminium 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 aluminium 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.

Advantages of HTLS conductors are:

- High ampacity
- Less elongation
- Increased thermal rating
- Ability to work under high temperature more than 200^{o} C
- Rapid re-conductoring of existing circuits without increase of right of way.

4.1 Classification of HTLS Conductors

The Carbon Composite Core (CCC)[1] **based HTLS conductor** consists of glass-carbon fiber/ epoxy matrix core. The core is organic in nature due to the epoxy matrix. The glass fiber/epoxy shell encases the carbon fiber/epoxy section. The function of the glass fiber/ epoxy shell is to isolate electrically the conducting carbon fiber/ epoxy section of the core. Thus, the glass fiber/epoxy acts like a dielectric medium and prevents galvanic corrosion between carbon fibers and aluminium wires. The core is not stranded; it is a single piece of rod running through the entire length of the conductor. The conductor wires, which surround the core, are fully annealed 1350^{o} C tempered aluminium. The conductor core is produced by pultrusion process. The aluminium wires can also be arranged in trapezoidal configuration to increase the Aluminum area for same outer dia of the conductor.

The advantages of HTLS conductor with carbon composite cores are manifold. It offers[4]:

a) large cross section area for the aluminium conductors, which consequently increases the ampacity compared to equivalent ACSR,

b) a high strength to weight ratio,

c) superior sag-temperature characteristics,

d) extremely low coefficient of thermal expansion and

e) High tensile strength.

Carbon fiber composite core is up to 25% stronger than steel core, which significantly reduces the sag of CCC[1] transmission lines at high temperatures. Thus CCC cables can carry more current while sagging less than ACSR cables. Additionally, CCC cables are up to 60% lighter than ACSR cables, which allow CCC cables to have longer spans and require fewer and shorter supporting structures, eliminate some RoW issues for Tower footings. The smaller number of supporting structures required also reduces the capital costs of transmission line projects. The losses incurred for same amount of power will be less in CCC conductors compared to ACSR conductors. Finally, CCC cables resist degradation from vibrations, corrosion, ultraviolet radiation, corona, chemical and thermal oxidation, and cyclic load fatigue.

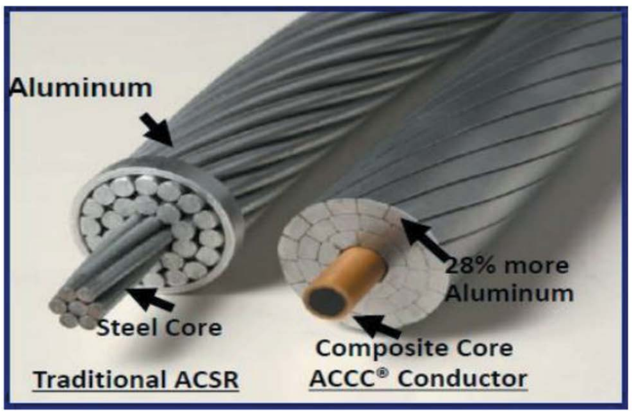

Figure 1. Steel-reinforced ACSR and composite-core ACCC conductors.
(Source: Brochure of manufacturer)

4.2 Other Types of HTLS/HPC Conductors[2]

Table 1. Few Types of HTLS Conductors

ACSS	Aluminium Conductor, Steel Supported
ACSS/TW	Trapezoidal Shaped Strands, ACSS
G(Z)TACSR	Gap Type Super Thermal Resistant Aluminium Alloy, Steel Reinforced
TACSR	Thermal Resistant Aluminium Alloy Conductor, Steel Reinforced
STACIR	Super Thermal Resistant Aluminium Alloy Conductor, Invar Reinforced

4.3 Sag Comparison

The sag of the conductor depends on the various parameters like the operating temperature, span of stringing, material properties of the core and other parameters like wind load, ice load etc. However, the comparison of sag under similar conditions is illustrated in the Figure below.

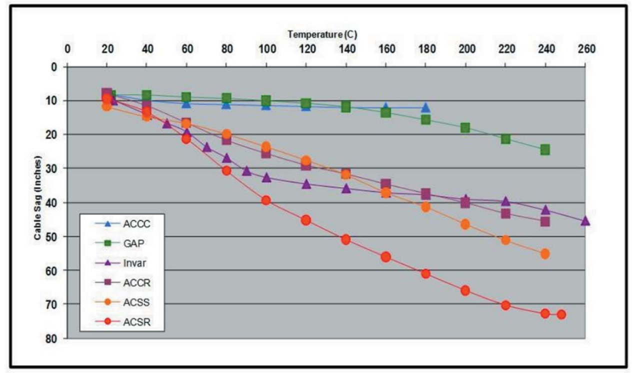

Figure 2. Sag Comparison ACSR and HTLS conductors.
(Source: Brochure of manufacturer)

4.4 Power Transfer Capability Comparison

By analysing all the above types, it can infer that CCC type gives better electrical as well as sag properties and other type follows. The cost and Electrical ampacity comparisons are also shown in tables below.

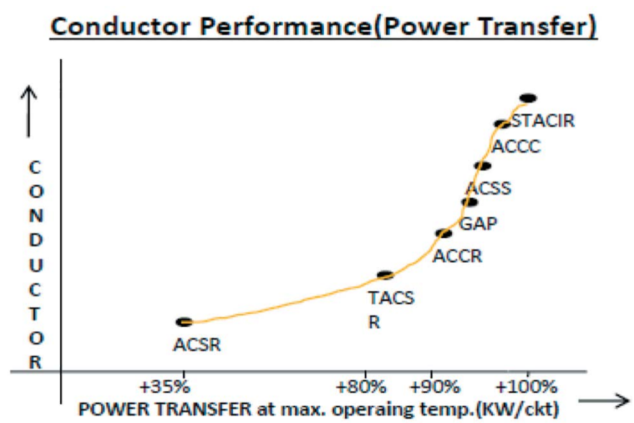

Figure 3. **Ampacity comparison.**
(Source: Brochure of manufacturer)

4.5 Price Comparison

Care must be taken for properly choosing the most suitable material option for conductors for the upgradation or uprating of the transmission lines, taking in to account the ampacity, sag and other properties, along with the cost of the conductor chosen.

4.6 Line Losses Comparison

For comparison line losses under the same operating conditions would be required while choosing the

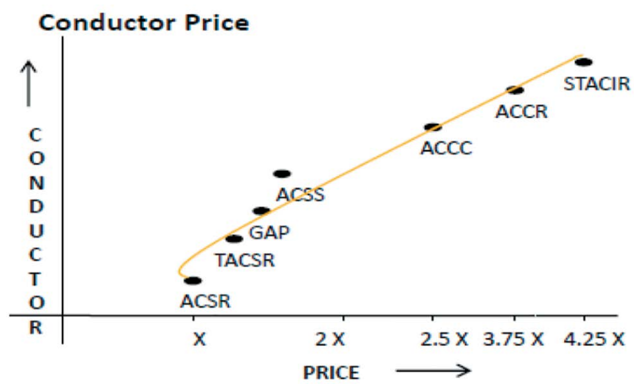

Figure 4. Cost comparison[3].
(Source: Brochure of manufacturer)

condctor to be used in a particular case. A tradeoff between cost, public issues related to ROW and easiness of implementation to be considered while taking decision with regard to the conductor and configuration of EHT line.

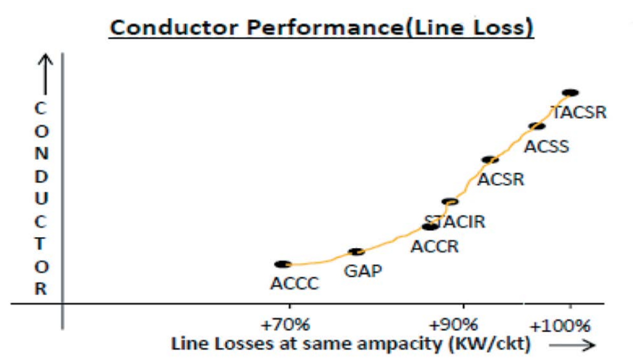

Figure 5. Line Loss comparison.
(Source: Brochure of manufacturer)

Various type tests and routines tests carried out on HTLS conductors concludes that HTLS conductors have[7]:

a) Higher current carrying capacity

b) Long term reliability

c) Low Sag-Tension Property

5. Multi Circuit Towers

Multi Circuit towers for 400kV & 220kV, 220kV & 132kV or 220kV & 66kV, 400kV & 400kV on a single tower are being used in the areas near city or areas having limited corridors. These multi circuit towers will have high voltage on top two circuits and lower voltage on bottom two circuits. These towers can be designed for narrow based towers or normal towers. These lines will carry 4 to 6 times power in same corridor. The narrow base will lead to heavy angles in bottom sections. Now even for 765kV & 400kV multi circuit towers have been developed. Each line will require a new design based on requirements.

6. Tubular/Monoblock Towers

Tubular / mono-blocks towers for EHT lines are being used in India but in limited way. For a 400kV towers dia can be 1.5M or 2.5M and normal foundation can be of 5M to 10M instead of a normal tower having foundation dimension in range of 10M to 20M. These tubular poles can be fixed on base plate with embedded foundation bolts etc. Thus there is reduction in overall dimension of foundations for these towers.

The dimensions of cross arms required for tubular poles also get reduced. There can be some reduction in ROW requirements compare to line on normal towers due to reduction in dimensions. However, cost of tubular / monobloks poles are about 2-2.5 times than normal towers. Foundation may also require piles. For lifting poles special arrangements will be required. These are mostly used in city areas from aesthetic point of view. These are uneconomical compared to conventional lattice towers hence being used in very limited way.

7. Covered Conductor

Future proposal is to use covered conductors in places where there are thick vegetation issues which can reduce the RoW considerably. Up to 66kV CEA has approved some design for use of the covered conductor and 110kV covered conductors are under testing in lab. At LT and EHT up to 66kV levels, covered conductors are widely coming up in the country, but above that level is still under testing. The issue of safety to the public is a major concern for utilities and hence the covered conductors are viewed as a solution compared to the bare OH conductors.

8. Use of Under Ground Cables

It is proposed to use UG Cable especially when there is no possibility of having OH lines and also when OH lines are avoided due to aesthetic issues. Especially in urban distribution and transmission system UG cable in ring main system will offer high amount of reliability in power.

9. Insulated Cross Arm Towers

Research is going on the use of FRP/Insulated cross arms, especially in the existing lines which needs upgradation in voltage level. The cross arms can be made from polymer/Fiber insulator instead of steel section. This will reduce ROW requirements to some extent. Lot of work is required to be done for modifying the cross arms. Few trials were made in India on some 66/132kV lines.

10. Narrow based Towers

These towers are mostly used in hilly terrain/urban areas where less space in available for putting foundation. But the towers sections become heavy leading to high weight and this high cost. The tower foundation cost also increases. There is no reduction in ROW requirements as the cage and cross arms are of same dimensions. Special design will be required to be made based on specific requirements as there are no general designs.

11. Gas Insulated Lines (GIL)

The world has only 30 years of experience with gas-insulated systems, which has high reliability and high safety because of the metallic enclosure. Also it is having low operating costs. Practically no ageing because of insulating gas and offers very low electromagnetic fields. No external influence in the case of an internal failure (low fire risk) and it can operate like an overhead line, with autoreclosure.

12. Conclusion

Consumption is increasing day by day and due to environmental concerns & high population density, the increase in generation is also not up to the expectations. Having enough transmission lines through new RoW is not at all a feasible solution. Many new projects are not anywhere near to completion or even abandoned and new projects are not been sanctioned due to severe RoW issues.

Thus in a thickly vegetated and densely populated state of Kerala, a frugal and innovative technological solutions are ideal to reduce the RoW and issues related to constructing lines and felling of trees.

The following innovations and Technological solutions address many of the issues.

- The use of V Strings in stringing line will obviously arrest the swing of the conductor and hence the live metal clearances also could be reduced and hence there by reduction in RoW.
- Moreover, the use of narrow based configuration reduces the RoW little to the extent of reduction in cage dimension.
- Even though Multi Circuit multi Voltage lines were existing earlier also, but Multi-circuit line with HTLS would be first of its kind especially at 400/220kV level in India. This configuration is also reducing the RoW issues for equivalent to three more lines.
- Due to the above the tower height can also be reduced which in turn will reduce the foundation requirement, which will reduce the issue of doing expanded foundation in the existing route.
- Use of High Temperature Low sag (HTLS) conductors resolved the issues of higher Power Transmission Capacity and reduced RoW due to reduced sag. High Temperature Low Sag Conductors provide a great way for expansion of the transmission system in Kerala.
- Lower power losses of CCC conductors with large current carrying capacity would make these conductors the preferred conductor for re-conductoring on the existing towers and new transmission line projects with very high power transfer capability. ACSS is also a viable option for new lines where the higher amount of sag at very high temperature can be accommodated but with lesser cost compared to CCC.

However, the author is very sure that the evolution of new conductors with the advancement of material science, related to insulators, conductors and structures, will be opening new trends in transmission line technology and reducing the environmental impact considerably. But the researches in this direction are comparatively less in India and it may take much longer time to adopt foreign technology than an indigenous one.

13. References

1. CTC Cable Corporation, Innovative conductors solutions are power transmission and distribution systems [Internet]. [cited 2014 Jun 19]. Available from: www.floridapsc.com/utilities/electricgas/.../CompositeTechnology.ppt.
2. Pat A. High capacity/low sag conductor for the power industry [Internet]. [cited 2014 Jun 19]. Available from: http://wyia.org/wp-content/uploads/2010/11/pat-avery.pdf

3. Campbell RJ. Regulatory incentives for electricity transmission - issues and cost concerns [Internet]. [cited 2014 Jun 19]. Available from: http://www.ieeeusa.org/ policy/eyeonwashington/2011/documents/electrans.pdf
4. Hill T. Experience and benefits of using High Temperature Low-Sag (HTLS) overhead conductors [Internet]. [cited 2014 Jun 19].
5. Making the Economic Case for Innovative HTLS Overhead Conductors: Final Project Report. Power Systems Engineering Research Center, Arizona State University; 2014.
6. Power system statistics :2012 – 2013. Kerala State Electricity Board Limited.
7. Burks B, Armentrout DL, Kumosa M. Failure prediction analysis of an ACCC conductor subjected to thermal and mechanical stresse., IEEE Transactions on Dielectrics and Electrical Insulation. 2010; 17(2):588–96. https://doi.org/10.1109/TDEI.2010.5448116
8. Burks B, Kumosa M. The effects of atmospheric aging on a hybrid polymer matrix composite. Composites Science and Technology. 2012; 72:1803–11. https://doi.org/10.1016/j.compscitech.2012.07.018
9. Burks B, Middleton J, Armentrout D, Kumosa M. Effect of excessive bending on residual tensile strength of hybrid composite rods. Composites Science and Technology. 2010; 70(10):1490–6. https://doi.org/10.1016/j.compscitech.2010.04.029
10. Burks B, Middleton J, Kumosa M. Micromechanics modelling of fatigue failure mechanisms in a hybrid polymer matrix composite. Composites Science and Technology. 2012; 72:1863–9. https://doi.org/10.1016/j.compscitech.2012.07.017