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Enhancement of Power Transfer Capability of Transmission Line using HTLS Conductor

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ABSTRACT

In India, ACSR and AAAC are most commonly used conductors for power transmission through overhead conductors. To meet the increased load demand either we need to construct the new UHV or EHV line or to upgrade the existing transmission line. Upgrading of transmission lines means the modifications in the existing transmission line to enable the increased current flow limits, but making a new transmission lines also have few major constraints i.e. ROW constraints (Lack of availability of land/corridors for construction of new transmission lines) and time constraints (due to short time schedule for the construction of transmission lines projects need to match with generation projects).To avoid such difficulty we need use a high performance conductor known as HTLS (High Temperature and Low Sag) conductor, which can carry approximately 2 to 2.5 times higher current that of conventional ACSR conductors of same size and it can be easily operated at higher temperature level (above 200°C) whereas the thermal limit of ACSR conductors is 85°C,hence by increasing the thermal limit the current carrying capacity can be enhanced.

Keywords: HTLS, INVAR, Ampacity.

I. INTRODUCTION

A rapid increase in electric power consumption is witnessed which results the increase in demand of the uninterrupted power supply. The new generation units are being built with increased installed capacity, but the existing transmission lines are reaching their critical limits of ampacity and there is shortage of corridors particularly in dense populated area. Most of the times it becomes impossible to obtain a right of way for the new transmission lines and hence present circumstances demands the use of available lines with cheaper solution than going in for an underground transmission and in present scenario the use of HTLS technology is quite cheaper and convenient solution (Dae-Dong Leea, 2011)

The constructions of new line have several disadvantages. In addition, there is a large limitation of construction space, ROW issues and construction costs are very high when rebuilding the towers, hence the best suited method is to increase the operating temperature by adopting heat resistant aluminum alloy conductors .The purpose of developing a new type ACSR conductor was to double the current capacity by restringing conductors on existing steel towers. Thus it is unnecessary to either rebuild or construct tower with longer in height, the steel towers to enlarge the capabilities of overhead transmission lines.Use of HTLS requires lower construction costs, has a shorter construction period and does not need larger towers, larger conductors, or bundled conductors. The structure, fittings, and construction methods of HTLS are designed to be the same as those of ordinary ACSR conductor. (S. Sakabe N. Mori, 1981)

During last few decades the world is going through a phase of rapid industrialization and at same time the electrification in developing countries in being carried out at a high rate and as a result the power demand is increasing day by day. In response government and private projects fare involved to increase the power generation, subsequently the transmission and distribution, to meet this increased power demand is becoming a great challenging for the utilities in terms of cost and capacity, where the existing lines have reached their maximum limits. Hence on the solution to build new lines parallel with existing one but this is not an economical solution. (Chatterjee, 2016),

One of most cost effective solution is to adopting high temperature low sag (HTLS) conductor for transmission and distribution. These are different from the conventional ACSR conductor in terms of material but same in size. It can carry approximately 2 to 2.5 times the current that of conventional ACSR conductors of same size and can withstand higher temperature (>200 °C),due to high current carrying capability the elongation of conductor is less, so the sag is very less. One of the major advantages of HTLS over conventional ACSR conductor is to re-conductoring the existing double circuit line with HTLS, without disturbing the another circuit. The possibility of replacing conventional overhead conductors with new generation's high performance conductor is called high-temperature low-sag (HTLS) conductors, it is attractive choice particularly in those corridors which are thermally limited and it can operate upto temperatures as high as 210°C, almost doubling the current carrying capacity of existing ACSR conductors. (Antonio Gómez Expósito, 2007).
Characteristics of HTLS (High Temperature Low Sag Conductors): G(Z)TACSR (Gap Thermal Alloy Conductor Steel Reinforced),ZTACIR (Thermal Alloy Conductor Conductor Invar Reinforced) and ACSS (Aluminum Conductor Steel Supported) .

Here G refers to Gap between steel and aluminum conductor and Z refers to trapezoidal shape of aluminum conductor. HTLS conductors are similar to conventional ACSR conductor in terms of electrical conductivity and geometrically. The main difference is that it offers the low coefficient of thermal expansion and due to this significant property of HTLS conductor, it can be operated at a higher temperature with an increased CCC (current carrying capacity) with maintaining same sag that of traditional ACSR conductors.

G(Z)TACSR:

In G (Z) TACSR type conductor is known as Thermal Resistance Aluminum Alloy conductor Steel Reinforcement as shown in Figure 1, where inner core is composed of galvanized steel and outer layers are composed of thermal resistant aluminum conductor. A small gap is maintained between the steel core and the innermost aluminum layer, and the gap is filled with heat-resistant grease to reduce friction between the steel core and the aluminum layer and to prevent ingress of water and hence it improves the corrosion resistance. (G.Filippone, 2014)

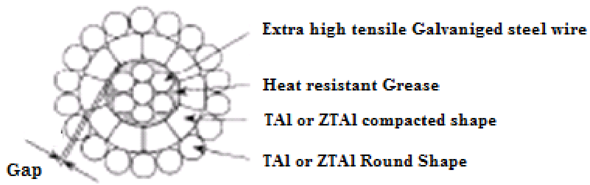

Figure 1. Crossectional view of G(Z)TACSR Conductor

ZTACIR:

Super thermal alloy (STAL) is made from Al-Zr (Aluminum Zirconium) alloy. The conductor comprises of an inner core of Aluminum clad Invar (36%Ni in steel) and outer layer are made of STAL wires.
Here the Figure 2 shows the cross sectional view of (Z) TACIR conductor. (G.Filippone, 2014)

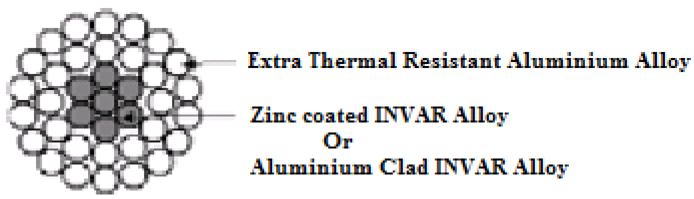

Figure 2. Cross sectional view of ZTACIR Conductor

Instead of using conventional steel in conventional ACSR conductor, in ZTACIR conductor, INVAR is used which is made of an alloy of steel and 36% nickel and as a results the coefficient of expansion practically become linear and it is invariable with application of heat and that's why the name was given as INVAR.

Super thermal alloy contains Zr which deposits over the grain boundary of Aluminum, thus increasing the recrystalizing temperature of Aluminum, which enables the STAL to operate at high temperature without any loss in strength.

ACSS :

ACSS is known as Aluminum Conductor Steel supported as shown in Figure.3. (G.Filippone, 2014) .In ACSS the core is made of round steel and aluminum strands are made of trapezoidal shape. The steel wires may either galvanized wires or aluminum clad (aluminum coating). In ACSS conductors the aluminum wires can be the standard round strand or it may be trapezoidal aluminum strand.

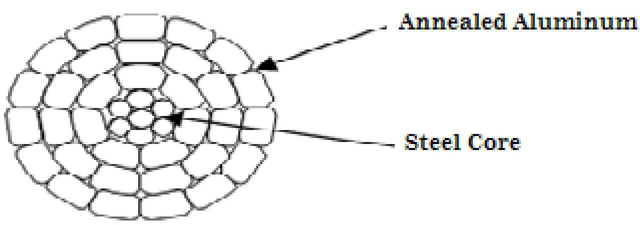

Figure 3. Cross section of ACSS Trapezoidal Conductor

In HTLS conductor, the main modification is done on aluminum strands which are completely annealed wires and steel core which is made of INVAR strand and conductivity of core is enhanced by 14%, where in ACSR conductor the conductivity of core is almost zero. During stringing when tension is applied on the HTLS conductors, the permanent elongation takes place quickly in aluminum wires, since the core is made of INVAR strands, where the coefficient of linear expansion is invariable with temperature and as a results the sag of the conductor will be greatly reduced. In operating conditions, the The new material includes INVAR steel (Fe-Ni alloy), temperature resistant Aluminum-Zirconium (Al-Zr) alloys, annealed aluminum, high strength steel and both metal & polymer composites. coefficient of expansion of conductors is close to the value provided by the steel core, in the order of (10to 13x10^{-6}°C),which is quite low as compared to conventional ACSR conductors i.e. Order of (18 to 22x10^{-6}°C) and results of this reduction in overall sag and therefore an increase in the ground clearance.

Conductor Parameters

Table1

Description	Different Conductor			
	ACSR	G(Z)TACSR	ZTACIR	ACSS
Area (mm^2)	307.7	308.4	306.9	307.7
Rated Ultimate Tensile Strength (kgf)	9945	10960	10065	9900
DC Resistance at 20 °C(ohm/km)	0.108	0.110	0.1106	0.107
Weight (gm/km)	1067	1097	1082	1067
Coefficient of linear expansion (10-6/°C)	18.8	11.4	16.3	11.5

Table 1 shows the parameters of different type of HTLS conductor having approximately same cross sectional area. (G.Filippone, 2014). The conventional ACSR and AAAC are designed to operate continuously at temperature of 85°C and 95 °C respectively. High Temperature Low Sag (HTLS) conductors are designed to operate continuously at temperature of at least 180 °C. Some HTLS conductors can be operated as high as 240°C. The new material used in HTLS conductor differs from conventional steel reinforced ACSR.

A conductor in general is a simple combination of core and aluminum and aluminum alloy. HTLS conductor is stranded with combination of aluminum alloy wires for better conductivity and reinforced by steel core.

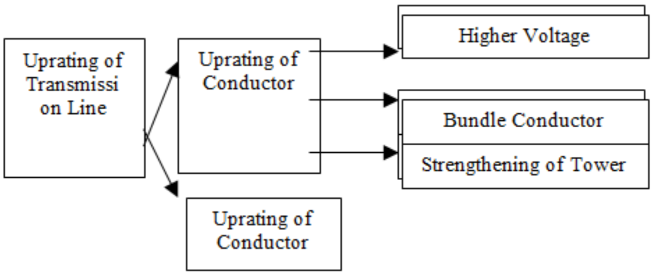

Figure 4 Different scheme of uprating of Transmission line

Figure 4 shown the two different way of upraitng of transmission line,firstly the uprating can be done by constructing a new transmisison line with traditional ACSR conductor,by extra HV lines or with bundling of transmission line or making bigger size conductor diameters.Secondan way to change the conductor with advanced material by increaing therir thermal raing. (Recommendation)

Different type of HTLS conductors are ZTACIR (with INVAR steel core), GZTACSR (with specified gap between steel core and inner layer of aluminum wires), ZTACSR (with steel core), ACSS (with steel core).The TACSR, GZTACSR, ACSS

and ACCR are available with both round wire and trapezoidal Al-Zr alloy wires in the outermost layer. ACCC uses only trapezoidal annealed aluminum wires. GZTACSR, commonly known as Gap type conductor, the Gap is filled with heat resistant grease (filler material) to prevent water ingress and improves the corrosive resistance, such type of conductors are mainly required in coastal areas.

Advantages of HTLS over Conventional ACSR conductor is as shown in Table 2

Table 2

		Build a new Line	Replacement of old conductor with HTLS conductor
Build period	Transmission line approx.30 km	18 month	6 month
Construction cost	Preliminary work	Required	Not req.
	Cost of right of way	High cost	No cost
	Tower foundation	Required	Not req.
	Conductor cost	Required	2 to 3 times the ACSR
	Stringing cost	Required	Required

Table 2 shows the comparative analysis of construction of new transmission line and replacement of old conductor with new HTLS conductor. (upgrading.)

Materials used: STAL wire containing Zr (Zirconium)element which has highly improved annealing property, without loss of tensile strength..HTLS using Al clad invar has low thermal coefficient of expansion (approx 1/3 rd) of steel at Temp 210°C.

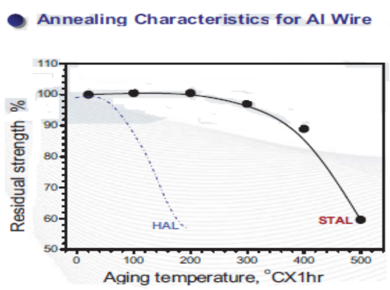

Figure5. Annealing characteristic of STAL wires

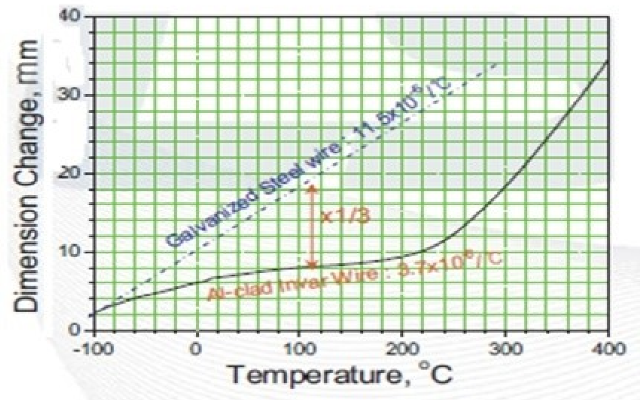

Figure 6. Coefficient of thermal expansion

The ordinary hard drawn aluminum wires used in conventional ACSR, start losing tensile strength at 90°C and therefore it is not suitable for long term use at temperature above this. Al-Zr aluminum alloys wires have the same conductivity and same tensile strength as ordinary EC Grade aluminum wire but it can operate at higher temperature range upto 150 to 200°C. In India since last few years, the need for use of HTLS conductors in some corridors has been felt. The power flow in those corridors has increased and congestion has been reduced by using such conductors. Such conductor would be required where the power transfer over the line is constrained due to consideration of thermal loading.

In Intra-state transmission system, requirement of such conductor is expected at 220kv, 132kv and 66kv level. The requirement of such conductor may not be much in ISTS, which is dominated by 400kv and 765kv network. In case of ISTS lines, the HT/ HTLS conductor would be a good substitute to Quad bundle ACSR and AAAC conductor, particularly at 400kv level when line length is short.Therefore the HTLS conductor can be considered for reconductoring of existing lines and can also be used in new lines. The cost of such conductor is about 2 to 3 times the cost of conventional ACSR conductor. (Draft guidelines for HTLS Conductors CEA, 2016)

Methodology

IEEE Standard 738-2006, IEEE Standard used for calculating the Current Temperature relationship of Bare Overhead Conductor, the standard shows the method of calculating of the current- temperature relationship of overhead conductor.The tool used for calculating the current- temperature relationship is PLS-CADD i.e.(Power Line System – Computer Aided Design and Drafting) which is the most powerful and comprehensive program/tools for the structural and geometric design of overhead lines. It covers all environment aspects of transmission line design, including terrain modelling, route selection, manual or automatic minimum cost spotting, sag-tension, clearance and strength checks, plan & profile drafting and much more. For new transmission lines projects PLS-CADD will significantly increase capabilities and productivity of line. By placing six numbers of 400 KV tower structure in plain terrain placed approx 400 meter apart in by using PLS CADD Tools as shown in

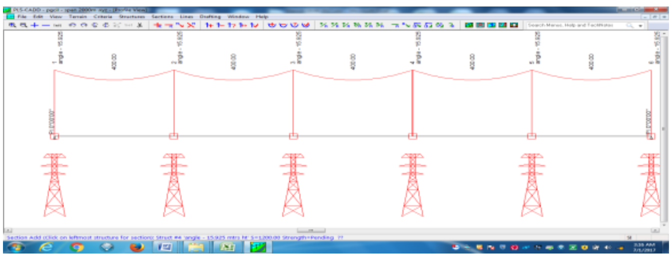

Figure7.

Figure.7 Model of 400KV Transmission line using PLS Cadd Case Studies:

Case 1: Comparison of ACSR and HTLS conductor maintaining same current and their operating temperature:

DESCRIPTION	MOOSE (ACSR)	ACCC-Moose (HTLS)
Calculations are carried out at temp degree	85	76.70
Current to be	902	902

maintained:		
AC Resistance (ohms/km)	0.0687	0.0532
Line losses in kw/ckt	168	130
Power Factor	0.85	0.85
Power Transferred in MW/ckt	531	531
Price Loss (in Lacs Rs/KW)	256	198

Table 3

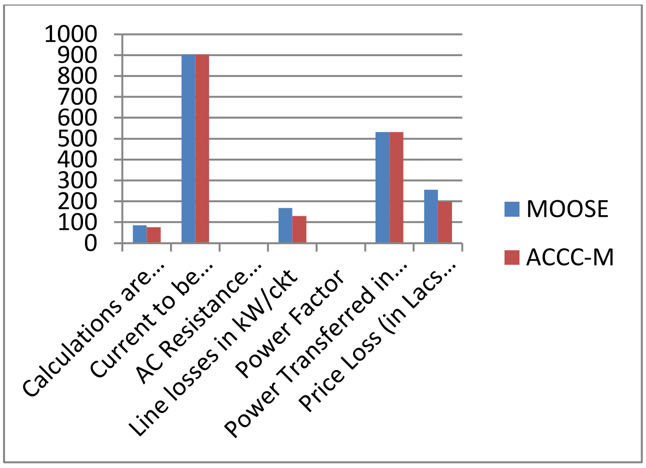

Figure.8 Comparison chart of ACSR Moose and ACCC Moose (HTLS) conductor when operated at same current rating

Conclusion of Case 1:

The maximum operating temperature of ACSR Moose conductor is 85⁰C and maximum current carrying capacity is 902 Amps in specified working condition, therefore the comparison is done at 902 Amps between ACCC-Moose (a type of HTLS conductor)conductor and ACSR conductor and all the calculation is done based this ampere rating. ACSR Moose conductor reaches 902 Amps at 85⁰ C (operated at maximum operating temperature level) and while ACCC-M achieved this current rating at reduced temperature level i.e. 76.7 ⁰C (well below the maximum operating temperature level i.e 180⁰C).

For ACSR conductor the ac resistance is 0.687 ohm/kms whereas for ACCC-M conductor the ac resistance is only 0.0532 ohm/kms which is quite lower as compared to ACSR Moose conductor and as a results of this the line losses will be lower side i.e.130 KW/ckt which is approximately % lower than the ACSR Moose conductor.

For ACCC-Moose the price losses will be only 198 (Lacs/kw/ckt) as compared to 256 (Lacs/KW/ckt) of ACSR Moose conductor.

Case-2: Comparison of ACSR and HTLS conductor maintaining maximum current in amp at maximum continuous operating temperature:

DESCRIPTION	MOOSE (ACSR)	ACCC-M (HTLS)
CALCULATIONS ARE CARRIED OUT AT TEMP DEGREE	85	180.00
CURRENT TO BE MAINTAINED:	902	1960
AC RESISTANCE (OHMS/KM)	0.0687	0.0706
LINE LOSSES IN KW/CKT	168	814
POWER FACTOR	0.85	0.85
POWER TRANSFERRED IN MW/CKT	531	1154
PRICE LOSS (IN LACS RS/KW)	256	1242

Table 4

Table 4, shown the comparison of ACSR and HTLS conductor was done when both the conductor were operated at their maximum thermal limit, i.e. For ACSR (Moose) can be operated at 85 ⁰C where

ACCC-M (type of HTLS conductor) can be easily operated up to 180 ^{0}C

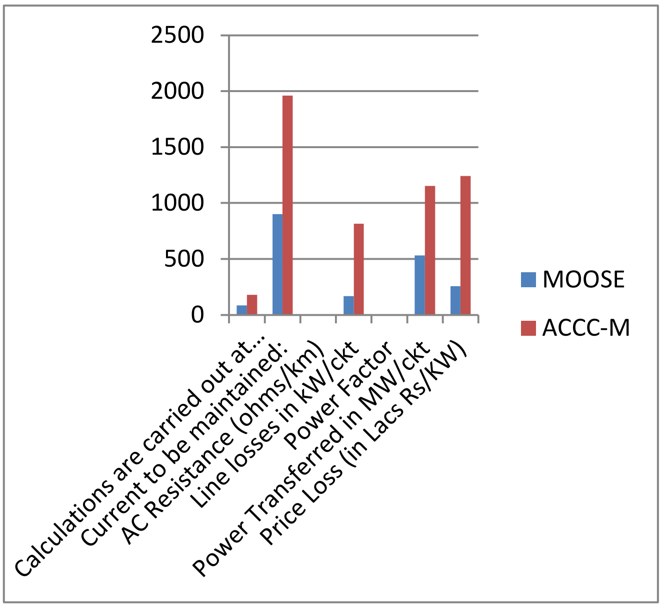

Figure.9 Comparison chart of ACSR Moose and ACCC Mumbai (HTLS) conductor when operated at maximum current and maximum rating

Conclusion of Case 2:

In this case both the conductors are operated at their maximum operating temperature and maximum current carrying capacity. The maximum operating temperature of ACSR Moose conductor is 85^{0}C and maximum current carrying capacity is 902 Amps in specified working condition, whereas the maximum operating temperature of ACCC-M conductor is 180^{0}C and maximum current carrying capacity is 1860 Amps and all the comparisons were done based their maximum operating levels.

ACSR Moose conductor is limited to operate upto 85^0 C maximum while ACCC-M can be operated upto much higher temperature level i.e. 180^0 C .

The power transfer capability of ACCC-M is 1154 (MW/Circuit) almost doubled the power transfer capability of ACSR conductor which is 531(MW/), it means by for transferring same amount of power by using ACSR conductor, we have to construct the transmission line, that will become another time consuming and costly project.

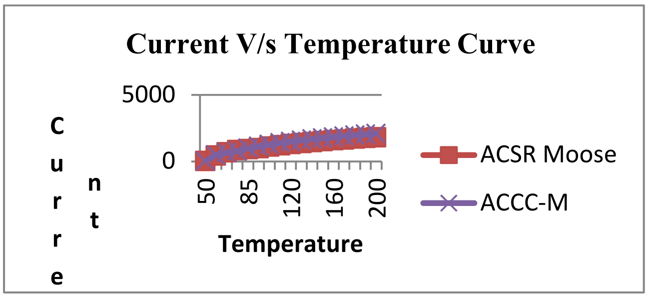

Figure.10 Current V/s Temperature curve for ACSR and HTLS conductor

Figure. 10 represents the Current V/s Temperature curve, curve shows that ACCC-Moose (HTLS) can be easily operated upto 200 ^{0}C, but the maximum operating temperature of ACSR Moose conductor is 85 ^{0}C only (Thermal limit).

Note: For comparison purpose only, upto 200 ^{0}C the report were calculated for the ACSR conductor, otherwise the ACSR conductor can't be operated above 85 ^{0}C .

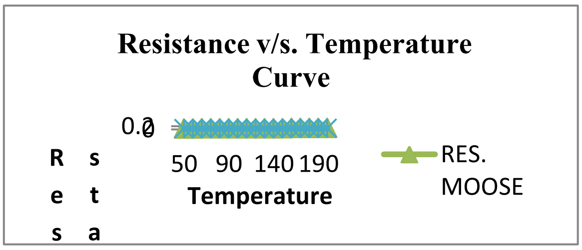

Figure. 11 Resistance V/s Temperature curve for ACSR and HTLS conductor

Figure.11 represents the Resistance V/s Temperature curve, curve shows that ACCC-Moose (HTLS Conductor) can be easily operated upto 200 ^{0}C with minimum resistance but the maximum operating temperature of ACSR Moose conductor is 85 ^{0}C only (Thermal limit) and because of less resistance as compared to ACSR conductor, HTLS conductor offers less (I^2R loss).

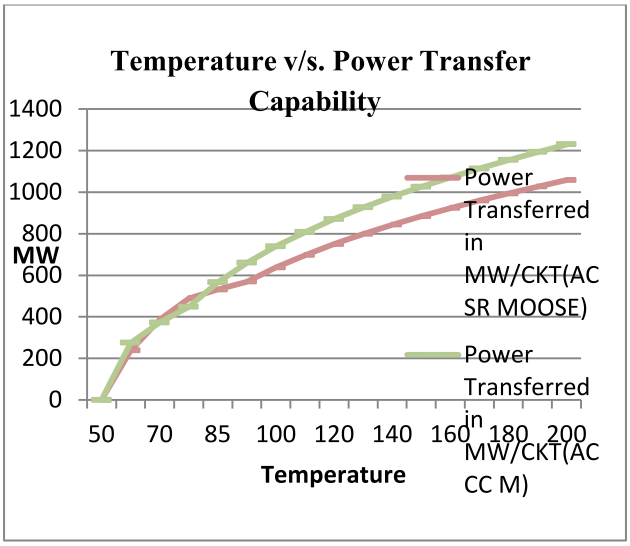

Figure.12 Temperature V/s Power Transfer Capability curve

Figure. 12represents the Temperature V/s Power Transfer Capability curve, which shows that ACCC-Moose (HTLS Conductor) can be easily operated up to 200 ^{0}C with better power transfer capability as compared to ACSR Moose conductor.

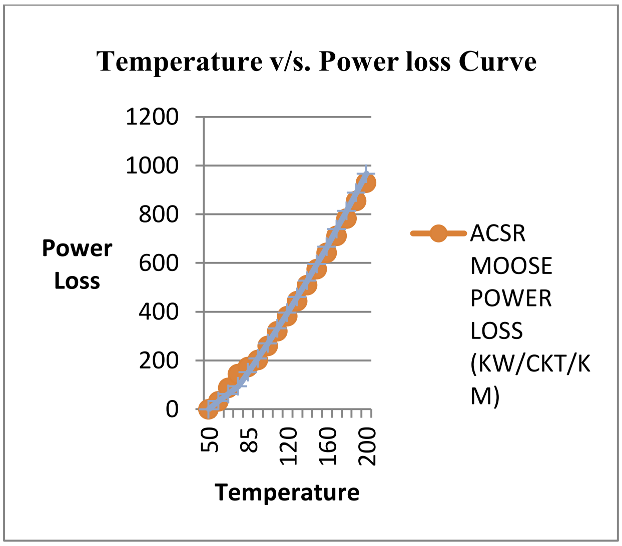

Figure.13 Temperature V/s Power Loss curve

Figure. 13 represents the Temperature V/s Power Loss curve, curve shows that ACCC-Moose (HTLS Conductor) can be easily operated upto 200 ^{0}C with better power transfer capability as compared to traditional ACSR Moose conductor.

II. Conclusion

In present scenario the major difficulties of construction of new transmission line is to get right of way (ROW) approval from public and local administrations. For this squeezing more power into existing corridors in becoming quite crucial and for which the HTLS constitutes a attractive and cheaper solution. These conductors being capable of working at over 200 °C,with double the ampacity as compared to conventional ACSR conductor with maintaining approximately same sag or ground clearance.

In growing congestion in existing corridor of transmission and distribution network, the enhancement of power flow per unit (or meter) of Right of Way and reduction in losses under normal as well as under emergency condition is highly recommended. High Temperature Low Sag (HTLS) conductors should be considered in those corridors where the power transfer over the line is constrained due to consideration of thermal loading of conductor. In Intra-state transmission system, requirement of such conductor is expected at 220kv, 132kv and 66kv level. In case of ISTS (Inter State Transmission System) the HTLS conductor would be a excellent substitute to Quad bundle ACSR and dual HTLS conductor, particularly at 400kv level when line lengths were short.

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