

# APPLICATION OF HIGH CAPACITY CONDUCTORS FOR UPRATING OF EXISTING TRANSMISSION LINES IN NEPAL

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## ABSTRACT:

Due to high power losses and relieve transmission line from overload operation, Nepal has to upgrade its transmission system. The main objective of this research paper is to investigate technical and financial aspects of uprating existing 132 kV line of Nepal by re-conductoring it with High Temperature Low Sag conductor. For this purpose, electrical, mechanical and financial aspects are evaluated using Institute of Electrical and Electronics Engineers (IEEE)-738-SA model for conductor capacity derating, Hybrid numerical method for sag calculation and Monte Carlo simulation for sensitivity analysis respectively. The derated capacity of existing conductor and proposed High Temperature Low Sag (HTLS) conductors are calculated which are less than manufacturer's rating. The sag of Aluminium Core Steel Supported (ACSS)-Dove, Thermal-Resistant-Aluminium Conductor Steel Reinforced (TACSR)-Dove and Super Thermal Resistant Aluminium Conductor Invar Reinforced (STACIR) is found to be greater than maximum permissible sag, while Aluminium Conductor Composite Core (ACCC)-Amsterdam, Gap Type-Super thermal Resistant ACSR (GZTACSR)-Hen and Aluminium Conductor Composite Reinforced (ACCR)-Oswego with permissible limit. ACCC is evaluated to be the most profitable conductor for re-conductoring. The result shows that capacity of existing line can be increased upto 290% with additional profit.

**KEYWORDS:** Up rating, transmission line, Derating, Re-conductoring, High Temperature Low Sag, Monte-Carlo Simulation

## 1. INTRODUCTION:

Transmission line in Nepal can be uprated using HTLS conductor. Uprating helps to increase capacity of existing transmission line. There are different types of HTLS conductor which have their specific mechanical and electrical properties which depend upon their construction and material used. Most of transmission

line in Nepal is strung with ACSR conductor which is conventional one but still being use due to low cost. There are other HTLS conductors which has capacity more than 3 times than that of ACSR. These conductors can be used in place of ACSR so that capacity per unit area of Right of Way (RoW) can be increased.

HTLS conductor has been used across the world to uprate existing transmission line. The investigation of different techniques to improve the 220 kV transmission system capacities in Egyptian Power Network shows that uprating by increasing voltage level were not possible due to air clearance issues but use of HTLS conductor was found helpful. 58%-78% of increase in capacity was found by replacing All Aluminium Alloyed Conductor (AAAC) 506 with ACSS conductor which was evaluated to be the best solution from the technical and economic aspects (Abdou et al., 2015). Other study shows that even 30% of total cost is associated with conductor, cost of ACSS is 50% higher than ACSR, re-conductoring has increased total cost by 15% but 84% of capacity was increased using ACSS conductor in 230 kV systems, however due to consideration of security factor, it was reduced to 69% (Dominguez et al., 2014). Analysis of different techniques to increase transfer capacity in which use of HTLS conductor was tested in IEEE 9 bus system find out use of HTLS conductor has eliminated congestion by 41% (Dave et al., 2012). Similarly, the use of HTLS is justified at high temperature operation (Beryozkina & Sauhats, 2015). The case study of 220 kV transmission line in Romania shows that ACSS, ZTACIR, GTACSR, ACCR and ACCC were technically feasible while ACSS and ACCC were found most economical including cost of power loss but ACSS were selected due to being familiar technology (Matesscu et al., 2011). Another study on profitability of HTLS conductors has concluded that even ACCC and ACCR meets technical requirement but it could be more economically justifiable if high price of ACCC and ACCR will be reduced for Latvian Power model (Berjozkina et al., 2013).

Studies on uprating using HTLS conductor shows that the capacity of the existing line can be increased with some investment. The amount of increased capacities is

different. Most of conductors are technically feasible however all are financially not feasible. Similarly, in Integrated Nepal Power System (INPS) many existing line are overloaded which can be studied in (Mishra et al., 2014) and (Paneru, 2012). Possibility of increase in congestion will increase with deregulation (Kumar, 2012). To address this concern, uprating can be the one solution but any analysis regarding its usability and its financial outcome in case of Nepal has not be studied.

The main objective of this study is to investigate the technical and financial performance High Temperature Low Sag conductors in uprating existing transmission lines of Integrated Nepal Power System. Here, six types are HTLS conductors are considered which are TACSR, ACCS, ZTACIR, GTACSR, ACCR and ACCC.

## 2. METHODOLOGY:

### DERATING OF CONDUCTOR:

The current carrying specified in manufacturer's datasheet is as per manufacturer condition. The actual working condition is different from specified condition. The service condition specified by Nepal Electricity Authority (NEA) is shown in **Error! Reference source not found.** In this table, the values of environmental parameter used by NEA is given.

Table 1: Service condition specified by NEA

S.N.	Parameters	Values
1	Elevation above sea level	0 m
2	Ambient temperature	45°C
3	Solar Absorption coefficient	0.8
4	Solar Radiation intensity	1045 w/m <sup>2</sup>
5	Emissivity Constant	0.45
6	Wind Speed	0.56 m/s
7	Wind angle	90°
8	Angle of incidence of sun ray	90°

The current carrying capacity at certain temperature depends upon these factors. Method specified by IEEE-738 SA can be used and detail procedure can be found in (IEEE SA, 2013). In this method, heat balance equation is used. Heat is generated by ohmic loss and the heat gain from sunlight and heat is dissipated by convection and radiation process. The final result of ampacity is given by:

$$I = \sqrt{\frac{q_c + q_r - q_s}{R(T_{avg})}}$$

Equation -1

Where,  $q_c$  is convective heat loss,  $q_r$  is radiated heat loss,  $q_s$  is solar heat gain and  $R(T_{avg})$  is the Resistance at  $T_{avg}$  temperature.

### LOAD FLOW ANALYSIS:

Load flow analysis is carried out in Electrical transient Analysis Program (ETAP). The load flow model is developed using data obtained from NEA with built in model in ETAP using Newton Raphson Method. The result of this simulation outlines the transmission lines which are being overloaded. The model is simulated for 3 cases i.e. Normal, Dry Peak and Wet peak of two categories which are Normal and Growth scenario.

### SAG TENSION CALCULATION:

Conventionally, sag tension calculation can be carried out as per procedure specified by Indian Standard IS-5613 Part-1 Section-2. But bimetallic conductors like HTLS with different elastic properties, modified method is required. The method described in (Alawar et al., 2006). The nonlinear relation obtained from this need to be solved by iterative method which is achieved using Solver in Microsoft-Excel. The calculation from this method is compared for ACCC-Drake with (Dong, 2016). The comparison is presented in Table -2.

Table -2: Results for ACCC Drake

Temperature °C	Tension on Conductor(kN)	Tension on Aluminium(kN)	Tension on Core(kN)	Sag (m)
20.00	27.49	10.85	16.64	6.28
46.60	23.84	4.27	19.57	7.25
180.00	21.10	0.00	21.10	8.19
200.00	20.99	0.00	20.99	8.23
<b>The following results are obtained from (Dong, 2016)</b>				
20.00	27.39	10.85	16.51	6.30
46.60	23.77	4.50	19.27	7.26
180.00	21.09	0.00	21.09	8.18
200.00	21.00	0.00	21.00	8.22

Table -2 presents the comparison between calculated result and the result from another paper (Dong, 2016). The results from two are almost same which validate this method.

### FINANCIAL ANALYSIS:

The result from sag tension calculation screens the candidate conductors which can be used. Those conductor which fails to meet sag criteria cannot be used. So, only those conductors which meet the criteria are considered. The cost estimate of re-conductoring the qualified conductor in the existing line is prepared. It was prepared for one of the congested line which was

evaluated in the load flow analysis. The line is chosen so that it can represent the characteristics of transmission line in Nepal. Further NPV and IRR calculation has been done on the base of the assumption in presented in table 3.

Table 3: Assumptions: Constants

Project life span	45-50 years
Income tax	20%
Cost of GWh in US \$	64,127.48
Exchange rate per USD	102.92
Insurance	0.25%

Table 4: Assumptions: Variables for sensitivity analysis

Description	Base	Minimum	Maximum
Wheeling charge percent of per unit cost	7.50%	5.00%	10.00%
Energy cost escalation rate	3%	2%	10%
Annual O&M cost	1.50%	1%	5%
Depreciation rate	5%	2%	10%
Contingency	10%	5%	15%
Interest rate	8.00%	5.00%	12.00%
Cost of ACCC in USD	\$7,182	\$6,529	\$7,835

As shown in, the project life of transmission line is assumed to be 45-50 years from which age of the line has to be subtracted. The average rate of per GWh is presented which is the average of dry and wet season Power Purchase Agreement (PPA) rate decided by NEA on 17<sup>th</sup> April 2017. It is calculated in US Dollar. The assumed values of income tax and insurance are also given.

Table 4 has 3 columns in which first one with base heading is used for the base case calculation. The Net Present Value (NPV) and Internal Rate of Return (IRR) are calculated as per this base case assumption. Basecase is the most likely values for sensitivity analysis. Other two values for each value are the maximum and minimum value used in the sensitivity analysis. Sensitivity analysis is carried out using Monte-Carlo Simulation in Crystal Ball Solver for each variable and all variable all at one time. The optimum length for profitable operation and loading condition for maximum profit was calculated using Opt Quest simulation in Crystal Ball Solver. The scenario without any modification in the existing line is considered as Business As Usual (BAU) scenario. Only additional energy transmitted and lost to the BAU is considered in this study. Assumptions are taken from (Pandey, 2014).

### POWER TRANSFER CAPACITY AND VOLTAGE REGULATION:

The line parameters, power transfer capability and voltage regulation are calculated using formula in (Gupta, 2006).

### 3. RESULTS AND DISCUSSION:

The calculated derated value of existing ACSR conductors is shown in Table 5

Table 5: Derating of Existing ACSR Conductors

Conductor Code	ACSR Dog	ACSR Wolf	ACSR Panther	ACSR Bear	ACSR Duck	ACSR Cardinal
Manufacturer Rating (A)	378	545	579	663	750	1010
DeratedRating (A)	253.08	320.36	379.83	429.66	464.11	597.69
Rated MVA	57.86	73.24	86.84	98.23	106.11	136.65

The derated value of ACSR conductors used in INPS is calculated which is lower than the value specified by the manufacturers. The calculated value is less because the ambient temperature, solar radiation intensity and solar absorption coefficient are higher than condition specified by the manufacturer cause increase in temperature and values of parameters like emissivity and wind speed cause heat loss are less than that of manufacturer. So, the temperature of the conductor is higher even at low value of current than that of specified by manufacturer. Same is the case for HTLS conductors of Table 7.

The overloaded lines as per Load Flow analysis are shown in Table 6.

Table 6: Overloaded lines from Load flow analysis

SN	Line	Length	Circuit type	Conductor
1	Pathlaiya-Chapur Transmission Line	32 km	Double	ACSR BEAR
2	Chapur-Dhalkebar Transmission Line	60 km	Double	ACSR BEAR
3	Marsyangdi-Bharatpur Transmission Line	25 km	Single	ACSR DUCK

Table 6 shows 3 lines overloaded. These lines were found overloaded in load flow simulation in one of the loading condition as specified in methodology. Among these, three lines, the 1<sup>st</sup> line is the most appropriate line. This line uses ACSR Bear which is the most used conductor in INPS and its length is moderate. Longer line results high cost of investment and may cause voltage issues. So, this line is chosen so that it represents most of line in INPS and profitable option.

The candidate HTLS conductor was derated so that there electrical performance can be calculated and comparative analysis can be done. The result of calculation using IEEE-738 method is shown in Table 7.

Table 7: Derating of HTLS conductors

Conductor Code	ACCC Amsterdam	ACCR Oswego	ACSS Dove	TACSR Dove	GZTA CSR Hen	STACIR -AW 240 sq. mm
Rated Temperature (°C)	180	210	200	150	210	210
Manufacturer's Rating(A)	1409	1407	1282	1027	1128	1203
Derated rating (A)	1257	1328	1158	958	1101	1148

The result shows that the derated values are smaller and the reason has already been discussed in derating of ACSR conductor. The change in resistance and ampacity with respect to temperature is shown in Figure 1 and Figure 2 respectively.

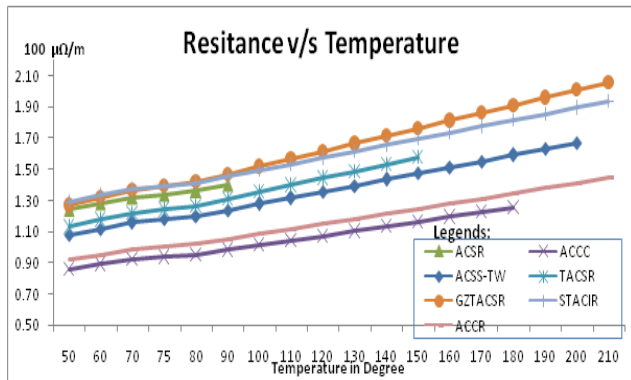


Figure 1: Relation between Resistance and Temperature

From the Figure 1, it was found that resistance of GZTACSR and STACIR is more than that of other. It was because the aluminium area of these two conductor are less than that of other conductors. Higher available size are heavier and has larger in diameter, so it cannot be used. The conductor like ACCC and ACCR has larger effective aluminium area due to having smaller core and compact trapezoidal aluminium strands.

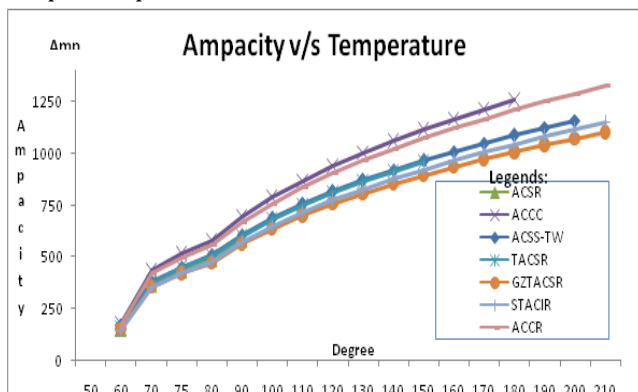


Figure 2: Relation between Ampacity and Temperature

From Figure 2, ACCC has highest ampacity upto 180 °C but ACCR has the highest due to having higher

maximum temperature than ACCC. STACIR and GZTACSR has lower ampacity due to less aluminium area. The result of sag tension calculation is shown in Figure 3.

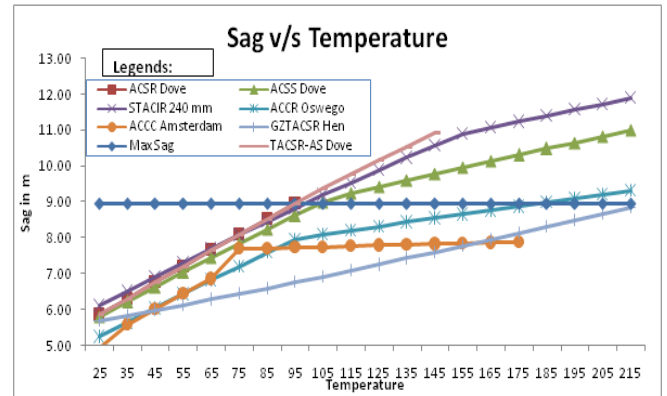


Figure 3: Relation between Sag and Temperature

The horizontal line in Figure 3 is the maximum sag of ACSR BEAR conductor at maximum operating temperature i.e. 90°C. So, it is the maximum permissible sag limit. Conductor like ACSS, TACSR and STACIR has sag more than permissible limit. So, if the lines are re-conducted with these conductors, it cannot be operated at temperature above 90° C. So, line cannot be operated at higher ampacity. Hence, these conductors are useless for this project. However, the sag of ACCC is the lowest among all and the reason is the composite core. The sag temperature drastically changed after certain value of temperature which is called knee Point Temperature (KPT). This is the temperature at which the total tension on conductor is transferred to the core only which was shared by both of them below that temperature. Similarly, for ACCR, it can be operated only upto 180 C due to sag limit.

Table 8: Calculation of NPV and IRR

Parameters	Unit	ACCC	ACCR	GZTACSR
Additional Energy transmitted	GWh	74.52	74.52	74.52
Additional Revenue	000' US \$	358.43	358.43	358.43
Depreciation	000' US \$	110.62	110.62	110.62
Project insurance	000' US \$	5.53	5.53	5.53
Net loss	000' US \$	-126.63	-126.63	247.41
Annual O & M cost	000' US \$	33.19	33.19	33.19
Profit before tax	000' US \$	335.72	335.72	-38.32
Income tax	000' US \$	67.14	67.14	-7.66
Free cash flow	000' US \$	268.57	268.57	-30.66
Project initial Cost	000' US \$	2,433.66	3,737.04	2,015.88

Net Present Value	000' US \$	5,783.49	4,476.61	(7,827.35)
Internal Rate of Return		29.70%	21%	#NUM!

Table 8 shows the calculation table of IRR and NPV. It shows the additional power transmitted at base case which is 2015/16 with ACSR conductor. Only additional revenue is calculated which has been generated due to increased capacity of the transmission line. The net loss is negative due to low resistance property of ACCC and ACCR. So, in this case, 1.97GWh of energy was saved which would have lost in BAU scenario. As per result, ACCC was evaluated to be the most profitable option and GZTACSR is the non-profitable option.

The sensitivity analysis was carried out for the base case of ACCC only for all the variables mentioned in methodology. The analysis was done for each variable alone and with all variables at a time. As per individual parameter considered, only one variable which is found most sensitivity and may result negative NPV is the wheeling charge. The impact of other variable on NPV and IRR is not as significant as that of wheeling charge. The result of sensitivity analysis with all variable included was shown in Figure 4.

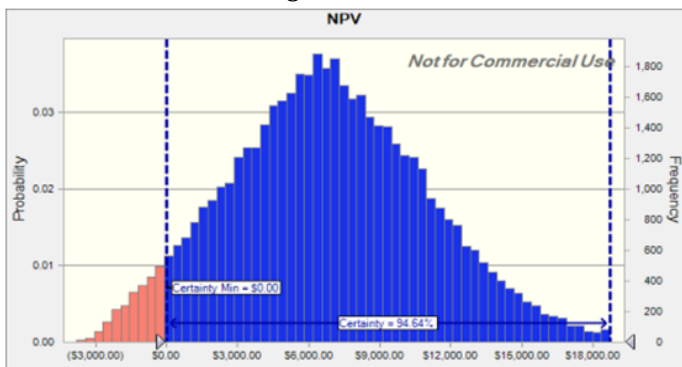


Figure 4: Impacts of assumed variables on NPV

As per result, the value of NPV can be as low as -\$ 3,791,000 and as high as \$ 23,569,000. The probability of positive NPV is 94.64%.

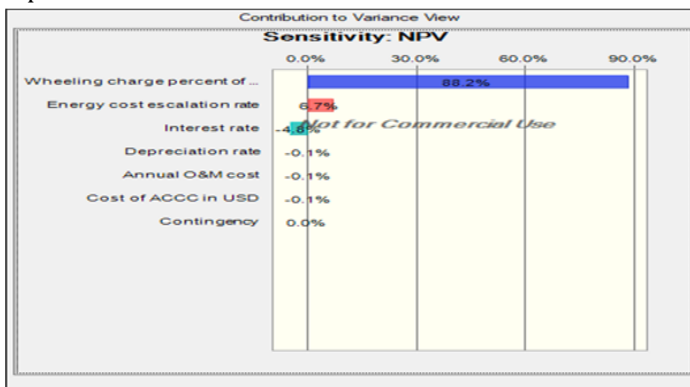


Figure 5: Sensitivity of variables

Figure 5 shows that significance of each variables on the NPV of the project. Result shows that

Wheeling charge is the most significant variable and escalation and interest rate is lightly significant. Other variables are not significant. Same is the case for IRR.

The result from Opt Quest simulation shows that the maximum length of line for which NPV is positive is 42.08 km.

The result from Opt Quest for optimum loading for maximum profit is shown in Table 9.

Table 9: Loading condition for maximum profit

Year		1	2	3	4	5
Annual Energy demand	GWh	775.9	849.2	926.0	986.9	1067.3
Demand Served	GWh	775.9	849.2	926.0	986.9	1067.3
Year		6	7	8	9	10
Annual Energy demand	GWh	1151.6	1244.8	1343.5	1447.5	1557.2
Demand Served	GWh	1151.6	1244.8	1343.5	1447.5	1557.2
Year		11	13	15		
Annual Energy demand	GWh	1673.1	1804.7	1948.6	2052.0	2052.0
Demand Served	GWh	1673.1	1630.4	1556.8	1504.1	1504.1

At the loading condition as specified in table, the maximum profit was found to be \$ 6,277,590.

As per result from derating and sag tension calculation, line with ACCC can be operated upto 1257 A. Maximum power that can be transmitted through Double circuit Transmission line is 488.56 MW at 132 kV voltage level with voltage regulation of 5.02 %. The efficiency at peak load is found to be 93.45%.

#### 4. CONCLUSION:

The derated values of conductors are less than specified by the manufacturers. Load flow analysis with derated value indicates line overloading in Pathlaiya-Chapur 132 kV Double circuit line, Dhalkebar- Chapur 132 kV Double circuit line and Marsyangdi-Bharatpur 132 kV Double circuit line. The derated values for HTLS conductors were evaluated to be less than specified value too. Sag evaluated for ACCC is minimum and STACIR, TACSR and ACSS are more than maximum allowable value which means it cannot be used for this project. Financial evaluation of remaining candidates i.e. ACCC, ACCR and GZTACSR, evaluated that ACCC is the most profitable and its profit can be negative if wheeling charge decreases less than value. Wheeling charge is found to be the most significant variable. The line can be profitable up to 42.08 km. The maximum profit that can be obtained for base case is \$ 6,277,590. The maximum power transfer capacity of line can be increased up to 2.92 times that of ACSR conductor by uprating it with ACCC conductor.

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