Proceedings of IOE Graduate Conference, 2017
Volume: 5 ISSN: 2350-8914 (Online), 2350-8906 (Print)

Uprating of Existing Transmission Lines in Nepal Using High Capacity Conductors

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Abstract

To relieve transmission line from overload operation, Nepal has to upgrade its transmission system. This paper investigates technical and financial aspects of uprating existing 132 kV line of Nepal by re-conductoring it with High Temperature Low Sag (HTLS) conductor. Electrical, mechanical and financial aspects are evaluated using Institute of Electrical and Electronics Engineers (IEEE)-738-SA model for conductor capacity derating, Hybrid Sag Method (HSM) for sag calculation and Monte Carlo simulation for sensitivity analysis respectively. The derated capacity of existing conductors and proposed HTLS conductors are less than manufacturer's rating. The derated maximum current carrying capacity of Aluminium Conductor Composite Reinforced (ACCR)-Oswego is 1328 A which is the highest among all conductors. Aluminium Conductor Composite Core (ACCC), ACCR, Gap Type-Super TACSR (GZTACSR), Aluminium Core Steel Supported (ACSS), Thermal-Resistant-Aluminium Conductor Steel Reinforced (TACSR) and Super Thermal Resistant Aluminium Conductor Invar Reinforced (S/ZTACIR) can be operated only upto 112 C, 113 C, 117 C, 120 C, 120 C and 120 C respectively because of having voltage drop exceeds maximum allowable voltage regulation of 10%. The calculated sag of ACSS-Dove, TACSR-Dove and S(Z)TACIR is more than maximum limiting sag value of 8.95 m at a temperature less than 105 C restricting them from high temperature operations. The Sags of ACCC-Amsterdam, GZTACSR-Hen and ACCR-Oswego are less than maximum limiting sag. ACCC is evaluated to be the most profitable conductor for re-conductoring with calculated Net Present Value (NPV) of Nepalese Rupees (NPR) 512,000,000 and Internal Rate of Return (IRR) of 28.71%. NPV and IRR are more sensitive to the transmission charge than any other variables. Transfer capacity of existing transmission with ACSR-Bear can be increased by 2.05 times if it is uprated using ACCC-Amsterdam and is profitable only if transmission charge is more than NPR 0.28/kWh.

Keywords

Uprating – Transmission line – Derating – Re-conductoring – High Temperature Low Sag – Monte-Carlo Simulation

1. Introduction

Transmission lines in Nepal can be uprated using HTLS conductor. Uprating helps to increase the capacity of existing transmission line. There are different types of HTLS conductors which have their specific mechanical and electrical properties which depend upon their construction and material used. Most of the transmission lines in Nepal is strung with ACSR conductor which is conventional one but still being used due to low cost. There are other HTLS conductors which have 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 was not possible due to air clearance issues but the 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 [1]. Other study shows that even 30% of total cost is associated with conductor and cost of ACSS is 50% higher than ACSR, re-conductoring has increased total cost by only 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% [2]. Analysis of different techniques to increase transfer capacity in which use of HTLS conductor was tested in IEEE 9 bus system find out the use of HTLS conductor has eliminated congestion by 41% [3]. Similarly, the use of HTLS is justified only at high temperature operation [4] . The case study of 220 kV transmission line in Romania reveals that ACSS, ZTACIR, GZTACSR, ACCR and ACCC were technically feasible while ACSS and ACCC were found most economical including the cost of power loss but ACSS were selected due to being familiar technology [5].

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 the conductors are technically feasible however all are financially not feasible. In Integrated Nepal Power System (INPS) many existing lines are overloaded. Details can be studied in [6] and [7]. The possibility of increase in congestion will increase with deregulation [8]. 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 been studied. The main objective of this study is to investigate the technical and financial performance of High Temperature Low Sag conductors in uprating existing transmission lines of INPS. Here, six types are HTLS conductors are considered which are TACSR, ACSS, ZTACIR, GTACSR, ACCR and ACCC.

2. Methodology

2.1 Derating of conductor

The current carrying specified in manufacturer's datasheet is as per manufacturer condition. The actual working condition is different from the specified condition. The service condition specified by Nepal Electricity Authority (NEA) is shown in Table 1 . In this table, the values of the environmental parameters used by NEA are given.

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 [9].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:

$$I = \sqrt{\frac{q_{\mathrm{c}} + q_{\mathrm{r}} - q_{\mathrm{s}}}{R(T_{\mathrm{avg}})}} \tag{1}$$

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.

2.2 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 study is restricted to 132 kV network of INPS.Three swing bus at Dhalkebar, Ramnagar and Kusha is assumed as in [10]. Shunt compensations are provided as per NEA and assumed to be operated when required. 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.

2.3 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

Table 1: Service condition specified by NEA

S.N.	Parameters	Values
1	Elevation above sea level	0 m
2	Ambient temperature	45 Deg C
3	Solar Absorption coefficient	0.8
4	Solar Radiation intensity	1045 w/m2
5	Emissivity Constant	0.45
6	Wind Speed	0.56 m/s
7	Wind angle	90 Deg
8	Angle of incidence of sun ray	90 Deg

HTLS with different elastic properties, modified method is required. So, the HSM described in [11] is used. A reference temperature of 32 C, span of 335 m and 25% of Rated Tensile Strength (RTS) were used. The nonlinear relation obtained was solved by iterative method using Solver in Microsoft-Excel. The calculation from this method is compared for ACCC-Drake with [12]. The comparison is presented in Table 2.

Table 2: Comparison between applied method and reference

Temp Deg C	H(kN)	H_a (kN)	H_b (kN)	Sag (m)
20	27.49	10.85	16.64	6.28
46.6	23.84	4.27	19.57	7.25
180	21.1	0	21.1	8.19
200	20.99	0	20.99	8.23
Results are obtained from (Dong, 2016)				
20	27.39	10.85	16.51	6.3
46.6	23.77	4.5	19.27	7.26
180	21.09	0	21.09	8.18
200	21	0	21	8.22

Table 2 presents the comparison between calculated result and the result from [12].Here, H, H_a and H_b indicate load carried by the whole conductor, the core and aluminium wire respectively. The results from two are almost same which validate this method.

2.4 Financial analysis

The result from sag-tension calculation screens the candidate conductors which can be used. Those conductors 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 is prepared for one of the overloaded line determined from the load flow analysis. The line is chosen so that it can represent the characteristics of transmission lines in Nepal. Further NPV and IRR calculation has been done on the basis of the assumption in presented in table 3 and 4.

Table 3: Assumptions: Constant parameters

Constant parameters	
Project life-span	45
Income tax	20%
Average rate in NRs. / kWh	6.6
Insurance	0.25%
Engineering and other expenses	10.00%
Cost of Conductor in NRs./km	806400

Table 4: Assumptions: Variables for sensitivity analysis

Description	Base	Minimum	Maximum
Annual O&M cost	5.00%	3%	7%
Transmission charge NRs./GWh	512,000	256000	768000
Escalation rate in %	3%	0%	15%
Depreciation rate in %	5%	2%	10%
Discount rate in %	12.00%	9.00%	15.00%

As observed in Table 3, the project life of the transmission line is assumed to be 45 years from which age of the line has to be subtracted. The escalation rate and average energy cost per GWh is presented which is an average of dry and wet season Power Purchase Agreement (PPA) rate decided by NEA on 17th April 2017. The assumed values of income tax and insurance are also given. Table 4 has three 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. Base case 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 minimum transmission charge required for profitable operation of the line is calculated assuming line length from source to sink. As per [13], 3.92% of loss is allowed and allowable line loss is calculated for the considered line. The minimum charge is calculated using solver in MS-Excel. 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. Assumed value of annual O&M cost, Depreciation, insurance, income tax are taken from [14] . The discount rate is taken from

Table 5: Derating of Existing ACSR Conductors

	ACSR Conductors					
Code	Dog	Wolf	Pan'r	Bear	Duck	Car'l
Standard A	378	545	579	663	750	1010
Derated A	253	320	380	430	464	598
Rated MVA	58	73	87	98	106	137

[15]. Engineering and other expenses is taken from [16]. Transmission charge is taken from [13]. Cost of the conductor is multiplying the cost of ACSR from Lumbini Vidyut with ration taken from [17].

2.5 Transfer capacity and voltage regulation

The line parameters, power transfer capability and voltage regulation are calculated using the formula in [18].

3. Results and Discussion

The derated values of current carrying capacity of ACSR conductors used in INPS is presented in Table 5 which is found to be 3%-11% less 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 the 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 a low value of current than that of specified by the manufacturer. Same is the case for HTLS conductors of Table 7.

Load flow analysis carried out in ETAP by simulation determined transmission lines being overloaded. These lines are tabulated in Table 6. 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^{st} line is the most appropriate for further analysis. This line uses ACSR Bear conductor which is the most common conductor in INPS and its length is moderate. Longer line results in high cost and losses and may cause voltage issues. So, this line is chosen so that it represents the most of lines in INPS and with the possibility of being the profitable option.

Table 6: Overloaded lines from Loadflow analysis

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

The HTLS conductors were derated so that its electrical parameters can be calculated and compared. Evaluated values of the current carrying capacity of conductors at service condition using IEEE-738 method is presented in Table 7.This table indicates that the derated values are smaller and the reason has already been discussed in the derating of ACSR conductor. The values of ampacity and resistance of each conductors at a different temperature is computed and plotted. Figure 1 shows plot of Resistance v/s Temperature from which, it can be seen that resistance of GZTACSR and STACIR is more than that of others. It is because the aluminium area of these two conductors are less than that of other conductors. Higher available sizes are heavier and larger in diameter, so it cannot be used.The conductor like ACCC and ACCR has larger effective aluminium area due to having a smaller core and compact trapezoidal aluminium strands. The resistance of ACCC is found to be minimum among all as evaluated in [19].

From Figure 2, ACCC has the higher ampacity than ACCR at 180 C but ACCR has the highest due to having higher maximum operating temperature than ACCC. STACIR and GZTACSR have lower ampacity due to less aluminium area. Figure 3 presents the state of voltage regulation at a different temperature. It was found that it increases with increase in the temperature. At higher temperature, there is higher current and resistance, so voltage drop increases due to increase in impedance and current. So, the voltage drops are higher at line operating at higher capacity. It can be seen that voltage regulation is more than allowable 10% at a temperature between 110 C and 120 C. So, all the

Table 7: Derating of HTLS conductors

Conductor	ACCC	ACCR	ACSS	TACSR	GZTACSR	STACIR-AW
Code	Amst'm	Oswego	Dove	Dove	Hen	240 sq. mm
Temp (C)	180	210	200	150	210	210
Rating (A)	1409	1407	1282	1027	1128	1203
Derated (A)	1257	1328	1158	958	1101	1148

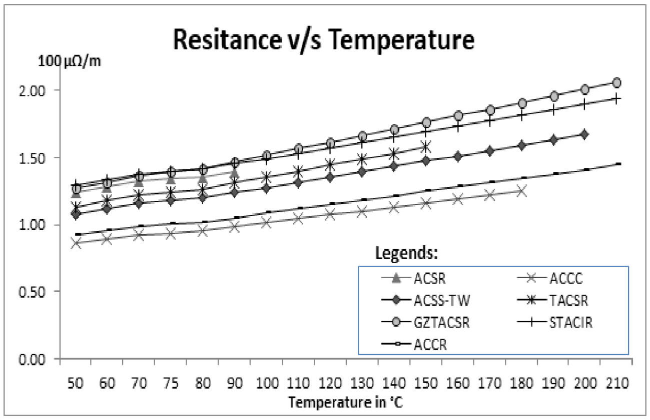


Figure 1: Resistance of conductor with respect to temperature

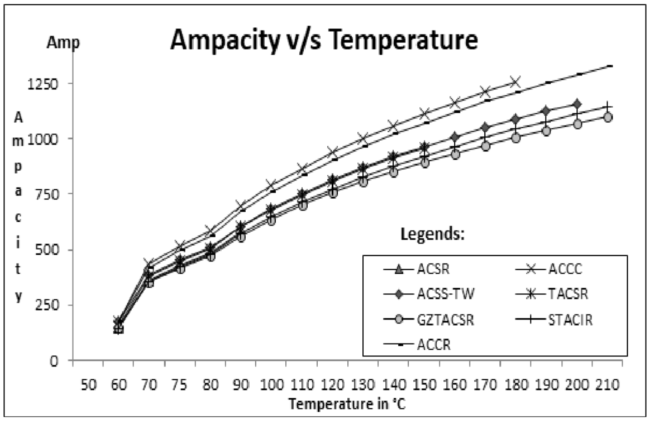


Figure 2: Relationship between Ampacity and Temperature

conductors can be operated only below this temperature. Maximum allowable temperature as per voltage regulation for ACCC, ACCR, GZTACSR, ACSS, TACSR and STACIR are 112 C , 113 C, 117 C, 120 C, 120 C and 120 C respectively. As per [20], the line loading limit for short line less than 50 miles are governed by thermal limit only. But in this study, it is found that the voltage drop limit restricts the line loadability. This result is observed because in this case line capacity is very high which is not possible with a conventional ACSR conductor. So, it can be said that for high capacity conductor, voltage limit also governs line loadability because of high current which increases voltage drop significantly.

HSM was used to calculate and predict sag temperature performance of ACSR Bear, ACSS-Dove, TACSR-Dove, GZTACSR-Hen, STACIR-240 sq. mm, ACCR-Oswego and ACCC-Amsterdam. The result obtained was recorded and plotted versus temperature. The plotted graph is shown in Figure 4. The horizontal line shown in Graph is the sag of ACSR BEAR conductor at maximum operating temperature i.e. 90 C. Since, conductors cannot be allowed to have more sag than this value, it is the maximum limiting sag. Each curve in graph represents sag temperature characteristics of each type of conductor. Sag exhibited by ACSS, TACSR and STACIR exceed the maximum limit at temperature less than 105 C. So, high temperature operation of these conductors cannot be achieved. Hence, these conductors are disqualified for re-conductoring in place of ACSR Bear conductor. So, further analysis of these conductors is not required. Similarly, the estimated value of sag of ACCC is found to be only 7.88 m at the maximum operating temperature which is the lowest of all and the reason for this is the small value of coefficient of thermal expansion of the composite core used in ACCC. Next, the sudden change in nature of curve after a certain value of temperature was observed for each curve in the graph. This transient temperature is called knee Point Temperature (KPT). This is the temperature at which the total tension on the conductor is transferred to the core only which was shared by both of them below that temperature. Similarly, ACCR exceeds maximum permissible sag after180 C. Even it can be operated upto 210 C continuously, its operation is restricted upto 180 C only because of sag. Observed result is compared with [21] in which ACCC, GTACSR, ZTACIR and

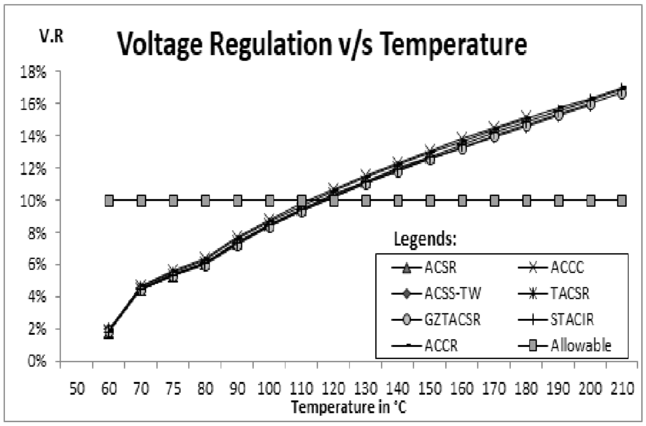


Figure 3: Relationship between Voltage Regulation and Temperature

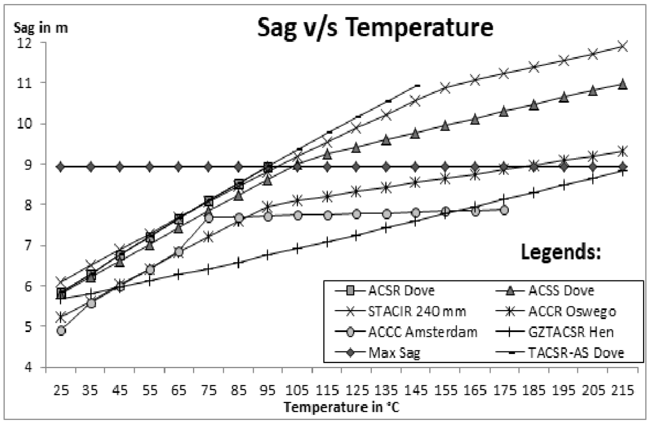


Figure 4: Relationship between Sag and Temperature

ACSS conductors are considered and sag is calculated for the operating current of 800A. ACCC has the lowest sag of 5.72 m and ACSS has the highest sag of 8.84 m more than ZTACIR. In case of ACCC, results are similar however sag of ACSS is greater than ZTACIR which is not the same as this case. The main reason is ACSS-Dove selected for this analysis is of high strength and same type for STACIR was not available and is smaller in size than ACSS.

Table 8: Computation of NPV and IRR of Reconductoring works with different conductors

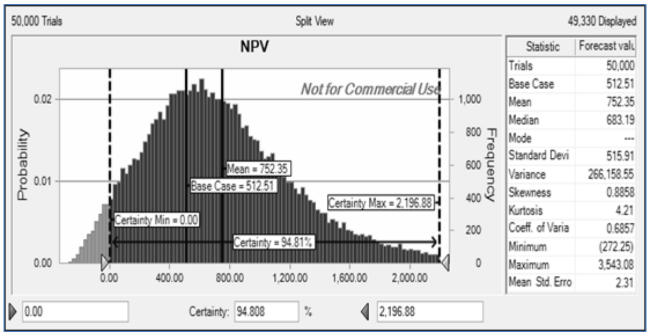
Parameters	Unit	ACCC	ACCR	GAP
Added Energy	GWh	78.91	78.91	78.91
Transmission charge/GWh	NPR	0.51	0.51	0.51
Added Revenue	NPR	40.40	40.40	40.40
Cost of Net loss	NPR	-13.27	-7.87	25.46
Depreciation	NPR	12.04	12.04	12.04
Insurance	NPR	0.60	0.60	0.60
Annual O &M cost	NPR	12.04	19.44	9.43
Profit before tax	NPR	29.00	16.20	-7.13
Income tax	NPR	5.80	3.24	-1.43
Initial Cost	NPR	295.30	475.86	231.70
NPV	NPR	512.51	178.06	-39.74
IRR		28.71%	16.55%	9.53%

Note:- All the monetary values in NPR are in million.

The evaluated value of IRR and NPV of reconductoring work using GZTACSR-Hen, ACCR-Oswego and ACCC-Amsterdam is presented in Table 8. Table shows the case of year 2018/19 in which the additional power of 78.91 GW than that of year 2015/16 with ACSR conductor is transmitted in the base year 2018/19. So, only additional revenue is calculated which has been generated due to increased capacity of the transmission line. The net loss is negative due to the low resistance of ACCC and ACCR. So, in this case, 2.01 GWh 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 not a profitable option. Similar result is observed in [5] in which analysis of HTLS conductors equivalent to ACSR 450/75 was done and it was found that ACCC has minimum loss and minimum actualized total cost. Similarly, GZTACSR has direct cost less than that of ACCC and ACCR but maximum actualized cost due to maximum loss. ACCR has maximum direct cost but has actualized cost less than GZTACSR. However, the size of conductor and voltage level is different than that of the case under study.

The sensitivity analysis was carried out for the option with the highest NPV i.e. ACCC only for all the variables mentioned in methodology. It is simulated by changing one variable and keeping others constant for each variable alone and another by changing all variables at a time. During simulation of each case, it was found that transmission charge is the most significant variable and may result negative NPV. The impact of other variable on NPV and IRR is not as significant as that of transmission charge. The result of the case in which all variables are allowed to be changed is presented in Figure 5.It shows that the NPV can be as low as -NPR 272 million and as high as NPR 3.5 billion. The probability of positive NPV is 94.80%.

The dependence of NPV on transmission charge shows that if its actual is less than assumed value, the project may suffer loss. However, further evaluation of minimum transmission charge shows that transmission charge more than NPR 0.28/kWh is required for the profitability of the project. 0.85% of loss is omitted from this calculation because it is the portion of loss which can be allocated for 32 km long line when the distance between source and load is 147 km and allowed total loss is 3.92%.



Statistic	Forecast valu
Trials	50,000
Base Case	512.51
Mean	752.35
Median	683.19
Mode	---
Standard Devi	515.91
Variance	266,158.55
Skewness	0.8858
Kurtosis	4.21
Coeff. of Varia	0.6857
Minimum	(272.25)
Maximum	3,543.08
Mean Std. Erro	2.31

Figure 5: Impacts of assumed variables on NPV

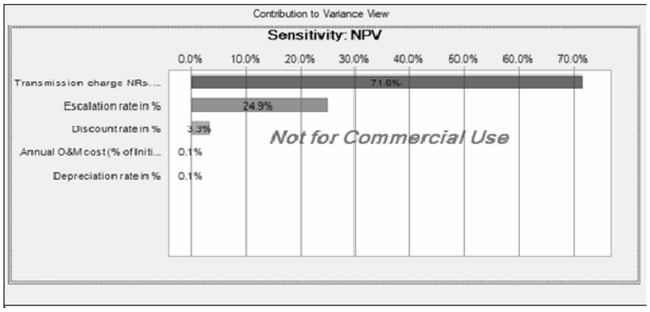


Figure 6: Evaluated sensitivity of variables on NPV

Figure 6 shows that measure of the impact of each variables on the NPV of the project. The result shows that Wheeling charge is the most significant variable with the sensitivity on NPV is 71.6%. and escalation and interest rate are less significant. Other variables are not significant. Same is the case for IRR.

As per result from derating, voltage regulation calculation and sag-tension calculation, line with ACCC-Amsterdam can be operated upto 882 A. Maximum power that can be transmitted through Double circuit Transmission line is 363 MW at 132 kV voltage level which was just 176.82 MW with ACSR-Bear with the efficiency of 95.86 %. at voltage regulation of 9.95%. The result observed here is similar to [5] in which the loadability increase by 2.78 times when ACCC is used in place of ACSR.

4. Conclusion

The derated values of conductors are 5% to 15% 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 the maximum allowable value which means it cannot be used for this project. Even as per sag calculation ACCC can be operated upto 180 C, but due to voltage drop restriction, it can be operated upto 112 C. Financial evaluation of remaining candidates i.e. ACCC, ACCR and GZTACSR evaluated ACCC as the most profitable conductor and its profit can be negative if transmission charge decreases less than value assumed in the base case. Transmission charge is found to be the most significant variable. The maximum power transfer capacity of line can be increased upto 2.05 times that of ACSR conductor by uprating it with ACCC conductor.

Acknowledgments

Authors gratefully acknowledge the support from Marsyangdi Corridor 220 kV Transmission Line Project, Nepal Electricity Authority, Shiva Ram Tamrakar and Bishal Lamichhanne.

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