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Efficiency Enhancements of Electric Power System and Economic Analysis- Practical Case Study

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Abstract

Power system operators and planners are always faced with the problem of how to minimize the transmission and distribution losses. There are several ways to achieve this goal. Reducing losses improves the power system efficiency and yields a substantial energy savings. Other benefits also include released system capacity, possible deferral of capital expenditures for system improvements and expansion, and reduction of greenhouse gas emission. This paper, presents the results of a practical case study for assessing both technical and non-technical losses of a transmission and distribution network. Power system modeling, reconfiguration and generation relocation have been performed to reduce the power losses. Moreover, changing power system operational philosophy and adding capacitor banks to further optimizing the power system performance have also been investigated. Furthermore, economic analysis based on Net Present Value (NPV) is presented to quantify the losses. The economic analysis is conducted based on a rate of $75/MWH with a discount rate of 8% and a life cycle of 25 years.

Keywords: *Losses Reduction, Technical Losses, Non-Technical Losses, Economic Analysis.*

1. Introduction

Electrical power losses reduction initiatives in power systems have been activated due to the increasing cost of supplying electricity, the shortage in fuel with ever-increasing cost to produce more power, and the global warming concerns.

Transmission and distribution losses are inevitable consequences of transmitting and distributing energy between the generation plants, substations and consumers. Losses do not provide revenues for the utilities and industrial plants, and are often one of the controlling factors when evaluating alternative planning and operating strategies. The transmission and distribution utilities concern themselves in reducing the losses of the transmission and distribution systems according to the standard level. The amount of losses will be influenced by a number of technical and operational factors, such as network configuration, load characteristics, substations in service, and power quality required. It is important to manage these factors in order optimize the amount of losses [1].

Reducing losses may have an added value to the cost of capital expenditure. It, on the other hand, will help in reducing the amount of electricity production required to meet demand, and this will have wider benefits. Therefore, it yields the necessity of direct trade-off between the cost of capital expenditure and the benefits gained from loss reduction. To do that, the losses should be estimated as accurately as possible [2].

Depending on a utility's size and network, generally between 7-12 % of the electricity produced at the generation site is lost between the generation facilities and the end users [3].

In general, losses are estimated from the discrepancy between energy produced (as reported by power plants) and energy sold to end customers; the difference between what is produced and what is consumed constitute transmission and distribution losses. Reduction of system power losses is a fundamental key. Studies have shown that losses in the distribution system approach 8 to 10% and that correct and proper capacitor bank placement and operation can reduce these losses in the distribution system by as much as 10 to 25% or more. In USA, the transmission and distribution losses were estimated at 6.6% in 1997 and 6.5% in 2007 [4].

This paper presents a case study to improve the efficiency of electrical power system by means of reducing both technical and nontechnical electrical losses of transmission and distribution networks. The analysis is performed for practical power system network, where the electrical losses are evaluated via supervisory control and data acquisition (SCADA) records and simulation of load flow model. Moreover, economic analysis based on Net Present Value (NPV) is presented. The economic analysis is conducted based on a rate of $75/MWH with a discount rate of 8% and a life cycle of 25 years [5].

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2. Means of Reducing the Transmission and Distribution Losses

The primary source of losses incurred by transmission and distribution system is in the resistance of the conductors. For a certain section of a line, the power dissipated in the form of useless heat as the current attempts to overcome the ohmic resistance of the line, and is directly proportional to the square of the rms value of the current traveling through the line (I^2R). It directly follows that the losses due to the line resistance can be substantially lowered by raising the transmission voltage level, but there is a limit at which the cost of the transformers and insulators will exceed the savings [6, 7]. This brings us back to the use of better efficient conductors. Aluminum Conductor Composite Core (ACCC) ability to reduce line losses can provide significant encampment to the electrical power system efficiency. This can be reflected in reductions in fuel consumption and their associated emissions for fossil fuel sources, or improvement of the overall efficiency and economic performance of renewable resources. Using carbon fiber as a replacement for the steel in Aluminum Cored Steel Reinforced (ACSR) enables ACCC conductors to incorporate a stronger, lighter smaller core. This in turn permits a design of conductor that contains 30% more aluminum conductive material than an equivalent ACSR conductor. Because of this increased volume of conductive material, ACCC conductors are much more efficient than their ACSR equivalents at all operating temperatures. ACCC technology should reduce the I^2R losses on the power grid over ACSR by around 30% on average [8]. ACCC conductors has been installed in different countries such as, USA, China, Poland, Spain, Portugal, Mexico, Chile, Indonesia, Belgium, Germany, South Africa, France (test), UK (test), and Brazil (test). A comparison among the different types of conductor from efficiency and current ampacity point views is shown in Figures 1 and 2 [9]. It is clear that the ACCC conductor out performs the ACSR, All Aluminum Alloy Conductors (AAAC), All Aluminum Alloy Conductor- Ultra High Conductivity (AAAC-UHC), and GAP conductors (G(Z)TCSR).

Currently, there is no industry standard on how utilities calculate and account for electrical losses and reductions in electric system losses. EPRI has not found an industry-wide strategy for the reduction of transmission line losses [10]. Some utilities are studying line losses while others are investigating lower losses in large power transformers. Still other groups are focused on more efficient distribution transformers. Some means for transmission and distribution power loss reduction are:

- Rebuilding existing power lines using larger conductors to enhance the efficiency. The larger conductor reduces the resistance of the lines, which in turn reduces losses;
- Adding new transmission lines to an overloaded system divides power flows over multiple paths, which reduces electric current and losses on each individual power line;
- Installing higher voltage lines allows demand to be met with lower levels of current and lower line resistance, which also reduces losses;
- Assessing new technologies to reduce losses on distribution circuits, such as smart distribution system;
- Revising distribution transformer applications, design specifications/material considerations, and loading guidelines;
- Developing operational guidelines for improved management of distribution transformers;
- Conducting low-loss distribution transformer research;
- Typically, the larger the transformer the greater the core losses are. Installing the right size of transformer to supply the load, will result in the most efficient installation. If the transformer is larger than required, the core losses will be higher than necessary;
- Relocating transformers and substations near to load centers, reducing low tension (LT) network, or increasing HT / LT ratio;
- Re-routing and re-conductoring such feeders and lines where the losses/voltage drops are higher;
- Power factor improvement by incorporating capacitors or any other mechanism of reactive power compensation at load end;
- Managing the demand to reduce the peaks on the distribution network;
- Balancing the loads on three - phase networks;
- Locating the embedded generating units as close as possible to demand, such as distributed generation;
- Minimizing losses due to weak links in distribution network such as jumpers, loose contacts, or old brittle conductors;

Some of the above mechanisms are adopted in this study and the results are presented in this paper.

3. System Technical and non-Technical Losses

In electricity supply to final consumers, losses refer to the amounts of electricity injected into the transmission and distribution grids that are not paid for by users. Total losses have two components: technical and non-technical. Technical losses occur naturally and consist mainly of power dissipation in electricity system components such as transmission and distribution lines, and transformers. Non-technical losses are caused by actions external to the power system and consist primarily of electricity theft, non-payment by customers, and errors in accounting and energy consumption records.

3.1. System Technical Losses

Technical losses are related to the physical property of the power system components' material. It can be computed and controlled and typically range between 3-6 % [11]. Technical losses comprise both variable losses and fixed losses. Variable losses (load losses) are proportional to the square of the current, which is depending on the power distributed across the network. They are often referred to as copper losses that occur mainly in lines, cables, and copper parts of transformers. On the other hand, fixed losses (no-load losses) occur mainly in the transformer cores and take the form of heat and noise as long as the transformer is energized. These losses do not vary with the power transmitted through the transformer and can be reduced by using high-quality raw material in the core (e.g., special steel or amorphous iron cores incur lower losses). Another way to reduce fixed losses is to switch off transformer

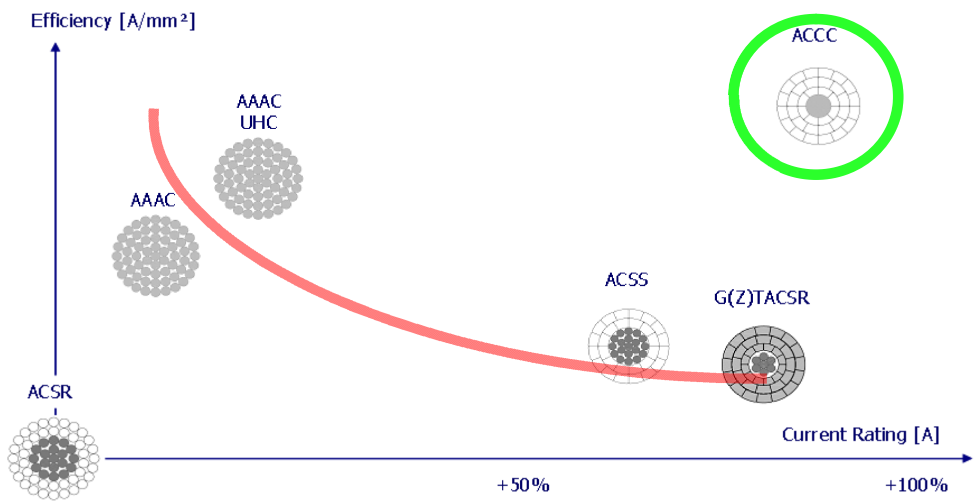

Fig.1. Efficiency performance of ACCC in comparison with other conductor types [9].

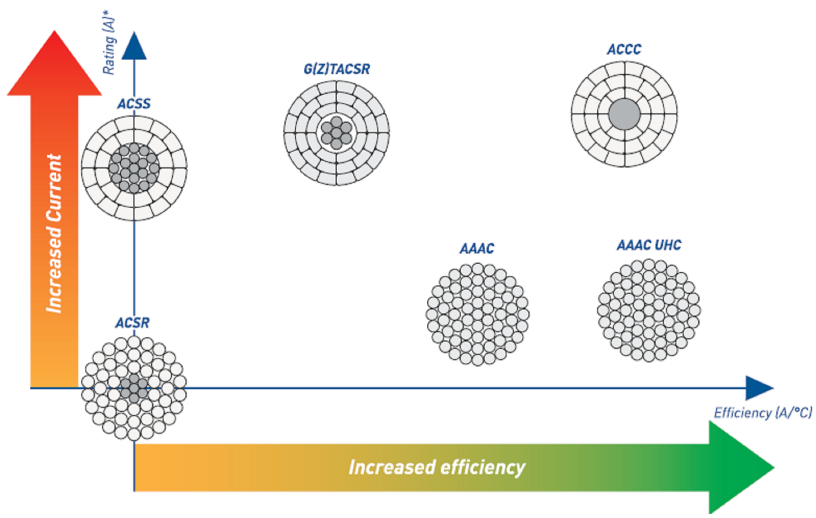

Fig.2. Efficiency versus ampacity of ACCC in comparison with other conductor [9].

operating at low demand. Of course, this depends on the network configuration that enables the operator to power some loads from other sources or lines in the distribution network.

3.1.1. Practical Case Study

In this study, evaluation of the technical losses is based on load flow modeling for the whole network including the generations and loads. The model includes distribution bus bars which are directly connected to 132 kV transmission network through step-down transformers. The model is used to evaluate the system losses under different operating scenarios. In addition, it is used to optimize the reactive power compensation via capacitor banks locations and sizes. Proper reactive power compensation will help improving the voltage and reducing the MVARs flow through the transmission lines thus the system losses are reduced. The transmission network model is updated to include all the projects and load growth expected during the next 5 years. The developed load flow model is used to carry out load flow analysis, the assessment of system voltage profile, real power losses and reactive power losses.

Initially, load flow model of the power system network for the year 2010 including the generation, 132 kV-transmission, and load has been developed to carry out load flow analysis for certain snapshot of power generation and corresponding load based on SCADA records.

Then, a model that reflects all the projects and load growth expected during 2011 and 2016 has also been developed and analyzed. Furthermore, the study has been extended to zoom in a selected distribution system in the network to quantify distribution system losses. The 2016 load flow model has been updated further to consider proposal of generation relocation and replacement of a planned transmission line to higher voltage level. In summary, the power flow analysis considers six cases of study as listed in Table 1.

Table 1. Power Flow Case Studies

Case	Description
1	This case represents peak operating condition of 2010 power system as per SCADA records.
2	This case represents 2011 power system with forecasted loads for 2011 loads.
3	This case represents the expected network growth of existing power system during the next 5 years (2016)-base case.
4	This case represents the expected load growth of existing power system during the next 5 years (2016) but with generation relocation.
5	This case study represents the base case of 2016 with installation of double circuit 220 kV bundled ARCURIA OHLs in replacement of the planned two 132 kV twin ELM OHLs .
6	This case study zooms in one area 33kV distribution network to quantify the typical distribution network losses.

The developed load flow models are used to carry out power flow analysis to check for any bus voltage violations and to evaluate the total power losses. The bus voltage upper and lower limits have been fixed to 1.1 pu and 0.9 pu for transmission network and 1.05 pu and 0.95 pu for distribution system. Any bus voltage beyond or less the limit values have been identified as violation.

Technical losses are affected with the system loading and power plants location. Figure 3 presents a comparison between the percentage network losses of cases 1-5. The calculated total transmission and distribution technical losses are found to be 3.0% for case 1, 3.2% for case 2, 4.4% for case 3, 2.5% for case 4, and 3.9% for case 5. In addition, the existing transmission network has sufficient VARs for case 1 and case 2 power systems as lightly loaded transmission lines act as VAR support to the system. However, additional 40 MVARs are needed for case 3. Similarly, an additional 20 MVARs will be needed along with the proposed 220 kV transmission lines (case 5). On the other hand, no additional VAR support is required for the proposed generation relocation (case 4).

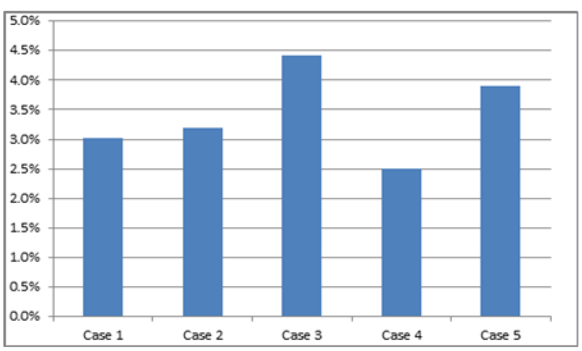

Fig. 3. Percentage network losses of cases 1-5

It is worth to mention that the relocation of planned two generation units showed significant saving in network losses, hence improving the network efficiency. Similarly, it is planned to construct two 132kV single-circuit, single-conductor per phase ELM transmission line. The lines will link southern part of the network to the north part with total lengths of 456 km for each line. Case 5, propose a replacement of both lines with one transmission line of double-circuit 220 kV bundled ARCURIA OHLs. The total network losses will be reduced from 4.42% to 3.9%. The economic analysis in the next section shows the feasibility of this proposal. Beside the gained losses reduction of the proposed 220kV transmission line, it is expected to provide sufficient VAR support to the northern grid. Such VAR support will relieve the generation facility and therefore improve the generation units' lifetime. In addition further benefits of such transmission line will be more valuable with the expected system growth after the year 2016.

3.2. System non-Technical Losses

Nontechnical losses (commercial losses) comprise of units that are delivered and consumed, but for some reason are not recorded as sales. They are attributed to metering errors, incorrect meter installation, billing errors, illegal abstraction of electricity, and unread meters. Use of smart meters or digital meters will help reduce those losses since such meters allow remote billing with higher accuracy. However, the non-technical losses cannot be predicted or calculated beforehand and very difficult to measure. The estimated energy theft in some countries is amazingly high: 10-20% in Mexico, 10-16% in South America, and 20-40% in India [12]. Also in developed countries the energy theft is not negligible. For example in the USA, the consensus seems to be that theft costs between 0.5% and 3.5% of annual electricity gross revenues in the US [12]. A world-wide transmission and distribution loss is shown in Table 2 [13].

Table 2. World-wide transmission and distribution losses [13]

Country	% T&D Losses	Country	% T&D Losses
Japan	4.0	Switzerland	6.0
Denmark	4.0	Sweden	6.4
Germany	4.0	United States	7.0
Ghana	4.0	United Kingdom	7.0
Singapore	4.0	Taiwan	7.0
Guam	4.5	Italy	7.4
Macau	4.81	London	8.3
Korea	5.4	Malaysia	10.0
France	5.9	Thailand	10.3
Australia	6.0	Fiji	10.52
Canada	6.0	Indonesia	12.0
China	6.0	Mexico	14.0
South Africa	6.0	Hong Kong	15.0

3.2.1. Practical Case Study

The generation and load SCADA records of 2010 have been selected to calculate the network losses and accordingly estimate the non-technical losses. The difference between total generation and total demand is the total network losses. Based on SCADA record, Figure 4 represents the measured daily generation, demand, and losses in MW. Figure 5 shows the percentage of daily total losses of the network. It can be noticed that the losses percentage vary between the first half of the year (January - June) compared to the 2nd half (July - December). The average percentage of the total losses during the first half was 13.4%, which increased to 21.71% during the 2nd half of the year. Such increase was associated with increase in total generated power. However, these figures are considered relatively too high compared to load flow model losses result. The difference is directly related as non-technical losses.

Non-Technical Losses in the Network

The non-technical losses can be found by subtracting the technical losses obtained from the load flow model from the total losses measured from SCADA during the same time. Table 3 presents the total losses measured by SCADA, the technical losses calculated by load flow and the estimated non-technical losses. The results reveal that more than 19% of the losses in this system are related to non-technical losses.

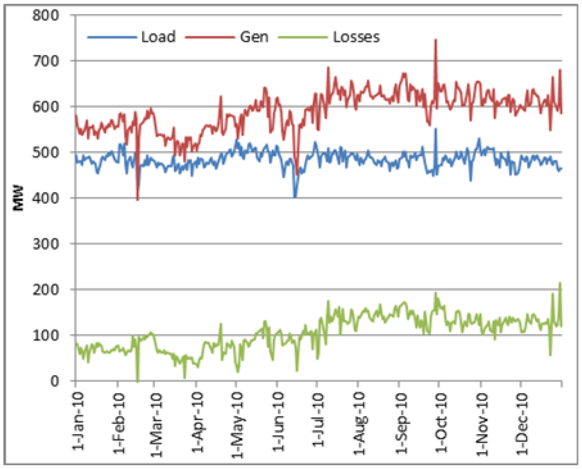

Fig. 4. Total Generation, Demand, Losses of the Network during year 2010.

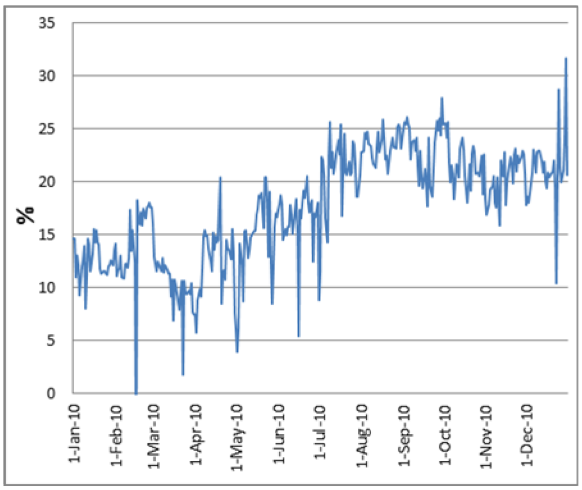

Fig. 5. Total Losses Percentage of the Network during year 2010.

Table 3. Load Flow Model & SCADA Records

Case 1	Total Demand (MW)	Total Generation (MW)	Total Losses (MW)	Total Losses (%)
SCADA	495.33	632.79	137.46	21.72
LF Model	667.236	681.000	13.8	2.04
Estimated Non-Technical Losses			123.66	19.54

The non-technical losses of this network may include, but not limited to uncelebrated meters, non-metered load, human errors, and SCADA system errors.

4. Economic Analysis

Optimization of technical losses in electricity transmission and distribution grids is an engineering issue, involving classic tools of power systems planning and modeling [14, 15]. The driving criterion is minimization of the net present value (sum of costs over the economic life of the system discounted at a representative rate of return for the business) of the total investment cost of the transmission and distribution system plus the total cost of technical losses. All the recommendations proposed in this paper are supported by economic analysis using the Net Present Value (NPV) method considering a life cycle of 25 years.

The Net Present Value (NPV) is an economic evaluation approach that uses the time value of money to convert future cash flow into a present value at a certain discount rate. Due to the time value of money, a hundred dollars today are more valuable than a hundred dollars in the future. Mathematically, the present value of future cash flow is defined by the following formula:

$$PV = \frac{FV}{(1+dr)^N} \tag{1}$$

where PV and FV are the Present and the Future Values, respectively; dr is discount rate, and N is number of years in the future.

For a recurring constant annual income/cost, the present value can be found using the following formula:

$$PV_A = A \times PWF \tag{2}$$

where PV_A is the Present Value of the recurring annuity A and PWF is the Present Worth Factor given by the following equation.

$$PWF = \frac{(1+dr)^n - 1}{dr(1+dr)^n} \tag{3}$$

The NPV of a project is the difference between revenues and costs in today's money. In any comparison of investing options, the project with the maximum NPV is the winning one.

Economic Assumptions

The economic evaluation is based on assumptions provided by the industry as listed in Table 4.

Table 4. Economic Assumptions

Discount rate (dr)	8%
Life cycle (n)	25 years
Cost of energy	75 $/MWh
Initial cost of 20 MVAR capacitors	0.5 $ million
Annual O&M cost of capacitors	1% of initial cost
132kV OHTL (twin ELM) single circuit	90,000 $/km
220 kV bundled ARCURIA OHLs	220,391 $/km
500 MVA 220/132 kV Transformer	3,094,628 $
Civil works for 220/132 kV grid station	1,942,220 $

4.2 Economic Evaluation of Technical Losses in the Selected Scenarios

The present value of the six different cases, which are presented in Table 1, is calculated. To compare between different load flow scenarios, the following steps are used to calculate the cost:

1. Using the calculated the power losses (MW), the total annual energy (E_{loss}) in MWh is obtained by equation (4).

$$E_{loss}(MWh/year) = P_{loss}(MW) \times 8760h/year \tag{4}$$

2. The corresponding value of the annual cost (A_{loss}) in $/year is found using the cost of energy as shown in equation (5).

$$A_{loss}(\$/year) = E_{loss}(MWh/year) \times 75\$/MWh \quad (5)$$

The present value of the losses (PV_{loss}) is found by multiplying the value of annual losses by the Present Worth Factor (PWF).

$$PV_{loss} = A_{loss} \times PWF \quad (6)$$

For an 8% discount rate and a 25-year evaluation period, the *PWF* is as following:

$$PWF = \frac{(1+0.08)^{25}-1}{0.08(1+0.08)^{25}} = 10.675$$

The results are summarized in Table 5. A comparison between the different operating scenarios is shown in Figures 6 and Figure 7.

Table 5. Cost Calculation Results

Case	Calculated losses (MW)	Annual losses (MWh)	Annual cost ($ Million)	PV_{loss} ($ Million)
1	13.805	120931.8	9.07	96.82
2	18.688	163706.88	12.28	131.07
3	46.059	403476.84	30.26	323.03
4	19.692	172501.92	12.94	138.11
5	38.421	336567.96	25.24	269.46
6	1.291	11309.16	0.85	9.05

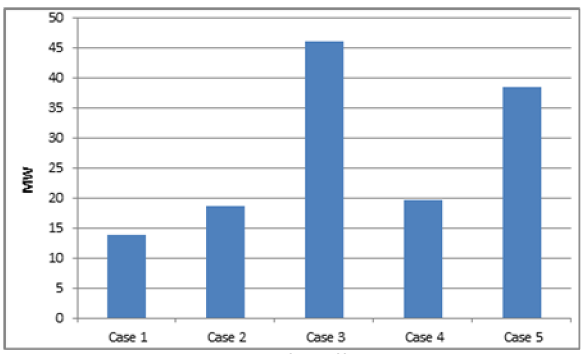

Fig. 6. Calculated losses (MW) for different scenarios

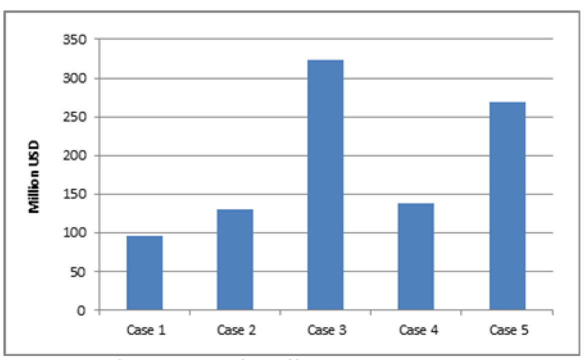

Fig. 7. PV of power losses for different scenarios

From the above results, one can conclude the following:

- Using 2010 operational model (SCADA Records), the technical losses are costing the system owner about $9.07 million annually. Over a 25-year evaluation period, the PV of this power loss is $96.82 million.
- Using the forecasted 2011 model, the technical losses are costing the system owner about $12.28 million annually. Over a 25-year evaluation period, the PV of this loss is $131.07 million.
- Using the forecasted 2016 model, the technical losses are costing the system owner about $30.26 million annually. Over a 25-year evaluation period, the PV of this loss is $323.03 million.
- Using the generation relocation for the 2016 model, the technical losses are costing the system owner about $12.94 million annually. Over a 25-year evaluation period, the PV of this loss is $138.111million.
- Using the generation relocation for the 2016 model, a 57% reduction in losses (reduction from 46.059MW to 19.692 MW) is anticipated. This represents an annual benefit of $17.32 million. The PV of this benefit is $184.92 million.
- Using forecasted 2016 model with 220kV OHTL, a 16.6% reduction in losses (reduction from 46.059MW to 38.421MW) is anticipated. This represents an annual benefit of $ 5.02 million. The PV of this benefit is $53.57 million.
- The calculated technical losses in a typical distribution system are costing the system owner about $0.85 million annually. Over a 25-year evaluation period, the PV of these losses is $9.05 million.

Economic Evaluation of Generation Relocation

For this scenario, the results are based on relocation of two F9E generators from the southern part of the network to the north. In this case, the system requires 40MVAr (2×20MVAr) capacitor banks, which already exist. Since the capacitor banks already exist and the generation units will be installed, the cost of these equipments is considered as a sunk cost. The NPV of this solution is difference between the PV of losses calculated using generation relocation model and the forecasted 2016 model.

$$NPV_{loss} = (30.26 - 12.94) \times PWF = \$184.92 \text{ million}$$

It is worth mentioning that this NPV is considering loss minimization only.

Economic Evaluation of the 220kV OHTL

A 456-km double circuit bundle conductor 220kV OHTL is proposed to transfer power from South to North. Considering a cost of $0.22 million/km for this OHTL, the initial cost of the line is about $100.50 million. In addition to the OHTL, eight 500MVA transformers for the four substation are required. Assuming an initial cost of $3.08 million per transformer, the total initial cost for the required 8 transformers is $24.66 million. In addition, the civil works for each of the 220/132 kV grid station is estimated to be $ 1.94 million. The total cost for the civil work of the 4 grid stations is $7.77 million.

From the above, the total initial cost of the new 220 kV OHTL is about $133.02 million. The benefits of this 220 kV OHTL include reduction in losses, replacement of the planned two 132 kV lines, reduction in the required number of capacitor banks.

Loss reduction: Using Forecasted 2016 model with 220 kV OHTL, a 16.6% reduction in losses (reduction from 46.059MW to 38.421MW) is obtained. This loss reduction represents an annual benefit of $ 5.02 million (30.26-25.24). The PV of this benefit is $53.57million (323.03-269.46).

Replacing two 132kV lines: This OHTL and associated 220/132 kV substations will replace the two 132 kV OHTL (twin ELM) single circuit on wooden pole of the same length. Considering an initial cost per km of this line as $ 0.09 million/km, the initial cost is about $41.04 million for each line. The total cost of the two 132 kV lines is $82.08 million.

Capacitor banks: For the 2016 base model, the system requires 80MVAr (4×20MVAr) capacitor banks, from which 2×20MVAr already exist. The PV of the cost of two 20-MVAr capacitor banks is $1.32 million. With the 220 kV OHTL option, the system requires 60MVAr (3×20MVAr) capacitor banks, from which 2×20MVAr already exist. This means that the 220kV OHTL option yields a reduction in the reactive compensation cost of $0.66 million.

The NPV of the total benefits of the 220 kV OHTL option is $136.31million (53.57+82.08+0.66). Since the benefits of the proposed 220kV OHTL overweighs the costs associated with the two 132 kV lines ($133.02 million), the 220 kV project is economically justified from loss minimization perspective. The NPV of this project is $3.28million (136.31-133.02). The same conclusion can be obtained from Figure 8 which presents a comparison between different cost components involved in both options (132 & 220 kV).

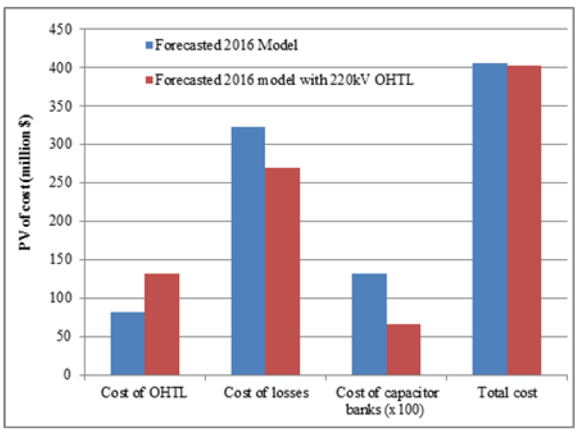

Fig. 8. PV of costs for 132kV and 220kV OHTLs

Economic Evaluation of Losses with Different Conductors

To evaluate different options of conductors in term of losses, a case study of four types of conductors is presented. The parameters of these conductors are obtained from literature. A 50 km 220kV two-bus system is considered. Having the power losses, the annual losses can be calculated ($8760\times 3I^2R$). The value of the annual losses is obtained using the energy price of 75$/MWh. The PV of the annual cost of losses is obtained by multiplying the annual cost of losses with the PWF (10.67). A comparison between the PV of the loss costs for different types of conductors is shown in Figure 9.

The results show that the ACCC conductor presents the lowest power losses; therefore, yields the highest energy cost saving. The 2nd best option is AAAC conductors followed by GAP and ACSR conductors.

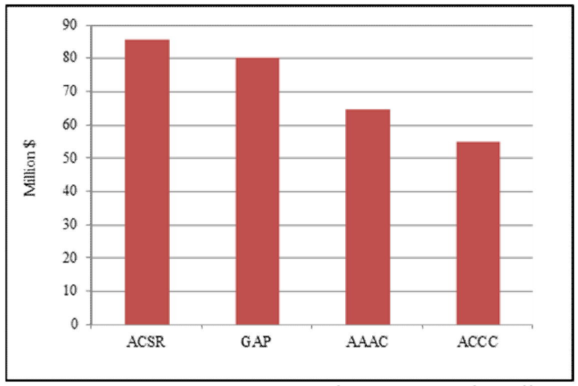

Fig. 9. Comparison between the PV of the loss costs for different types of conductors

5. Conclusions

In this paper, a case study for efficiency enhancements of power transmission and distribution system based on system reconfiguration, VAR enhancement and generation relocation is presented. The study is enhanced through economic analysis using Net Present Value approach. The non-technical losses of the power system based on 2010 generation and load daily reports were identified. The data show high level of losses that requires remedial corrective actions in metering and reporting process. Using 2010 operational model (SCADA Records), the technical losses are costing the system owner about $9.07 million annually. Over a 25-year evaluation period and 8% discount rate, the present value of this cost is $96.82 million. In this work, it was found that a 57% reduction in power losses which can be achieved through optimized generation relocation presents an annual benefit of $17.32 million. The present value of this saving over a 25-year evaluation period and 8% discount rate is $184.92 million. Similarly, a 16.6% reduction in losses through upgraded OHL represents an annual benefit of $ 5.02 million with a PV benefit around $53.57 million. The calculated technical power loss in a typical distribution system is costing the system owner about $0.85 million annually with a PV of $9.05 million over 25 years of service. Furthermore, the case study reveals that ACCC conductor have the lowest power losses; therefore, the highest energy cost saving, followed by AAAC, then GAP and ACSR conductors, respectively.

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References

[1] A. A. Sallam and O. P. Malik, Electric Distribution Systems, IEEE Press, NJ, USA, 2011. http://dx.doi.org/10.1002/9780470943854

[2] A. Al-Hinai and A. Al-Badi, "Optimal VAR Compensation for Electrical Distribution Systems Using Particle Swarm Optimization, Application to SQUH Distribution Network", SQU, January 2011

[3] SunShine Green Energy, "Smart Grid," Available: http://www.sunshineusainc.com/index.html.

[4] Ali Nourai, V.I. Kogan and Chris M. Schafer "Load Leveling Reduces T&D Line Losses," IEEE Transactions On Power Delivery, 2008.

[5] A. Al-Hinai E. Feilat, M. Al-Badi, H. Al-Nasseri & A. Al-Badi, "PDO Power System Losses Optimization Study", External Research Grant Technical Report submitted to PDO, January 2012.

[6] M. C. Anumaka, "Analysis Of Technical Losses In Electrical Power System (Nigerian 330kv Network As A Case Study)," IJRRAS, Vol. 12, No. 2, August 2012.

[7] E. Benedict, T. Collins, D. Gotham, S. Hoffman, and D. Karipides "Losses in electric power systems", Technical Report, Purdue University, 1992.

[8] Dominic J. Majendie, "India now has an energy-efficient conductor to improve its power transmission capacity,"Electrical Monitor, April 28, 2011.

[9] CTC Cable Presentation – November30, 2009. Available: http://www.auptde.org/newsite/UploadFiles/Activitypaperfile/413.ppt.

[10] EPRI, "Efficient Transmission Systems - Program 172," 2010 Research Portfolio, pp. 1-4, 2010.

[11] B. Nesbit, 2000, "The sizable problem of stolen electricity", Electrical World T&D, September/October 2000.

[12] Albana ILO, et. al "on-line estimation and location of non-technical losses in a distribution system" 17th International Conference on Electricity Distribution Barcelona, 12-15 May 2003.

[13] Electric Power in Asia and Pacific, United Nation, 1997.

[14] A. Al-Hinai, K. Ellithy, R. Al-Abri & S. Al-Hinai, "Energy Saving Study by Power Factor Correction for Sultan Qaboos University Hospital", Financial Affairs Department (SQU), January 2008.

[15] K. Ellithy, A. S. Al-Hinai, and A. H. Moosa, "Optimal Shunt Capacitors Allocation in Distribution Networks Using Genetic Algorithm- Practical Case Study", International Journal of Innovations in Energy Systems and Power, IJIESP, Vol 3, no. 1, April 2008.

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