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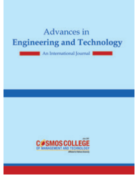

Techno-Economic Analysis of the placement of the Capacitor in the Integrated Nepal Power System

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Abstract

With the increasing load demand, Integrated Nepal Power System (INPS) is facing a stiff challenge to maintain voltage profile within the standards and reduce system loss. Among the loss reduction strategies, an immediate solution would be installation of reactive power compensators at the grid substations. The power flow study of existing system is performed and a genetic algorithm is used to find optimum placement of suitable size of the capacitor banks to be added in system. 6 substations with a total reactive power supply of 80 MVAR was determined as optimal size and location and the installation is also financially feasible. Moreover, the analysis of capacitors placed at the varying voltage levels implied that the most suitable voltage level for the capacitor installation is 11kV.

1. Introduction

The annual loss in transmission system of INPS has increased from 4.35% to 4.51% according to the reports published by the Transmission Directorate in last couple of years. The cause for this increase in loss is overall increase of load from 7583.92 GWh to 7894.47 GWh with the increase in peak power demand from 1320.28 MW to 1407.94 MW[1], [2].

Along with increase in loss, numerous substations are having voltage issues with the minimum voltage below their normal range of 0.9 pu. This loss can be reduced along with voltage improvement following the upgradation of transmission voltage level and conductor. Though various transmission projects are undergoing and many have been proposed and completed, it seems to be behind the trend of the load growth. Along with the future considerations, an intermediate solution for this reduction in loss along with the increase in the substation voltage can be the installation of capacitors in the grid substations of the system.

In case of the INPS of Nepal, though the capacitors are placed in some of the substations, with a total of 546.144 MVAR, the resource seems to be still insufficient[2]. If NEA had generated a sufficient amount of reactive

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power, the loss would have been lower. For this, an algorithm is required which finds optimum placement of the capacitors to be added with suitable size, considering minimal real power loss as the objective function, power flow equations as the equality constraints and deviation in the voltage, and power factor of the terminal bus as inequality constraints. Moreover, as capacitors are placed at almost all the voltage levels: 11, 33, 66, and 132kV in the grid substations [2], a techno-economical analysis needs to be carried out to find the most suitable voltage level for capacitor placement.

Various optimization techniques have been suggested for the placement of capacitor as a means for improving the quality of solution of the problem. Some of thesepractices include simulated annealing[3], the tabu search[4], expert system[5], dynamic programming[6]. While these methods can easily handle discrete variables, they have several drawbacks, the major of which is speed and the fact that they use certain control parameters that may be system dependent and difficult to determine.Another optimization tool is Genetic Algorithm(GA) . GA like some other optimization techniques uses probabilistic transition rules and is good for the situations with less information about the problem[7]. So, genetic algorithm is used for the optimal placement and sizing of capacitors.

Research[8]has presented optimum placement of capacitorsfor radial distribution systems considering the parameters of the distribution system: capacitor cost, voltage, angle, and loadchanges. The objective function considered the minimization of the loss in the system performing the load flow with the inequality constraints of the parameters listed above. It then provides specific location of the capacitors to reduce system's energy loss. The capacitors of general size connected to the INPS previously were selected as fixed-sized capacitors for the optimum placement. A research paper [9]performed optimum capacitor placement for IEEE 118 bus system using the optimum capacitor module of ETAP.

In this study, genetic algorithm is used to determine the optimal size and location of the capacitor banks in INPS and perform a techno-economic analysis of the system. Moreover, the impact upon the transmission lines of KGD is compared and a brief analysis of addition of capacitors on varying voltage levels is presented to find the suitable voltage level of addition of capacitor.So, the main aim of this paper is to analyze INPS after addition of fixed capacitors on grid substations with the analysis of technical and financial parameters associated with it as the solution for lower substation voltage and higher system loss.

2. Material and Methods

For INPS modeling, the ETAP software is used with genetic algorithm as an optimization tool for capacitor placement.

2.1 Mathematical Formulation

The objective function for genetic algorithm with equality constraints and inequality constraints associated is presented herewith:

Objective Function:

The cost associated with system can be mathematically represented as:

Minimization function = $\sum_{i=1}^{Nbus}(x_i C_{0i} + Q_{ci} C_{1i} + B_i C_{2i} T + C2 \sum_{i=1}^{Nbus}(T_l P_L^1))$ (1)

- Nbus= No of bus candidate
- x_i – 0/1,0 means no cap installed at bus i
- C_{0i} – Installation cost
- C_{1i} – per kVAR cost of a capacitor bank

- Q_{ci}– Capacitor bank size in kVAR
- B_i – Number of capacitor banks
- C_{2i} – Operating cost per bank, per year
- T – Planning period(years)
- C_2 – Cost of each kWh loss in Rs/kWh
- L – Load levels, maximum, average and minimum
- T_l – Time duration, in hours, of load level 1
- P_{Li}– Total system loss at load level l Constraints

The equality constraints are:

$$P_i(V,\delta) - P_{Gi} + P_{Di} = 0 \tag{2}$$

$$Q_i(V,\delta) - Q_{Gi} + Q_{Di} = 0 \tag{3}$$

The inequality constraints considered for the genetic algorithm is:

$$V_{i_{min}} \le V_i \le V_{i_{max}} \tag{4}$$

$$Q_{j_{min}} \le Q_j \le Q_{j_{max}} \tag{5}$$

Wherei is the number of buses and j is the number of reactive power sources. The voltage considered in this case is: $0.9\ pu \le V_i \le 1.1\ pu$ (6) as per the Electricity Regulatory Act for the substation to be within the standard voltage level.

2.2 INPS and Modeling

The INPS has a total of 58 grid substations with a transmission voltage of 66-220kV with a total of about 546 MVAR capacitors installed in the system [2]. The modeling of the system was performed in ETAP software with load considered as constant kVA load and is shifted to the higher voltage for ease in the analysis. The load flow is carried out considering the peak load of the annual peak (Bhadra) with the existing system with Dhalkebar Grid considered as the swing bus. For the financial analysis, the energy savings is taken into account. Since, the load flow was performed at the system peak, to calculate the energy the load factor needs to be determined from the annual energy dispatched.

So, Load Factor = 7894.47*1000 MWh / (1407.94 MW *365*24hr) =0.64 and the reduction in the peak loss needs to be multiplied with this factor and annual hours to find the annual energy savings.

3. Results and Discussions

3.1 Simulation Results

From the results of load flow, it is observed that 11 of the substations have voltage levels below 0.9pu. with a 4.16% loss in INPS during the system peak as in Table 1.The voltage issue is mostly in substations of Lumbini province and some of the Kathmandu Grid Division (KGD) as well. Using GA, the capacitors of optimum sizes areplaced in the different substations as shown in Table 2

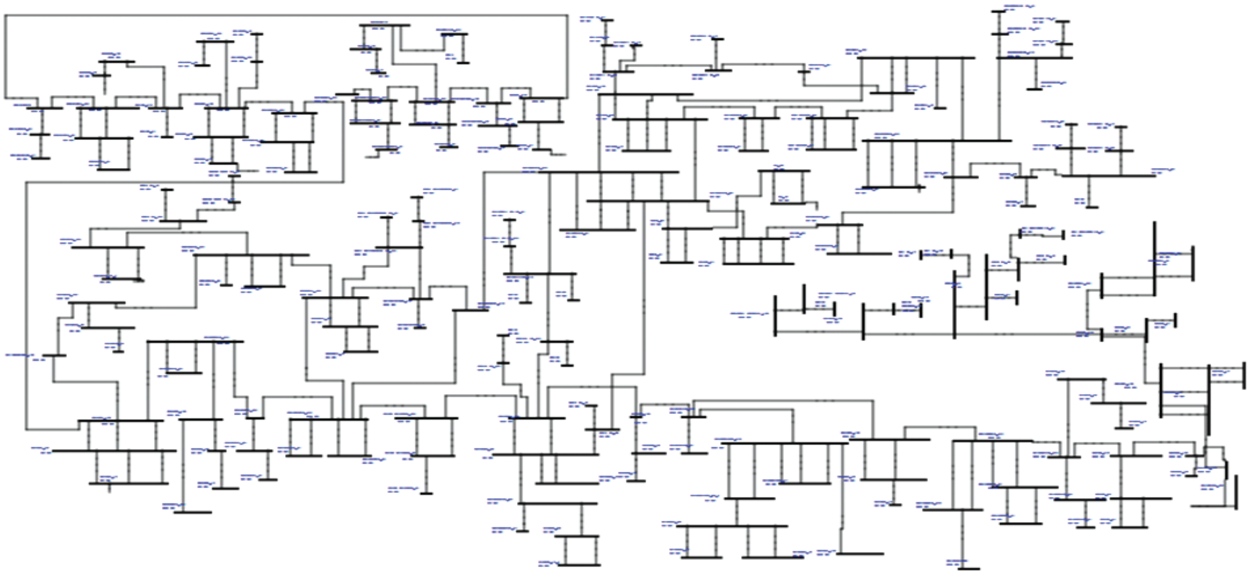

Figure 1: ETAP model of INPS Grid System

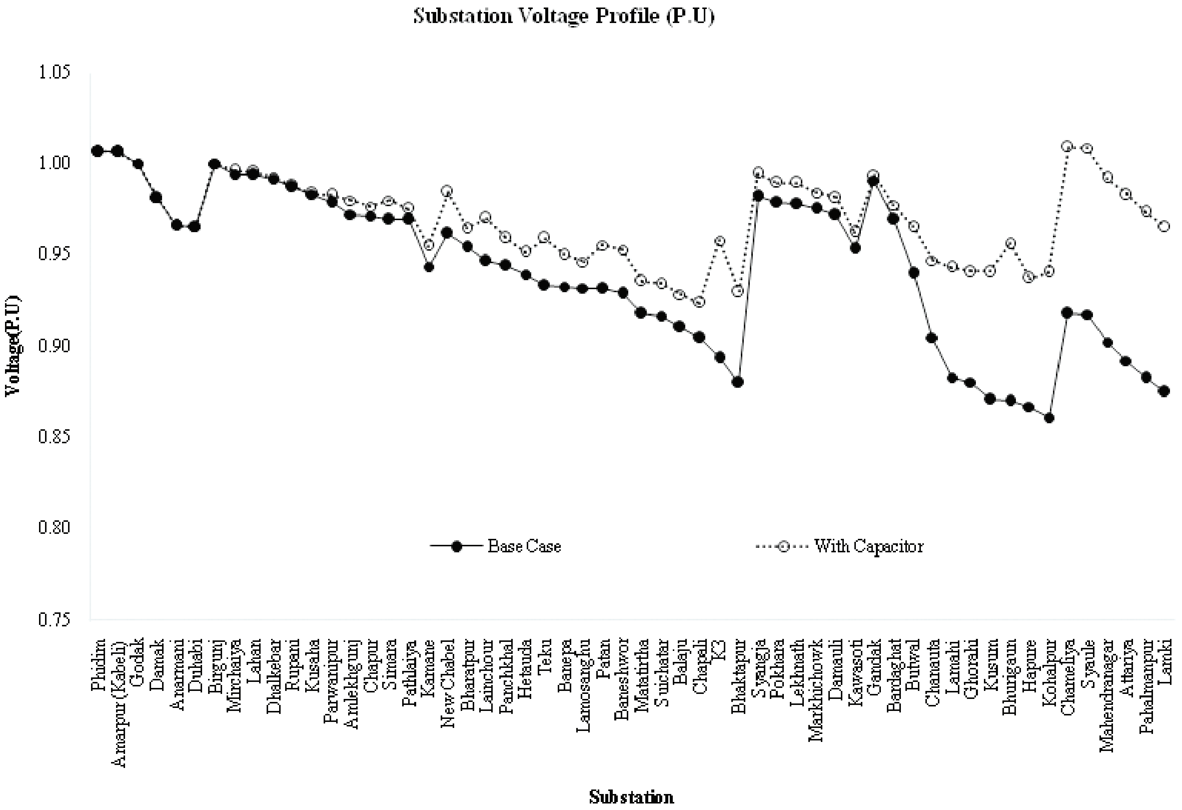

Figure 2: Substation Voltage profile of INPS with and without capacitor placement

With the capacitor placement, voltage of all substations is abovethe standard level of 0.9puas depicted in Figure 2; along with reduction in line loss to 3.96% during the system peak. Considering the system load factor of 0.64, it is seen that around 16.02 GWh of energy can be saved every year.

Table 1: Load flow Summary

S.N.	**Description**	**Base Case Value**	**With Capacitor Value**
1	Generation-MW	1367.302	1,364.444
2	Generation-MVAR	279.045	161.153
3	Loss-MW	56.933	54.075
4	Loss-MVAR	67.62	47.29
5	No. of SS below 0.9 pu voltage	11	0
6	Loss %	4.16%	3.96%
7	Average Load Factor	0.64	0.64
8	Annual Energy Loss (GWhr)	7,665.64	7649.62

Table 2: Optimal location and size using GA

S.N.	**Substation**	**Capacitor size (MVAR)**
1	Bhaktapur	12.5
2	Butwal	2×12.5
3	K3	10
4	Lamahi	12.5
5	Lamki	10
6	Mahendranagar	10

On studying impact upon the transmission lines in the KGD, the placement of capacitor in two of the substations, Bhaktapur and K3 have decreased loadings and loss of the interconnected lines. However, the loading of lines connecting Bhaktapur substation has increased with a supply of reactive power from substation with the corresponding increase in line loss. It is seen that with the capacitor placed at substations, the line loading and loss of the source line decrease significantly as in Table 3.

Moreover, a brief analysis for the most suitable voltage level is performed.From the results, it is inferred that the placement of capacitor on either side of transformer does not have many significant differencesfrom the loss and loading aspects. The line is found to have a similar loading irrespective of the placement of transformer. However, the transformer loading will increase or decrease based on the net power flow, i.e., if the substation delivers more reactive power to other substations than the previous supplied value, then transformer loading and loss would increase and if a scenario is opposite, so is the condition for transformer loading and loss. However, the cost of the capacitor bank installation increases with the voltage level, it is lower for 11kV and the most for 132kV.

Technically the effect of a capacitor placed on either side of the transformer will not vary the loss and loading and loss by a significant factor, however financially the 11kV side would be most economical. So, the most suitable voltage level for capacitor placement is 11kV.

3.2 Financial Analysis

When the capacitors are placed in the INPS system, the overall system loss decreases with an annual energy savings of 16.02GWh. To understand the financial scenario associated with the installation of the capacitor, the following considerations were made:

- Energy Cost = NRs. 10/unit[10]
- No of years under analysis =20 years

From the analysis, it is evaluated that the NPV, BCR and IRR are NRs. 7,40,86,472.2, 1.97 and 20.5% respectively with the discounted payback period of 5.5 years.

Table 3: Line loadings and loss of KGD

S.N.	Voltage (kV)	Line Section	Line Loading		Line Loss	
			Base Case	With Capacitor	Base Case	With Capacitor
1	132	Balaju - Suichatar	57.1%	52.3%	0.35%	0.30%
2	132	Chapali - Balaju	20.6%	18.4%	0.35%	0.29%
3	132	Chapali - Bhaktapur	18.9%	19.2%	0.22%	0.23%
4	132	Lamosanghu - Bhaktapur	80.9%	78.7%	1.90%	1.80%
5	132	Suichatar - Matatirtha	37.4%	34.5%	0.09%	0.07%
6	66	Balaju - Suichatar	25.85%	23.18%	0.51%	0.41%
7	66	Balaju - Lainchour	23.71%	23.10%	0.12%	0.11%
8	66	Banepa - Bhaktapur	10.45%	16.66%	0.28%	0.71%
9	66	Baneshwor - Patan	30.16%	33.49%	0.19%	0.22%
10	66	Bhaktapur - Baneshwor	84.69%	86.95%	2.76%	2.99%
11	66	Chapali - New Chabel	94.62%	91.65%	1.06%	1.00%
12	66	K3 - Teku	43.04%	37.06%	0.09%	0.07%
13	66	New Chabel - Lainchour	18.34%	17.72%	0.50%	0.47%
14	66	Panchkhal - Banepa	51.59%	48.74%	0.94%	0.83%
15	66	Suichatar - Teku	51.22%	46.13%	0.46%	0.37%
16	66	Suichatar - Patan	64.60%	63.71%	0.87%	0.84%

4. Conclusion

With the current trend of load growth, there is necessity to provide reactive support in INPS system to maintain the substation voltage within standards and reduce the system loss as well. The introduction of capacitors in optimal locations can be one of the alternatives for reactive support. The voltage profile of substations, especially of province 5, can be solved with the installation of capacitors at Lamki, Lamahi and Butwal Grid substations. Moreover, the addition of capacitors at K3 and Bhaktapur will enhance the substation voltage within KGD. The implementation of this study has all financial parameters positive. Hence, the addition of capacitor is appropriate from both technical (voltage, loss) aspects and financial aspects as well. Moreover, the 11kV side is more suitable for connection of the capacitor dominated with financial aspects. In future studies, research can be done for the installation of the capacitor in the grid substations with the projected scenario of generation and loading conditions of 5-10 upcoming years and the transient impact upon the switching at lightly loaded conditions can be performed.

Conflict of Interest

Not declared by the authors.

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