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Techno-Economic Analysis of Reactive Power Generation Strategies in Proposed Integrated Nepal Power System

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Abstract

Increment in generation and load of Integrated Nepal Power System (INPS) without consideration of reactive power flow in the grid results in poor voltage regulation in future. In order to mitigate the problem, two strategies have been identified, one includes support from Independent Power Producers (IPPs) (termed as decentralized in this study) and other one does not (termed as centralized). The purpose of this study is to make the techno-economic analysis of above mentioned reactive power compensation strategies in 2023 A.D. and 2028 A.D. Sensitivity index dV/dQ has been used for finding candidate locations of shunt compensators. For finding optimal sizes of shunt compensators for both strategies, genetic algorithm has been used with minimization of grid loss as objective function. Coding was done in Matlab while power flow solutions were obtained from DIGSilent Powerfactory interfaced with Matlab. For both projected years mentioned, it was found that reactive power support provided by Independent Power Producers (IPPs) would result in reduced size of shunt compensators and reduced power loss in grid. This study clearly points that reactive power support from IPPs would be the best strategy and some charges should be paid to them for their support.

Keywords

Integrated Nepal Power System (INPS), Reactive Power Generation, Techno-Economic Analysis, DIGSilent PowerFactory

1. Introduction

With the increment of installed capacity of Nepal's Power system to 5000 MW in 5 yrs and 10000 MW in 10 years as per the White Paper published in 2018 by then Ministry of Energy, there would be an abnormal flow of reactive power in the system if reactive power generation strategy is same as in present years. In present condition, IPPs rarely generate reactive power since it does not provide any remuneration to them. For most of the time these companies run their plants at unity power factor. With this condition, voltage would deviate from their normal range (0.9pu-1.1pu) in many buses.

If only state owned electric utility (i.e. Nepal Electricity Authority in case of Nepal) should generate required reactive power with private producers running in unity power factor then the size of VAR compensators required is high and power loss would also be more. On the other hand, reactive power may also be generated by IPPs if suitable charges are paid to them by market. In both of the above strategies, an algorithm is required which calculates optimal reactive power dispatch with minimization of real power losses as objective, power flow equations as equality constraints and voltage deviation as well as line loading as inequality constraints.

I.E. Samahy, C.A. Canizares [1] have proposed a reactive power dispatch model in which real power generation is decoupled and assumed fixed; however, due to the effect of reactive power on real power, real power generation is allowed to be re-scheduled within given limits. Real power dispatch is assumed fixed in this study as well and optimization is performed only on reactive power dispatch using voltage constraints. B. Mozafari, T. Amrace [2] have presented a methodology for optimal reactive power procurement which is run in sebsequence of primary electricity market, allowing active power modification in light of available transmission capacity and reactive power sources. R. Ucheniya and A. Saraswat [3] have used genetic algorithm for solving optimal reactive power dispatch problem in which power flow calculation was done in DIGSilent and the necessary genetic algorithm coding was done in MATLAB. This paper used real power loss as the objective function and voltage deviation has been incorporated by using a tool of DIGSilent Power Factory. It is to note here that, control variables contains only the size of shunt compensators while the reactive power dispatch from IPPs are controlled by DIGSilent tool itself. So, in this study, genetic algorithm only selects optimum size of shunt compensation while optimum dispatch from IPPs are governed by DIGSilent tool.

Though, both of the aforementioned strategies that would be studied in this research are technically feasible strategies, we would perform techno-economic analysis of both strategies to identify which strategy is optimal for Integrated Nepal Power System in 2023 and 2028 year.

2. Parallel Operation of Matlab and DIGSilent

For implementing the reactive power optimization using parallel operation of Matlab and DIGSilent PowerFactory, following procedures are followed in this study;

Initially, Matlab is initialized with number of variables, population, mutation and crossover ratio, limits for variables, plot function, etc. Matlab contains two script files, one is main file (eg: matcomcheck5yrspfctrl.m) and another script contains fitness function (eg: myFitness5yrspfctrl.m) which takes population as input and output fitness value to the 'ga' function of Matlab. The communication actually takes place by using excel file in .csv format name "gentrf". Since, both software needs to access the "gentrf" excel file, another comma separated file named "flag.csv" is used to prohibit access from another software while still being in use. It contains value either "0" or "1". When flag is "0", DIGSilent performs load flow by taking input from "gentrf" through a DPL script named "comm.", it also stores fitness value in fourth row of "gentrf" file and when flag is "1", matlab feeds the data from genetic algorithm to the file name "gentrf" and takes fitness value from fourth row of that file which is the ultimate output of fitness function of Matlab. Procedures are clearly visualized from following points:

- Matlab generates population containing control variables which is reactive power generation from Shunt Compensation. Sets the value of flag to 0.
- DIGSilent, as soon as it sees flag equal 0, it gets reactive power data from "gentrf" file performs voltage constrained load flow and saves the fitness value to fourth row of "gentrf" and sets the value of flag to 1.

This process is repeated till the fitness value reaches the optimal point which is the final value containing sizes of reactive compensation for concerned power factors.

3. Configuring DIGSilent PowerFactory

Since the fitness value would be calculated by DPL script, load flow is called from DPL script to calculate fitness value. But instead of load flow "ComLdf", in this thesis, for simplicity, "ComOpf" is used. Using "ComOpf" has two major advantages. First, the number of control variable is reduced by using optimization of generators from "ComOpf" function itself. The remaining control variables which is the size of capacitors is selected from genetic algorithm and fed to the *qcapn* of shunt compensators modeled in DIGSilent. IPPs would be optimized for reactive power generation with upper and lower limits as specified in opf tool itself while upper and lower limits of capacitor sizes would be provided in genetic algorithm in Matlab. Second, voltage limits could be easily selected in "ComOpf" and there is no need to use penalty function for voltage control in fitness function.

Since, with the use of "ComOpf", loss is already optimized, genetic algorithm does the function of finding minimum value of compensation size such that IPPs would remain in their operational limits of given power factor and also voltage remains within range of $\pm$ 10%.

In this way, by using this methodology, optimal size of shunt compensation as well as optimal loss reduction is obtained at once.

4. Mathematical Formulation

The objective function, equality constraints and inequality constraints associated with genetic algorithm is explained as below.

Objective Function:

$$Minimize f(x) = \alpha * P_{\text{loss}}(x) + \sum_{i=1}^{n} x_i \tag{1}$$

where,
x is size of shunt compensators,
n is total number of compensators used (n = 5 for year 2023 and n = 11 for year 2028),
P_{loss} is system real power loss,
α is the penalty factor for P_{loss} (α = 10 in this study)

Equality Constraints:

$$\begin{aligned} P_i(V,\delta) - P_{G_i} - P_{D_i} &= 0 \\ Q_i(V,\delta) - Q_{G_i} - Q_{D_i} &= 0. \end{aligned} \tag{2}$$

where,

$$\begin{aligned} P_i(V,\delta) &= \mid V_i \mid \sum_{i=1}^{n} \mid V_i \mid\mid Y_{ij} \mid cos(\delta_i - \delta_j - \phi_{ij}), \\ Q_i(V,\delta) &= \mid V_i \mid \sum_{i=1}^{n} \mid V_i \mid\mid Y_{ij} \mid sin(\delta_i - \delta_j - \phi_{ij}), \\ Y_{ij} &= \mid Y_{ij} \mid \angle\phi_{ij}. \end{aligned} \tag{3}$$

and load balance equation,

$$\sum_{i=1}^{N_G} (P_{G_i}) - \sum_{i=1}^{N_D} (P_{D_i}) - P_L = 0 \tag{4}$$

Inequality Constraints:

$$\begin{aligned} V_{i_{min}} \leq V_i \leq V_{i_{max}} \\ Q_{j_{min}} \leq Q_j \leq Q_{j_{max}} \end{aligned} \tag{5}$$

where, i = 1 to total no. of buses,
j = 1 to total reactive power sources (i.e. generation plants and shunt compensators)

5. System Modeling and Simulation

Modeling of 2023 and 2028 scenario was done in DIGSilent PowerFactory simulation software version 15.1.7. This software is used for Digital Simulation and Network Calculation functions like Load Flow, OPF (Optimal Power Flow) tool. For the purpose of coding required for thesis, two coding platform were used. They are, DIGSilent Programming Language(DPL) and Matlab R2018b.
For the purpose of modeling of 2023 and 2028 year scenario, as per the data obtained from various organizations like Nepal Electricity Authority, WECS Nepal, National Transmission Grid Company, Nepal, INPS was divided into five zones. The total generation in the year 2023 was assumed to be 5023.85 MW and 10675 MW for the year 2028. From the NEA forecast table, expected load for the year 2019/20 was 2225 MW but present peak load as per the data obtained from System Operation Department is 1400 MW. So, this study has put a multiplying factor for the respective 2023 A.D. and 2028 A.D.
Multiplying Factor (m.f.) = 1400/2225 MW = 0.629.
Thus, Assumed Load for 2023 = 0.629*3703.3 MW = 2329 MW.
Assumed Load for 2028 = 0.629*5561 MW = 3497 MW.
Excess generations were proposed to be exported to India through 400 kV lines.

6. Results and Discussions

6.1 Simulation Results

For the year 2023 and 2028, in order to reduce the size of problem and number of scenarios, a comparison was made initially between 0.90 lag and 0.90 lead lag mode for the year 2028. Let's look at the two scenarios first.

Table 1: Comparison of lag only and lead-lag mode for 2028

Mode	Compensation Size (MVAr)	P_{loss} (MW)	Remarks
0.90 lag	216	240	Not Selected
0.90 lead-lag	128	190.36	Selected

From Table 1, it is evident that, operating IPPs in lagging mode as well as in leading mode would be more beneficial from system loss point of view and from reactive compensation cost point of view. So, in year 2023 and 2028, operating IPPs in both lead lag mode is recommended.

Table 2 and Table 3 shows the reactive compensation required for year 2023 A.D. and 2028 A.D. respectively for various power factors with the methodology mentioned in this study. It shows the decreasing trend of required reactive compensation and real power loss as the IPPs were made to run in lower power factors. Curve of buses voltage before

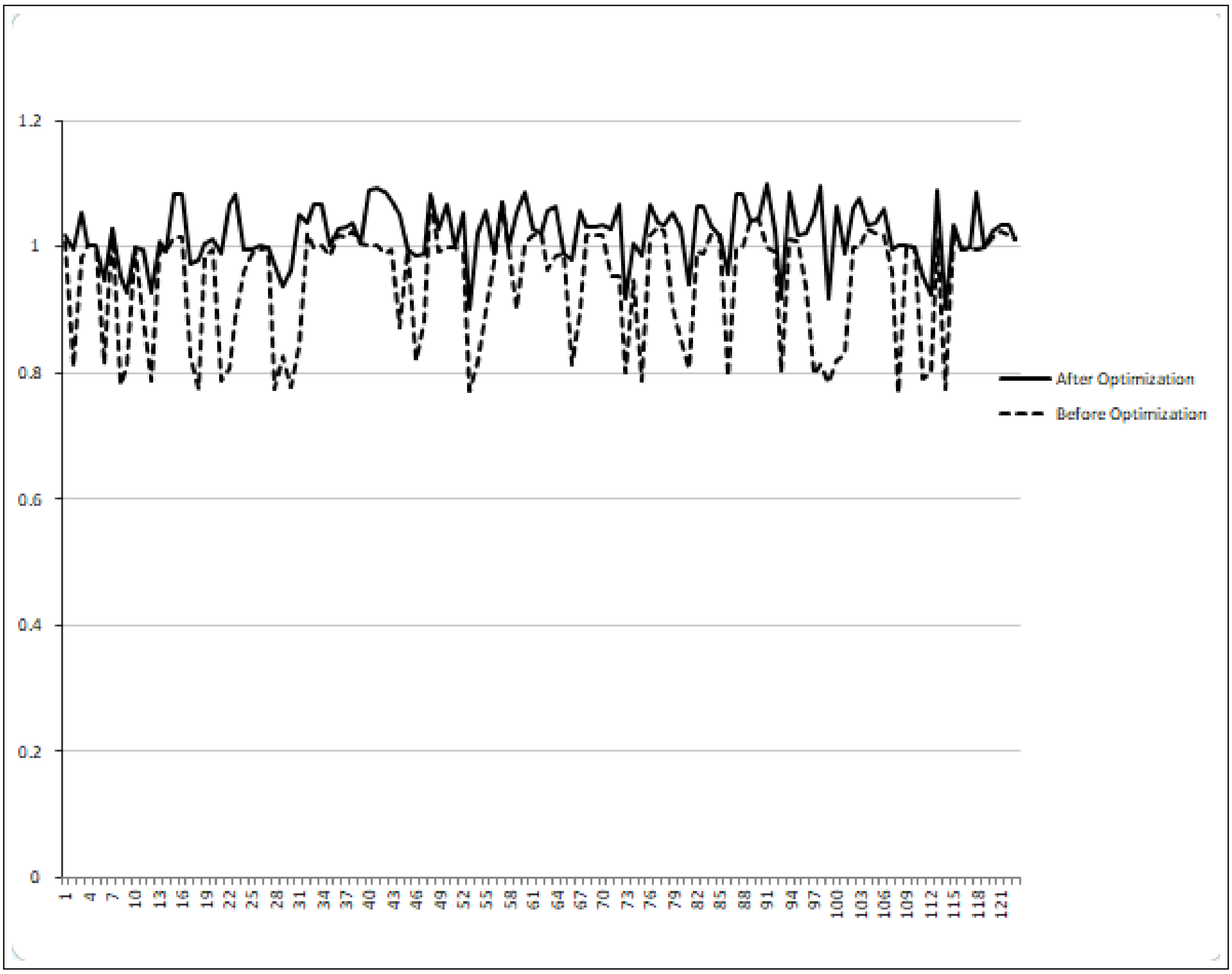

Figure 1: Curve showing voltage deviation before and after optimization for year 2023

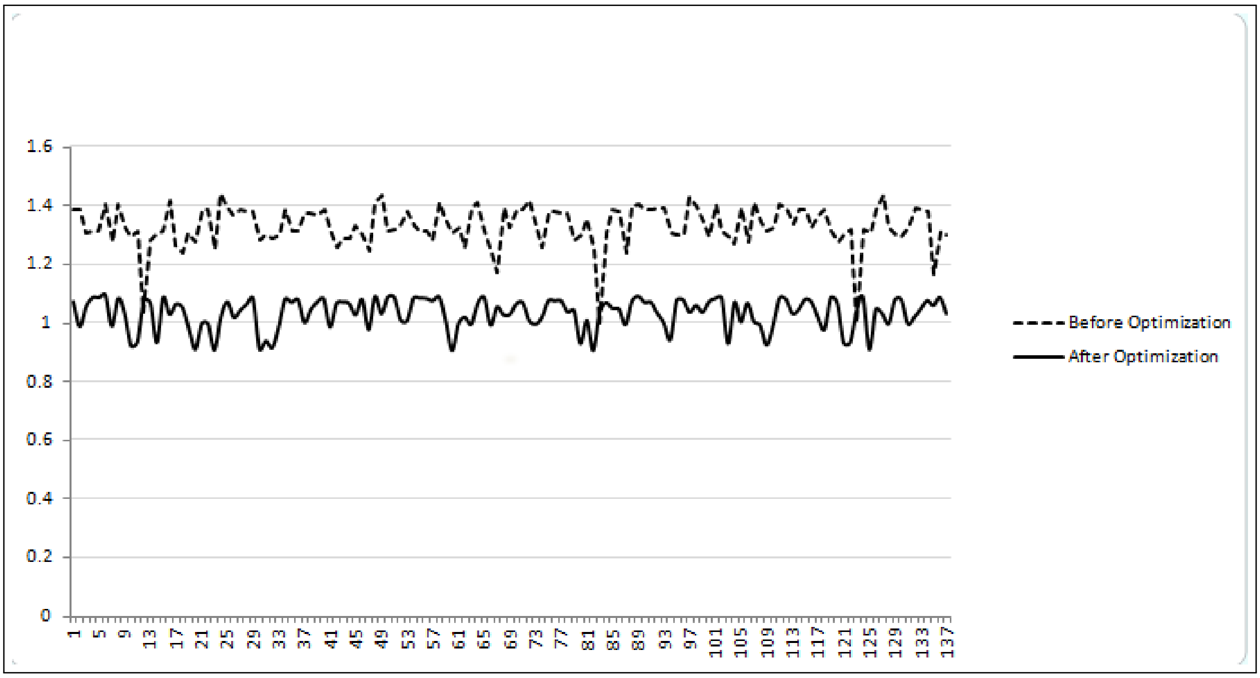

Figure 2: Curve showing voltage deviation before and after optimization for year 2028

and after applying compensation strategies for the respective year 2023 A.D. and 2028 A.D. are shown in Figure 1 and Figure 2 respectively.

Table 2: Reactive Compensation requirement and P_{loss} for year 2023 A.D.

Power Factor	Compensation Size (MVAr)	P_{loss} (MW)
1	851	274
0.95	643	262
0.90	525	258
0.85	452	260

Table 3: Reactive Compensation requirement and P_{loss} for year 2028 A.D.

Power Factor	Compensation Size (MVAr)	P_{loss} (MW)
1	397	242.14
0.95	125	190.73
0.90	128	190.36
0.85	124	190.45

6.2 Financial Calculations

When IPPs are allowed run at power factor other than unity (i.e. to generate or consume reactive powers), loss as well as reactive compensators size was decreased. In order to find out the optimal scenario, some assumptions were made for financial calculations which are given as;

- Energy Cost = NRs. 10/unit [4]
- Reactive Compensators Cost = NRs. 2.88 million/ MVAr [5]
- Reactive Energy Charge paid to IPPs = NRs. 0.232/ kVArh [6]
- No. of years analyzed = 20 years

6.2.1 Cost Calculation for year 2023

For year 2023, cost comparison for various power factors is shown in Figure 4 . From the comparison, we can see that, operating IPPs at 0.90 is more beneficial. There is noticeable difference in compensation size and loss for unity power factors and 0.95 power factor. This difference gradually decreases as the power factor is decreased even more. Since, considering the reactive charges which would be made to IPP for their reactive support, net cost is found to be less for operating IPP in 0.90 pf. So, it is recommended to operate IPPs in 0.90 pf in 2023 projected year. It has happened so because as power factor decreases,power loss(P_{loss}) decrease by very small amount.

Table 4: Cost calculation for various scenarios of year 2023 A.D.

PF	PL(MW)	Compensation (MVAr)	Annual loss cost	Compensation cost	Annual compensation cost	Total Cost	Payment to IPP	NET
1	273.93	851	2.37E+10	2.45E+09	3.92E+08	2.41E+10	0.00E+00	2.41E+10
0.95	262.09	643	2.26E+10	1.85E+09	2.96E+08	2.29E+10	4.17E+08	2.25E+10
0.9	**258**	**525.49**	**2.23E+10**	**1.51E+09**	**2.42E+08**	**2.25E+10**	**2.36E+08**	**2.23E+10**
0.85	260	452	2.25E+10	1.30E+09	2.08E+08	2.27E+10	1.47E+08	2.25E+10

6.2.2 Cost Calculation for year 2028

For year 2028, cost comparison for various power factors is shown in Figure 5. From the comparison, we can see that operating IPPs in 0.90 power factor in both lead and lag mode would be beneficial from system loss point of view and from net cost point of view including the price to be paid to IPPs for their reactive energy support.

Table 5: Cost calculation for various scenarios of year 2028 A.D.

PF	PL(MW)	Compensation (MVAr)	Annual loss cost	Compensation cost	Annual compensation cost	Total Cost	Payment to IPP	NET
1	242.14	397	2.09E+10	1.14E+09	1.83E+08	2.11E+10	0.00E+00	2.11E+10
0.95	**190.73**	**125**	**1.65E+10**	3.60E+08	**5.75E+07**	**1.65E+10**	**5.45E+08**	**1.60E+10**
0.9	190.36	128	1.64E+10	3.69E+08	5.89E+07	1.65E+10	6.01E+06	1.65E+10

7. Conclusions

In the upcoming years, there is necessity of reactive support in the INPS system which would be either by shunt compensators or by introducing reactive power market for which private developers would be paid for the reactive power thus generated. Use of unity power factor opeartion of IPPs for centralized approach is justifiable since during the peak months of year (i.e. during rainy season) when the active power output from IPP is at full potential, no IPPs would want to generate reactive power by decreasing their active power. This has occurred because there are no such guidelines in our system which forces IPPs to be within the limit of 0.85 lead or lag. From the results and discussion as seen above, this study supports decentralized reactive power generation strategy and recommends making IPPs run at the range of unity to 0.90 power factor for year 2023 and at the range of unity to 0.95 for year 2028.

References

[1] K. Bhattacharya I. E. Samahy, C. A. Canizares and J. Pan. An optimal reactive power dispatch model for deregulated electricity markets. 2007.

[2] A. M. Ranjbar B. Mozafari, T. Amrace and A. R. Shirani. Optimal reactive power dispatch in a joint active/reactive market model. 2006.

[3] R. Ucheniya and A. Saraswat. Optimal reactive power dispatch through minimization of real power loss and voltage deviation. 2018.

[4] *Annual Report*. Technical report, Nepal, 2019.

[5] *National Electricity Plan(Volume 2 Transmission)*. Technical report, India, 2019.

[6] Central Electricity Regulatory Commission. *Indian Electricity Grid Code*.