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Identification of Potential Solar PV Generation Strategy for Province 2 of Nepal

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Abstract
Access to electricity may be taken as granted by many people in the twenty first century but still there are many people who are either deprived of it or do not have access to quality electricity. Providing access of electricity to all is certainly a challenging task and capital intensive too. If a detailed study of existing system is done and points for upgradation, construction are found out, then considerable amount of energy can be saved along with speeding the development process. This study involves the study of the identification of potential solar PV generation strategy for province-2 of Nepal. For this, work is divided into two parts, in first part existing status of electricity grid in Province 2 has been done as a base line requirement for study of Grid Access to all in Province 2 to know about the voltage status and line loading of the grid and second part covers the study of centralized and distributed PV generation in province-2 for existing case, five years scenario and ten years scenario for different forecasted value from system planning department of Nepal Electricity Authority[1]. Optimal solar PV size is calculated for both generation configuration on the basis of power loss minimization. Study shows that, power loss in Decentralized PV generation is less than centralized PV generation in all prospects. All system are Modelled and studied in Dig-silent Environment.

Keywords
Photovoltaic system, voltage stability, centralization, Decentralization, line losses reduction

1. Introduction

The demand for power and energy has been consistently increasing by an average annual rate of 8% for the last few decades.[2] However the increase in generation has not been in the same rate. Consequently, the energy has to be imported from India or the load has to be shed for generation demand balance. To fulfil the gap of delaying mainstream hydropower plants and alleviate the country from power shedding or dependency on India for energy import, development of alternative power generation schemes, like wind and solar PV technologies, is essential. The alternative power generation can serve two purposes in the context of Nepal. Firstly, it provides immediate relief from Power shedding and dependency On India , as the construction time of the alternative power plant is considerably shorter; and secondly, it helps utilizing locally available resources for electricity generation and reduces reliance of electricity and energy from other places/regions.

Renewable source of energy is clean and environmental friendly. They can provide many immediate environmental benefits by avoiding the emission of greenhouse gases and can help conserve fossil resources as electricity supply for future generation. Using Photovoltaic (PV) cells to convert solar irradiance to electricity is quite popular these days. PV generation is the current subject of much commercial and academic interest. Recent work indicates that there will be large term of PV generation is commercially so attractive that large scale PV is implemented in many part of the developed world. The integration of Photovoltaic (PV) energy into the grid has increased significantly over the last decade [2].

Energy security has been defined by the United Nations as "the continuous availability of energy in varied forms, in sufficient quantities, and at affordable prices". At present time energy security is vital thing and for secure energy supply in any load centre there must be self-energy supply or multiple connection to the grid. In province-2, currently there is no self-generation and lack of hydropower potential in future. So, to make self-sufficient generation in province 2, solar PV is the good option. This also improves the reliability of system that affects in economic part of province-2.

This province has flat lands and is suitable for industries as well as other energy intensive works. Part of the population in this region lacks quality electricity. The distribution loss is high in this region. This is a result of ad-hoc basis of distribution of electricity to some extent. Proper study of electricity distribution in this region could lead to efficient planning. This should enhance the quality of electricity in this region making it more reliable and voltage within the standard limits. The erection of poles and line stringing being a capital-intensive job could be optimized to some level. This study focuses on Distribution System study and planning for Province-2.

Utilization of renewable energy comes from the perspective of environmental conservation and fossil fuel shortage. Recent studies suggest that, in medium and long terms photovoltaic (PV) generator will become commercially so attractive that large-scale implementation of his type can be seen in many parts of the world. [3]

In [4], the impact of a grid-connected PV system on the steady-state operation of a Malaysian grid is discussed. The main objective of the research was to investigate the voltage profile and power losses of a grid connected solar PV system for residential, commercial and industrial load pattern categories at Peninsular Malaysia. After data collection, the study modelled the photovoltaic generation as a negative load connected to the distribution generation bus. The single line diagram voltages were 132 kV/11 kV. For commercial load category (>1MW) it was discovered that the voltage increases from 6:00 am to 6:00 pm, but the voltage rise did not cause over-voltage when compared with the standard permissible voltage of 1.05 p. u. in Malaysia. The study also concluded that there was some substantial reduction in power losses when the solar PV was injected into the grid.

In [5], the influence of large-scale PV on voltage stability of sub-transmission systems has been reported. The study used the IEEE-14 bus test system to report the result of static voltage stability with large-scale PV penetrations on sub-transmission system for realistic load composition.

Ministry of Energy, Nepal has published white paper showing its plan to emphasize on electricity development in Nepal. The energy white paper includes the name of hydropower proposed in each state under the plan of “Ek Pradesh Ek Mega Project”. Province 2 which comprises of flat lands of Southern part of Nepal, has been proposed to build a 200 MW Solar Project.[6]

But, the purpose of electricity generation is to eventually utilize it. There shall be no use of a generated electricity if it cannot be utilized when needed, where needed. If the 200 MW solar plant is divided into a block of approximately 1 MW each, then the 136 local municipalities in Province 2 can install a MW of solar plant each. Such approach is known as distributed generation approach. The generation in earlier times used to be central with load varied in different places. This was possible as alternating current could be stepped up and the transmission could be done in higher voltages to reduce losses. The transmission system evolved to be more reliable with interconnected generations. With electricity being major part of day to day life, the reliability of generation has often being questioned. Now, the time has come the generation has to evolve to follow the load design. The load is distributed, and in case of Nepal with majority of loads being residential load, this point can be further justified. The generation if distributed can then first supply the local load itself allowing less transmission of energy in the transmission lines. This means the loading of the transmission line also decreases if the power grid consists of the distributed generation.

The installation cost per MW of power plants of 1 MW and 50 MW in solar PV system are almost the same whereas for a hydropower plant there is mammoth difference in price for installation cost per MW of those 2 capacities plants.

To study the effect of increasing PV penetration, the size of the PV plants is increased by 1 MW step. In simulation, the DPL Script is used in DigSILENT PowerFactory.[7]

Impacts on Voltage level

Voltage rise is caused by high penetration of solar PV into the utility grid. But Studies presented [8] in and attempted to establish the impact on the voltage and determination of the maximum PV generation to the distribution grids in Sweden. Additionally, the studies showed that voltage level and profile is not the ultimate factor in determining the maximum penetration level.

Other parameters, for example line loading and losses, should be analyzed together with voltage level and profile in determining the hosting capacity of the grids.

Voltage stability

Voltage stability is defined as a phenomenon where a power system maintains steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating condition. Voltage stability depends on the ability to maintain or restore equilibrium between load demand and load supply of a power system. When the need for reactive power in a power network system is met; voltage stability can be achieved. Inverters are responsible for keeping the power factor of the PV system at unity. When the power factor is at unity there is no exchange of reactive power between the inverter and the grid. This becomes problematic when solar PV is connected to a weak grid and the capacity is large, static voltage instability problems will occur since the PV system will draw reactive power.

Impact on losses and line loading

Losses and line loading are very important parameters of a power system. Transmission lines and feeders have a limit to which they can be loaded. Additionally, losses can either reduce or increase the operation costs of a distribution grid. The studies conducted in [4] and presented the effects of photovoltaic integration on the grid losses. Different penetration levels were used to determine the impact of increased PV penetration on grid losses.

2. SYSTEM DESCRIPTION

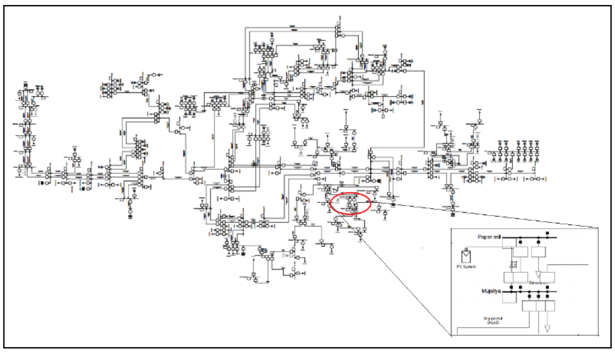

Figure 1: INPS system with 33 kV line and distributed PV system of province 2

Modeling of the power system is foremost step in system analysis. For the study, the Integrated Nepal Power System (INPS) has been modeled based on the data available from Nepal Electricity Authority for current scenario, 5 years scenario and 10 years scenario. In INPS model 33 kV feeder line of privince-2 is also added to get real line losses according to this study.

Modelling of INPS

INPS with 73 Bus has been chosen as the base case for the study which contains 117 Branches.The total system load of INPS for the current fiscal year is 1,318.8 MW and total generation of the system is 1,333.8 MW and 53 MW is imported from India.[1, 9]

Solar Power Generation

To determine the hourly solar power generation throughout the year, solar insolation data estimated by the NASA are adopted for the desired sites as horizontal solar insolation at clear sky. Due to lack of historic solar data at the sites, a general statistical weather condition is assumed based on the data from department of metrology and airports. The summary is presented in table. Based on the data, statistical tool is used to get the expected solar insolation at a particular hour of day.

Table 1: The clear sky situation in nepal

SN	% solar radiation at the surface	Days/year
1	0	40
2	25	25
3	50	25
4	75	25
5	100	250

Solar Site Selection

The location of solar farm (Centralized) significantly affects the economic and technical aspect of the overall power production and transmission. Therefore, while selecting the site for solar farm, special focus should be given on the availability as well as on the economic aspects of the space or land required. Considering all this factor, we considered various locations in the INPS, within Province 2, which are nearer to the main substation and had ample amount of space required for the solar farm. Since the substation is near to the solar farm, the distance of transmission line required for the transfer of power from the Solar Farm is less. Based on the above factors, the locations chosen for the solar farms is near Dhalkebar Substation.

Mathematical Formulation

$\min f(x) = P_{loss}\ (x)$
where x=control variable which is the PV real power generation

Equality Constraints
$P_i(V,\delta)$ - P_{Gi} +P_{Di} = 0 ....(1)
$P_i(V,\delta) = |V_i| \sum_{i=1}^{N} |V_i||Y_{ij}|\text{Cos}(\delta_i - \delta_j - \phi_{ij})$...............(2)
$Y_{ij} = |Y_{ij}| < \phi_{ij}$
and Load balance equation,
$\sum_{i=1}^{N_G}(P_{Gi}) - \sum_{i=1}^{N_D}(P_{Di}) - P_L = 0$ ....(3)
$V_{i,min} \leq V_i \leq V_{i,max}$; for i=1.....N ....(4)
$P_{Gi,min} \leq P_{Gi} \leq P_{Gi,max}$; for i=1.....N ....(5)

Simulation

The simulation has been carried out separately for Centralized and Decentralized system.

In centralized approach, Solar PV has been placed based on availability of land and distance from the substation. In decentralized approach, the location has been selected based on availability of land and distance from 33 kV substation. The sizing of each unit has been carried out based on the methodology described above.

3. Methodology

The methodology of the system comprises of following steps.

1. Collection of data of INPS and 33 kV feeder data of Province-2 for existing scenario, 5 years scenario and 10 years scenario.
2. Modeling of INPS and distribution feeder system of Province-2 for existing scenario, 5 years scenario and 10 years scenario.
3. Identification of existing issues in transmission and distribution system in Province-2 from power flow resulting from existing status load flow.
4. Calculation of Optimal size and location of Centralized and decentralized Solar PV in Province-2 based on the results from load flow in DigSILENT of current scenario INPS, five year scenario and ten year scenario. This shall be done by observing the voltage profile and power loss.
5. Obtain the optimal solar PV size for centralized and decentralized generation configuration.

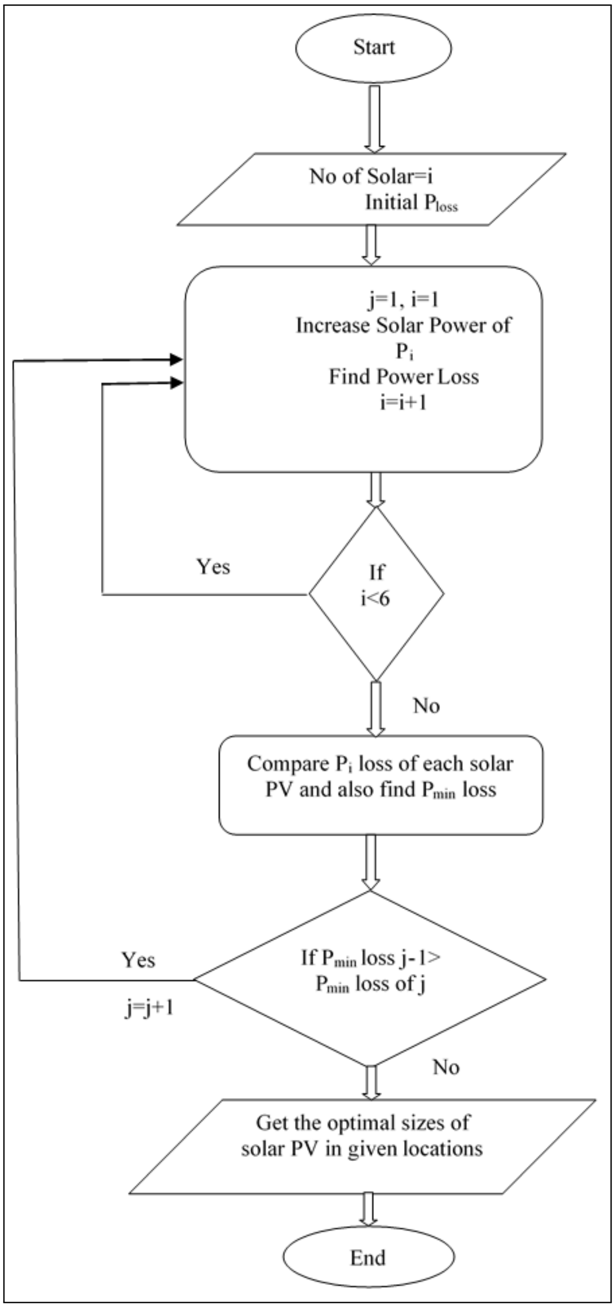

Figure 2: Flowchart showing the simulation me.thodology based on power loss Minimization

4. Results

The model system in Fig. 2 was implemented in DigSILENT PowerFactory and the algorithm mentioned the methodology section was implemented using DPL script.

In existing scenario, INPS, the generation is 847.81 MW, load is 1157.25 MW, and the grid loss is 57.1 MW. In the system with centralized PV system, The PV system size is determined to be 44 MW, so the generation is 891.81MW. The load is still 1157.25

MW. With this centralized PV system, the grid loss reduced by 0.11 MW to 56.99 MW. In the system with decentralized PV system, the PV size is determined as 90 MW. The PV size at the relevant bus is tabulated in table 2. So the generation now becomes 938.81 MW. In this case, the grid loss reduced by 9.75 MW to 47.35 MW as compared to existing case. In Fig. 3.The voltage profile considering the existing scenario of INPS is shown. It is observed that the output voltage variation is lesser for INPS system with decentralized PV system than that with centralized PV system.

Table 2: Solar PV size considering Decentralized PV system for INPS

SN	Bus Name	Solar PV optimal size, MW
1	Mujeliya	29
2	Haripur	25
3	Gaur	10
4	Rajbiraj	18
5	Rupani	1
6	Birgunj	7
	Total	90

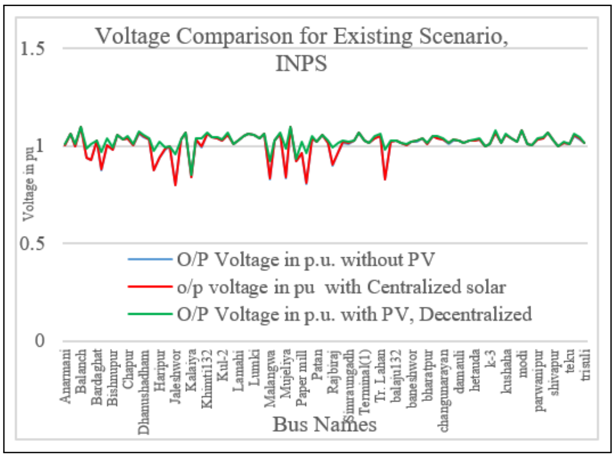

Figure 3: Bus voltage comparison with PV installation for existing scenario, INPS

In case of Province 2, the generation is 0 MW when grid is considered without PV system. The load for the province is 355.96 MW whereas the grid loss is 39.8 MW. Now, with centralized PV system connected, the PV size was calculated to be 0 MW and so the generation is still 0MW. The load and the grid loss remains the same. Hence for this case the grid loss reduction is zero. Similarly, grid is provided with decentralized PV system. In this the PV size is calculated to be 103 MW, making total generation to be 103 MW in the province. The PV size at the relevant bus is tabulated in table 3. The grid loss reduced by 16.83 MW to 22.97 MW. In fig. 4. it is observed that the output voltage variation is lesser for INPS system with decentralized PV system than that with centralized PV system complying with the earlier case.

Table 3: Solar PV size considering Decentralized PV system for Province 2

SN	Bus Name	Solar PV optimal size, MW
1	Mujeliya	32
2	Haripur	27
3	Gaur	12
4	Rajbiraj	21
5	Rupani	1
6	Birgunj	10
	Total	103

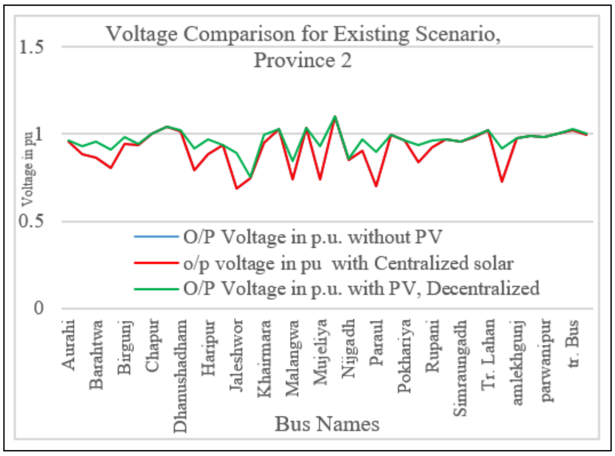

Figure 4: Bus voltage comparison with PV installation for existing scenario, Province-2

Considering five years scenario for province 2, we have three cases, namely base case, previous forecast case, optimistic case. In all the cases, the generation is 0 MW when grid is considered without PV system.

For base case: the load is 517.69 MW and the grid loss is 91.91 MW. When centralized PV system of capacity 171 MW is added, the generation rises to 171 MW. The grid loss reduced by 33.87 MW to 58.04 MW. Similarly, with decentralized PV system with capacity of 200 MW is added, the generation and corresponding grid loss are 200 MW and 36.94 MW respectively. In this case the grid loss reduced by 54.97 MW. Hence, it is again observed that grid loss with decentralized PV system is lesser than in case of centralized PV system. In fig. 5, the voltage profile of province 2 considering base case is shown. It indicates that the output voltage variation is lesser for INPS system with decentralized PV system than that with centralized PV system complying with the earlier case.

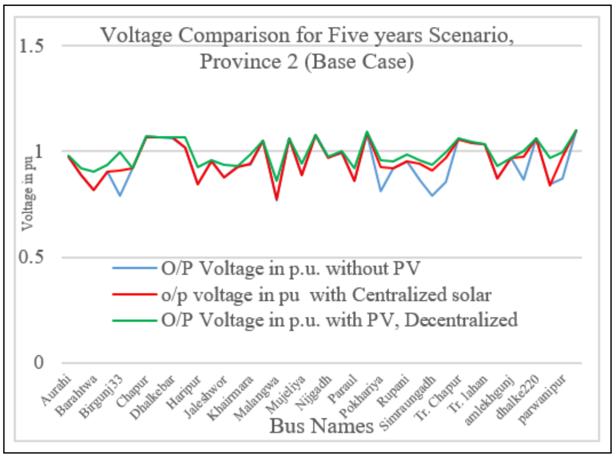

Figure 5: Voltage Comparison for Five years Scenario, Province 2(Base Case)

For previous forecast case: the load is 549.62 MW and the grid loss is 125.56 MW. When centralized PV system of capacity 200 MW is added, the generation rises to 200 MW. The grid loss reduced by 58.14 MW to 67.42 MW. Similarly, with decentralized PV system with capacity of 200 MW is added, the generation and corresponding grid loss are 200 MW and 40.98 MW respectively. In this case the grid loss reduced by 84.58 MW. Hence, it is again observed that grid loss with decentralized PV system is lesser than in case of centralized PV system. In fig. 6, the voltage profile of province 2 considering previous forecast case is shown. It indicates that the output voltage variation is lesser for INPS system with decentralized PV system than that with centralized PV system complying with the earlier case.

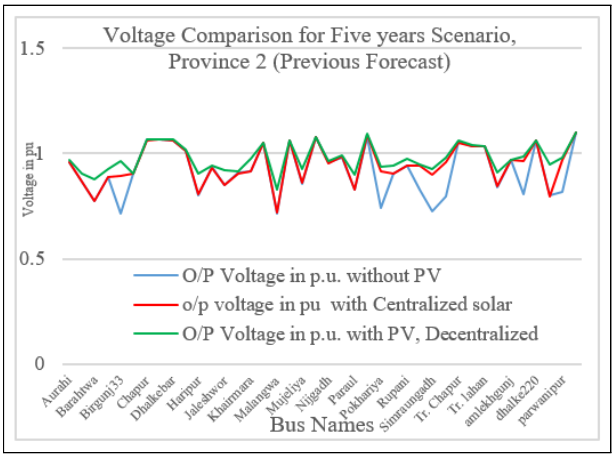

Figure 6: Voltage Comparison for Five years Scenario, Province 2(Previous Case)

For optimistic case: the load is 579.09 MW and the grid loss is 201.02 MW. When centralized PV system of capacity 200 MW is added, the generation rises to 200 MW. The grid loss reduced by 118.37 MW to 82.65 MW. Similarly, with decentralized PV system with capacity of 200 MW is added, the generation and corresponding grid loss are 200 MW and 47.69 MW respectively. In this case the grid loss reduced by 153.33 MW. Hence, it is again observed that grid loss with decentralized PV system is lesser than in case of centralized PV system. In fig. 7, the voltage profile of province 2 considering optimistic case is shown. It indicates that the output voltage variation is lesser for INPS system with decentralized PV system than that with centralized PV system complying with the earlier case.

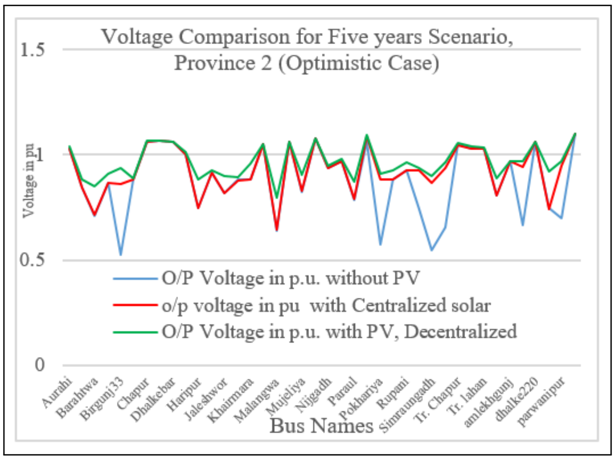

Figure 7: Voltage Comparison for Five years Scenario, Province 2(Optimistic Case)

The optimal size of PV system for differ cases of five year plan for province 2 is tabulated in table 4.

Table 4: Decentralized solar PV size for five year plan

S.N.	Bus Name	Solar PV optimal size, MW		
		Base Case	Previous Forecast	Optimistic
1	Mujeliya	37	36	34
2	Haripur	52	48	44
3	gaur	35	35	35
4	Birgunj	32	39	47
5	Rajbiraj	25	24	23
6	Rupani	19	18	17
	Total	200	200	200

Similarly, considering ten years scenario for province 2, we have three cases, base case, previous forecast case, optimistic case. In all the cases, the generation is 0 MW when grid is considered without PV system.

For base case: the load is 766.19 MW and the grid loss is 116.56 MW. When centralized PV system of capacity 200 MW is added, the generation rises to 171 MW. The grid loss reduced by 334.64 MW to 111.92 MW. Similarly, with decentralized PV system with capacity of 200 MW is added, the generation and corresponding grid loss are 200 MW and 69.57 MW respectively. In this case the grid loss reduced by 46.99 MW. Hence, it is again observed that grid loss with decentralized PV system is lesser than in case of centralized PV system. In fig. 8, the voltage profile of province 2 considering base case is shown. It indicates that the output voltage variation is lesser for INPS system with decentralized PV system than that with centralized PV system complying with the earlier case.

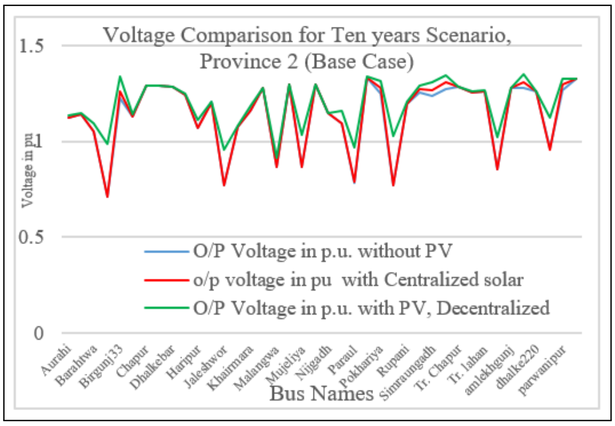

Figure 8: Voltage Comparison for Ten years Scenario, Province 2(Base Case)

For previous forecast case: the load is 816.94 MW and the grid loss is 149.15 MW. When centralized PV system of capacity 158 MW is added, the generation rises to 158 MW. The grid loss reduced by 15.13 MW to 134.02 MW. Similarly, with decentralized PV system with capacity of 200 MW is added, the generation and corresponding grid loss are 200 MW and 82 MW respectively. In this case the grid loss reduced by 67.15 MW. Hence, it is again observed that grid loss with decentralized PV system is lesser than in case of centralized PV system. In fig. 9, the voltage profile of province 2 considering previous forecast case is shown. It indicates that the output voltage variation is lesser for INPS system with decentralized PV system than that with centralized PV system complying with the earlier case.

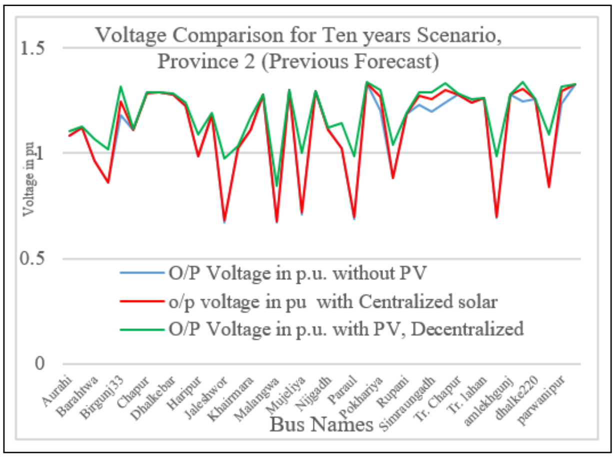

Figure 9: Voltage Comparison for Ten years Scenario, Province 2(Previous Case)

For optimistic case: the load is 857.96 MW and the grid loss is 147.09 MW. When centralized PV system of capacity 186 MW is added, the generation rises to 186 MW. The grid loss reduced by 20.99 MW to 126.1 MW. Similarly, with decentralized PV system with capacity of 200 MW is added, the generation and corresponding grid loss are 200 MW and 82.53 MW respectively. In this case the grid loss reduced by 64.56 MW. Hence, it is again observed that grid loss with decentralized PV system is lesser than in case of centralized PV system. In fig. 10, the voltage profile of province 2 considering optimistic case is shown. It indicates that the output voltage variation is lesser for INPS system with decentralized PV system than that with centralized PV system complying with the earlier case.

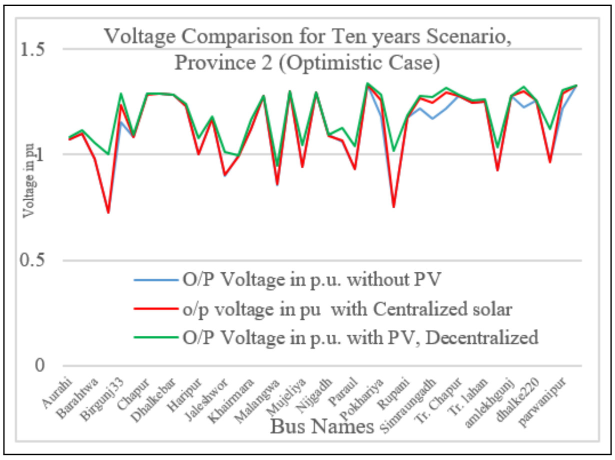

Figure 10: Voltage Comparison for TEN years Scenario, Province 2(Optimistic Case)

The optimal size of PV system for differ cases of ten year plan for province 2 is tabulated in table 5.

Table 5: Decentralized solar PV size for Ten year plan

S.N.	Bus Name	Solar PV optimal size, MW		
		Base Case	Previous Forecast	Optimistic
1	Mujeliya	49	57	54
2	Haripur	20	39	37
3	gaur	26	30	31
4	Birgunj	45	38	33
5	Rajbiraj	37	36	45
6	Rupani	0	0	0
	Total	177	200	200

5. Conclusion

In this paper, we have selected the site on the basis of availability of land and their economic price. After finalizing the site optimal load flow was performed to calculate optimal PV size on the basis of power loss minimization.

INPS model was developed considering 33 kV system of province-2 only. Dhalkebar substation was chosen for centralized Solar PV location and 6 different locations were selected for decentralized solar PV installation in province-2.

Optimal size was determined for both cases considering power loss minimization. The analysis was carried out for existing scenario, five year and ten year scenario for Province 2. It was observed that the grid loss was reduced considerably in case with decentralized PV system. Similarly, the voltage profile in case with decentralized PV system was found to be less deviating than that compared with Centralized PV system. So finally we conclude that Decentralized PV generation for province 2 is best strategy for solar PV generation.

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