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Impact of Inertia-Less Generation in the System Stability: A Case Study with Nuwakot PV

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Abstract

In this paper, the simulation has been performed for the interconnected system encapsulating the Kathmandu valley, considering the scenario of injection of inertia-less generation at Nuwakot. The load flow analysis before and after the placement of PV infers that the generation being placed away from the load center increases the overall network loss with minor change in the voltage at the nearby substations. The transient analysis indicate that for the higher value of generation, the impact on the frequency and voltage is severe however is within the limits for the case of Nuwakot PV. Finally, the small signal stability analysis confirms that the existing system is stable even due to the small disturbances. However, the system with synchronous generator is more stable than that with inertia-less generation.

Keywords

PV, inertia-less generation, transient response, small signal stability

1. Introduction

Renewable energy, also known as clean energy, is produced using replenishing natural resources or technologies [1]. As innovation drives cost lower and begin to fulfill the promise of a clean energy future, the generation of renewable energy is rising. Renewable energy sources are taking on greater significance as a source of power as we discover more such inventive and affordable ways to capture and store wind and alternative energies. The use of renewable energy is growing in both large and small sizes, from enormous offshore wind farms to rooftop solar panels on houses that might sell power back to the grid. For lighting and heating, some rural communities even entirely rely on renewable energy.

The two strengths of renewable energy to fulfill the anticipated plant capacity in the future are wind energy and solar energy harvesting.[2] Due to sunlight's accessibility, solar photovoltaic (PV) systems are practically universally applicable, which gives them a significant advantage over wind energy systems. Wind energy systems rely on a very variable source for power generation[2].

The average amount of solar radiation received by Nepal is from $4.7kWh/m^2/day$ in average. In comparison to several European nations where PV systems have been extensively used, this level of radiation is higher. Nepal has yet other benefits for such a system. Firstly, as altitude increases, so does the solar irradiation. Nepal has a larger potential for solar output because it is a mountainous, hilly country[3]. Second, the cost of PV technology has decreased by about 80% since 2008, which has led to a rise in interest in solar power recently [4].

It was traditionally assumed that, the grid inertia is sufficiently high with some small variations with respect to time. But this is not valid for the power system with high Renewable Energy Sources (RES) shares. With the integration of the 25MW PV generation at Nuwakot and various other PV generation at different location, the inertia-less energy is injected in the grid. This can cause different synchronization and stability issues along with the implication over frequency dynamics. A quantitative formulation of penetration, as well as evaluation metrics that account for the impact of dispersed photovoltaic (PV) generation on grid voltage, system power loss, and network element loading, are presented in the article [5]. Additionally, it examines the test grid's maximum PV capacity that is accessible and suggests the essential location of high penetration.

The effects of high infiltration of distributed PV generation on grid voltage, system power loss, and network loading are then examined using continuous load flow calculations. The [6] model mimics changing levels of traditional power plant inertia, power imbalance, and renewable integration. The techniques examined here offer crucial knowledge for facilitating the extensive integration of renewable energy sources without compromising the stability and transient response of the grid.

These studies [7, 8, 9, 10] examine the small-signal stability in a power system incorporating renewable energy . Several renewable energy sources, including wind generation systems, PV systems, and micro hydro systems, stability have been studied. The eigenvalue analysis is performed for the test system without any PV penetration and with various levels of PV penetration, the results are compared in [11]. The impact of high penetration solar installation on the small signal stability of the power system is examined in the [12]. The paper [13] looks into the transient and small signal stability of a big multi-machine system with PV coupled to it. Both scenarios including and without the PVs undergo eigenvalue analysis, and the results are compared.Time domain simulation is used to analyze transient stability by simulating a three-phase short circuit fault at a crucial site.

This paper simulates the performance and the energy yield for the PV generation system installed at Nuwakot and also studies the effect of this PV with varying generation on the interconnected grid substations on the transient stability of the system, small signal stability. The study encapsulates the response on rotor angle and frequency and power variation for the varying generations.

2. Methodology

Weak modes may be activated in a vast, interconnected system by brief, sharp perturbations. Also, the transients effects can be caused due to the outage of some equipments, faults and other various contingencies. The Load Flow Analysis (LFA) is performed using Newton-Raphson method. The simulation has been performed for the Kathmandu valley and the effect of the other is considered to be negligible. The one time load is considered for the analysis purpose considering the Tamakoshi generation as the slack bus being the largest generation in Nepal.

2.1 Transient Stability

The ability of the power system to sustain synchronism in the presence of a significant transient disruption, such as a breakdown on transmission infrastructure, a loss of generation, or a loss of a sizable load, is known as transient stability. Large deviations in generator rotor angles, power flows, bus voltages, and other system variables are among the effects of these disruptions. If the resulting angle between the machines in the system stays within the limit, the system is still in synchronism. If temporary instability causes a loss of synchronism, it will typically become apparent within 2 to 3 seconds of the disturbance. PV and generator outage conditions are considered for the transient analysis.

2.2 Eigen Value Analysis

A series of n first-order nonlinear differential equations and a set of algebraic equations can be used to depict the behavior of a dynamic power system.

$$\begin{aligned} \dot{x}_i &= f_i(x,y,l,p) \\ O &= g_i(x,y,l,p), \end{aligned} \tag{1}$$

where l and p are uncontrolled: AVR points and controllable: active and reactive load variation parameters, respectively, and $\dot{x}$ is a vector of state variable: generator internal angle and rotor speed, y is a vector of algebraic variables: load voltage magnitudes. The preceding set of equations can be linearized to investigate the system oscillatory behavior because the disturbance considered here is minimal. Thus, the linearized system can be expressed as follows:

$$\begin{aligned} \Delta\dot{x} &= A\Delta x + B\Delta u \\ \Delta y &= C\Delta x + D\Delta u, \end{aligned} \tag{2}$$

The eigenvalues (λ) of the state matrix A indicate the linearized system's stability, and the right eigenvector (φ) and left eigenvector (ψ) determine the participation of each system state in a given eigenvalue. The following definitions apply to the ith eigenvalue and related eigenvector of the system matrix A:

$$\begin{aligned} A\Phi_i &= \lambda_i\Phi_i \\ \Psi_i A &= \lambda_i\Psi_i, \end{aligned} \tag{3}$$

The frequency (f) and damping ratio (ς) for a complex eigenvalue that corresponds to an oscillatory mode of the system are represented as,

$$\begin{aligned} \lambda_i &= \sigma_i + j\omega_i \\ f_i &= \frac{\omega_i}{2\pi} \\ \zeta_i &= -\frac{\sigma_i}{\sqrt{\sigma_i^2+\omega_i^2}}, \end{aligned} \tag{4}$$

Damping ratio, which is connected to the real component of the eigenvalues controls how quickly the oscillations' amplitude decrease. Key characteristics of the eigenvalues of linearized system in regard to stability are:

- The system is said to be asymptotically stable if all of the eigenvalues have negative real parts, which means that after a brief disturbance, the system resumes its stable state.
- If one of the eigenvalues has a positive real part, the system is unstable as it can not return to its initial position after a disturbance.
- If the system contains all the eigenvalues with negative real part but one with purely imaginary portion, then the system demonstrates oscillatory behavior; dubbed critically stable or marginally stable.

One or two zero eigenvalues can be found in the majority of research or commercial analysis development tools for eigenvalue analysis. The reason for those zero eigenvalues is that if all machine angles are held (not changed), there is no infinite bus in the system for the reference angle. Machines in the system might continue to synchronize at a speed other than the initial synchronous speed. According to traditional power system stability, this is considered stable. The absence of turbine governor control model can also lead to eigenvalues of zero. In this study, eigenvalues have been determined together with damping ratio and frequency of oscillation for different instances.

2.3 Tools and Technique

The simulation of the interconnected network of Kathmandu valley and some interconnected nearby grid substations are modeled and the simulation is performed in DIgSILENT PowerFactory 15.1. The performance analysis of the PV system at Nuwakot is performed in PVsyst 7.2.

3. Results and Discussions

3.1 System Analysis of Nuwakot PV

The comparison of the voltage variation in the INPS system before and after the interconnection of the Nuwakot PV is shown in Figure 1.With the placement of the 25MW PV system at Nuwakot, the voltage of the nearby substation increases while the others at distant was negligibly affected.However, with the PV connected to the existing system, the 132/66kV loss increases from 8.4MW at peak to 9.98MW i.e., to 3.96%. Though with this generation, the voltage at the nearby substations is improved and the loss decreases in those line sections, but as the power needs to be transmitted either to the Balaju substation with the double circuit (DC) Dog/ and single circuit (SC) Wolf conductor of about 35km length or to the Chapali substation at 29km length of DC Dog and underground cable, the loss would be higher.

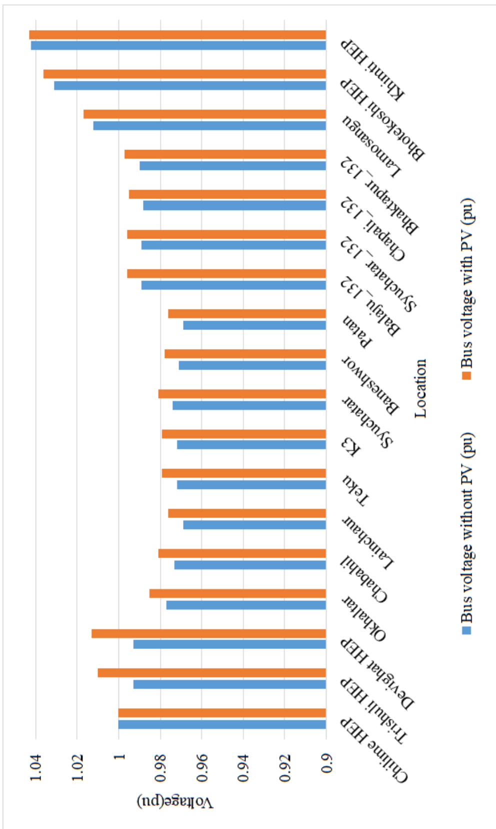

Figure 1: Substations voltages before and after PV integration

To check the limit of the generation from the PV generation, the generation was increased. The results in Table 1 shows that the generation beyond 46MW would cause an overloading of the line in between Nuwakot PV station and Devighat substation, with a

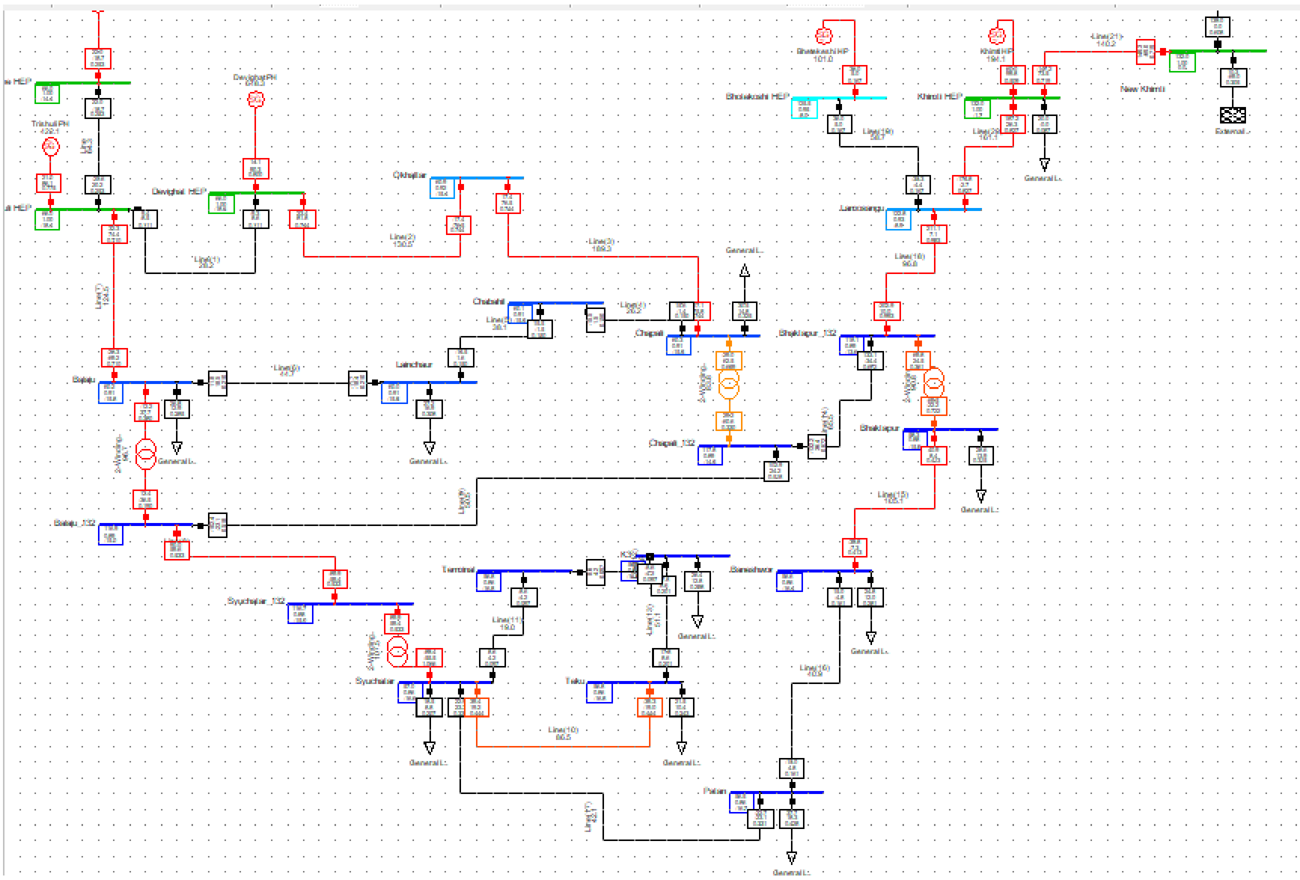

Figure 2: Simulation network of Interconnected system)

significant increase in the bus voltages. As the generation exceeds 73MW, the line from Devighat to Trishuli substation would also get overloaded. So, for the Nuwakot PV, the magnitude of the generation cannot be increased above 46MW for all the line loading to be below 100% loading.

Table 1: Bus voltage and line loadings at various generation values

Generation (MW)	0	25	46	73
Bus Voltage Devighat Station(pu)	0.990	1.005	1.012	1.020
Line Loading (Devighat to PV station) (%)	0	55.1	100.4	157.6
Line Loading (Devighat to Trishuli) (%)	29.8	22.4	31.8	100.5
Line Loading (Devighat to Okhaltar) (%)	39.3	60.6	78.2	51.8

3.2 Transient Analysis

The response of the interconnected system with the sudden outage of the Nuwakot PV station is observed in terms of the voltage, frequency and power at the connected Devighat grid substation.

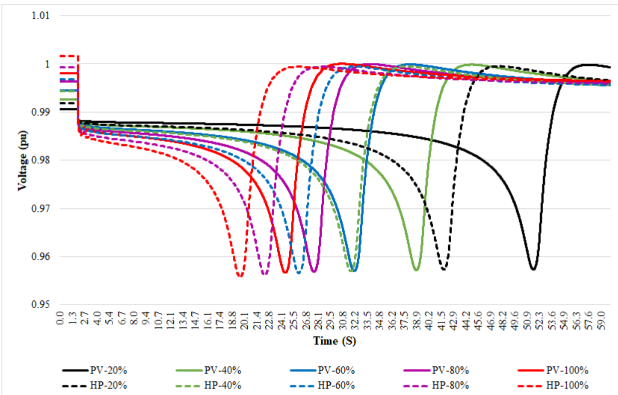

Figure 3: Voltage response on Devighat substation with HP and PV shutdown

Figure 3 shows that transient drop in the voltage is higher in case of the large generation values for PV. Also, the response of the system is much quicker, the minimum transient voltage is reached faster and also, the transient value settles quicker for higher PV generation. The minimum voltage reached was about 0.956pu which is within the acceptable limits of the system. In comparison with the equivalent size of the synchronous generator, the voltage drops more aggressively and also stabilizes quickly in case of the synchronous generator. So, the transient response is quicker in case of the synchronous machine with the equivalent size of hydro power as PV system.

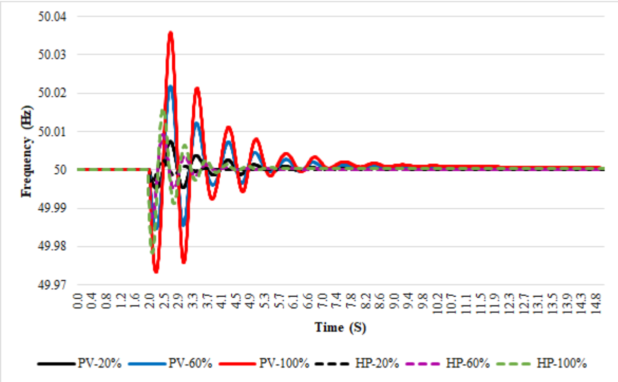

Figure 4: Frequency response on Devighat PH with HP and PV shutdown

The response on the system frequency with the shutdown of the various magnitudes of the PV station is shown in Figure 4. The magnitude of the variation is high for higher value of generation and vise-versa. In comparison with the synchronous machine, the response of the PV is more oscillating, though is within the limits.

The Figure 5 infers that the oscillation in the power generation is for shorter duration than the frequency response. Also, the power generation of the nearby Devighat powerhouse fluctuates more with the shut down of the synchronous generator than the equivalent PV generation.

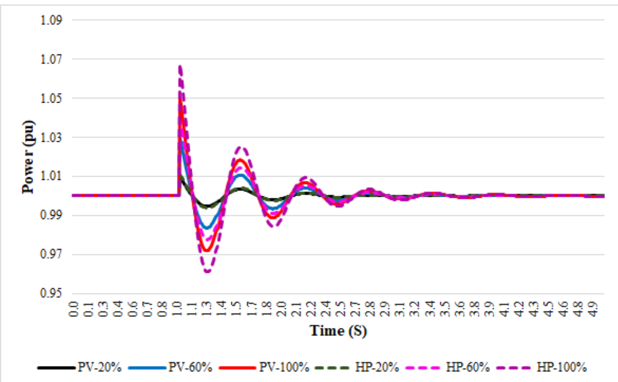

Figure 5: Frequency response on Devighat PH with HP and PV shutdown

3.3 Small Signal Stability Analysis

The Table 2 shows the eigen plot of the system with the injection of a small amount of additional torque in the synchronous generator at Devighat power house. This small additional torque can be due to the sudden decrease in the load. In this case, as shown in the Table2, all the eigen values are in the negative real parts representing that the system is stable under the small fluctuations in the initial parameters.

Table 2: Small signal stability: eigen values for 25MW system

S.N.	Mode	Eigen Values	
		Real Part (1/s)	Imaginary Part (rad/s)
1	00025	-19.46728	0
2	00026	-18.606	0
3	00020	-1.3603	8.476
4	00011	-1.16	-9.85
5	00041	-0.119	0
6	00046	-0.0000008	0.016
7	00034	-0.8324	1.20
8	00036	-0.934	1.07
9	00038	-0.979	1.02
10	00040	-0.180	0

With the technical considerations, the PV is considered at 46MW and the eigen values for the system is performed and the results are presented in Table 3. The table shows all the eigenvalues with negative real part but one with purely imaginary part. The then the system shows oscillatory behavior in stability conditions.

Table 3: Small signal stability: eigen values for 46MW PV system

S.N.	Mode	Eigen Values	
		Real Part (1/s)	Imaginary Part (rad/s)
1	00025	-19.46728	0
2	00026	-18.606	0
3	00020	-1.3603	8.476
4	00011	-1.16	-9.85
5	00041	-0.119	0
6	00046	-0.0000008	0.016
7	00034	-0.8324	1.20
8	00036	-0.934	1.07
9	00038	-0.979	1.02
10	00040	0.178	0

For the same side of synchronous machine considered, the eigen values are so obtained that all those lies in the negative axis indicating the stable operation in Table 4.

Table 4: Small signal stability: eigen values for 46MW DG system

S.N.	Mode	Eigen Values	
		Real Part (1/s)	Imaginary Part (rad/s)
1	00025	-19.46728	0
2	00026	-18.606	0
3	00020	-1.3603	8.476
4	00011	-1.16	-9.85
5	00041	-0.119	0
6	00046	-0.0000008	0.016
7	00034	-0.8324	1.20
8	00036	-0.934	1.07
9	00038	-0.979	1.02
10	00040	-0.180	0

4. Conclusion

So, from the analysis it was seen that with the addition of the Nuwakot PV, the system voltage of the nearby substation increases. However, the system loss increases from 3.34% to 3.96% with the placement of the 25MW PH due to the generation being far from the load centre. The transient stability results indicate that the fluctuation in system frequency is higher for PV system than the synchronous generator. Moreover, the response in the active power generation and voltage in the nearby source is slightly higher for synchronous machine and increases with the increase in the generation. The small signal stability indicate that the system is stable for existing 25MW system. The PV generation is increased to the technically viable limit, 46MW and it was observed that the system becomes unstable for the voltage level. While for the same size of synchronous generator, the system is stable.

The future extension can be performed for the other pv stations and also be generalized for PV and wind systems.

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