VOLTAGE STABILITY ANALYSIS OF SPV AND WECS INTEGRATED INTO THE WESTERN GRID OF BHUTAN

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Abstract

Global warming has become an increasingly significant concern today because of the excessive emission of greenhouse gases. This concern has arisen interests of researchers and power generating companies to venture into renewables. Among all the renewables, solar and wind are two of the most promising resources today. However, unpredictable nature of solar and wind power still remains a challenge while integrating to the grid. In addition, integration of solar photovoltaic (SPV) system and wind energy conversion system (WECS) introduces instability in the voltage profile. This paper discusses on voltage stability issues of the western grid of Bhutan with integration of renewable energy sources (RESs) as a case study by performing Load flow analysis to examine voltage profile at varying penetration levels. Also, the paper presents an analysis on transformer loading, line loading and grid losses to understand grid's withstanding capabilities at higher penetration level. The behavior of the grid at every penetration level is observed and the results of voltage stability analysis showed an improved voltage profile of the grid when integrated with solar PV and WECS. However, higher penetration of both solar PV and WECS resulted in violation in bus voltages of the network and over-loading of number of transformers and lines above 20% penetration level.

Key Words : *SPV system,WECS, Grid-connected, Load flow Analysis, Voltage Stability, High penetration*

1. INTRODUCTION

Renewable energy has been globally accepted as the cleanest source of generation which has not only ensured environmental protection but also contributed in an efficient utilization of the abundantly available energy resources (Passey, 2011). The 2019 report on the global status of renewables has recorded a rise of the global renewable capacity to around 2,378GW with installation of 181 GW of new renewable sources in 2018. Also, this rise in the global capacity of renewable sources included addition of 55% by solar followed by 28% by wind. Overall, renewable sources contribute around 33% of the total installed capacity of the world (REN, 2019). Based on the report, for the first time with the total of 505. 5 GW the annual global solar PV market crossed 100 GW at the end of the year. Similarly, with addition of nearly 52% of total capacity by renewable energy in 2018, Asia appeared as the largest regional market of the year. Moreover, building new solar PV and wind power plant has become more cost-efficient than running the fossil fuel-based plants (Makido, 2020).

With expanding role of renewable sources, a sharp decline of CO_2 emission from fuel-based plants has been observed in 2019 (IEA, 2020). The report also shows that almost 33 Gt of drop of CO_2 emission with 85% drop responsible from power sector. Integration of RESs also escape the unnecessary efforts in constructing additional power lines and large generators to increase the overall generating capacity in order to meet the increasing demand (Lopes, 2006). Despite these benefits, there are issues with RESs integration into the grid such as power quality issues, frequency stability, voltage stability and equipment protection.

Considering these challenges of grid integration with renewable sources, the objective of the paper is to evaluate the influence of renewable sources on the western network with respect to voltage stability. Thus, load flow analysis has been carried out using newton Raphson method in DigSILENT powerFactory. This paper also highlights some of the important technical requirements for grid integration with simulation results illustrating steady state performance of the transmission system with injection of large scale renewable energy into the grid. The penetration level is doubled every step to study the consequences of increasing penetration level of renewables into the grid. Impact of the penetration of renewable energy resources on a system is demonstrated through non-linear simulations using the western grid of Bhutan. Also, the behavior of the integrated grid in terms of loading and losses are studied. During the analysis a significant impacts of the renewable sources is observed on voltage stability of the existing systems.

2. SITE SELECTION

In an assessment carried out by NREL to mark potential sites for the development of PV system, adequate solar radiation and temperature was noticed in the country with peak sun hour ranging from 4.0 to 5.5 kWh/m^2 (Bhutan Energy Data Directory, 2015).

Similarly, with a potential of 761MW (DRE, 2015) Bhutan has the most attractive sites in Chhukha and

Wangduephodrang for generation of wind power. Table 1 highlights the proposed sites for SPV and WECS integration.

***Table 1**: Site Selection*

SPV Integration	WECS integration
Paro	Haa
Thimphu	Chhukha
Samtse	Wandue phodrang
Wangdue phodrang	

3. MODELING

The western grid of Bhutan was modeled in Power-Factory version 2015.1.2 with real time line, load, transformer and machines data acquired from the Bhutan power system operator (BPSO). The western grid consisted of four hydropower plants, the Basochu upper stage, Basochu lower stage, Chuukha, Daga and Tala hydropower plant with installed capacity of 24 MW, 40 MW, 336 MW, 126 MW and 1020 MW respectively. The grid also included the 600 kW Rubesa wind farm making a total installed capacity of 1546.6 MW. The substations were interconnected using 220 kV, 132 kV and 66 kV transmission lines. The grid also included 5 MVA and 10 MVA 66/33 kV, 10 MVA 66/11 kV, 50 MVA 220/66 kV, and 105 MVA 220/11 kV two winding transformers. Newton-Raphson method was adopted for the load flow calculation employing classical power equation as it involved large transmission system. The active power control was selected ‘As dispatched’ and the active power balance was to be maintained by the distributed slack based on their generation. The temperature dependency of the loads and cables was according to the resistances as stated in the basic data.

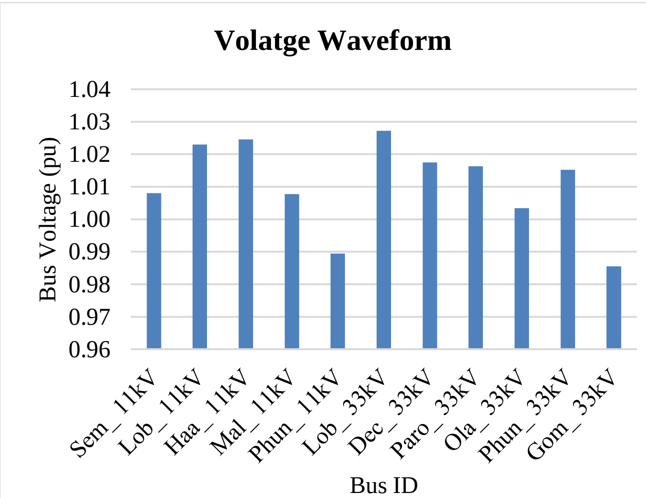

Figure 1a: Bus Voltage (p.u) at base case

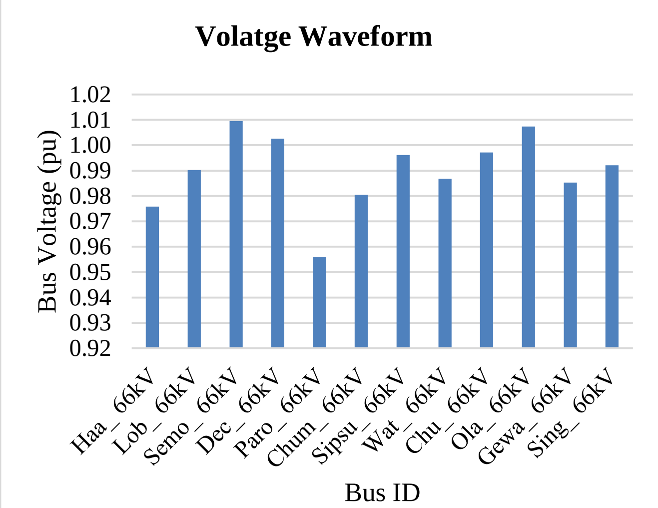

Figure 1b: Bus Voltage (p.u) at base case

Wind energy conversion systems and SPV systems are integrated on various buses according to the site selection and its voltage profile is obtained for comparison with the base level. Three WECS systems and four SPV systems are interconnected into the western grid by a 0.4/11kV, 5MVA and 3MVA transformer and 11/66kV, 5MVA transformer respectively. The nature of grid after integration is studied and depicted in graphical form.

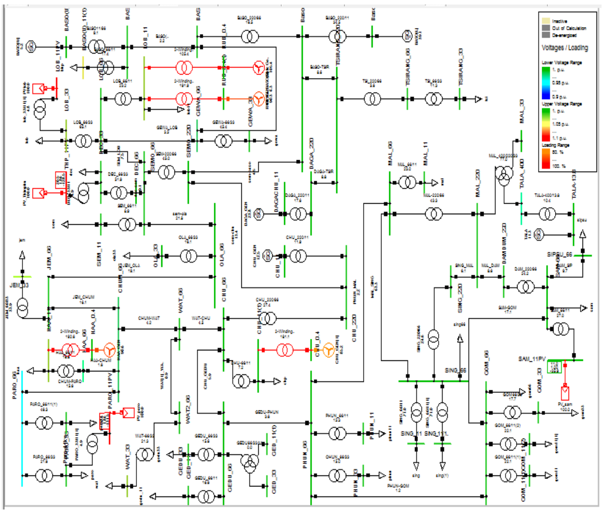

Figure 2: Integrated SPV and WECS system with the grid

4. VALIDATION

4.1 Validation of Grid

Grid validation is carried out by comparing the simulated bus voltages with the measured value. Root mean square deviation and mean absolute percentage error methods were employed in order to calculate error between the simulated and measured value. With very small deviation of 0.046756 root mean square error and 0.91% of mean absolute error, the grid was validated for further analysis.

Figure 3 shows the deviation of bus voltages between the simulated and the measured values.

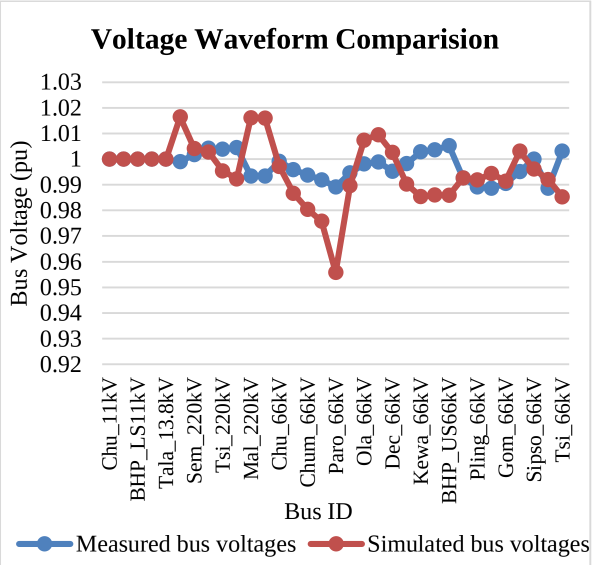

Figure 3: Measured and simulated value of base voltage

4.2 Validation of WECS

For wind power, output data of Rubesa wind farm for every five minutes interval is used to validate the inbuilt wind model. The output power of selected DFIG model for the Rubesa wind farm showed a close resemblance to the existing one.

With very small deviation of 0.010138801 root mean square error and 0.007% of mean absolute error as depicted in the figure, the WECS was validated for further analysis.

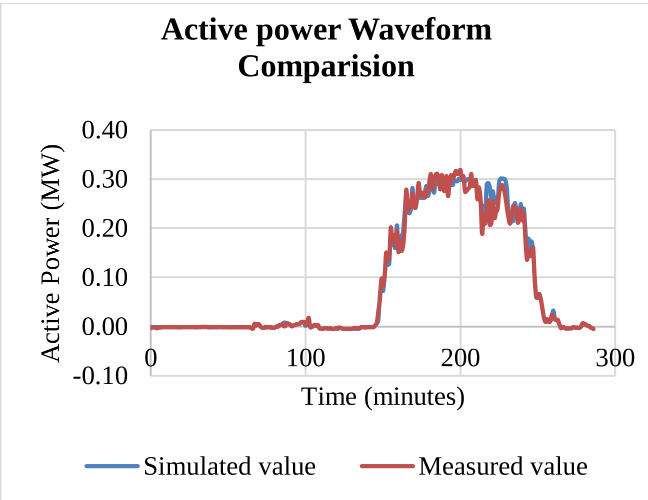

Figure 4: Measured and simulated value active power of WECS

5. SIMULATION RESULTS AND ANALYSIS

5.1 Voltage stability with SPV integration

One of the characteristics of solar PV is its power flow reversal ability from the load to transmission system. Solar PV has very less reactive power generation ability or no reactive power generation at all (Appen et al., 2013). This attribute of solar results in voltage instability at higher penetration level due to surfeit of active power supply and its inability to meet the demands for reactive power.

From base case (0%) up to 15% of PV penetration level of total load, the bus voltage increase. However, from 20% of PV penetration level, the bus voltages started to decreases or dip in Malbase, Phuentsholing, Gedu and Singaygoan for 11kV feeder. Similar observations were made in Gedu, Phuentsholing, Gomtu and Lobesa for 33kV feeder and for 66kV feeder.

With 53% penetration level of solar power into the grid the voltage magnitude of 66kV Paro and 66kV Gewathang dropped below the lower stability limit. The deviation was by a very small percentage with 0.36% and 0.246% at each place respectively.

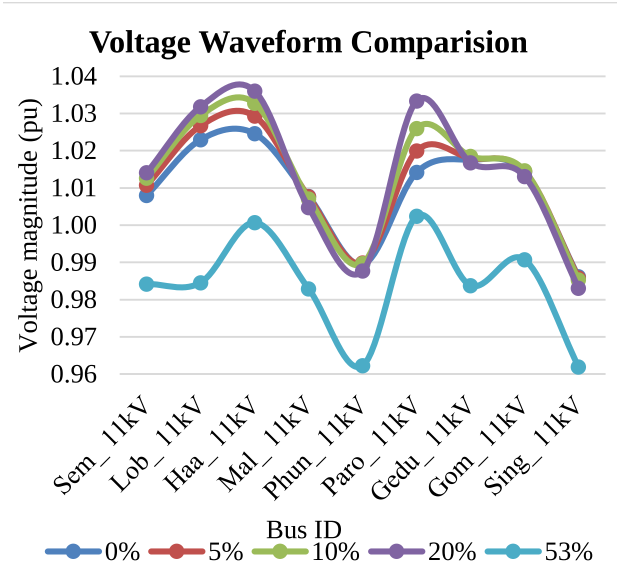

Figure 5: 11kV Bus voltages with SPV integration

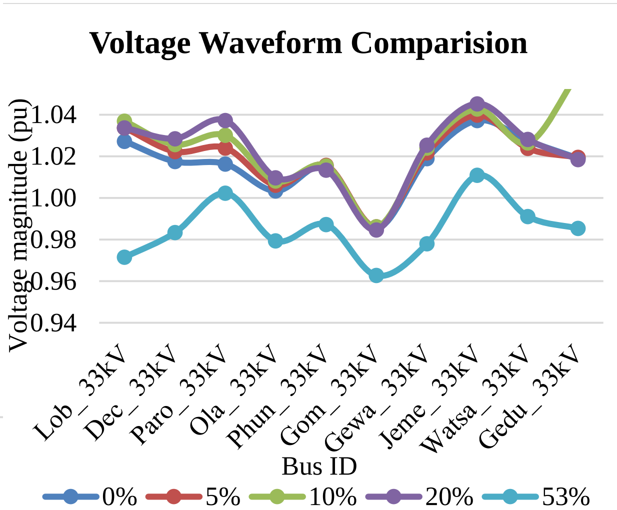

Figure 6: 33kV Bus voltages with SPV integration

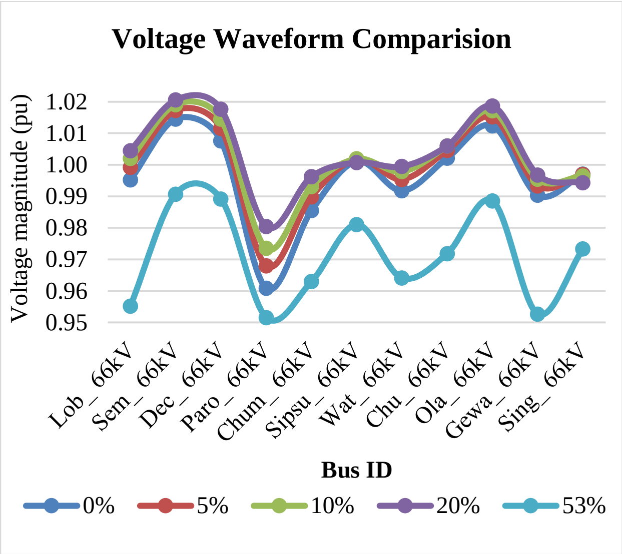

Figure 7: 66kV Bus voltages with SPV integration

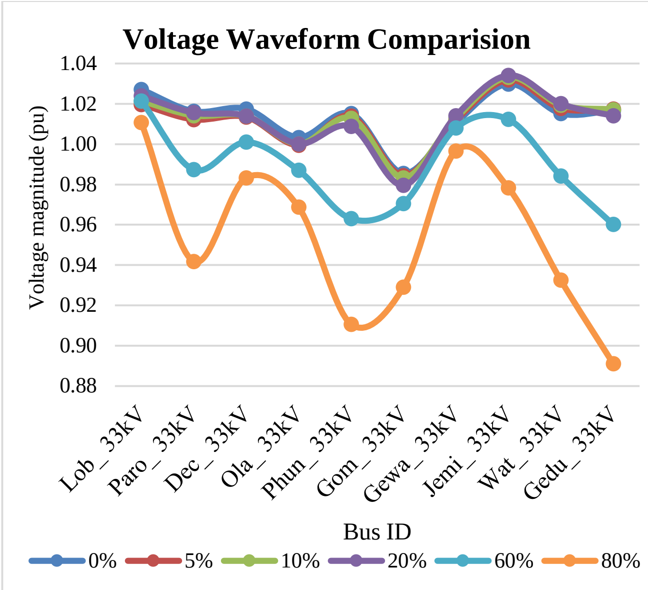

Figure 9: 33kV Bus voltages with WECS integration

5.2 Voltage stability with WECS integration

The voltage profile of the buses was observed to improve and increase up to 10% penetration level of wind power. However, beyond 20% penetration level the voltage profile decreased and with the increase in penetration level voltage violation were observed in more number of buses.

The voltage magnitude of the buses PHUN_11kv and SING 11kv were violated above 60% penetration level of wind power. Similarly, for 33kv buses, voltage violation were observed after 60% penetration level of total generation in WECS. Major violations were observed in places such as Paro, Phuentsholing and Gedu. For 66kv buses, voltage violation starts from 60% penetration level where 66kv buses at Paro and Singhigoan experience voltage instability.

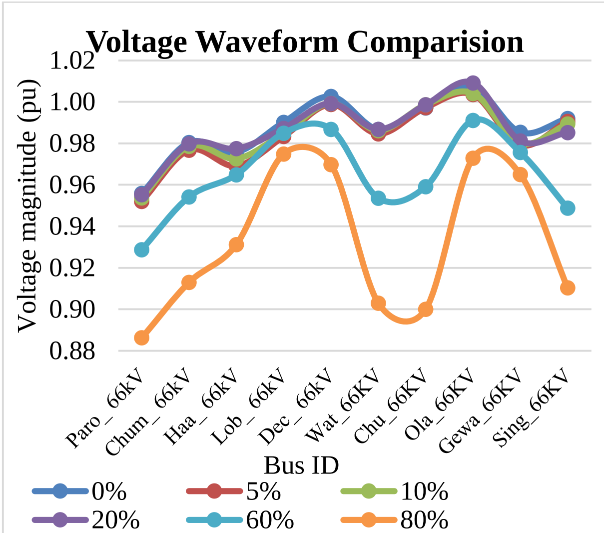

Figure 10: 66kV Bus voltages with WECS integration

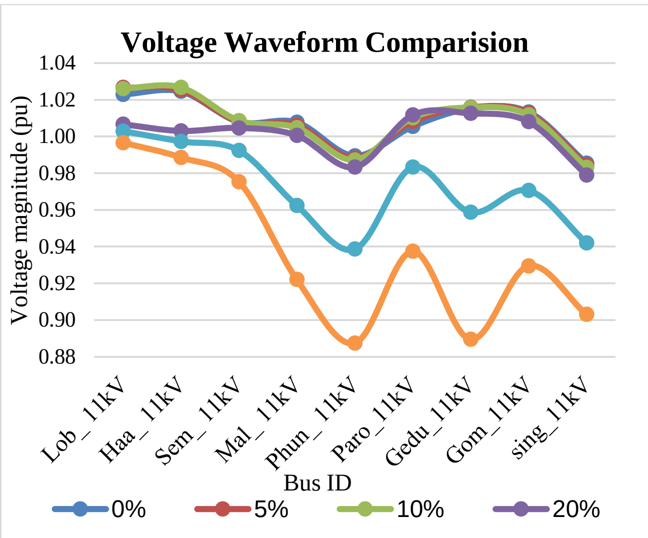

Figure 8: 11kV Bus voltages with WECS integration

5.3 Voltage stability with both WECS and SPV integration

With increaseing penetration level of SPV and WECS into the grid, the bus voltage tends to increase upto 10% penetration level. However, above 10% of the potential, a number of buses showed decrease in its bus voltages. Voltage violation was observed at higher penetration level. For most of the 11kV buses, the voltage was found within the stable range till 24% penetration level where one of the 66kV bus became unstable. Also, there was more variation in voltage profile at lower magnitude buses as compared to that of higher magnitude buses.

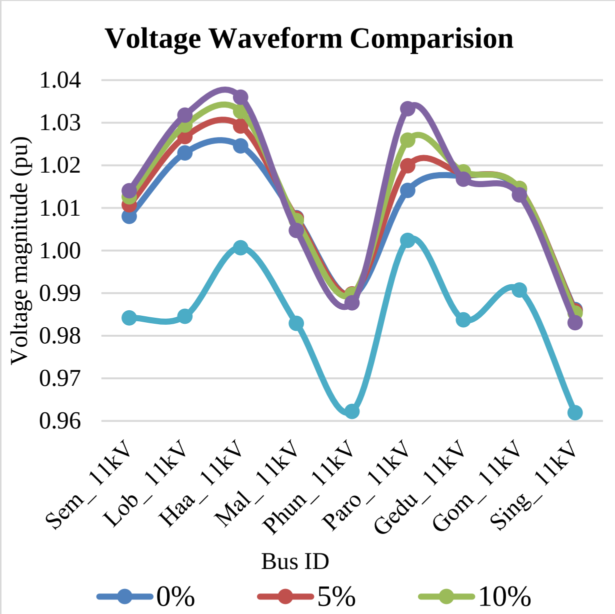

Figure 11: 11kV Bus voltages with WECS and SPV integration

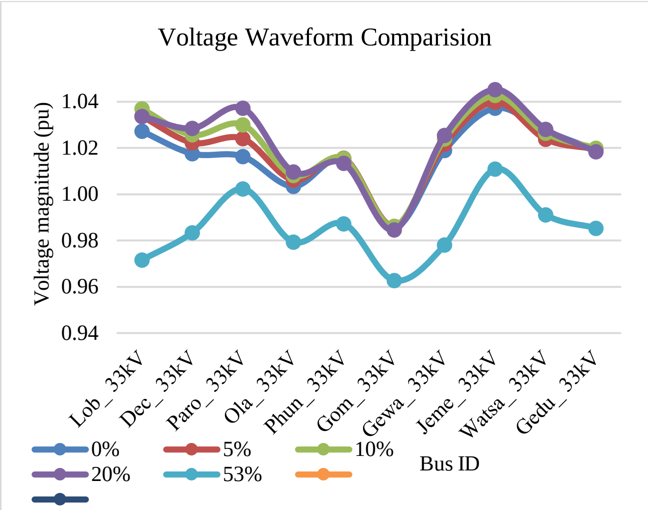

Figure 12: 33kV Bus voltages with WECS and SPV integration

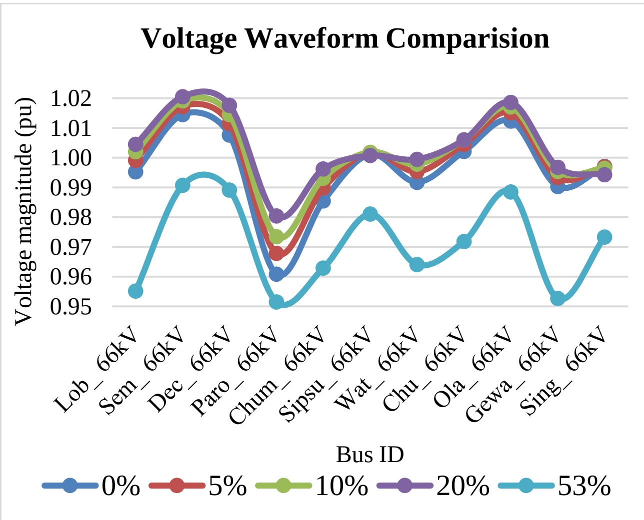

Figure 13: 66kV Bus voltages with WECS and SPV integration

5.4 Losses

With PV integration, the grid was able to maintain a stable voltage profile upto 15% penetration level above which voltage dips were observed at a number of buses. Also, an increase in grid losses were observed at higher penetration of PV power because of the increasing receiving end voltage and reverse power flow. Consequently, with the increase in line loading in feeders the overall power losses of the grid also increased. The grid losses with SPV integration was comparatively lower than that with WECS integration.

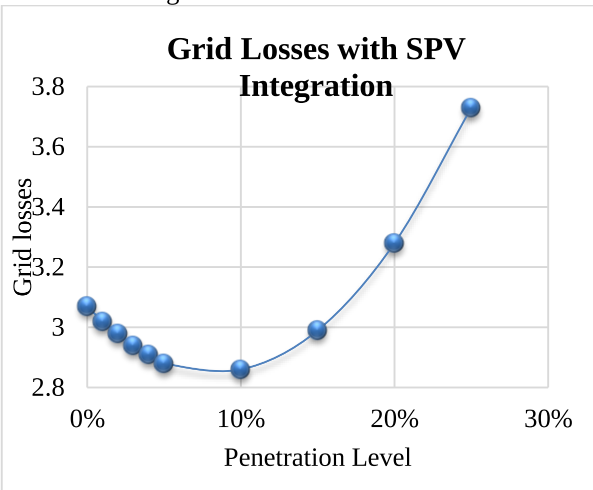

Figure 14: Grid losses with SPV integration

With WECS integration the power losses in the grid were observed to decrease at lower penetration level. With increased power generation and constant demand, the power tends to flow in reverse order. With no load to consume the power, it is lost as losses. Till 5% penetration level, the power losses were less compared to higher penetration level. From certain penetration level the losses increased exponentially reaching around one fourth of the total generation at 90% penetration level.

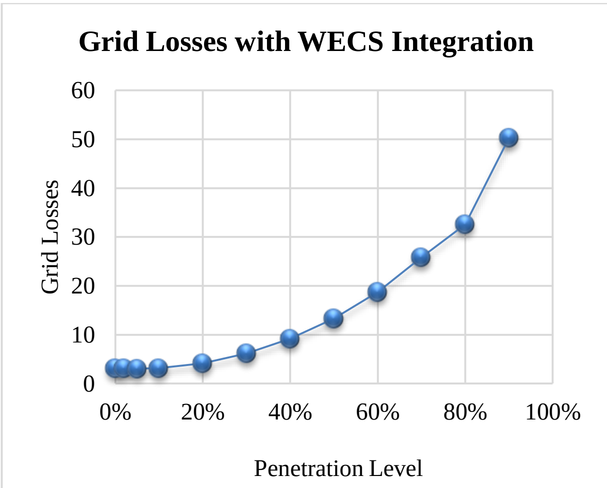

Figure 15: Grid losses with WECS integration

An increase in power losses was observed at very beginning of the penetration (Both SPV and wind integration) unlike with SPV or WECS integration. The losses mainly accounted for the line and the entire system losses which according to the grid code should be 2% of the total generation.

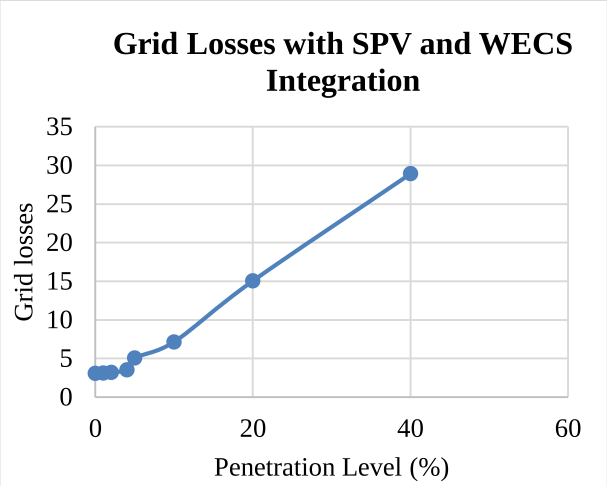

Figure 16: Grid losses with WECS and SPV integration

5.5 Overloading

While most of the transformer showed no overloading with increasing penetration level few were heavily loaded. This was mainly because with current rating the existing transformer fails to handle the increasing power transmitted from various renewable sources.

As a result, higher the power injected from the renewable sources more heavily was the transformer overloaded. Also, a number of these transformers were the one located near the point of integration or the one connected to the load bus. Figure 17 shows the loading of the three 66/11 kV 5MVA transformer with higher penetration level of wind power.

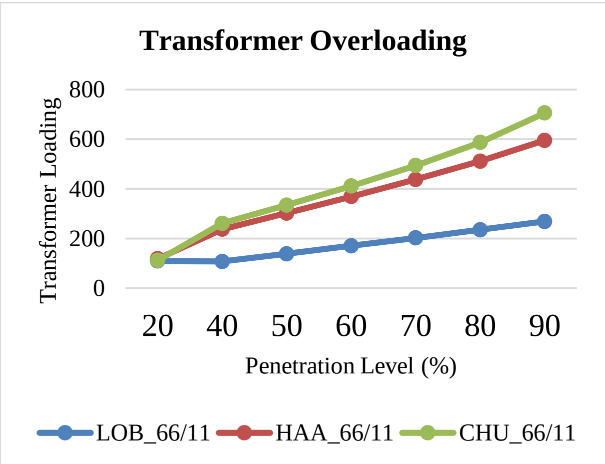

Figure 17: Transformer Overloading at higher WECS penetration level

The impact of WECS emerged more on transformer loading when both SPV and WECS was integrated into the grid. Consequently, transformer near WECS integration point got overloaded at much lower penetration in comparison to the one connected near SPV integration point. In addition, with the SPV and WECS distributed throughout the grid the impact on transformer loading was observed at much higher penetration level than when individual sources were connected independently.

6. CONCLUSION

In this paper, the western grid of Bhutan under study is modeled using DigSILENT Power Factory. The impacts of different types of RE sources on the voltage stability of the western grid of Bhutan are investigated. In medium voltage transmission networks, RES accommodation is normally limited by the constraint of voltage rise and drop. Simulation results are obtained for both with and without the integration of solar PV and WECS system such that voltage limits are compared after the integration to analyses its stability. In addition, voltage stability is analyzed at higher penetration level of solar and wind power. Following conclusions were drawn after the analysis;

- ✓ With SPV integration, the steady state voltage increased for most of the buses till 20% penetration level. Also, a decrease in grid losses and is observed at lower penetration level with the overloading of transformer at Lobesa substation. However, with increasing penetration level, the bus voltage started to violate the grid code limit of ± 5%.
- ✓ Similar rise in voltage magnitude and decrease in grid losses is noticed in case of WECS integration. However, the grid didn't allow for higher power injection due to violation of the bus voltages. Also, a greater number of transformer and lines were overloading with integration of WECS into the grid with a gradual increase in grid losses with increasing penetration level.
- ✓ The research showed that RES integrated into the grid can improve voltage profile at lower penetration level at same time causes voltage dip at higher penetration level. RE integration may be limited by the steady state voltage instability on a weak grid affecting the stability of the grid at higher penetration level.

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