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Effect of Maximum Level of PV Injection in Low Voltage Network: A Case Study of Baluwatar Feeder

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Abstract

World electricity demand is continuously increasing and fossil fuel supplies are not sustainable. Solar Photovoltaic (PV) energy is one of the emerging resources around the world, which produces emission free electricity. Nowadays, the advancements in rooftop solar PV technology, government subsidies, decreasing capital cost and feed - in -tariffs have promoted installation in residential and commercial applications. The exponential uptake in widespread integration of PV systems in existing low voltage (LV) distribution networks is raising additional new challenges in terms of power quality, stability and protection. Therefore, the main objective of this research is to investigate and understand the impacts of high PV systems injection on distribution network and aim to alleviate them.

In the first part of this thesis, the investigation of voltage quality challenges in the LV distribution network with high PV injection is discussed. In this research, various voltage quality issues such as voltage rise, unbalance, and sag/swell issues have been explored. Primarily, the analysis of results has been carried out through Dig Silent Power factory simulations in various case studies. To evaluate the severity of voltage quality issues in real - time grid connected PV systems, field measurement based investigations have been performed on Baluwatar feeder, Maharajgunj substation, Kathmandu Nepal as a case study.

In the second part of this thesis, the voltage profile of LVDN due to PV and their aggregations during operating conditions are assessed. Analysis revealed that individual voltage and current magnitudes are additive in nature due to increased PV system injection. Results confirm that the voltage profile and line current capacity exceeding the limits when the number of PV systems increases in the network. The PV injection have been found to 1.2MW in the scheme of Uniform distributed due to voltage limit, 1.25MW in the scheme of end aggregated due to voltage limit and 2.33MW in the scheme of start aggregated due to line current limit with PV injection level of 51, 52.5, and 99 percent of transformer rating respectively at 30 percent of peak load and 0.95 load power factor.

Keywords

PV Injection, Dig Silent

1. Introduction

1.1 Background

It has been a long time that engineers are looking forward to substitute the fossil energy with renewable energies which are using the natural energy without polluting the environment. However, they are always dealing with drawbacks and limitation of these types of energies. Solar energy has been recognized as of the easiest and cheapest resources considering the recent vast improvements in PV array materials which decreased the solar panel price drastically (Steffel et al., 2012). The photovoltaic systems are becoming more famous among the sources of renewable energy for electric power generation since they have pretty small size and no moving mechanical part in their structure which results in smooth operation without any noise. High injection PV systems is one of the recent topics in this field which tries to disperse the solar generation throughout the entire distribution system and even can be generalized to the fact that each home can be considered as a source of PV generation individually (IEEE 1547, 2003).

Surveying the present situation in Nepal, there are significant challenges to address and overcome, the declining hydro resource, the crippling dependence on foreign governments for oil and petroleum products, sensitivity and vulnerability of the national energy assets to earthquakes. The solution is to employ a mix of energy technologies. Among the renewable, solar photovoltaic technology is growing in popularity with its rapidly increasing installation capacity on a distribution network for residential, commercial land industrial sector. Global operating capacity has reached almost 301 GW in 2016. On average Nepal has 6.8 sunshine hours per day with the intensity of solar insolation ranging from 3.9 to 5.1 kWh/m -day (the national average is about 4.7 kWh/m2/day) (Martin, 2008). Using photovoltaic(PV) modules of 12 percent efficiency and assuming peak sunshine of 4.5 hour per day, the total energy generated would be 80,000 GWh/day or 2064 million tons of oil equivalent (Mtoe) per year. Jul 3, 2017-Nepal Electricity Authority, the state owned power utility is gearing up to sign power purchase agreement (PPA) with 22 projects for generation of 61 MW of solar energy. Currently, the NEA board is reviewing the PPA template to be signed with various developers to install solar plants at 22 different locations and Department of Electricity Development (DOED) issued the survey licence for 30 solar project of capacity about 180.9 MW.

PV injection or solar micro grids are of strategic importance to Nepal in meeting these challenges. Use of PV systems for domestic power supply can greatly reduce the generation of greenhouse gases and Government of Nepal is trying to encourage use of Solar PV cells, developed Subsidy policy and delivery mechanism. The Alternative Energy Promotion Centre (AEPC) has been established to encourage additional generation of electricity from renewable energy sources.

1.2 Need

Solar photovoltaic technology is the fastest emerging renewable energy technology. Different needs and requirements of power are met from the solar systems. To make an appreciable reduction in dependency on Hydro power and the greenhouse gas, rooftop PV systems could be embedded in the distributed network from consumer level. However, large scale installation of PV generators in distribution networks will give rise to potential power system problems. This includes line loading problems, reverse power capacity of transformer issues, voltage fluctuation, and protective device coordination problems (Martin, 2008). In order to allow successful large scale injection of PV cells in existing distribution network, the impact of PV units on voltage stability, protection coordination and fault withstand capacity of devices has not been investigated in details for low voltage networks. The fact that the existing network was designed with a concept of centralized generation and a vertically integrated generation system contributes to much of the protection problems. The distributed generation sources throughout the network increases the probability of unintentional islanding in absence of a central control and monitoring system. However, a control and monitoring system across the network would have to be highly reliable and communication link failures can cause network wide power system stability problem.

1.3 Assumption and Limitation

- The research is limited to the baluwatar feeder of Maharajgunj substation inside Kathmandu.
- The effect of PV injection is calculated as function of load power factor, solar power availability, voltage profile, current carrying capacity of line and reverse power capacity of transformer only.
- Effect of solar irradiance is collected from the solar generation station available at national college of engineering.
- For higher accuracy, solar stations need to be installed beside experimental set up. Non-possibility of that in case of this research may not point exact effect.
- The research has been carried with the collection of both primary and secondary data for single location only. The result for Nepal as a whole may change under the increment of sample size.
- This study deals with maximum possibility of PV injection in low voltage distribution network.
- This study deals with three phase balanced load and battery less PV system.
- In the present study, proposed model have been analysed using static PV generator in Dig silent power factory software.

2. Literature Review

To make an appreciable reduction in the dependency on Hydro power by the use of PV systems, a large number of PV generators have to be embedded in the distributed network. However, large scale installation of PV generators in distribution networks will give rise to potential power system problems. This includes voltage stability problem, protective device coordination problems and unintentional islanding. Some of the literatures that have been addressed are presented below.

L.M. Cipcigan (2007 IET): The research carried out to investigate the ability of power transformers to facilitate the required power flows associated with the anticipated high injections of small scale embedded generation (SSEG), within small-scale energy zones (SSEZs) is described (Cipcigan and Taylor, 2007). The research focused on identifying the reverse power flow and thermal-rating constraints imposed by power transformers. It was observed that in some cases the reverse power flow capability of the primary transformers would exceed if each customer installed an SSEG with a rating of approximately 1 kW.

Xiaohu Liu, (2012 IEEE),Proposed a coordinated control of distributed energy storage system (ESS) with traditional voltage regulators including the on-load tap changer transformers (OLTC) and step voltage regulators (SVR) to solve the voltage rise problem caused by the high photovoltaic (PV) injection in the low-voltage distribution network (Liu et al,. 2012). The main objective of this coordinated control is to relieve the tap changer transformer operation stress, shave the distribution network peak load and decrease the transmission and distribution resistive power losses under high solar power injection.

According to S. Ali, N. Pearsall and G.Putrus(2012), This paper assesses the effect of high injection levels of small-scale grid connected PV systems on the voltage quality of a residential electricity distribution network in the UK (Ali et al., 2012). Different scenarios for both injection and solar irradiation level are considered under various loading conditions. The MATLAB/Simulink software package was used to carry out this assessment.

M. Chidi,(2012 IEEE) ,Investigated the problem of voltage rise in the grid which might be caused by high level of injection of on-grid HBSPV systems (Chidi et al., 2012). In this study, the HBSPV system is modelled as a static generator and different bus voltages were recorded and studied for different levels of HBSPV injection on a 9-bus test system.

Reza Ahmadi Kordkheili,(2014), the main focus of the paper is to determine maximum photovoltaic injection level in the grid. Three main criteria were investigated for determining maximum injection level of PV panels; maximum voltage deviation of customers, cables current limits, and transformer nominal value (Kordkheili et al., 2014). The proposed model was simulated on a Danish distribution grid, considering grid parameters and operating condition in Denmark. Three different PV location scenarios were investigated for this grid: even distribution of PV panels, aggregation of panels at the beginning of each feeder, and aggregation of panels at the end of each feeder.

Ghullam Mustafa(2014 SGRE)The study about the islanding protection in Low Voltage (LV) CIGRE distribution and networks like selective, fast, reliable and the cost effective has been proposed in this paper. The selection of the islanding protection devices in this paper is made to protect the network against bi-directional currents at the time of short circuit fault(ghullam, 2014). The simulations are carried out by using Dig SILENT power factory software version 15.0.

3. Objective

Main Objective:

- To find the maximum level of PV injection and analyse their effect in low voltage distribution network of Baluwatar feeder.

Specific Objectives:

- To find the optimal PV injection in low voltage distribution network.
- To analyse the location of PV injection in existing feeder.
- To find the impact of PV injection in various location.
- To find the effect of load power factor in PV injection level.
- To find the effect of PV injection in reverse power capacity of transformer.

4. Metodology

In order to carry out the research, a step by step method has been used to achieve the final target of the work. Research methodology is intended to provide a guideline of systematic steps to address an issue and find its solution. The study has been dominated by quantitative analysis followed by deductive approaches. The data have been collected from both primary sources and secondary sources which include meteorological data from Nepal Electricity Authority (NEA). Based on the theoretical framework, the analysis and interpretations of data was made by using appropriate software for statistical analysis.

The methodology generated for the research can be summarized as follows:

- Review the existing literature and Nepalese design code provision for designing PV system.
- Selection of an existing INPS low voltage distribution network.
- Selection of software - For the research work to be carried out it is important that the selected software should have adequate features to allow modelling of PV system and equivalent sources, simulate symmetrical and asymmetrical faults and perform relay coordination. The software's suitable for suitability are ETAP, PSCAD and Dig salient power factory. ETAP and Dig salient are a power system design, modelling, analysis and planning software developed by Operation Technology Incorporated. This software can be used for short circuit analysis, load flow study, transient study, user-defined dynamic model, protective devices coordination and modelling of Photovoltaic arrays. For this research, Dig silent power factory software has been chosen for the analysis of distribution network
- The selected bus configuration has been modelled with and without considering PV generator in the proposed distribution network.
- Load flow analysis of the selected model has been done and comparative study on the result was obtained from the analysis.
- Determination of impact on operational limit in residential network due to high injection of PV generators. Case study has been done using selected simulation software and test network to support the theoretical assumptions made regarding possible outcomes.
- Conclusion of research outcomes – The outcome of the research works analysed and concluded in order to provide a clear understanding of the voltage stability issues identified and Recommendations made to address issue.

5. Data Analysis

5.1 Analysis of Primary data

The major variables defining the output of solar panel are current and voltage along with power flow which is stored in power analyser data loggers connected to the panel output. However, Product of current and voltage can simply give the power output of a solar panel.

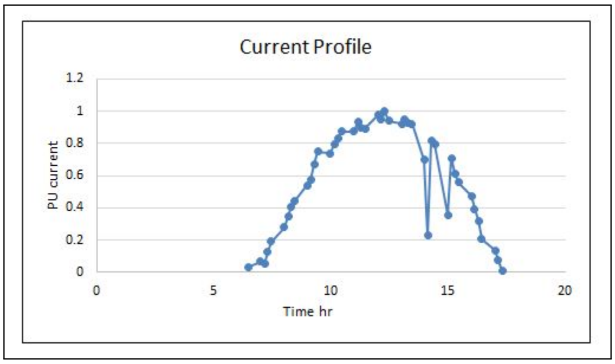

Figure 1: Imp Data of Solar Panels(March 6, 2018 AD)

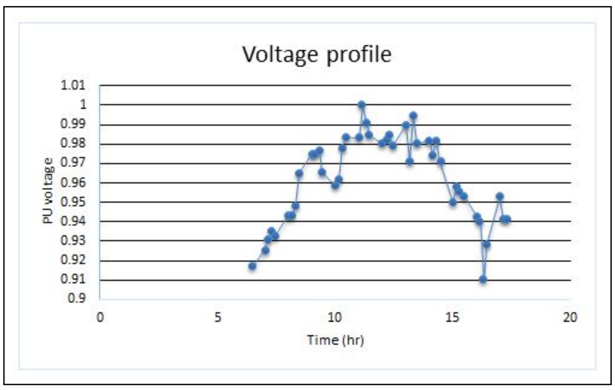

Figure 2: Vmp Data of Solar Panels(March 6, 2018 AD)

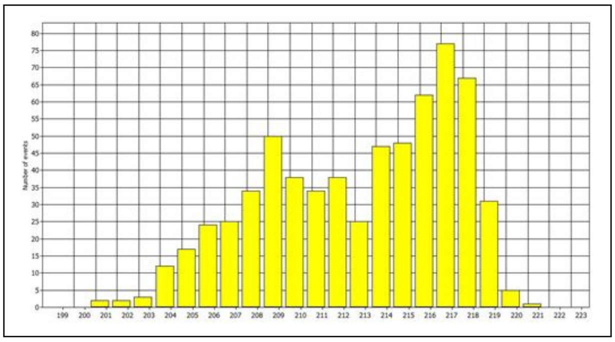

Figure 3: Voltage Statistics of Solar Panels (March 6, 2018 AD)

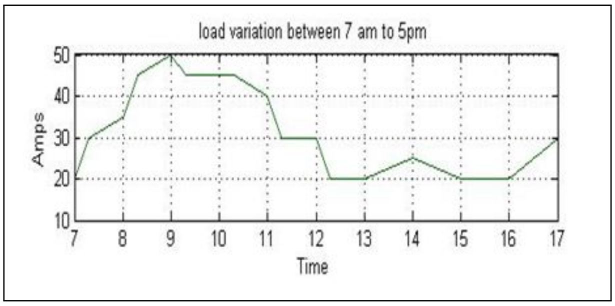

Figure 4: Daily Load Variations(November 21, 2016 AD)

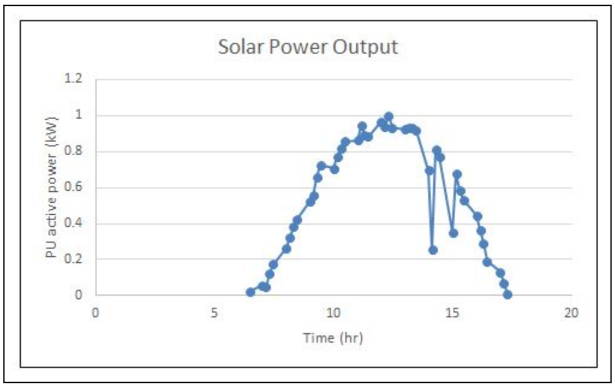

Figure 5: Power output from the panels(March 6, 2018 AD)

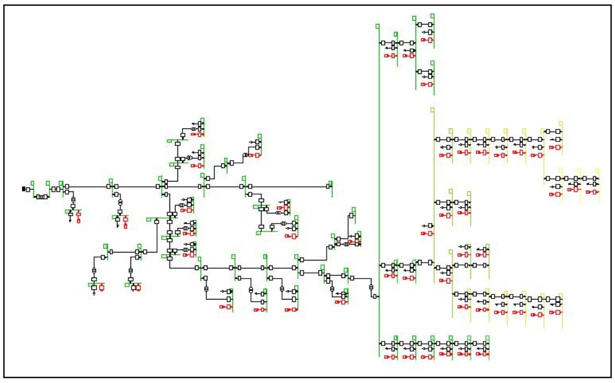

Figure 6: LVDN Analysis with PV Panels

5.2 Analysis of Secondary data

Secondary data were collected from the MSS from the month of September 17, 2016 to August 17, 2074. Line length, line parameter and current flows in a time axis were the relevant parameters collected. The data for line flows was collected from MSS for the Baluwatar feeder. Figure 4.4 shows the average minimum load of 20 amp is flowing between 7 am to 5pm.

5.3 load Estimate

The load on the Baluwatar feeder was analysed and the maximum load current of 70 amp was noted in the month of Falgun and the minimum current of 20 amp was noted during day time. The primary load current in each case was then averaged among the 18 numbers of transformers and secondary load current was calculated according to the rating of transformer. For the sake of simplicity, the detailed analysis was done for the transformer named as T15 of rated capacity 200Kva located at chandol motor garage and for the rest of the transformer; proportional load was aggregated near the secondary side of the transformer.

5.4 LVDN Analysis

Using grid parameters, steady state analysis of the grid in existing situation (no PV panel) was carried out first. Then, PV panels were added to the grid and the analysis was carried out. PV panels are normally considered as active power sources, but in present, special inverter technology can be used to supply the reactive power. This is especially the case for household level and distribution systems.

Case-I: Grid Analysis without PV Panel:

Load flow was first carried out for the grid in its existing operating condition. The voltage profiles of grid buses are also presented. As the distance from transformer increases, the voltage drop increases as well. Annex-B shows the voltage profile at different buses in the LVDN. In this condition, maximum busses have low voltage profile and some of them have poor voltage regulation, exceeded the voltage range and considered as critical bus in respective feeders. From the Annex 1, the buses LV15.2 (20), LV15.2 (21), LV15.2 (22), LV15.2 (23), seemed to have very poor voltage as it crossed the range of -5 percent. The transformer T15-200 is 63.1 percent loaded, the lines are normally loaded under their capacity and maximum loading of 94.8 percent seemed on line LB15-2. The total load of 1.34 Mva is recorded with external in-feed of 1.36Mva. The grid losses of 0.01Mw and 0.04Mvar are seen from the network in this configuration Annex-C. Generally the maximum solar power is available between 12:30 pm to 1 pm but the load is varying between 20 and 30 percent of peak load current. The grid was then simulated with solar panel at two different load power factors of 0.85 lagging and 0.95 lagging to find out the PV level that can be injected in LVDN.

Case II. Grid Analysis in Presence of PV Panels:

To determine grid capability for installing PV panels, injection should be defined first. Different definitions have been proposed in different papers. These definitions depend on the grid operating conditions and applicable limits for the grid. In some research works, injection level is defined as the ratio of installed PV to the overall system capacity. However, such definition might not be the best case for a distribution grid. Therefore, in this work, injection is explained as

$$\text{PV Injection} = \frac{\text{Peak Power of Pannel}}{\text{Transformer Rating}} \quad (1)$$

In this equation, the denominator stands for maximum value of total demand of grid consumers. Considering load profile of LVDN, the power factor taken 0.85, as per Nepalese LVDN standard and 0.95 as per seen in load profile to consider the effect of power factor. Therefore, Different scenarios were defined to find out grid capability for PV panels after the numerous levels of PV injections.

Table 1: Effect of Load PF and Loading in Injection Level

Loading	Load PF	% Injection in Scheme		
		Uniform	Start Point	End Point
30 %	0.85	51	101.5	53
	0.95	51	99	52.5

6. Result

6.1 Conclusion

This research has been started with the objective of finding the effect of maximum PV injection on performance of LVDN. After analysing the voltage profile, line loading and reverse power flow through transformer, it has been found that the voltage profile plays vital role to limit the maximum PV injection in the existing LVDN. For the effect of solar irradiance, output of solar panel has been data logged. The experiment showed a relatively large effect of irradiance on output of solar modules. The LVDN have been simulated on the basis of data obtained from the MSS of baluwatar feeder and it was found that the load occurrence is 30 percent only at the time of maximum solar power point. The maximum voltage fluctuation without PV generation has been found 0.97 pu at 30 percent of peak load. Now PV injections have been done in the same configuration of LVDN, the voltage profile found to be improved and within the range of 5 percent. The PV injection have been found to 1.2MW in the scheme of Uniform distributed due to voltage limit, 1.25MW in the scheme of end aggregated due to voltage limit and 2.33MW in the scheme of start aggregated due to line current limit at 30 percent of peak load and 0.95 load power factor, Annex-H. The effect of load power factor has not much on PV injection level as well as in transformer reverses power capacity. The PV generation have been injected maximum of 51 percent, 52.5 percent and 99 percent of transformer rating in uniformly distributed, end aggregated and start aggregated scheme respectively at 30 percent loading condition, table 1.

6.2 Recommendation

PV injection would make up the existing voltage drop in the system which decrease the power losses and make the better system stability by improving the voltage profiles. It has been concluded that splitting the PV generation throughout the entire system improves the voltage profile drastically. Total power loss in the distribution system which is directly influenced by the voltage profile is also much less in the dispersed generation.

- Optimal allocation and sizing of solar PV systems can provide voltage support and reduces line losses.
- Uniformly PV integration could improve the under voltage and voltage unbalance issues as well as sags in the distribution network.
- Another network solution is upgrading of distribution feeders cross - section, which is very expensive for the utilities to change all the lines. Further, regulation of the distribution transformer between two pre-defined tap settings can be proposed, which is based on the feeder loading data.
- This work refers the uniformly distributed scheme of PV injection most efficient for domestic LVDN network
- Proper division of PV generation among domestic consumer must be done otherwise it would make a serious voltage rise problem if the maximum PV generation limit exceed at each LVDN bus.
- Proper switching and isolating devices must be installed at each LVDN bus to handle the consequence of any fault and maintenance.
- No extra safety devices is needed for the transformer as the transformer loading and line loading limit is within the range.
- Weekly cleaning of solar panels is recommended for moderate dust accumulation and daily cleaning for intense dust accumulation.

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