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Impact of Photovoltaic Power Generations on Voltage Level of Low-Voltage Distribution Systems

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Abstract: *This research studies and analyzes the impact of penetration level and grid connected location of rooftop photovoltaic (PV) on low-voltage (LV) distribution network of Provincial Electricity Authority (PEA), Thailand. The configuration of studied distribution network, solar insolation and load profile have been analyzed and simulated by DIgSILENT Power Factory. This research focused on voltage variation at the point of common coupling (PCC) and the dead end (DE). Simulation results show that over voltage is occurred when penetration level of rooftop PVs is more than 16%. As these results, PEA regulation might be revised for the appropriated amount of Rooftop PV could be allowed to connect to the LV distribution network. In addition, this study reveals various impact factors of rooftop PVs such as the amount and a duration of the of PV generated power, the load profile, the grid connected location and the penetration levels of the installed rooftop PVs and the structure of the distribution networks.*

Keywords: *rooftop PV generation, penetration of rooftop PVs*

1. INTRODUCTION

In recently years, among renewable energy resource, solar power is one of the promising resources. Solar power has been installed in many areas worldwide. For example, in Japan, a system in Gunma provinces has been studied by measuring and observing on 550-houses rooftop PVs connected to LV network with overall capacity of 2.2 MW, 4.1 kW per house. Technologies of PV are continuously developed, the installation cost of PV system rapidly reduces to less than 1$ per watt [1]. It is evident that, solar power will be increased in the near future. The previous researches shown over voltage will be occurred when rooftop PVs generated peak power and the customer load is very low [2] and concentrating of rooftop PVs around DE [3].

Thailand government promotes a policy of using PV system in the next 10 years with the target 1, 000 MW. This policy promotes installing rooftop PV and building integrated PV (BIPV) by using feed in tariff (FIT), 6.85 baht per watt-hour. In year 2013, government distributes this target to the Metropolitan Electricity Authority (MEA) for 40 MW and Provincial Electricity Authority (PEA) for 60 MW.

Traditional LV distribution network of the system in Thailand is a passive network, a single in direction power flow is considered [4]. This system is not supported or designed for penetration of rooftop PVs. Especially, penetration to LV distribution network. Therefore, this penetration would impact the power quality (PQ) on the LV network.

Generally, PQ issues could be found in voltage variations and current harmonics [5]. For Thailand power quality standards voltage variations of LV network is limited between 10% (0.9 p.u.-1.1 p.u.) of its voltage nominal voltage level.

MEA regulation for rooftop PVs connection of LV network requires as follow:

1. Capacity of rooftop PV generates less than 10 kW per house.
2. Overall of capacity in LV network must be less than 15% of rate distribution transformer.

PEA prepares regulation for support rooftop PVs connected PEA’s LV network, as follow:

1. Case of single-phase rooftop PVs, less than 25% of rate distribution transformer is allowed to connected to LV network and less than 10 kW is allowed to energize per phase.
2. Case of three-phase rooftop PVs, less than 80% of rate distribution transformer is allowed to connected to LV network and less than 56 kW is allowed to energize.

As mentioned above, all these criteria are questionable. Therefore, PEA should study impact of rooftop PVs connects to LV network, in order to revise the regulation and find methods to alleviate this problem by utilities.

This research focuses on voltage variation issue, when rooftop PVs is connected to the LV network of PEA. The

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studied area is LV network in urban of Nakhon Ratchasima province, Thailand. This area is high solar insolation [6].

2. METHODOLOGY

2.1 STUDIED ELECTRICAL NETWORK

The studied electrical network is radial system. It consis of 250 kVA distribution transformer, cable of 95 mm^2 (main line), cable of 50 mm^2 (sub main line), terminal buses and load buses. This network supplies electrical power to 279 customer via 2 feeders. The data from GIS (Geographic Information System) program from provided by PEA is used. The meters have been connected to phase A for 65 units, phase B for 69 units, phase C for 3 units, three-phase meter for 3 units and unknown data for 130 units. This network distance is 2.38 circuit-kilometers. The details of studied electrical network are shown in figure 1.

2.2 LOAD PROFILE AND SOLAR INSOLATION

The studied daily load profile and the solar insolation are shown in figure 2. The recorded load profile is collected from TOU (Time of Use) meter installed at the studied distribution transformer. The duration of record is in April-May 2012. The solar insolation data has been received from the faculty of Physics, Silpakorn University, Thailand.

The studied data of real power and reactive power is 76, 410 W and 38, 115.2 Var (at 11.00 am, 25 May 2012), respectively, is focused due to the lowest load. Because unavailable load of each house, therefore, this study utilized total watt-hour usage of every house. This data has been received from CIS (Customer Information System) program PEA in 1 billing cycle and was then divided into percentage of usage real and reactive power of each house.

Data of solar insolation selected at 12.30 pm, 18 May 2012 due to highest. Which is about 1, 166 W/m^2.

2.3 ROOFTOP PV POWER GENERATION

Power generation of rooftop PV can be calculated by

$$P_{PV}=\text{InsolationAreaEFF}_{PV\ Cells}\ EFF_{DC\ to\ AC} \quad (1)$$

and an efficiency of DC to AC conversions can be calculated by

$$EFF_{DC\ to\ AC}=INS_{PV}\ CC_{PV}\ COP_{PV}\ EFF_{INV} \quad (2)$$

Where,

P_{PV} is power generation of Rooftop PV

$EFF_{PV\ Cells}$ is an efficiency of PV modules

INS_{PV} is installing PV array (90%)

CC_{PV} is efficiency temperature PV array (85%)

COP_{PV} is efficiency wiring losses (97%)

EFF_{INV} is efficiency inverter (94%)

From the measurement data by Google Earth application, the total rooftop area in this study is 28, 500 m^2. By onsite surveying and detailed consideration on the rooftop characteristic, this studied define the PV module installation area of 40%. Poly crystalline silicon PV from Sharp Company, model ND-120T1D with 12.1% efficiency is selected.

From the calculation, the average of power generation from rooftop PV for each house is 4 kW. In addition, PEA has defined that a distribution transformer is operated, at PF 0.9. Then this studied considers the amount of 45 customer houses or about 16% of 279 houses where PV system was installed, connected and generated 180 kWp to this LV network.

3. SOLUTION AND RESULT

3.1 SOLUTION

This research define network is balance three-phase distribution network because does not collected data of meters connected to this network, 130 units.

Firstly, by utilizing DIgSILENT program, the base case has been simulated. The result indicates that the voltage level of PCCs and DEs in this network is in between 0.971-0.990 p.u. as shown in figure 3. As expected, the highest voltage level is at secondary of the distribution transformer. Based on the studied condition, the lowest voltage level occurs at DE 02 and DE 19, which are 0.971 p.u. At the farthest distance, i.e. DE 03 (about 0.414 km), the voltage level is 0.973 p.u.

To investigate the impact of the rooftop PVs connected to PEA's LV network, four main cases have been selected in this study. By considering the distance from the transformer, the lowest voltage level at DEs and different sub main line diameter, those 4 cases are as follow:

Case 1: Rooftop PVs concentrate around DE 02 (the lowest voltage level(0.971 p.u.)).

Case 2: Rooftop PVs concentrate around DE 03 (the farthest distance (0.415 km)).

Case 3: Rooftop PVs concentrate around DE 19 (the lowest voltage level(0.971 p.u.)).

Case 4: Replace cable size along sub main line DE 19 to 95 mm^2.

For case 1, Figure 4 shows installed rooftop PVs concentrating around DE 02. The simulation results of this case are shown in figure 5.

For case 2, Figure 6 shows installed Rooftop PVs concentrating around DE 03. The simulation results of this case are shown in figure 7.

For case 3, Figure 8 shows installed Rooftop PVs concentrating around DE 19. The simulation results of this case are shown in figure 9.

For case 4, as shown in figure 10, replaces the cable along the sub main line DE 19 with 95 mm^2. The voltage level of this case shown in figure 11.

3.2 DISCUSSION

From the simulation, when the rooftops PVs are connected to the grid, the voltage level of LV network in case 1 is varied between 0.973-1.062 p.u. This variation does not impact the LV network. Voltage level at DE 02 is around 1.1 p.u. This is because DE 02 near distribution transformer.

For case 2, voltage level of LV network is varied between 0.973-1.074 p.u. This case does not impact this LV network because penetration level rooftop PVs around DE 03 is low. However this case is more harm than case 1.

For case 3, voltage level of LV network varied between 0.965-1.111 p.u. This case is worst case due to over voltage is occurred at some PCCs and DE 19. This is because penetration level rooftop PVs around DE 19 is high. The dropping of voltage level is found at DE 02 (about 0.965 p.u.) This case can make electronic devices of customer to break down.

For case 4, voltage level of LV network is varied between 0.971-1.083 p.u. This result shows over voltage at DE 19 could be mitigated by replacing of cable size along sub main line DE 19, 95 mm^2. Consequently, voltage level found at DE 19 is reduced to 1.083 p.u. and voltage level at DE 02 is increased to 0.971 p.u.

4. CONCLUSIONS

Rooftop PVs penetration of 45 from 279 customer houses (16%), where overall capacity 180 kW, 4 kW per house are connected to PEA's LV distribution network will impact the power quality. Especially, over voltage is occurred when rooftop PVs concentrating around DE 19 (worst case)

As the above results, PEA regulation does not support for rooftop PVs connection for this LV distribution network. From this study, in addition, various impact factors of rooftop PVs connected LV distribution network can be reveal such as the amount and duration of PV generation power, the load profile, the location and penetration levels of the installed rooftop PVs and the structure of the distribution network. PEA can replace cable size in order to mitigate this problem.

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REFERENCES

[1] Ipackchi, A.; Albuyeh F. Grid of the future. IEEE, power & energy magazine, 7, 52-62

[2] Ueda, Y.; Oozeki T.; Kurokawa, K.; Itou T.; Kitamura, K.; Miyamoto, Y.; Yokota, M.; Sugihara, H.; Nishikawa, S. Detail performance analysis results of grid connected clustered PV system in Japan First 200 System results of Demonstrative Research cluster PV system. 20th European PVSEC

[3] Miyamoto, Y.; Sugihara, H. Demonstrative research on clustered PV system. Photovoltaic Specialist Conference (PVSC), 2009, 34th IEEE, 512-516.

[4] Shawara, R.A.; Bleijs J.A.M. Impact of Grid Connected PV System on Voltage Regulation of a Residentail Area Network in Saudi Arabia. Nuclear and Renewable Energy Conference (INREC), 2010, 1st International, 1-5.

[5] Katiraei, F.; Mauch, K.; Dignard-Bailey, L. Integration of photovoltaic power system in high penetration clusters of distribution networks and mini grids. Published in the International Journal of Distribution Energy Resource, 3.

[6] Janjai, S.; Laksanaboonsong, J.; Munez, M.; Thongsathiya, A. Development of a method generating operational solar radiation maps from satellite data for a tropical environment. Solar Energy, 78.