# Simulation of Low Voltage Distribution Network Threshold for PV Rooftop Penetration

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*Received: 3 January 2022, Revised: 2 February 2022, Accepted: 2 March 2022*

**Abstract**

The rapid increases of photovoltaic (PV) rooftop on residential houses in low voltage (LV) distribution network cause several impacts in Provincial Electricity Authority (PEA)'s distribution network. Voltage profile is one of the most important technical factors that the utility has to maintain within the proper limit. This research investigates the impacts of PV rooftop on low voltage distribution network complying with PEA's regulation on power network system interconnection code B.E.2016. The scenarios comprising seasonal and working periods are considered. The studied criteria are divided into 3 cases; 1) the connection of PV rooftop at 15% of distribution transformer capacity 2) the connection of PV rooftop at 100% of transformer capacity 3) the increase of PV rooftop causing voltage profile up to 1.10 p.u. The simulation is studied in the DIgSILENT power factory with DPL script and Python programming language due to the diverse criteria. The results show that the limit of regulation is able to control the voltage profile within the operation range. Moreover, the low voltage distribution network threshold is about 293.75% of the distribution transformer capacity that PV rooftop causes the voltage level reaching to the limit. However, the result should be considered before reference, because this research focuses on the voltage profile, not others significant issues.

**Keywords:**

*Photovoltaic (PV) Rooftop, Voltage Profile, Low Voltage Distribution Network*

## 1. Introduction

Thailand Ministry of Energy (MoE) Alternative Energy Development Plan 2018 (AEDP2018) [1] has adopted policies to encourage renewable energy stakeholders develop and invest in renewable energy to support Thailand economic and social development. This plan targets to replace 30% of the country's final energy consumption (in the form of electricity, heat and biofuels) by the year 2037. For solar power, the target cumulative installed capacity is 12,139 MW. The objectives of AEDP 2018 are to reduce net import energy, ensure stable power supply, support renewable energy research and development, help reduce global warming impacts and support the environmental circular economy.

The future trend in solar power generation is driven now by rooftop SPV (solar PV) systems due to the continuing reduction in the cost of SPV, and the simplification of the administrative procedures of the government agencies for the installation and operation of rooftop SPV systems. Additional schemes to support installation of rooftop SVP systems have been announced such as offering to household SPV systems a feed-in tariff of 1.68 baht per kilowatt-hour that rises to 2.20 baht per kilowatt-hour for a 10-year contract [2].

Moreover, the ERC (Energy Regulatory Commission) launched in 2021 a scheme to buy solar power from schools, hospitals, and agricultural water pumping systems for those with installed capacity of between 10 kW to 200 kW, offering a feed-in tariff of 1.00 baht per kilowatt-hour for a 10-year contract [3]. Therefore, in the near future, it is expected that installation of rooftop SPV systems will dramatically increase.

In Thailand, the PEA (Provincial Electricity Authority) is the electric utility which distributes the electricity in all provinces nationwide, except in Bangkok, Nonthaburi and Samutprakarn provinces. PEA is responsible for providing reliable and high-quality supply of electricity not only to the residential sector but also to the commercial and industrial sectors too. PEA dispatches electricity at low voltage of 220/380 V, at medium voltage of 22/33 kV and at high voltage of 115 kV. All in the mainland, including the rural areas, and the island communities are PEA customers. This accounts for about 20 million electricity users [4].

Electricity supply by area; 51.74% of electricity supply goes to the central region, 16.98% to the southern region, 16.51% to the northeastern region and 14.77% to the northern region. Most of PEA customers are residential consumers, which is about 85% of the 17.8 million PEA electricity consumers.

With the decreasing cost of rooftop SPV systems and the policies for incentive programs, the number of residential rooftop PV have been increasing consistently. From 2019 and 2021, the number of residential customers who submitted applications for installation reached to 1,400 users, which equivalent to a cumulative installed capacity of about 7 MW [5].

## 2. Study Objectives

This research investigated the impacts of rooftop SPV systems on low voltage distribution networks and their compliance with PEA regulation on power network systems, particularly with PEA Interconnection Code B.E.2016 [6]. This is a code that PEA adopted for power network systems to regulate the connection of DG (Distributed Generators) on the network.

This research studied different scenarios to learn the limitations in the penetration of rooftop SPV systems in low voltage distribution networks. The research aimed to find the threshold for rooftop PV system installation till when the PV systems feedback power to the low voltage distribution network causing a voltage rise.

## 3. Research Methodology

The study is divided into six steps as given below (see Fig. 1). Each step is discussed in more details in the following paragraphs.

*(1) Select a network to study*

This research focused on low voltage distribution networks located in areas with high density of electricity users. Pathumthani province in the Central region was selected for this case study. The data for the model network was imported from Geographic Information System (GIS) and then exported to the DIgSILENT power factory software. Fig. 2 shows the model network.

The DIgSILENT power factory software was selected to be uses in the analysis of the of the network power flow. This software was used together with DPL script and Python programming language due to a lot of studied scenarios.

*(2) Collect data on the network, loads, and solar profiles*

The low voltage network consisted of a 160 kVA, 22kV/380V distribution transformer supplying electricity to 2 feeders. There were 88 electricity customers and all of them consumed electricity from phase 1 of the electrical network. The maximum load of each customer was limited at 9.9 kW. The average load profile of a PEA residential customer was based on the load profile of the whole electricity users during the year of 2012 to 2014. The solar profiles came from the weather data obtained from a solar power plant near the study area. Loads and solar profiles in both the summer and winter month, and on weekdays and weekends were considered in this study (see Fig. 3).

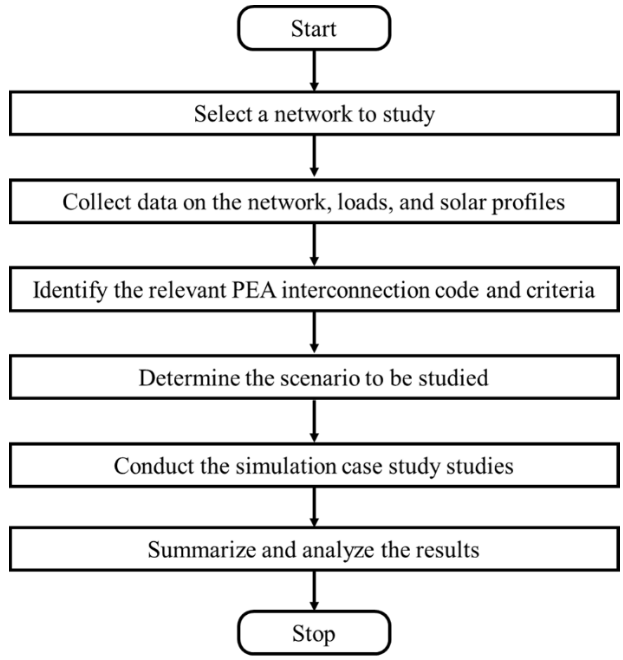


Fig. 1 Research Methodology.

*(3) Identify the relevant PEA interconnection code and criteria*

PEA provided the minimum design criteria, technical specification of electrical equipment, and the installation standard, which are issued under PEA regulation on Power Network Systems Interconnection Code B.E.2016. The main objectives of the regulation were to establish appropriate methods to connect distributed generators or electrical equipment to a power network system; to clarify and set up the fundamental regulations for the minimum requirements, technical specification and interconnection standard at the connection points; to ensure the efficiency and safety of synchronization of generators to PEA power system network, and to maintain the quality of power dispatching to general consumers within standard after the connection of distributed generators.

The connection criteria for distributed generators in a 380/220 V distribution system allow power producers to connect to the power network as follows:

- A power producer can connect a distributed generator with a capacity of not more than 5 kW on a single-phase distribution network. If a power producer wishes to install several capacities of distributed generators, they must be stable and the difference between each phase must be lower than 5 kW.
- Under the same distribution transformer, the total capacity of each requesting connector must not exceed 15% of its load (kVA)

Moreover, the regulation determines the power quality control in terms of voltage level which must be within the range of +/-10% of rated voltage or between 0.90 and 1.10 p.u.

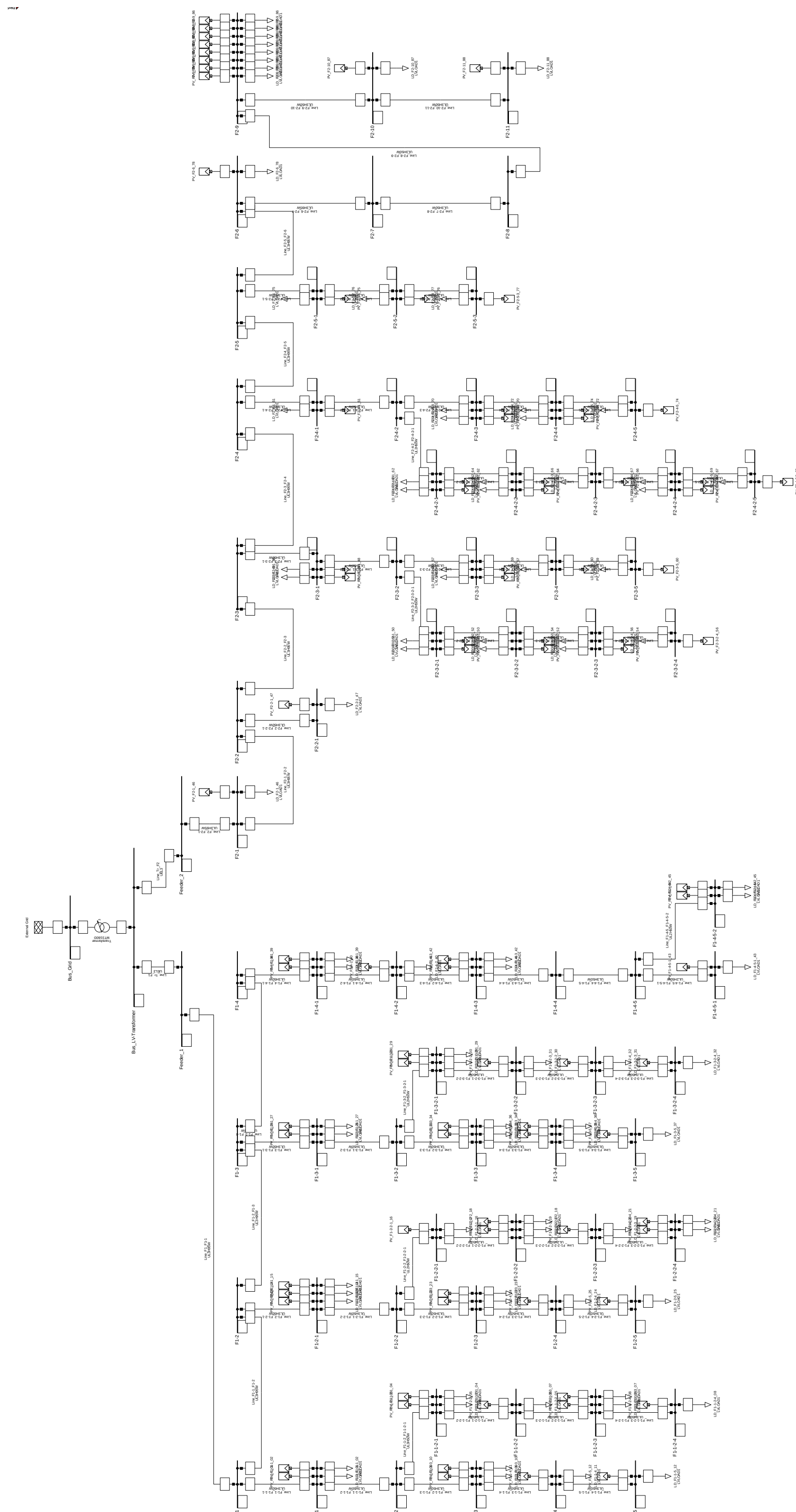

Fig. 2 Studied network model.

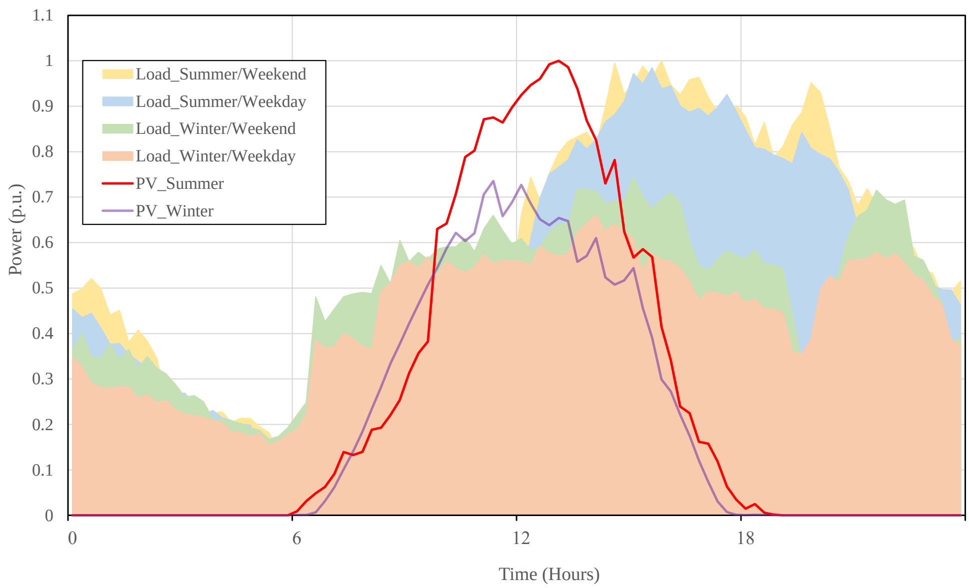


Fig. 3 Load and solar profiles.

PEA provides the minimum criteria for designing techniques, technical specification of electrical equipment, and installation standards, which were issued under the Regulation on Power Network System Interconnection Code B.E.2016. The main objectives of regulation are to establish appropriate methods to connect distributed generators or electrical equipment to a power network system; to clarify and set up the fundamental regulations for the minimum requirements, technical specification and interconnection standard at the connection points; to ensure the efficiency and safety of the synchronization of generators to PEA power system network, and to maintain the quality of power dispatched to general consumers within standards after the connection of distributed generators. The connection criteria of distributed generators on 380/220 V distribution system allow power producers to connect to the power network as follows:

- A power producer can connect to the distributed generator a capacity of not more than 5 kW on a single-phase distribution network. If a power producer wishes to install several capacities of distributed generators, they must be stable and the difference between each phase must be lower than 5 kW.
- Under the same distribution transformer, the total capacity of each requester's connector must not exceed 15% of its load (kVA)

Moreover, the regulation determines the power quality control in terms of voltage level which must be within the range of +/-10% of rated voltage or between 0.90 and 1.10 p.u.

*(4) Determine the scenario to be studied*

The study considered changes in the seasonal and working day patterns to cover all cases and effects of loads and rooftop SPV generation. The load and solar profile in summer/winter and weekend/weekday are set in different scenarios as shown in Table 1. Three main conditions were studied; 1) the connection of rooftop SPV systems at 15% of distribution transformer capacity 2) the connection of 5 kW rooftop SPV systems at 100% of transformer capacity, and 3) the increase in installation of rooftop SPV systems until the voltage profile rose to 1.10 p.u. or the lower voltage network threshold.

Table 1 Studied scenarios.

| Scenarios | Seasonal | Working day |
|---|---|---|
| Base | Summer/Winter | Weekend/Weekday |
| 1 | Summer | Weekend |
| 2 | Summer | Weekday |
| 3 | Winter | Weekend |
| 4 | Winter | Weekday |

(Remark: Summer is in April, winter is in December. The weekend is Saturday and Sunday, and weekday is from Monday to Friday.)

*(5) Conduct the simulation case study studies*

As mentioned earlier, this study selected the DIgSILENT power factory software and DPL script together with Python programming language, to simulate the case study because of this a standard software and is a flexible software.

(6) Summarize and analyze the results

The results of the simulation of each scenario under the criteria used were summarized and visualized under several perspectives. The voltage profile of the network at the distribution transformer and the end of 2 feeders were determined. Additionally, graph were prepared to present the power flow at every point of consideration in the network.

## 4. Results and Discussions

### *4.1. Case1: Connecting rooftop PV at 15% of distribution transformer capacity*

This involved the installation of 5 kW rooftop PVS (PV system), which was 15% of distribution transformer load or about 25 kW, and was for a simulation of the characteristic of a low voltage distribution system. The results showed that the rooftop PV system generated reversed power flow, at a maximum of 25 kW at 1 p.m. and reduced the load of transformer. During the daytime, the rooftop PVS produced the maximum power to supply the residential load and there was some excess power fed back to the network when the generation was larger than the consumption. Fig. 4 shows the voltage profile and power flow at the points considered in the study It was clear that, the PEA criteria were effective in controlling the stability and power quality low voltage distribution network.

### *4.2. Case 2: Connecting 5 kW PV rooftop at 100% of distribution transformer capacity*

This case simulated the characteristics of the low voltage distribution network when there was a 5-kW rooftop PVS installed at 100% of the distribution transformer capacity with overall capacity about 160 kW and there was no limitation to feedback power. As a result, the rooftop PVS created the highest feedback power flow to the network during weekend periods of the summer season due to the larger generation than the household consumption this time. It affected the voltage profile, up to a maximum of 1.042 p.u. at 11.00 a.m. at the end of feeder 2 (F2-11). In the same time, there was reversed power flow at the distribution transformer of about 10.89 kW upstream. However, the voltage profile at the transformer bus and the end of 2 feeders, was still within the range of 1.10 p.u. The voltage profiles and power flow are shown on Fig. 5.

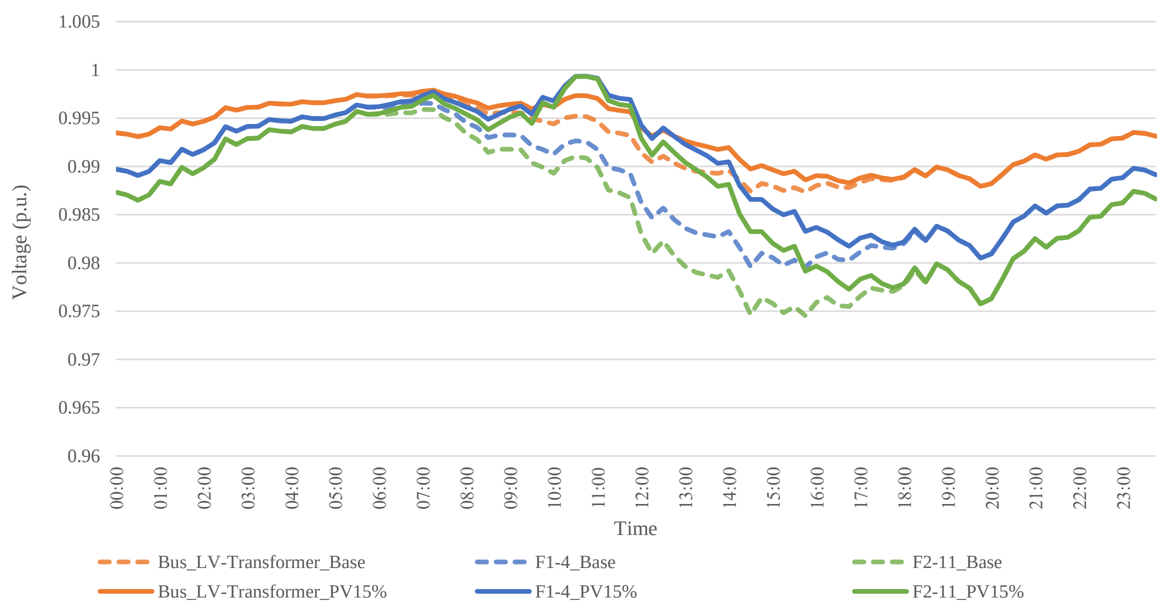


Fig. 4 (a) Voltage profile at 3 points.

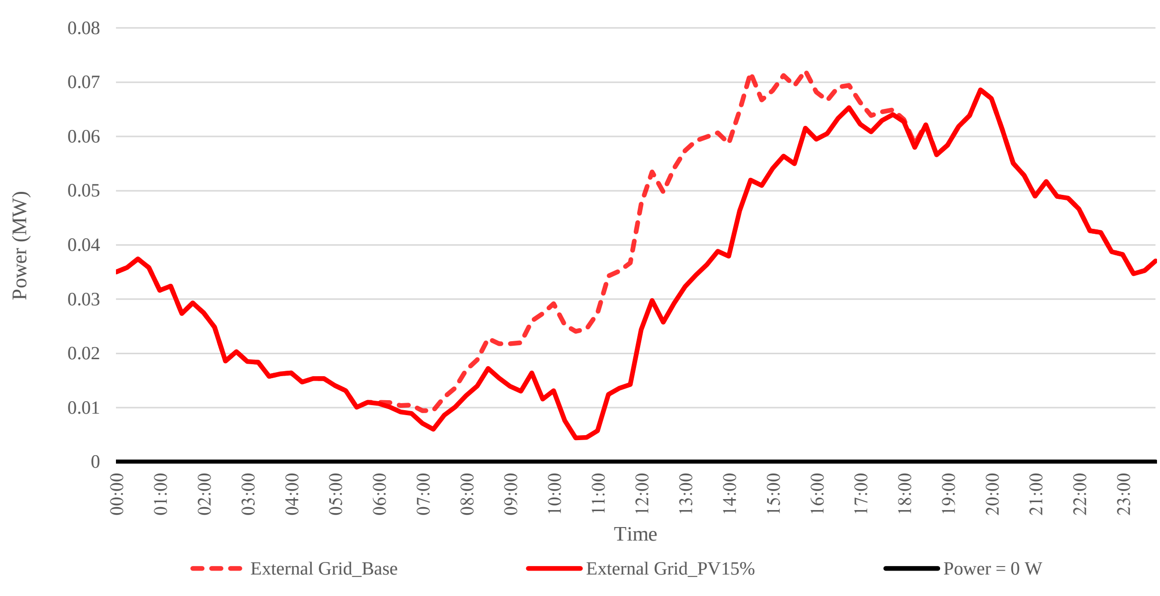


Fig. 4 (b) Power flow at the transformer bus.

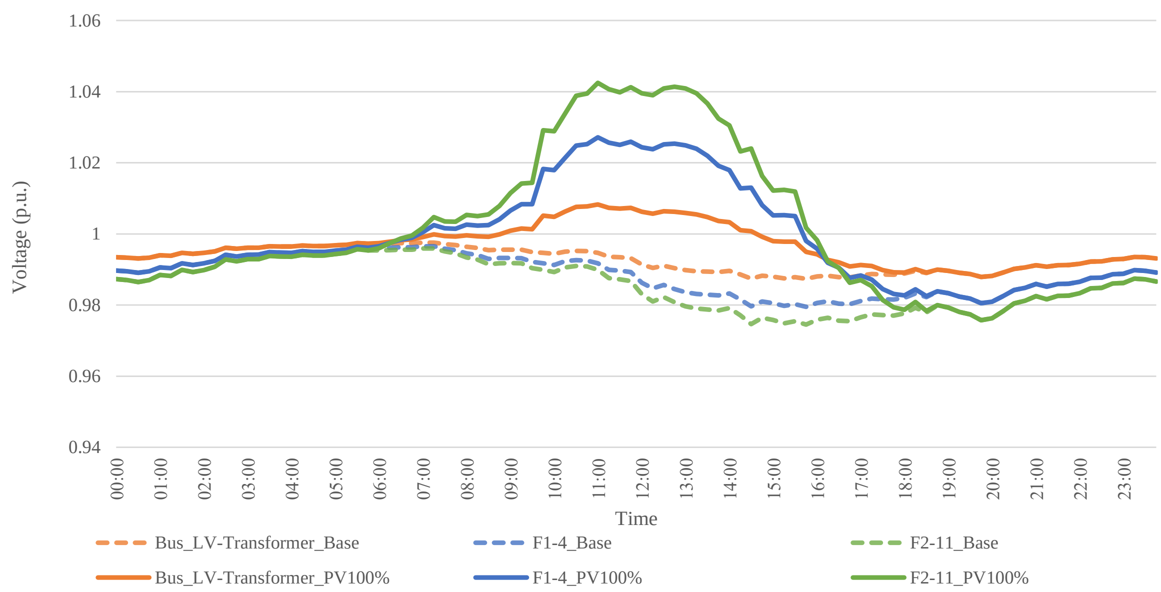


Fig. 5 (a) Voltage profile at 3 points.

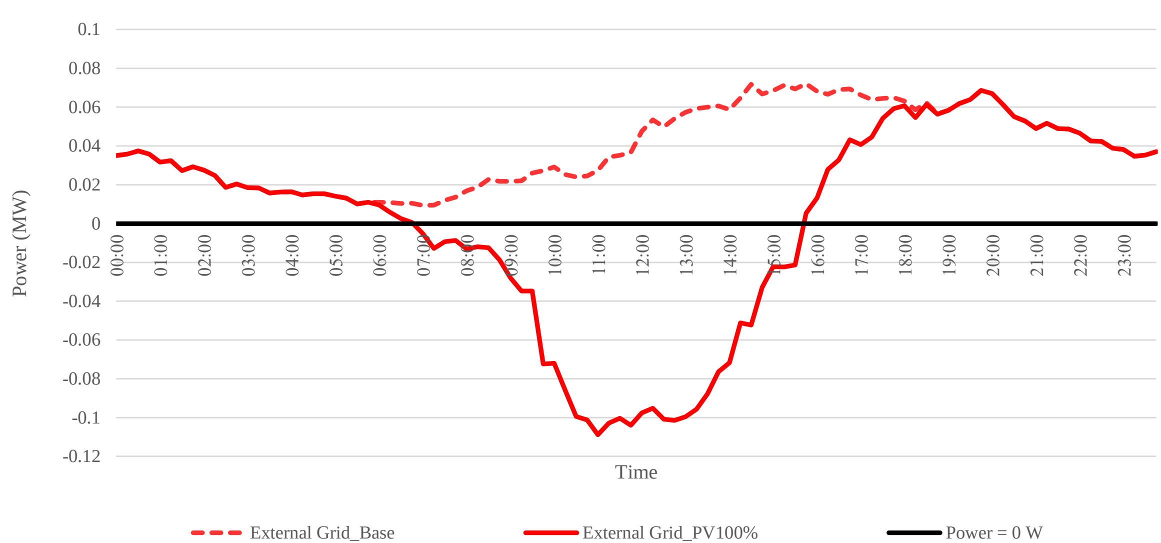


Fig. 5 (b) Power flow at the transformer bus.

### *4.3. Case 3: Increasing rooftop PV capacity until the voltage profile rises to 1.10 p.u. or the low voltage network threshold*

This case involved increasing the number of rooftop PV and tracking the voltage profile, until the low voltage network threshold of 1.10 p.u. was reached. The variation of the voltage level and power flow at the transformer bus and the end of 2 feeders are shown in Fig. 6 to Fig. 8.

The highest voltage level was at the end of feeder 2 which had low load density and large rooftop PV generation. The increase in the number of solar PV systems increased the power supply to the load and the excess power supply was fed back to the network. The overall rooftop PV capacity was 470 kW or approximately 293.75% of distribution transformer load. This caused the voltage profile at the end of feeder 2 (F2-11) to rise to 1.10 p.u. at 12.45 p.m. Meanwhile, the voltage at other points of consideration was within the limit. The rooftop PV rooftop systems generated a large amount of power flow at the transformer bus of more than 400 kW which was reversed back to the upstream as shown in Fig.9.

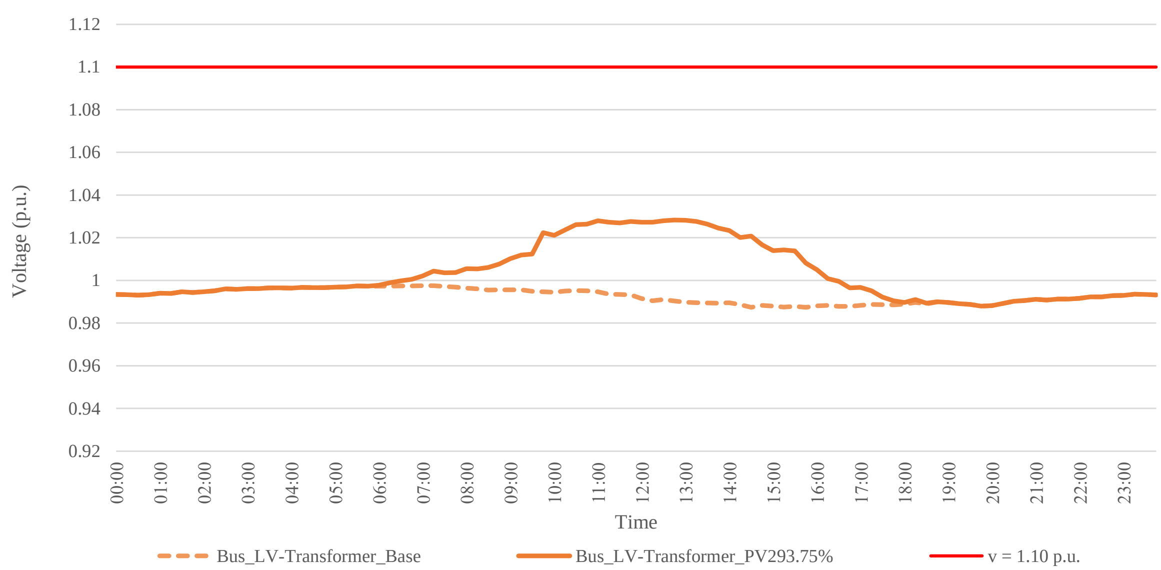


Fig. 6 Voltage profile at transformer bus.

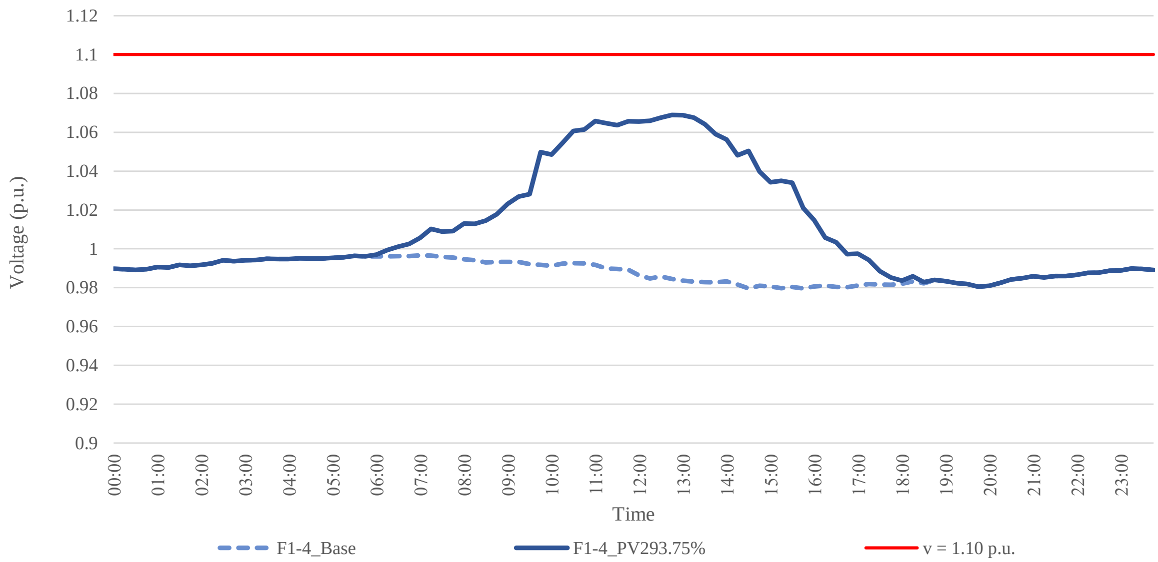


Fig. 7 Voltage profile at the end of feeder 1 (F1-4).

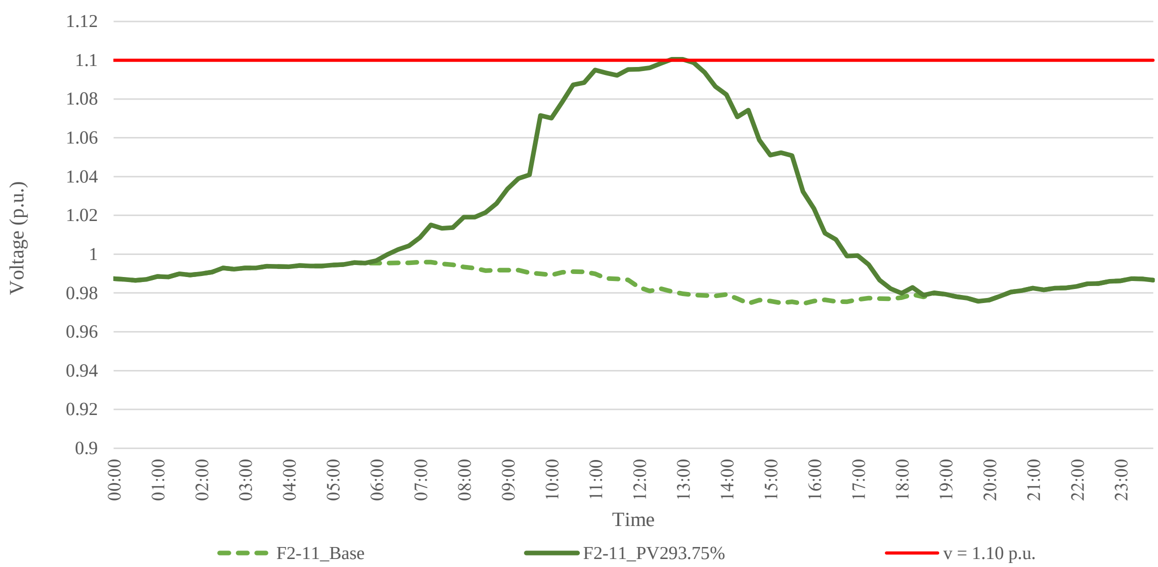


Fig. 8 Voltage profile at the end of feeder 1 (F2-11).

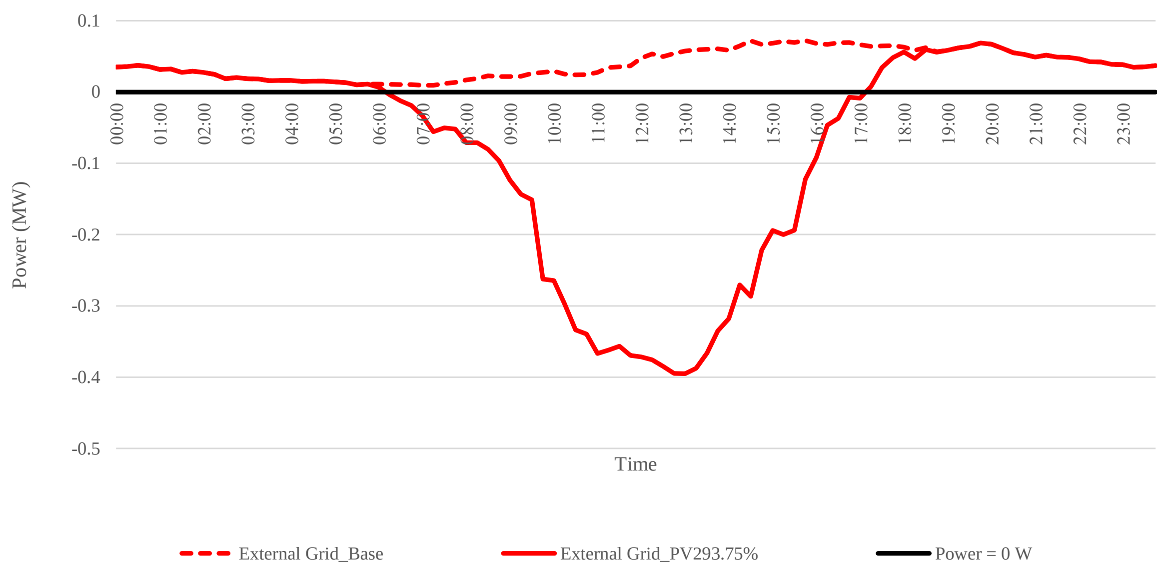


Fig. 9 power flow at the transformer bus

## 5. Conclusion

The case studies show results of the simulation studies demonstrating that the PEA Regulation on Power Network System Interconnection Code B.E. 2016 has efficient criteria for supporting and controlling the connection of distributed generators to the electrical network. The details of power quality control, the minimum requirements of the fundamental regulations, the equipment specifications and interconnection standard at the connection points are all defined in the code. The first simulation demonstrated the criteria that the limit of distributed generator capacity is at 15% of distribution transformer load to effectively control the power flow and voltage level within the standard. The second simulation demonstrated the criteria that overall capacity of the rooftop PV rooftop was about 160 kW or 100% of transformer load, which allowed the low voltage distribution network to maintain the voltage characteristic within the 1.10 p.u. However, there was reversed power flow that passed through the transformer bus to another feeder. Lastly, the case study showed that the network threshold to support increase penetration of rooftop PV systems in the low distribution network was approximately 293.75% of transformer load. This research however, focused only on the voltage profiles, and not on other significant issues.

## Acknowledgements

Author would like to thank the Provincial Electricity Authority for the education scholarship and supporting information for the research. Moreover, I would like to give my attitude to Assoc.Prof.Dr. Nipon Ketjoy for the precious time, encouragement, advice and recommendation.

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