# The Analysis Framework for High Penetration PV Rooftop in LV Distribution Network: Case Study Provincial Electricity Authority

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ABSTRACT

The analysis framework for high penetration PV rooftop in low voltage (LV) distribution network, case study Provincial Electricity Authority (PEA), is investigated in this study. The study will examine the voltage profile impacts in the LV distribution network due to PV rooftop connection by designing the analysis framework to find out the existing distribution system threshold. The analysis framework will be able to repeatedly adapt to other interesting areas. The study is simulated in power system analysis software with DIgSILENT power factory by deploying DPL script together with Python programming language. Various scenarios such as summer/winter season and weekend/weekday are considered together with varying PV rooftop installation sizes of 1 to 5 kW and its installed number, to carry out the worst-case scenario. The study network consists of 88 customers within 2 main feeders, under the common 160 kVA distribution transformer at 22 kV/400 V. As the results, the voltage profile will increase higher than 5% of rated low voltage in case of 3 kW PV rooftop installed with 100% penetration, 4 kW PV rooftop installed with 70% penetration, and 5 kW PV rooftop installed with 60% penetration for summer both in the weekend and weekday scenarios. In the winter season during the weekend, 4 kW PV rooftop installed less than 100% penetration and 5 kW PV rooftop installed below 80% penetration will not affect the voltage profile in the system. The system can support the penetration of PV rooftop up to 4 kW with 100% penetration and 5 kW with 70% penetration in the winter season during weekday.

## 1. INTRODUCTION

Due to the Thailand energy policy which encourages people and investors to develop and invest the renewable energy generating projects, especially PV rooftop, both for electricity sale and self-consumption. Alternative Energy Development Plan 2015 (AEDP2015) targeted the solar energy generation to 6,000 MW by the year 2036[1]. Consequently, the high penetration of PV rooftop has been rapidly increasing to the half of goal accounted to 2,753 MW at the end of 2016. Furthermore, incentive programs such as Feed-in Tariff (FiTs) with different purchasing rate significantly drove the number of PV rooftop installations up to almost 3,976 residential customers with 32.48 MW installed capacity as well as 156 buildings/factory customers with 66.66 MW by the year 2018. Additional self-consumption and producer customers or prosumers will continuously rise in the distribution network.

Provincial Electricity Authority or PEA as the electric utility in Thailand, who owns the distribution network throughout nationwide except for Bangkok, Nonthaburi and Samutprakarn provinces, is responsible for maintaining the reliability and stability of the system as well as to continuously and efficiently supply electricity to customers. The most important number of residential, who was interested in applying to install PV rooftop during a government program in 2013 and 2015 was more than 9,318 customers, accounted up to 75.06 MWp of installed capacity [2]. Presently, the larger amount of PV rooftop is increasingly installed whether in case of Feed-in Tariffs (FITs) or self-consumption. Those widely spread in PEA’s low voltage (LV) distribution network, they might cause several problems such as reversed power, voltage regulation and losses. The limitation of PV penetration in low voltage networks and voltage variations has been reviewed in [3]. Therefore, this study will find out the appropriate analysis framework to represent the technical impacts, which includes the procedures considering the realistic data and context of Thailand’s LV distribution network. To cover the worst case throughout a year, this study will consider the highest load peak in

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summer and the lowest load peak in winter, including weekday and weekend conditions.

## 2. METHODOLOGY

This section explains more details about the framework of technical impact analysis in PEA's low voltage network due to the high penetration of PV rooftops. PEA's regulation on power network system interconnection code B.E.2016 [4] that limits 15% of distribution transformer capacity is able to support distributed generation connected to the LV network is ignored in this study in order to clearly understand the tolerance of LV distribution network. Loss is also neglected due to the small network and low voltage level. The analysis framework has been designed to facilitate the distribution network operator to manipulate the network. Fig.1. shows the framework consists of the explanations of analysis tool, data input, process, and output step by step.

### *2.1 Define the studied scenarios and areas.*

The scenarios have been determined in order to cover the most relevant cases that PV rooftops of residential impacts to the low voltage network. The study considers the variation of PV rooftop installed capacity and % PV rooftop penetration. All scenarios are concluded in Table 1.

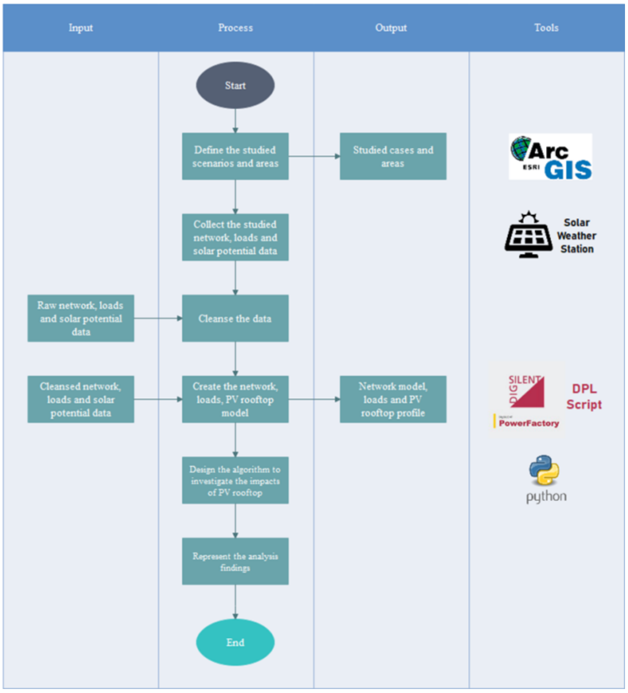


**Fig. 1: The Framework of Technical Impact Analysis in PEA's Low Voltage Network due to PV Rooftop Penetration.**

**Table 1: The Overall Studied Scenarios**

| Scenario | Seasonal | Weekend/ Weekday | PV rooftop installed capacity (kW) | % PV rooftop penetration |
|---|---|---|---|---|
| Base | Summer/ Winter | Weekend/ Weekday | No PV | No PV |
| 1 | Summer | Weekend | Vary from 1 to 5 kW | Vary from 10 to 100% |
| 2 | Summer | Weekday | | |
| 3 | Winter | Weekend | | |
| 4 | Winter | Weekday | | |

**Remark:** Summer is in April, winter is in December.

The weekend is Saturday and Sunday, weekday is from Monday to Friday.

### *2.2 Collect the studied network data, loads and solar potential profile.*

The network data and loads of study are able to be exported by Geographic Information System (GIS) in term of *.dgs files which will be compatible to import into power system analysis software as DIgSILENT power factory as illustrated in Fig.2. This research selects the PEA's central region area 1 (C.1) located in Lad Bua Luang subdistrict (LBL), Pathumthani province. It comprises of 88 customers within 2 main feeders, under the common distribution transformer, accounted to 160 kVA capacity at 22kV/400V. This transformer is dispatched by Lad Bua Luang substation, feeder 10 (LBL10). This study considers the solar potential from the nearby weather station in solar power plant, which suitably indicates the solar generation in the studied area. It is clear that this model distinctly represents the future trends of PV rooftop installation in the community or village that is able to internally exchange or trade their energy among customers.

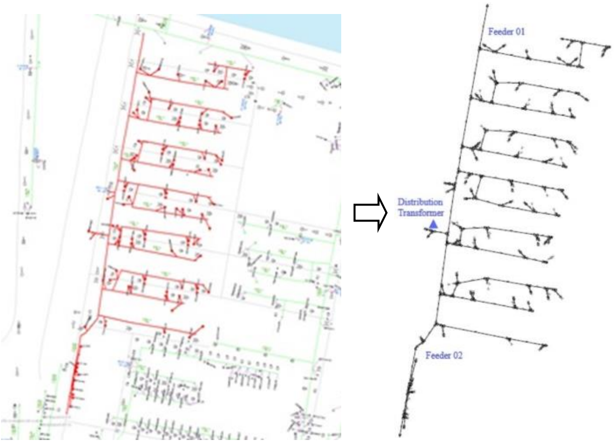


**Fig. 2: The Case Study LV Distribution Network from GIS.**

### 2.3 Cleanse the data

The technique to transfer data between analysis software is complicated and some data need to be cleansed before properly passing across the software. The small script that rearranges the network data from GIS in *.dgs form is deployed to be compatible import to DIgSILENT power factory. In the case of loads, GIS stores the average load of each customer that integrates with the average load profile of residential in PEA's central region area during the year 2012 to 2014. Solar irradiation profile in the year 2018 from a close solar power plant illustrates the characteristic of PV generation. The average load profile of the residential customer and solar potential profiles are represented in Fig.3 and Fig.4, respectively.

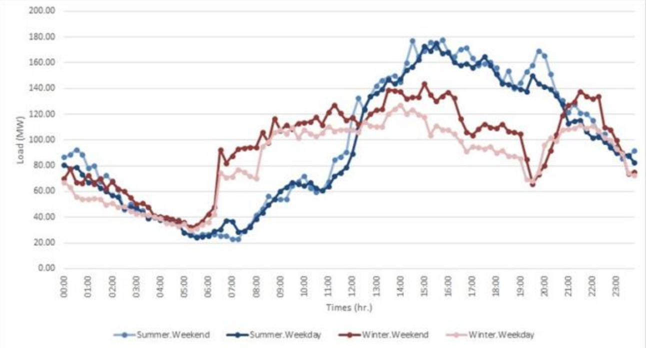


**Fig. 3: Average Load Profile of Residential Customer in Central Region Area. a) Summer/Weekend b) Summer/Weekday c) Winter/Weekend d) Winter/Weekday**

### 2.4 Create the network, loads, PV rooftop in power system analysis software.

Fig. 5 shows the synthesized network data that contains all components, for instance, transformer, feeders, lines, loads PV inverters, and their properties in the LV distribution network.

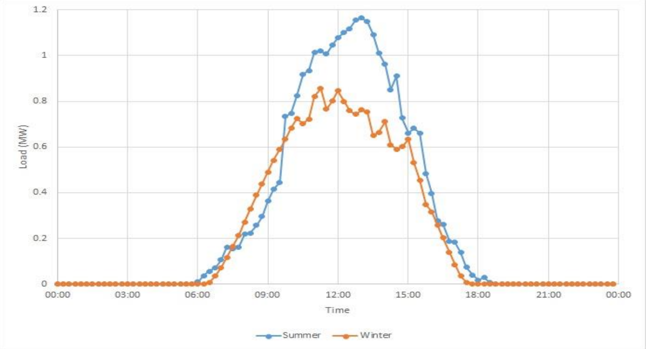


**Fig.4. Average Solar Potential Profile in Central Region Area. a) Summer b) Winter.**

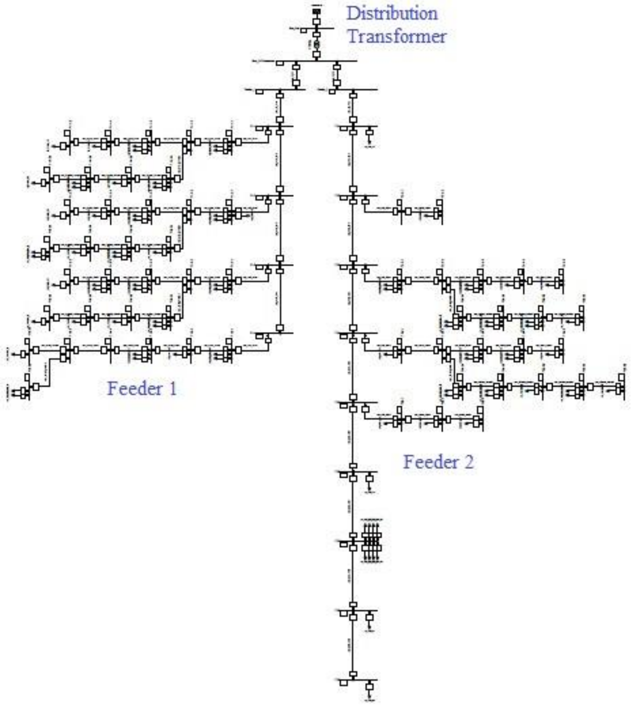


**Fig. 5: Synthesized Network Model of the Study.**

### 2.5 Design the algorithm to investigate the impacts of PV rooftop.

The voltage profile at the point of connection of PV rooftop in low voltage distribution network is approximately given by Equation 1 [5, 6].

$$\Delta V = \frac{(P_G - P_L)R + (Q_G - Q_L)X}{V} \tag{1}$$

where, $P_G$ and $P_L$ are the active powers of the PV rooftop and load; $Q_G$ and $Q_L$ are the reactive powers of the PV rooftop and load; R and X are the resistance and reactance between the point of connection of the PV rooftop and load; V is the line voltage at the PV rooftop connection point.

Initially, this study will consider the voltage profile at 3 different points where are at the distribution transformer bus, the end of feeder 1 (bus F1-4) and the end of feeder 2 (bus F2-11). Those imply the most PV rooftop penetration impact in the study network. Lastly, the voltage profile of the whole system will be analyzed and visualized that the studied network has the limitation to support the PV rooftop penetration. It is obvious that this study takes into account various conditions in order to represent the most relevant factors affecting the impact of PV rooftop penetration. Therefore, the algorithm of study is determined to cover the whole conditions, which is shown in Fig.6.

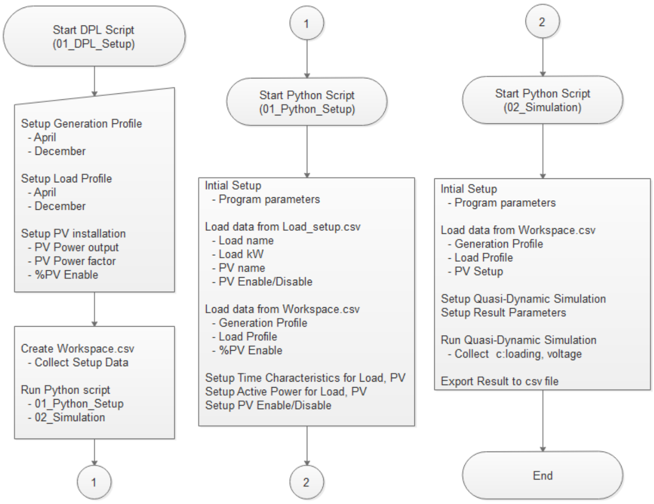


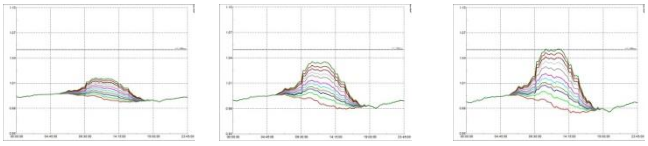
**Fig. 6: Studied Algorithm.**

### *2.6 Represent the analysis findings.*

The simulation results will be determined in different scenarios, according to Table 1. The results represent the specific impact level of PV penetration in voltage profile of the low voltage distribution network as shown in Fig. 7-13. Furthermore, the visualization of findings is going to apparently present the limited range of low voltage distribution network that be able to support the PV rooftop penetration in Fig. 14-15.

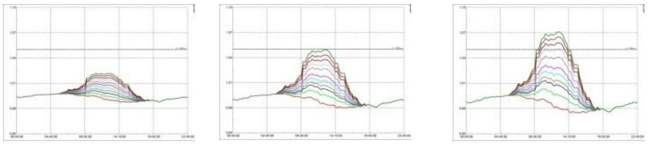
## 3. RESULTS AND DISSCUSSIONS

3.1 Scenario 1 and 2 in Table 1 consider the impacts in summer season during the weekday and weekend. Likewise, both scenarios illustrate that voltage profile will increase higher than 5% of rated low voltage in case of 3 kW PV rooftop installed at every customer (100% PV rooftop penetration), 4 kW PV rooftop installed at 70% of the overall customer, and 5 kW PV rooftop installed at 60% of the whole customer. Those are represented in Fig.7-9 which indicate that the most problems occur at the end of feeder prior to the distribution transformer.



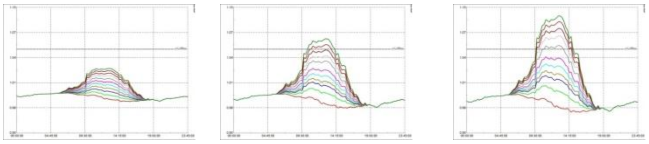
**a) TR bus b) F1-4 c) F2-11**

**Fig.7. Scenario 1/2 : Summer/Weekend with 3 kW PV Rooftop**



**a) TR bus b) F1-4 c) F2-11**

**Fig. 8: Scenario 1/2 : Summer/Weekend with 4 kW PV Rooftop**

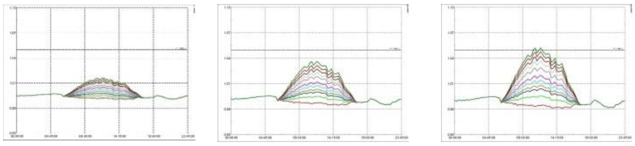


**a) TR bus b) F1-4 c) F2-11**

**Fig. 9: Scenario 1/2 : Summer/Weekend with 5 kW PV Rooftop**

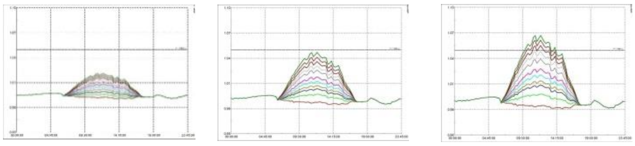
3.2 Scenario 3 represents the case in winter season during weekend period. This indicates that the system is able to support the number of 4 kW PV rooftop installed almost every customer with no voltage profile effect as shown in Fig.10. Similarly, in case of 5 kW PV rooftop installed with the number of PV rooftop penetration less than 80% in Fig.11 will not affect the voltage profile in the system.

3.3 Scenario 4 presents the case in winter season during weekday. The distribution system is able to maintain almost 100 percent PV rooftop penetration with 4 kW PV rooftop size as illustrated in Fig.12. Also, Fig.13 displays the impact of 5 kW PV rooftop installation that the percentage of PV rooftop penetration less than 70 will not affect the system voltage profile.



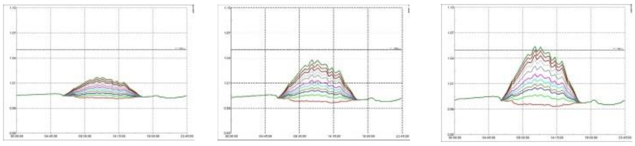
**a) TR bus b) F1-4 c) F2-11**

**Fig. 10. Scenario 3: Winter /Weekend with 4 kW PV Rooftop**



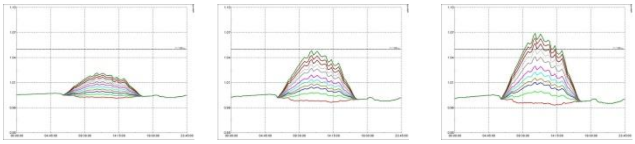
**a) TR bus b) F1-4 c) F2-11**

**Fig. 11. Scenario 3: Winter /Weekend with 5 kW PV Rooftop**



**a) TR bus b) F1-4 c) F2-11**

**Fig.12: Scenario 4: Winter /Weekday with 4 kW PV Rooftop**



**a) TR bus b) F1-4 c) F2-11**

**Fig.13: Scenario 4: Winter /Weekday with 5 kW PV Rooftop**

In order to clearly represent the most impact of PV rooftop penetration in the studied network, the voltage profile visualization in case of summer/weekend with PV rooftop 1 – 5 kW installed 100% of entire customers are illustrated in Figures 14 and 15 for feeders 1 and 2, respectively. It is noticed that the far away feeder from the distribution transformer will have more voltage profile impacts. Fig.14 and 15 showed that the closer feeder 1 could support larger PV penetration than feeder 2.

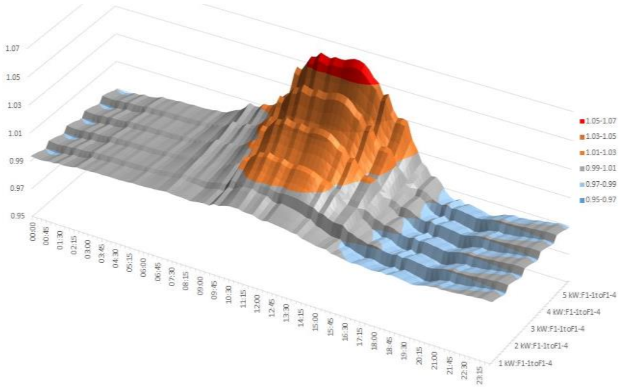


Fig.14: The Visualization of Worst-case Scenario for Feeder 1.

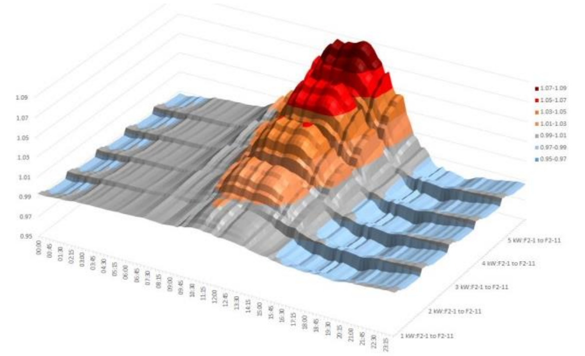


Fig. 15: The Visualization of Worst-case Scenario for Feeder 2.

## 4. CONCLUSION

In conclusion, it is not significantly different between weekends and weekdays in the summer case. The existing system can maintain voltage within the limitation when PV rooftop installation is up to 100% penetration with 3 kW PV rooftop installed size, 4 kW installed with 70% penetration, and 5 kW PV rooftop installed size with 60% penetration. On the other hand, the system could be more tolerant reaching 4 kW PV rooftops installed with 100% penetration, and 5 kW PV rooftops installed with 80% penetration during the weekend in winter. Meanwhile, in a weekday scenario, the system can support less capacity, accounted for a 5 kW PV rooftop installed with 70% penetration. Therefore, the worst-case scenario occurs in summer whether on weekends or weekdays. However, the entire results were simulated in the case of PEA networks by neglecting the interconnection regulations. The adoption of reference to these findings has to take this condition into account.

## 5. FURTHER WORKS

Several methodologies how to enhance PV penetration in low voltage networks has been studied such as using reative power control and on load tap changer with existing transformers [7]. However, the optimal battery capacity and location to minimize the PV rooftop negative impacts will be carried out in further study. The objective functions are to optimize size and location of community battery storage in order to minimize voltage regulation within the studied network. Moreover, the study will identify the optimal price by cost-based pricing methods in accordance with the Thailand context. The results consider the overall cost of both utility and customer as well as demand and supply.

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