Analysis of Hosting Capacity in Smart Distribution Network With Solar PV and EV penetrations

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ABSTRACT

Since solar rooftop PV and EV are upcoming technologies that are continuously increasing in a distribution system because they are a part of the key to developing green energy resources. However, a huge amount of them could provide non-standard system properties into feeders and create technical challenges for the distribution network. This paper presents a quantification of maximum PV and EV penetration for a residential low voltage grid of Provincial Electricity Authority (PEA) and the hourly EV scheduling charge integrating with PV generations in order to increase the numbers of EV penetration is studied and compared. All the simulations to identify the maximum numbers of both PV and EV penetration in this study are conducted in DigSilent program.

KEY WORDS: Distribution system hosting capacity, Maximum PV, and EV penetration. EV scheduling charge, PV and EV synergy, DigSilent.

1. INTRODUCTION

In the context of reaching the environmental target especially on greenhouse gas reduction from electricity generation and transportation is a rapidly growing concern. Consequently, people are interested in Photovoltaic (PV) rooftop and Electric vehicle (EV) more than before. The technological advancements of both PV and EV are a reason for people to install more PV and buying EVs into their houses. Conversely, they also contribute negative impacts that significantly violate the system constraints

Photovoltaic rooftop generation is one of the distributed generation resources from solar energy at the household level that earning much popularity these days. Due to some interesting reasons such as reduce the power demand from the grid, their decreased cost, and less installation constraint, the increasing penetration of PV becomes unstoppable. With this trend of increasing on PV rooftop, it will bring technical problems to the low-voltage feeders. Under this circumstance, these problems can lead to damage to electric appliances in the system. Because of the large number of rooftop-PV feed the power back into the system and create reverse power flow, hence the voltage at the end of the feeder will be higher than the voltage near the distribution transformers.

Currently, In Thailand, the usage of Electric Vehicles has the trend to increase because of some factors such as they use electricity fuel instead of gas fuel, the innovation of battery production technology, developed energy management, the need of reducing the greenhouse effect, especially the increase of gasoline price. So, the more EVs means the more charging station, therefore, increasing energy demand along with the number of EVs in the future.

With the upcoming deployment of solar rooftop PV and EV charging load in near future on the low voltage networks, the network is tending to upgrade or reinforce themselves in order to handle those two technologies. Since the network sometime were not designed to support PV and EV penetration. The maximum limitation of the network’s constraints should be investigated based on Provincial Electricity Authority (PEA) standard.

This study focuses on the quantification of solar roof-top photovoltaic (PV) and electric vehicle (EV) in a distribution system of Provincial Electricity Authority (PEA) within the system constrains. The term hosting capacity is used for define the maximum numbers of PV and EV penetration while maintain the system constrains stay in the limitation.

This paper is organized as follow. Section II is the literature review of maximum PV and EV penetration or hosting capacity calculation. Section III provides the criteria and test system parameters for simulations. Then the algorithms for identify the maximum PV and EV penetration of both non-scheduling and hourly scheduling is presented in Section IV. The result of the simulations is given and compared between non-scheduling and hourly scheduling in Section V, Finally, Section VI concludes all of this study and recommendation for future research.

2. LITERATURE REVIEW

The penetration of distributed energy resource (DER) such as solar rooftop PV is increasing these days consequence the mismatch between the PV production and household consumption which provide the surplus reverse power flow back to the system and disturb the system performances. Therefore, the study of calculation how much DER can be penetrated into a distribution system while maintain the system performance stay in the acceptable range and not modify the original system is necessary. It is called hosting capacity calculation. The general overall structure in hosting capacity calculation consists of 3 main parts 1) limiting factors 2) assessment methods and 3) tool for calculations.

Limiting factors can define as the distribution system properties that are affected by the integration of DER. For example, in case of PV penetration, bus voltage and line overloading can set as limiting factors. For the assessment methods used for hosting capacity calculation depend on the objectives, data, information and perspective of the calculators e.g. the probabilistic type is suitable for customer aspect because of the load consumption, location and size of DER can’t control by the utilities. There are many programs used for hosting capacity calculation both free and licensed programs which are capable of power system simulation and analysis such as PSS Sincal, DigSilent PowerFactory, NEPLAN, and CYME.[1]

Another assessment framework that aims to identify the combined thresholds of increasing EV and PV penetration levels is divided into 2 approaches 1) uncoordinated EV charging 2) coordinated EV charging. In the uncoordinated charging constitutes the simplest charging conduct whereby EV users plug in their vehicles upon arrival to obtain a full battery State Of Charge (SOC) at a fixed charging rate and without any charging control or coordination performed via customer energy management or energy management aggregator. In the coordinated charging intended to assess the EV penetration level and also enable functional synergy between the EVs and the PV distributed generation, while taking into account the distribution network constraints. [2]

3 TEST SYSTEM PARAMETERS AND CRITERIA

Sub-urban grid configuration locates in the outskirt of the city where the main loads of the systems are residential buildings and household loads. Therefore, this kind of area has the highest chance to face technological problems from PV and EV. Because people in sub-urban areas have high income; they have high capability to install both technologies. The layout of the housing estate “Varabodin” located in Pathumtani is selected as a test distribution system for simulations in this study. Characteristics of test system configuration are as following:

3.1. Distribution transformer 400 kVA 22/0.4 kV

Table 1. Distribution Transformer.

Power (kVA)	Vector Group	Short circuit voltage, uk	Copper Loss (kW)
400	Dyn11	5	-

3.2. 2 Distribution feeders

Feeder 1 (30 Households) 95 CV, Cu.

Feeder 2 (30 Households) 120 CV, Cu.

Table 2. Cable Parameters.

Cross section (sq.mm.)	Type	R (Ω/km.)	L (m henry/km.)
95	CV., Cu	0.2469	0.266
120	CV., Cu	0.1961	0.261

3.3. EV Charging Specification

Table 3. EV Charging Detail.

Description	Characteristic
Voltage	220V
Current	16A
Charging Time / Type	6 Hrs / Type 2
All electric range	166 kms

3.4. PV and EV incremental step

The increasing step of PV and EV penetration level in this study is that each step increasing by 3 Units (5% incremental level) i.e. one unit in each phase (Balanced increasing) and randomly the position

Limiting factors are chosen from the system properties as 1) Voltage at the end of the feeder. 2) Feeder current. 3) Transformer loading and the criteria for checking these limiting factors based on PEA's standard as follow:

1. Voltage at the end of the feeder (Vend), must stay in the range of 0.9 – 1.1 p.u. (0.9 p.u. < Vend < 1.1 p.u.)

2. Current in the distribution feeder must not exceed 80% of the rated current of the conductors

3. Transformer loading must not exceed 90% of the rated loading of the distribution transformer

3.5. Load profile and PV generation each house

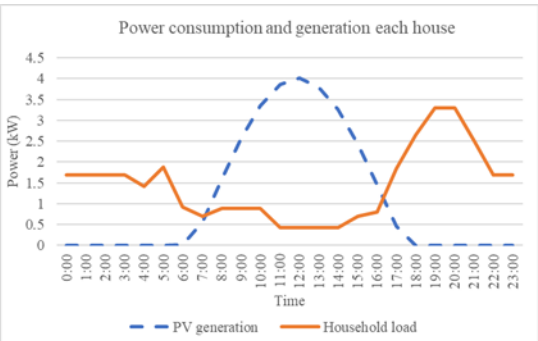

Figure 1.Load profile and PV generation each house.

3.6. Test distribution system circuit in DigSilent.

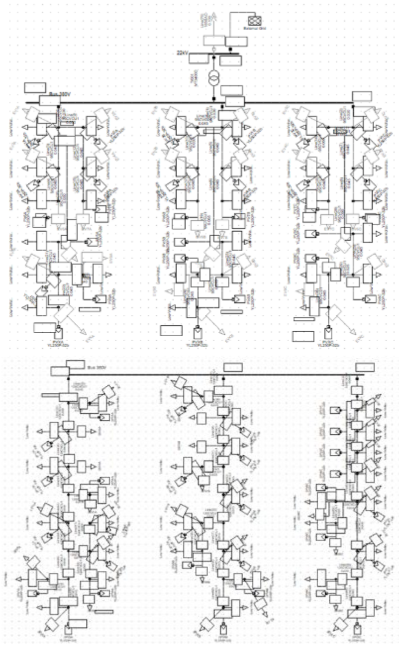

Figure 2.Test distribution system circuit in DigSilent program

4. ALGORITHM FOR MAXIMUM PV AND EV CALCULATION

4.1.Simulation on maximum PV penetration and install capacity per house

4.1.1 According to PEA interconnection code, PV solar rooftop that connect to single phase distribution system is allowed only if the system can supply capacity not more than 5 kW. PV generation profile is modeled as PV system model in DigSilent and PV generation profile at each of them are described in Figure.1 which obtain from PVWatts website. The assessment framework for identify the maximum PV penetration is shown in Figure.3

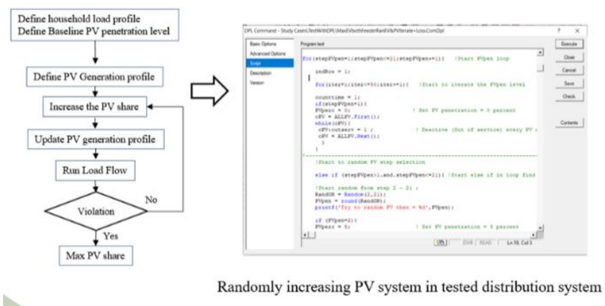

Figure 3. Assessment framework for identify the maximum PV penetration

4.1.2 For identify the maximum PV install capacity in each house, every house installs a rooftop solar PV system (100% penetration level) and then varying install capacity at each house starting from 5 kW DC rating and increasing 1 kW each step until the main factors in the system is/are violated

4.2. Simulation on maximum EV penetration level when there are PV generations.

- In this case, is to simulate the test distribution system with both PV and EV penetration in order to find what are the maximum EV penetration level corresponds to each hour along with each PV penetration level. The flowchart for identifying the maximum EV charging load at each hour is shown in Figure. 4 and for the increasing step of PV and EV penetration level is described in Section 3.

4.2.1 Identify the maximum EV penetration fully charge in a day basis

- The term EV(PV) penetration mean the numbers of EV when there are PV generations exist in the concerned system. Fully charge in a day basis is designed to define the maximum EV penetration on 4 periods of time in a day (In each period cannot exceed this number) The maximum number in each period is defined from the smallest number among the numbers on its period.

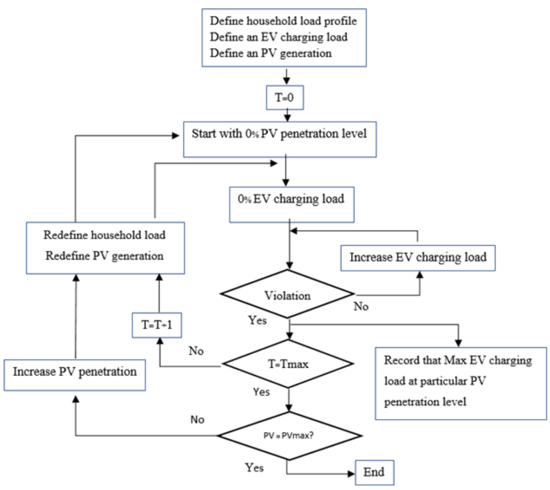

Figure 4. Identify the maximum EV charging load at each hour flowchart

4.2.2 The maximum numbers of EV(PV) penetration fully charge in a day with hourly scheduling.

- The hourly scheduling is one of scheduling charging that use a advantage of available power whether from the system or the surplus PV generation at each hour for managing the EV charging loads by hour to hour. The numbers of EV(PV) penetration fully charge in a day with non-scheduling charge will be used as a base load then hourly scheduling on top of this base load. This study uses the hourly scheduling by first in first serve basis that means EV users who plug-in first will get charged first until fully charge. The flowchart of coordination with PV generation by hourly scheduling is shown in Figure. 5

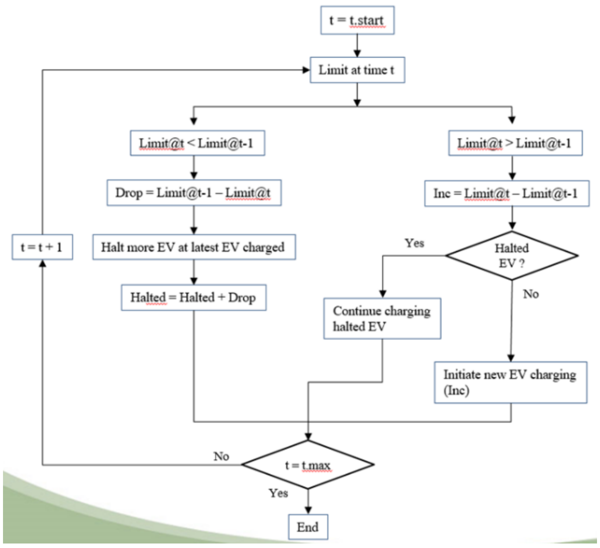

Figure 5. The flowchart of coordination with PV generation by hourly scheduling

5. RESULTS AND DISCUSSION

1. Result for maximum PV penetration and maximum PV install capacity

1.1 Result for maximum PV penetration

Table 4.Limiting Factors at noontime with PV penetration increasing of feeder 1

PV penetration level (%)	Limiting factors		
	Vend	Current of feeder	Transformer loading
	p.u.	(%)	(%)
0	0.996	9.007	7.721
20	1.002	8.014	7.326
40	1.005	23.426	18.144
60	1.008	39.278	29.821
80	1.009	54.940	41.542
100	1.010	70.945	53.639

Table 5.Limiting Factors at noontime with PV penetration increasing of feeder 2

PV penetration level (%)	Limiting factors		
	Vend	Current of feeder	Transformer loading
	p.u.	(%)	(%)
0	0.994	7.835	7.721
20	1.002	6.967	7.326
40	1.010	20.218	18.144
60	1.017	33.730	29.821
80	1.021	47.107	41.542
100	1.022	60.940	53.639

Table 4 and 5 show that the overall maximum PV penetration level in the test distribution system is 60 PVs or 100% penetration level and at the maximum PV penetration level there is no violation on limiting factors

1.2 Result for maximum PV install capacity per house

Maximum PV install capacity per house for feeder 1 is 5 kW/house and for feeder 2 is 6 kW/house. For both feeder 1 and 2 it is limited by the Feeder current as shown in Table 6 and Table 7

2. Result for the maximum EV penetration level when there are PV generations.

2.1. Result for the maximum EV penetration fully charge in a day basis

Table 6. Limiting factors at noon time by PV varying install capacity of feeder 1

PV install capacity	Limiting Factors		
	Vend	Current of feeder	Transformer loading
	p.u.	(%)	(%)
5 kW/house	1.01	73.193	53.638
6 kW/house	1.012	86.558 (Violation)	65.369

Table 7. Limiting factors at noon time by PV varying install capacity of feeder 2

PV install capacity	Limiting Factors		
	Vend	Current of feeder	Transformer loading
	p.u.	(%)	(%)
5 kW/house	1.022	60.94	53.638
6 kW/house	1.028	74.183	65.369
7 kW/house	1.032	86.856 (Violation)	76.976

Table 8. Maximum numbers of EV(PV) penetration fully charge in a day

Time	PV penetration level (%)					
	0	20	40	60	80	100
0:00 – 5:00	30	30	30	30	30	30
6:00 – 11:00	47	47	47	47	47	49
12:00 – 17:00	33	34	34	35	38	38
18:00 – 23:00	10	10	10	10	10	10
Total	120	121	121	122	125	127

Table 8 demonstrates the maximum numbers of EV penetration fully charge in a day on different PV penetration levels; this table provides useful information that recommend the distribution system operator (DSO) to apply some control strategies in order to handle the numbers of EV charging load without any upgrade the system. For instance, if there are 60 EV cars are arriving their home and plug in the cars for charging simultaneously, the DSO should put 10 cars in the evening period (18.00 - 24.00) then delay 30 cars to the midnight to dawn period (24.00-06.00). For the rest of 20 cars DSO should offerings some options to those EV owners for charging in the daytime period (06.00 – 18.00) such as discount electricity rate in daytime period.

2.2. Result for the maximum numbers of EV(PV) penetration fully charge in a day with hourly scheduling.

Figure.6 shows the different numbers of maximum EV penetration between non-scheduling charging and hourly scheduling charging without PV penetration. The numbers of EV fully charge in the nighttime of hourly scheduling is better than non-scheduling by around 7 Cars. In the daytime, the numbers of EV with hourly scheduling is better by 17 cars. Thus, the numbers of EV fully charge in a day with hourly scheduling outweigh non-scheduling around 24 cars. Moreover, the number of EV fully charge in a day is increasing along with the PV penetration level, the more PV exist in the system the more EV can penetrate and higher when apply hourly scheduling charging as in Figure.7

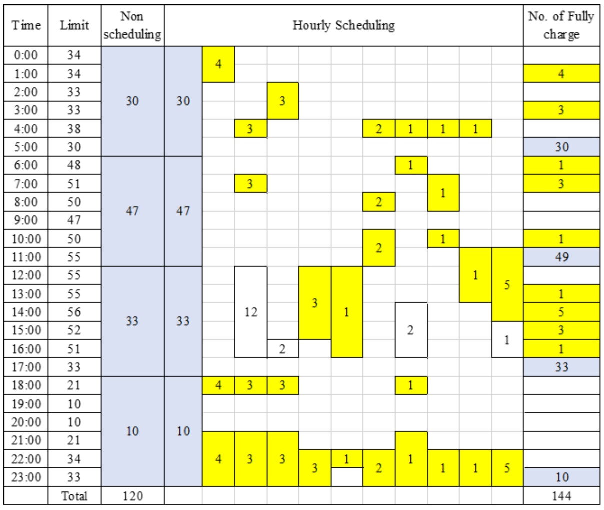

Figure 6. Maximum numbers of EV penetration fully charge in a day between non-scheduling charging and hourly scheduling without PV penetration

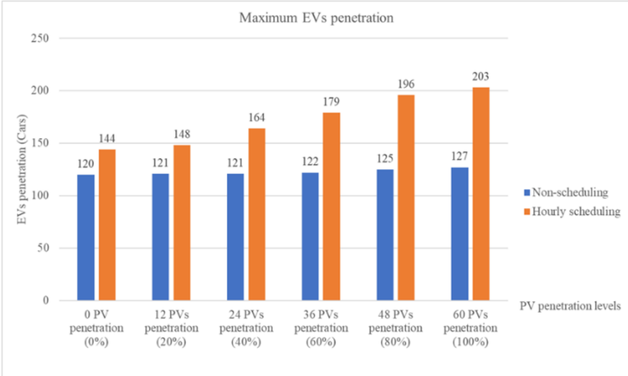

Figure 7. Summary of the maximum numbers of EV(PV) penetration comparison between non-scheduling and hourly scheduling

6. CONCLUSION AND RECOMMENDATION

Results prove that every house can install PV system with install capacity should not more than 5 kW according to PEA standard. The numbers of EV penetration at each hour vary along with the numbers of PV existing in the system and get higher when EV do the hourly scheduling charging. In addition, on both identify maximum PV and EV penetration process, the limiting factor that is most violated is the feeder current. Therefore, the conductor constraint should be the first priority to concern in terms of PV and EV penetration.

To be more realistic, in the identify the numbers of EV penetration method, charging with the random SoC when EVs arrive home or fast charge scenario and also the varieties of EV battery capacity should be considered. In addition, other alternatives to increase numbers of EV(PV) penetration such as battery storage system application or other EV schedule charging should be included to the effectiveness comparison.

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