OPTIMAL PLACEMENT OF EV CHARGING STATION CONSIDERING THE ROAD TRAFFIC VOLUME AND EV RUNNING DISTANCE

BY

SURAT SAELEE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF MASTER OF
ENGINEERING (ENGINEERING TECHNOLOGY)
SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
THAMMASAT UNIVERSITY
ACADEMIC YEAR 2016

OPTIMAL PLACEMENT OF EV CHARGING STATION CONSIDERING THE ROAD TRAFFIC VOLUME AND EV RUNNING DISTANCE

BY

SURAT SAELEE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF MASTER OF
ENGINEERING (ENGINEERING TECHNOLOGY)
SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
THAMMASAT UNIVERSITY
ACADEMIC YEAR 2016

OPTIMAL PLACEMENT OF EV CHARGING STATION CONSIDERING THE ROAD TRAFFIC VOLUME AND EV RUNNING DISTANCE

A Thesis Presented

By
SURAT SAELEE

Submitted to
Sirindhorn International Institute of Technology
Thammasat University
In partial fulfillment of the requirements for the degree of
MASTER OF ENGINEERING (ENGINEERING TECHNOLOGY)

Approved as to style and content by

Advisor and Chairperson of Thesis Committee ______________________
(Asst.Prof.Dr. Teerayut Horanont)

Committee Member ______________________
(Asst.Prof.Dr. Itthisek Nilkhamhang)

Committee Member ______________________
(Dr. Teera Phatrapornnant)

MAY 2017

Abstract

OPTIMAL PLACEMENT OF EV CHARGING STATION CONSIDERING THE ROAD TRAFFIC VOLUME AND EV RUNNING DISTANCE

by

SURAT SAELEE

Bachelor of Engineering, King Mongkut's University of Technology Thonburi, 2011
Master of Engineering, Sirindhorn International Institute of Technology, 2017

The number of the Electric Vehicles (EVs) has been increasing rapidly owing to environmental friendliness. However, it is necessary to prepare an effective charging station infrastructure to support the demand of battery charging in daily energy consumption. Then the electric vehicle charging station must be extensively installed to sufficiently serve a number of EVs. The location of charging station supplying the need of charge and less to disturb to distribution systems are a key factor to make EVs car completely as gas car. In this work, we propose a new approach to select the location of charging station by using the road traffic volume and the driving range from real mobile data log. The proposed algorithm is used to determine the effective layout of charging station based on running out point of electricity. Especially, the voltage impact in distribution line is affected by EV charging behavior which is a serious problem of power quality. A simulator of the power flow analysis is simulated for power quality of the best location that suggests basic guide-line for alleviating the problem.

Keywords: Electric Vehicle , charging station, optimal location, voltage impact.

Acknowledgements

Firstly, the author would like to express his deepest thankfulness to his advisor, Asst.Prof.Dr.Teerayut Horanont for his invaluable advices, enthusiastic guidance, and kind encouragement during the completion of this thesis and also supervision for the entire duration of his study in SIIT. The author would like to give gratitude to the thesis study examination committee, Asst.Prof.Dr.Itthisek Nilkhamhang and Dr.Teera Phatrapornnant for their useful advices and suggestion.

Thanks to all faculties, staff and secretaries in Energy Field of Study for their assistance and encouragement. Grateful thanks to Provincial Electricity Authority for permitting to collect the necessary data.

Thankful expression is given to his friends, classmates and colleagues for their help and moral support during her study in SIIT. Furthermore, special thanks are given to Miss Jittima Limkrayarot and Mr.Kanarat Khumchoo for them helps and guidance.

Last but not least, deepest appreciation is expressed to his family for their most support and understanding during his study in SIIT.

Table of Contents

List of Tables

Tables **Page**

List of Figures

Figures **Page**

Chapter 1

Introduction

1.1 Introduction

Nowadays, the global warming problem is a main problem in the world which is caused by carbon emission from combustion car that can effect to the climate change and the natural disaster. According to Smart grids (SG) provide energy greener than the traditional grids do, while electric vehicles (EVs) are more environmentally friendly than gas vehicles. Hence, the combination of smart grids and EVs would bring huge benefits to the environment.

Accordingly, Provincial Electricity Authority (PEA) announces a bold step into the future with the SG Roadmap project, which will apply advanced technologies to optimize power generation and distribution of renewable energy. The project will also lay the groundwork for a charging infrastructure of EVs throughout Thailand.

The increasing of fuel cost and environmental concerns have stimulated recent take-off of EVs car market. However, the battery technology is the bottle neck of EV users. A small capacity of battery is taken a short driving range about 50-100 kilometers that not deal with the demand of EVs driving range. Thus public re-charging station is very necessary issue to support a short driving range of EVs and help EVs car to complete same as the gas cars. EVs re-charging can affect directly to distribution system. It may impact to a decreasing of power quality profile and voltage level drop below standard. Thus, where is the best location and how to implement be a challenge of this work?

In this work, we purpose selecting the location of EV charging station by using the real behavior of mobile usage in Phuket approached to driving range of EV users and running out point of electricity. In addition to, the re-charging installation location is reminded PEA power quality standard and charging effect to distribution systems.

1.2 Problem Statement

Author purpose to study how to find the location of EV charging station by related with the real behavior of EVs user and concerning a charging impact to power distribution by adaptive using Geographical Information Systems (GIS) from PEA Accordingly, I hope this work can help to implement a model of charging infrastructure with charging stations competing to serve EVs in real transportation systems.

Finally I hope to simulate by using computer applications to determine the best location of charging station that concern with the distance and traffic volume

1.3 Objective of study

(1) To find the optimal placement of fast charging station considering the EVs running out point of energy and EVs running distance.

(2) To analyze the factors of EVs fast charging station affected on the distribution system.

(3) To analyze the voltage levels impact of EVs fast charging stations to the PEA distribution system.

(4) To study a using Monte Carlo simulation to find a charging profiles of EVs and use to analyze the voltage level impact in the distribution system of PEA.

1.4 Scope and Limitations

This work is one shot planning to find the optimal location of fast charging station model in years 2020**.** The data such as number of EVs are forecasted. In the future the behaviors of mobile usage data and charging technologies may change which are affected a changing result too.

1.5 Organization of Research Study

The report will consist of literatures related to the issue about method to find optimal charging station placement, impact on PQ especially impact on voltage drop impact, the theoretical background about distributed systems and also the influence of power flow calculation which are mentioned in chapter 2. In chapter 3, the modeling and methodology are described. The simulation, result and discussion are in chapter 4 and the last chapter is the conclusion and recommendation

Chapter 2

Literature Review

2.1 Literature Review

Tsz Kin Au's study in 2012 show that the impact of the EV connected into the distribution system is the voltage lower than standard and power distribution transformer overload. A study of 26-bus-21-load distribution network is used 3 levels charging power to make the case study. The charging power of level 1 is used power transformer capacity 1.3 kW, the charging power of level 2 is used power transformer capacity 3.3 kW and the charging power of level 3 is used power transformer capacity 50 kW. The simulation results of the load flow calculation by study impact of voltage and the transformer power quality show that the terminal voltage level is lower than the standard. (Lower 0.95 pu.) The simulating impacts of power transformer are divided into 4 cases. Firstly, the result of the no EV penetration model show that electric power is changed in range 1 – 3 MVA following the electricity power customer, Secondly, the result of the 30% electric vehicle penetration in system show that power transformer is loading exceed 9.1 % from base power level. Third case, the result of the 50% electric vehicle penetration in system show that power transformer is loading exceed 21 % from base power level. The last case, the result of the exceed 50% electric vehicle in system show that power transformer is loading exceed 60 %. The result of EVs charging issue will affect to the electrical system which must be managed the power quality unit into the standard.

Due to the internal combustion engine are affected directly to environment, low efficiency of cars and the increasing price of fossil fuels, So that EV technologies are developed (Vliet et al., 2011). EV battery is a key component to store energy for use as fuel for driving. To charge an electric vehicle for supporting a long distance are required. So that EV will have consider the particular electricity Authority that delivers electrical power to the EV user and has to be plan to measure the impact that will occur due to the EV charging station. (Shadidinejad et al., 2012)

Veneri et al. (2012) said the detailed mode of EV chargers have 4 modes. First mode, the electric vehicle charging via AC at 50-60 Hz voltage up to 250 volts alternating current for the 1 phase system and voltage up to 480 volts alternating current, 3 phase system using plug with up to 16 amperes and protection standards set charging is slow (Slow charging) for charging at home. Second mode, the electric car charging via AC voltage is the same as the first model using plugs up to 32 amperes and protection systems as standard and a function to communicate with the control system of supplier that is slow (Slow charging) for charging at home. Third mode, the EV charging systems with AC power supply and features of specially charging and electric currents up to 63 amperes and protection systems as standard and functions to control the user interface to the distribution system permanently. The format is a Semi-fast charging for a charging group or the charging station. The last mode, the EV charging converter to change the direct current into alternating current power before the EV fast charging takes time about 20-30 minutes for converters. Battery charging from 0-80 percent is in less than 15 minutes to be called Ultra-Fast Charging. Fast charging for example, as converters of CHAdeMO charger for charging currents up to 125 amps at a given voltage, 500 volts.

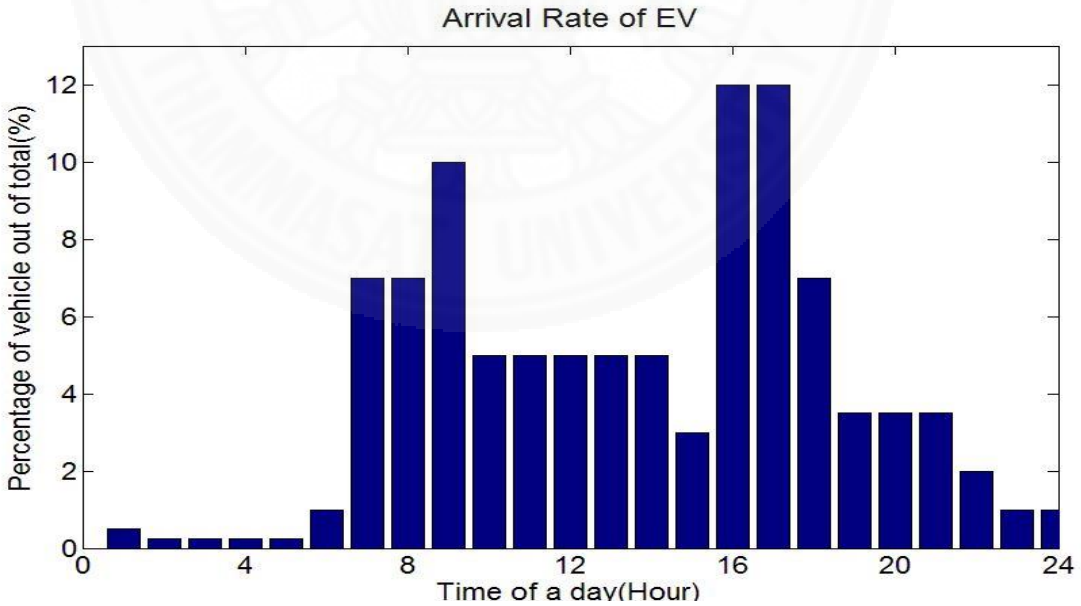
The EV charging standard SAE J1772 (Liu et al., 2011) divided the charging of EV on the voltage level and power in table 2.1

Table2.1: Power level of the EV (kW)

Type	Power Level (kW)
Level 1 120 V AC	1.2-2.0
Level 2(low) 208-240 V AC	2.8-3.8
Level 2(high)208-240 V AC	6-15
Level 3 208-240 V AC	> 15 – 96
Level 3 DC charging 600 V DC	> 15 – 240

Source: Liu *et al*. (2011)

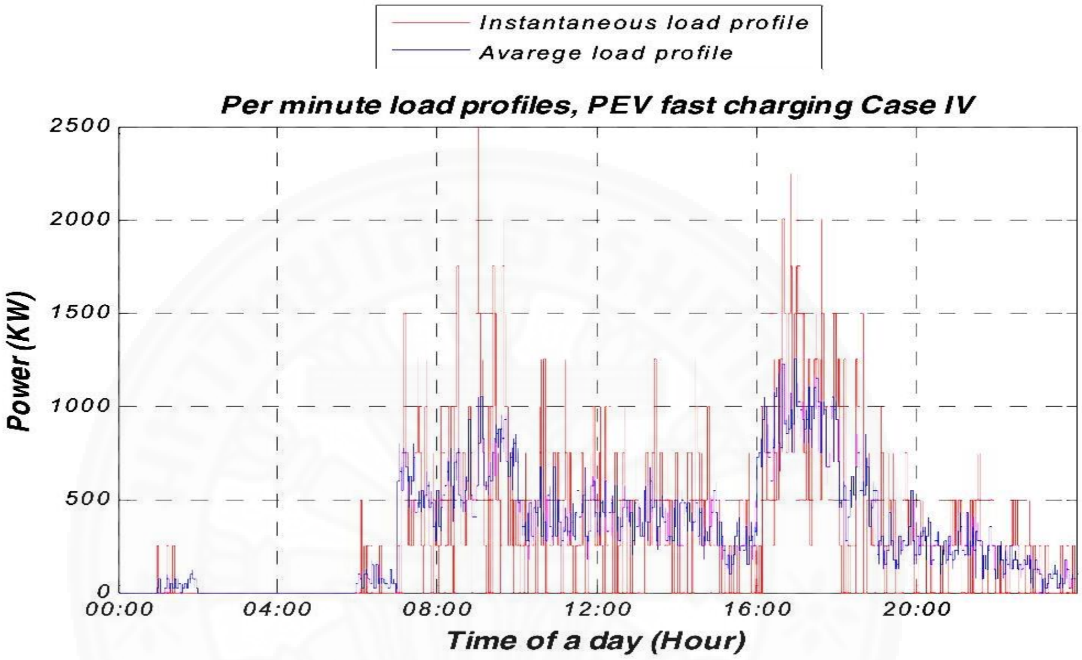
The behavior of the electric car driver, who use serviced at a fast charging station a day (Yunus et al. 2011) has studied the effect on the both of voltage system in medium voltage system and low voltage system. Based on survey data, the demand charging of EVs are captured as the Figure 2.1, the demand of charging will start in the morning (go to work period) and again in the evening (back home period) which relate with the behavior of life-cycle time of day. These periods have peak load demand which may be resulted of highest voltage drop in a day.



Source : Yunus *et al*. (2011)

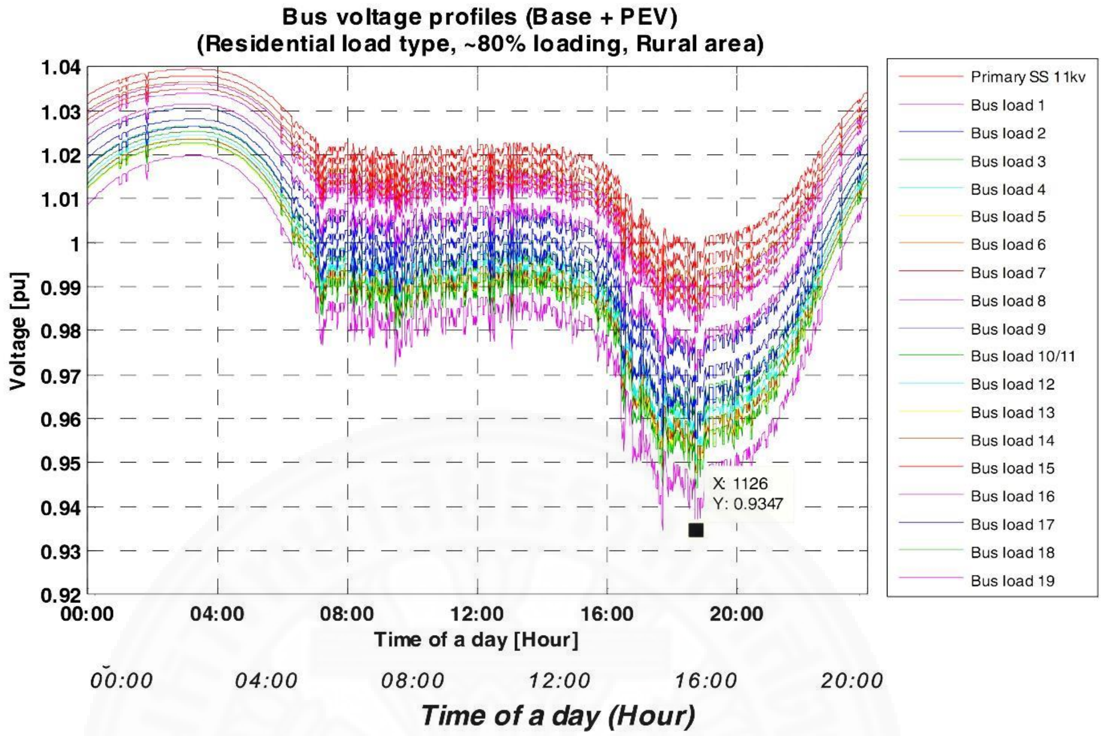
Figure2.1 Time of a day to recharge the EV fast charging stations

The EV fast charging profile can change the power consumption in each day as the Figure 2.2. The changes in EV fast charging will cause voltage ripple on Figure 2.3 and Figure 2.4, which the voltage changes will affect electrical components such as the use of electric power transformer overload, That the electric authority must to find solutions to solve the problems such as installing equipment to maintain voltage levels.



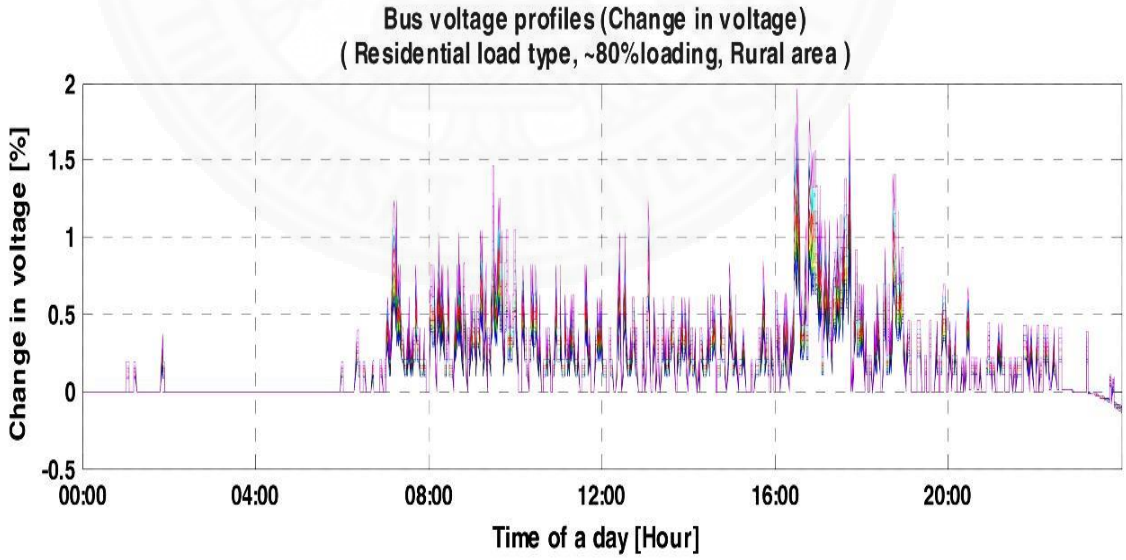
Source: Yunus et al. (2011)

Figure2.2 Change of the power electric vehicle fast charging in one day



Source: Yunus *et al*. (2011)

Figure2.3 Voltage fluctuations into electrical system



Source: Yunus *et al*. (2011)

Figure2.4 Change of voltage fluctuations into electrical system

The problem of electric cars when it into the power grid system.

When EVs car comes into the system will run the problems to the distribution system, (Papadopoulos et al., 2009) as the following,

(1) Voltage Drop

To charge an EV can add the load demand in the electrical system, thus is causing of the voltage drop in the electric system.

(2) Power transformer overload

In the current, power transformer are designed to serve the power consumption for supported load demand less than 80 percent of power transformer maximum load. In the future, the electric cars will need to be improved, although the transformers in the distribution system can load up to 160 percent.

(3) Distribution of overload of low voltage lines.

When the rechargeable car can be overload in distribution line. Especially, during the maximum load demand and a lot of rechargeable car charging in the same period will have more distributed the electric power.

(4) Losses increase

Charging electric cars will make a net loss in the distribution system increasingly. Charging position, charging time and the number of electric vehicle are a primary factor in causing the losses increase.

(5) Frequency Drop

Charging an EV is an increase the load, so it affects the frequency of the electrical system. The problem is more serious when the system is in a state Islanding Mode.

(6) Voltage imbalance

EV chargers in household are mainly charged in the single phase, so it is likely to cause of voltage imbalance.

(7) Harmonic currents

Charging the battery of the device could cause problems harmonic currents. From gathering information about the impact of electric vehicle have to study and compile the relevant theory.

2.2 Background and Theory

2.2.1 Geographic Information System

Geographic Information System (GIS) is about spatial data in a computer system. The set of data and information are related with the spatial position location as the number corresponds to a location coordinate in latitude, longitude position information. The databases that are associated with spatial data would be displayed on image or map for easier to translation and interpretation of space. GIS is a system of stored information on the computer which can be interpret other location conditions to linked the geographical area related to the ratio of the distance and spaces on the map and the GIS information in the spatial data can be referred to the existence of the earth by geocoding (Geocode), which will refer to Earth's surface in coordination number to the reality space on the ground or map, such as road, building, etc. According to the house address information (including house number Soi province, region and zip code), we can know this house is located at a place on the earth, because every house has a unique address.

2.2.2 A feature of Nissan Leaf

A feature of the EV of Provincial Electricity Authority (PEA, 2012), Nissan Leaf, is according to Table 2.2.

Table 2.2: A feature of Nissan Leaf

Feature	Details
Distance	160 km
Electric motors	AC motor with 80 kW
Battery	Laminated Lithium-ion amount 48 set, a capacity of 24 kWh.
The battery charge	Load Speed DC 50 kW (0-80%) , <30 minutes The charge from their homes AC 3 kW, 8 hours.

Source: PEA (2012)

2.2.3 Patterns of connection and installation of charging stations.

The connection pattern of charging stations in the distribution is shown in Figure 5. The quick charger of electric vehicle is connected to the distribution system through transformers for changing voltage levels to suitable charger voltage level. Then, an inverter helps to modifies voltage from the alternating current to direct current. The installation of the charger pattern may not occur same as a simple connection pattern in figure 2.5, It can be install the EV charger more than one charger, in order to the charging station can accommodate the number of electric vehicle. However, the installation of EV charging stations are applied directly increasing the transformer load. The big of charger can be taken a big voltage profile change and risk to over loading of power transformer. The power profile will be decrease from standard when it takes a peak demand period to charge. Thus, the optimal connection patterns are considered according to the number of EV area and the accommodation sizing of power transformer.

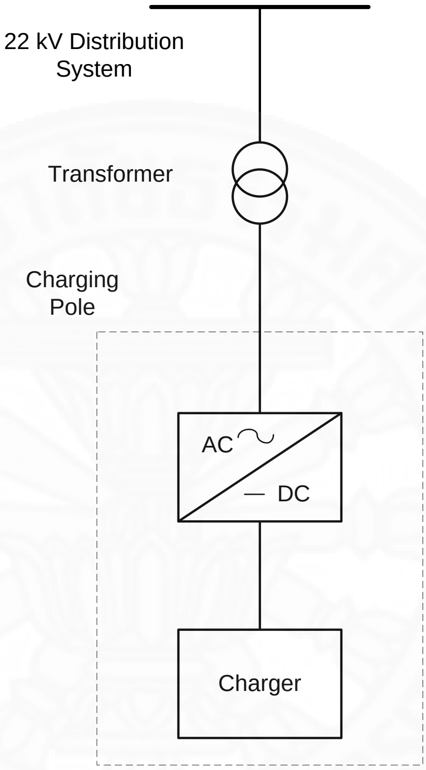


Figure2.5 connect the charger to the electrical distribution system.

2.2.4 Types of electric vehicles

EVs considering with batteries to drive can be divided into 4 types.

(1) Hybrid electric vehicle (HEV)

Hybrid electric vehicle (HEV) combines both of a combustion engine and an electric motor. When the vehicle break or slow down, the production of electricity are stored in batteries and the electrical energy are used to help drive the vehicle to reduce fuel using, HEV vehicle can save the energy between 10-50 percent as depending on driving range and driving behavior.

(2) Plug-in hybrid electric vehicle (PHEV)

Plug-in hybrid electric vehicle (PHEV) is a hybrid vehicle that can store electrical energy increasing, which can be driven by using electric power for a distance about 20-80 km. PHEV vehicle can reduce to use the fuel consumption up to 70 percent.

(3) Extended-range electric vehicle (EREV)

Extended-range electric vehicle (EREV) is a supreme of PHEV vehicle, which are more running distance to with electric power from the battery than PHEV.

(4) Plug-in electric vehicle (PEV)

Plug-in electric vehicle (PEV) is an electric vehicles which only have the electric motor, the vehicle was moving by using only electrical energy in the battery and no other engine in vehicle.

2.2.5 Patterns of electric vehicle chargers

An EV charging has many levels depending on how long it takes time to charge and electrical power systems of charger using. In this example has used the Mitsubishi i-MiEV to charge in different levels of charging mode (Yunus, 2010). The detail can be shown in Table 3.

Table2.3 : The patterns of electric vehicle chargers

Charger Mode	**Power Systems**	**Voltage (V)**	**Current (A)**	**Power (kW)**	**Required time (min)**
Slow charging	1 phase AC	230	6	1.4	558
	1 phase AC	230	10	2.3	336
Quick charging	1 phase AC	230	15	3.5	222
	3 phase AC	230	16	11.0	70
	3 phase AC	230	32	22.1	35
AC Fast charging	3 phase AC	230	63	43.5	18
DC Fast charging	DC	330	151.5	50	15
DC Fast charging	DC	330	303	100	8
	DC	330	606.1	200.0	4
	DC	330	1212.1	400.0	2

Source: Yunus (2010)

2.2.6 PEA planning criteria of power system

In this study has analyzed the impact of the installation of EV charging stations in voltage criteria of distribution systems, so that it has made a detailed study on standards and criteria of the PEA electrical system. The criteria of voltage can be shown in Table 2.4.

Table2.4 : The PEA's voltage criteria

Voltage (V)	Normal		Urgent	
	Lowest (V)	Highest (V)	Lowest (V)	Highest (V)
230,000(1)	218,500	241,500	207,000	253,000
115,000(1)	109,200	120,700	103,500	126,500
33,000(1)	31,300	34,700	29,700	36,300
22,000(1)	20,900	23,100	19,800	24,200
380(2)	342	418	342	418
220(2)	200	240	200	240

Note: (1) A voltage maximum and minimum 5 percent.
(2) A voltage maximum and minimum 10 percent.
Source: PEA (2008)

From the regulation of grid connecting in voltage criteria, the connecting of charging station must be supported level 22 and 33 kV of PEA distribution systems, can keep the same voltage level standard of the PEA and not affect to the reliability of power system. The stability of the power system must not reduce to a crisis criteria. The voltage level changing must not exceed ± 5 percent of the nominal voltage standard.

2.2.7 The distribution systems of the PEA.

In general, the distribution system of PEA has electrical source from Electricity Generating Authority of Thailand (EGAT) and distributed the electrical power in radial system via a substation. The substation is mainly combined with 2 transformers (115 / 23.1 kV) for transferring power supply from high voltage into medium system, which a transformer can supply 5 electric circuits or 5 feeders, as show in figure 2.6.

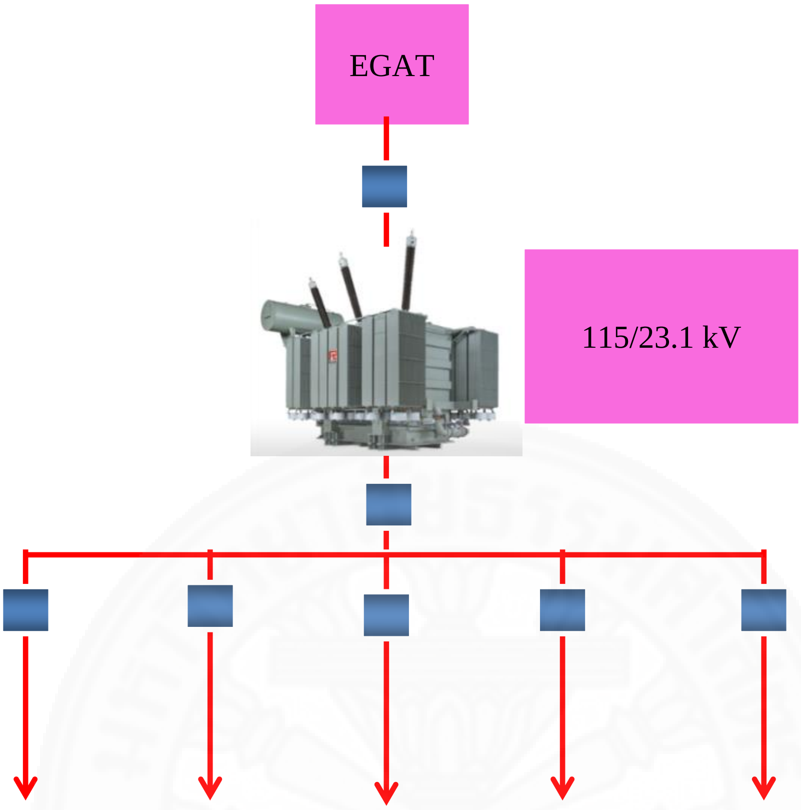


Figure2.6 Pattern of power distribution systems 22 kV of PEA.

2.2.8 Behavior of the vehicle and the stage of charge

State of Charge (SOC) is one of the main issues of EV chargers and use to produce the profiles of charging. SOC is associated with the usage of vehicles and distance electric car driving range, which is based on the behavior of the electric vehicles, traffic conditions and other factors.

The simulation of remaining battery is associated with the usage of vehicle, that has been used data of vehicles usage in Seattle, Washington, United States (Clark et al., 2003), shown in Table 2.5, Almost vehicle are driven in a driving range during distance between 4.1 to 8.0 miles, and little vehicles driving range during the distance between 28.1 to 32 miles.

A result can be used to determine the cumulative probability density function of the vehicles driving range in one day and convert into the status of the battery remaining. This research, we have assumed the SOC of the battery remaining in the start by following step.

(1) The power consumptions of the electric vehicle are directly proportional with the traveled distance.

This research determines that the electric car sizing is 24 kWh and can take a distance about 47 miles (80 km) and the traffic volume and other facilities are according to Table 2.6.

(2) The stage of charge (SOC)

Finding SOC can be following to the equation (1)

$$SOC = \frac{D_{\max} - D_{drive}}{D_{\max}} x100\% \tag{1}$$

Where,

SOC is the stage of charge (%)

$D_{\max}$ is distance of electric vehicle can drive max.

D_{drive} is distance of electric vehicle driving within a day.

Table2.5 : The commuting distance of residence change status

Commute (Miles)	All (%)
0 - 4.0	19.19
4.1 – 8.0	22.95
8.1 – 12.0	16.67
12.1 – 16.0	13.77
16.1 – 20.0	9.37
20.1 – 24.0	6.07
24.1 – 28.0	4.59
28.1 – 32.0	2.69
32.1+	4.70

Source: Clark *et al*. (2003)

Table2.6 : The distance of electric vehicle (Nissan Leaf) can drive on different conditions.

Condition	Velocity (km/hr)	Temperature (°C)	Distance (Miles)	Air conditioner
Ideal	61	20	138	Off
In the city	39	25	105	Off
On freeway	89	35	70	In use
Traffic Jam (winter)	24	-10	62	Heater on
Traffic Jam	10	30	47	In use

Source: Loveday (2010)

2.2.9 A simple simulation distribution system

The power distribution system can be simulated in Figure 2.7, the obtained voltage drop can calculate by equation (2).

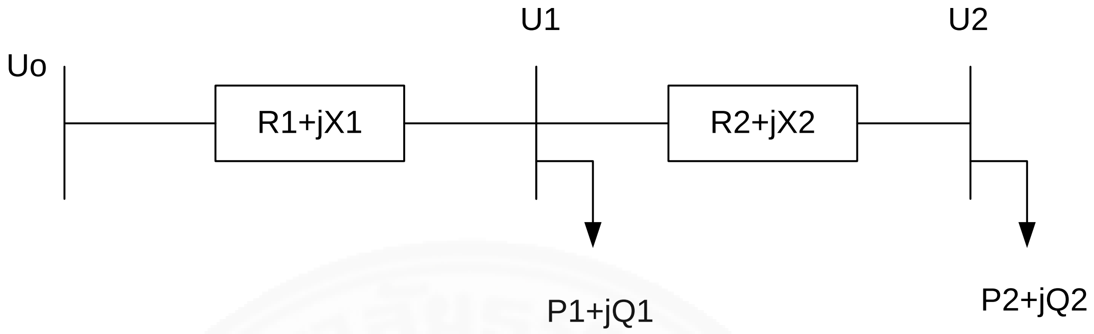


Figure2.7 The simple load distribution system simulation

$$\Delta U_i = \frac{P_i R_i + Q_i X_i}{U_N} \tag{2}$$

Where,

ΔU is the voltage drop due to load at bus i.

P_i is real power of load at bus i.

R_i is the resistance of the bus line between i and i-1.

Q_i is reactive power of load at bus i

X_i is reactance of bus line between i and i-1

U_N is a system nominal voltage

From relationship of equation (2), when the voltage at the second bus to the bus voltage by Equation (3).

$$U_2 = U_0 - (\Delta U_1 + \Delta U_2) = U_0 - [(\frac{P_1 R_1 + Q_1 X_1}{U_N}) + (\frac{P_2 R_2 + Q_2 X_2}{U_N})] \tag{3}$$

We add the electric vehicle to the electric power system shown in Figure 2.8. It will be the second bus voltage by Equation (4).

$$U_2 = U_0 - (\Delta U_1 + \Delta U_2) = U_0 - [(\frac{(P_1 + P_{charger})R_1 + Q_1 X_1}{U_N}) + (\frac{P_2 R_2 + Q_2 X_2}{U_N})] \tag{4}$$

Where,

ΔU is voltage drop due to the load at bus i.

P_i is loading real power at bus i.

R_i is the resistance of the bus line between i and i-1.

Q_i is virtual load electric power at bus i

X_i is reactance of bus line between i and i-1

$P_{Charger}$ is electric power to recharge electric vehicles.

U_N is nominal system voltage

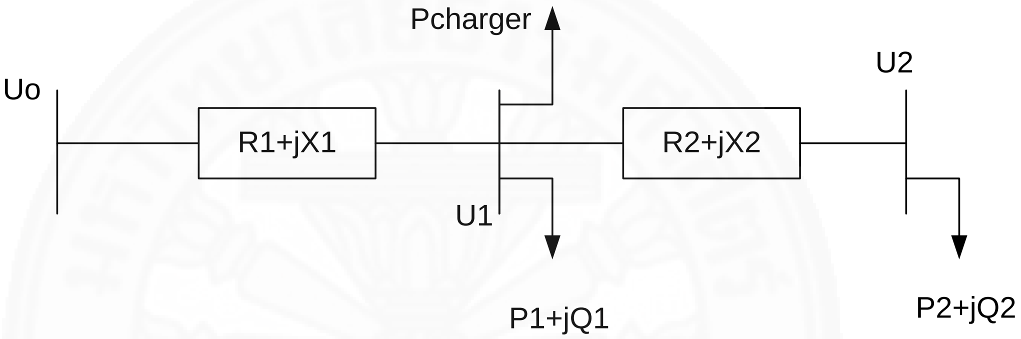


Figure2.8 A Simulation model of the load distribution system

Chapter 3

Equipment and Methodology

3.1 Equipment

(1) Computer Notebook
(2) Window 7 Professional
(3) Microsoft Office
(4) MATLAB
(5) DIgSIENT Power Factory 14.0.523
(6) Q-GIS
(7) PEA GIS Software

3.2 Methodology

3.2.1 Review related Paper

(1) To study many paper or literature related with methodology to find the optimal location of EV charging station and affect from EV charging station
(2) To study the standard of power quality in PEA distribution system for support EV charging and affect from EV charging Station

3.2.2 The estimation number of charging station

In this work, Author set up a scheme to implement charging station for Phuket city in year 2020. Based on a data of the Department of land transport of Thailand (DLT), Estimated that the register number of vehicles in Phuket on 31 March 2015 is about 441,120 vehicles. In addition to, Thailand Automotive Institute (TAI) have forecasted about 5% of the increasing cars in 2020. Asia Pacific Automotive Forecasting expected that all vehicles will be EVs about 3.5% in 2020. Therefore, author will estimate the number of EV in Phuket in 2020 about 16,000 vehicles and using this number of EVs as the fundamental data of number of EVs in Phuket city in 2020.

According to equation (5), author will determine the number of charging station using the following equation;

$$N = \frac{P \times E \times l_{fv} \times chg\_time}{s \times f \times q \times Cap \times l_f \times \cos\theta} \qquad (5)$$

Where
P is the average charging power for each vehicle
E is the total number of EVs that must be charged per day
l_{fv} is the daily load factor of vehicle
s is the service time of EV charging station
chg_time is the charging period of each vehicle
Cap is the charging station capacity
q is the charging efficiency
f is the demand factor of charging machine
lf is the daily load factor of charging station
$cosØ$ is the power factor of charging station.

Table 3.1: Parameter of traffic flow and electric vehicle charging station

Name	Parameter	Unit
Load factor of charging station (l_f)	0.95	
Load factor of EV car (l_{fv})	0.5	
Service time of EV charging station (s)	18	hour
charging time of each vehicle (chg_time)	0.25	hour
Charging station capacity (Cap)	800	kVA
Power factor ($cosØ$)	1	
Charging efficiency (q)	0.9	
Demand factor (f)	0.95	
Number of EV (E)	16,000	vehicle
Average charging power for each EV (P) (Nisleaf @SOC 0 to 80)	50	kW

Followed by equation (5) and using the parameter from the table 3.1, the optimal number of charging station in Phuket can estimate about 10 stations. In this research, please note that the experiment is set up to find the best 10 locations of electric vehicle charging station.

3.2.3 Methodology to find the optimal placement of EVs Charging Station

We propose a new approach by used the mobile log data to select the optimal place of charging station. By a long-term of the collecting mobile data log in Phuket, author could estimate the origins and destination of location hence use them to simulate the real mobility for each EV running path in a day. The open source of routing software, such as PG-routing software, is used to calculate the distance of energy running out points. Overall step will follow as the following.

(1) Using mobile log data to generate the Real behavior of EVs Using

Form long-term collecting mobile usage data in Phuket, author could know the location of each mobile using in a day that could estimate into the real behavior of traveling trip of day of EVs using. The 2 point of frequently location has used to determine to start and end point of each EV, and assume to home and work location for each EV traveling a day. In this step illustrate followed figure 3.1.

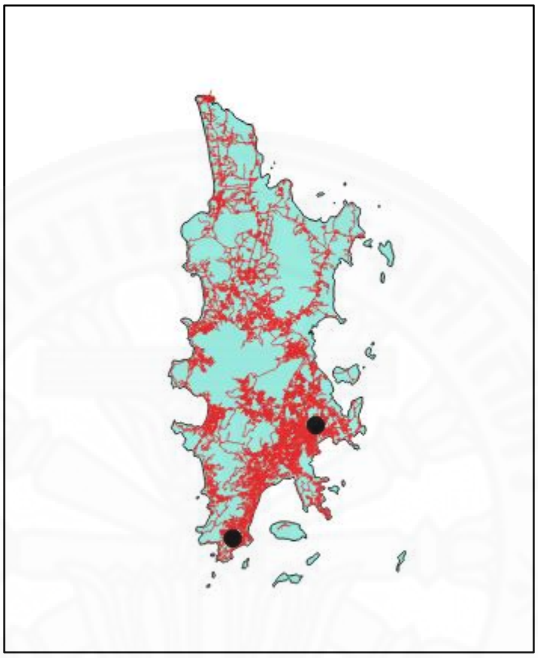


Figure3.1 The estimation location of each EV start and end point

(2) Creation the real traveling path by using the start and end location of each EV

From 2 point of location author could make up the traveling route of each EV. Based on Phuket traffic layout is used to input into x-y data (start and end location) for finding the real route of EVs daily traveling pattern in Phuket. The EVs daily traveling pattern is used to simulate to determine the point of EVs running out. Which EVs traveling path is calculate base on the dijktra's shortest path algorithm.

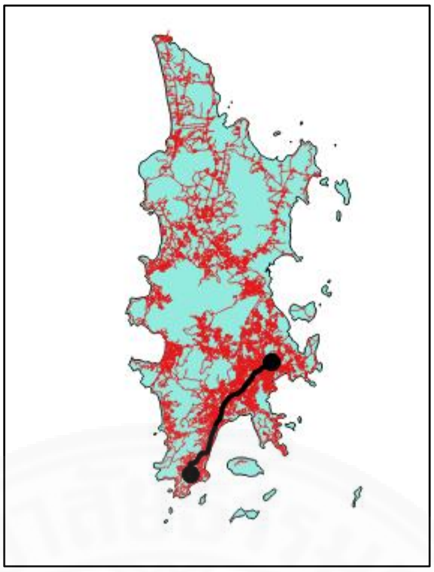


Figure3.2 the creation route of real traveling trip of each EV

(3) Simulation of EV running out point

The assumption is used to determine to all EVs also fully charge (SOC 100%) at home, and then will be decreased according to the traveling distance of each EV. Until battery remaining is 40 percent of SOC which is considered the running out point of electricity in this work.

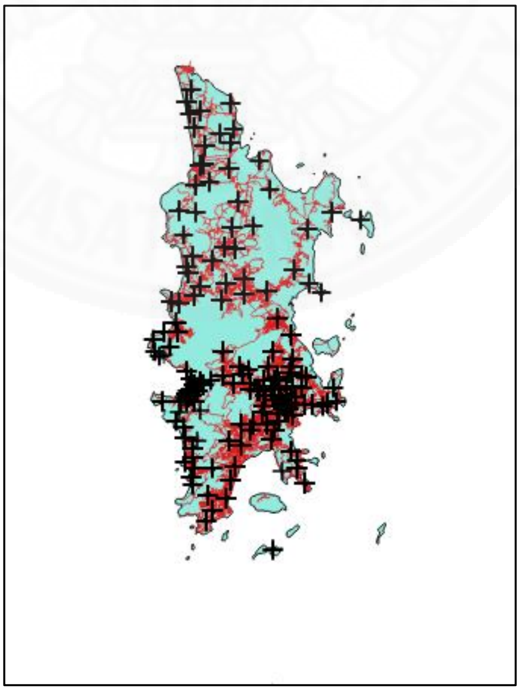


Figure3.3 EVs running out point layout

(4) The simulation result of running out point of electricity

The simulation result of running out point of electricity is used to determine the selection point of charging station by using clustering K-mean algorithm. Author utilize Phuket GIS map to create the charging station layout. The QGIS software is used to illustrate the map by following these steps

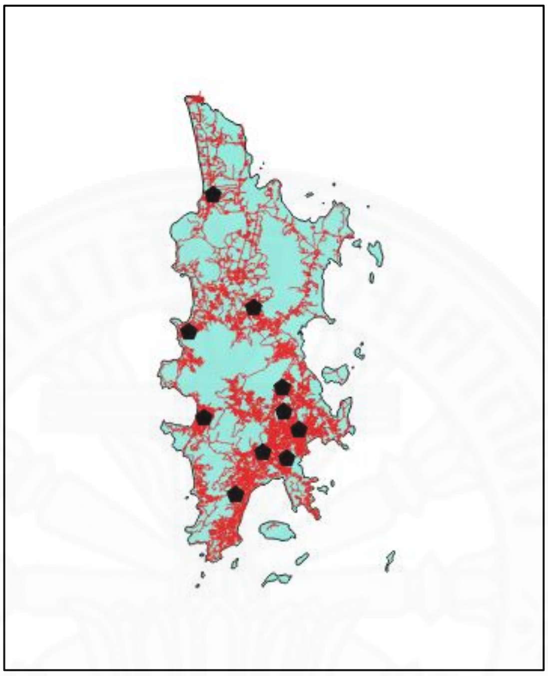


Figure3.4 Charging Station layouts

3.2.4 PEA distribution Systems in Phuket

3.2.4.1 Electrical distribution systems in Phuket

Normally, the distribution system in Phuket is similar to all of PEA distribution network system which receive power source from EGAT and supply in radial system. In Phuket, there are 7 substations that consist of Phuket1 substation (PKA), Phuket2 substation (PKB), Phuket3 substation (PKC), Talhang substation (TLG), Patong substation (PAT), Patong compact substation (PAV), and Karhon substation (KRN). All substations is combined with 2 power transformer size 50 MWA (115 / 33.9 kV) supplying power system 33 kV which a unit transformer could supply 5 feeder , as a result in figure 3.5.

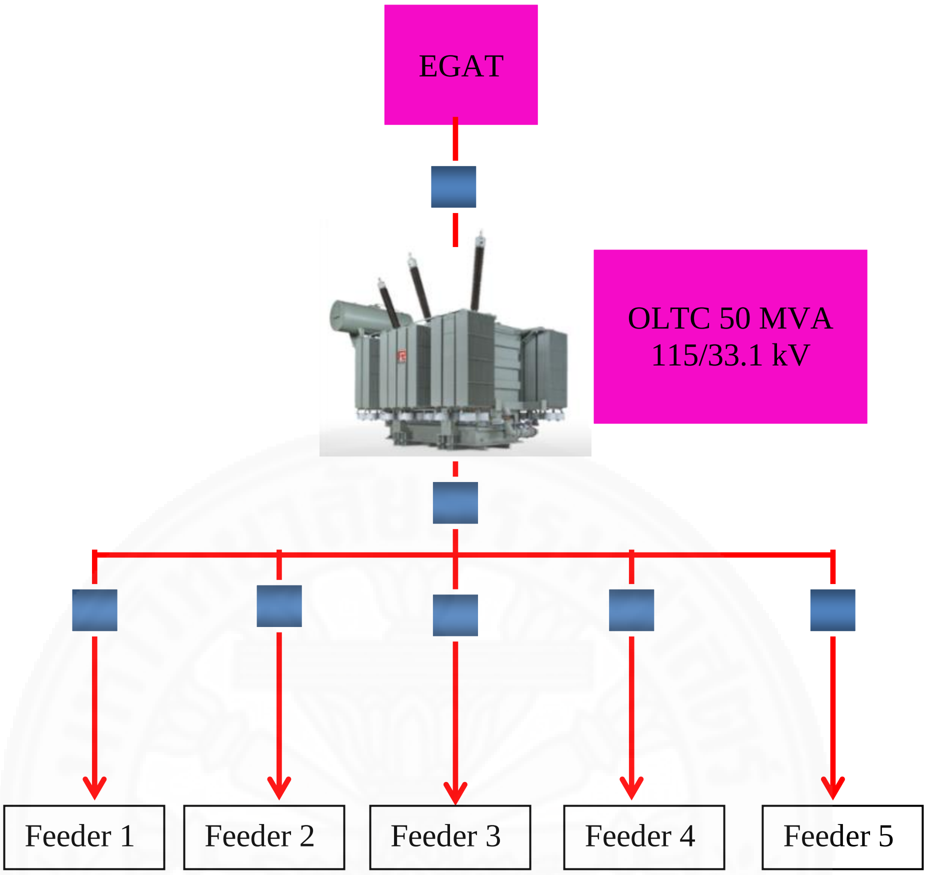


Figure3.5 Phuket distribution systems

3.2.4.2 The GIS data base of distribution network.

This work, author use the GIS distribution network from PEA. GIS data are following the real construction of PEA distribution systems which consist of the layer of pole, distribution transformer, power distribution line, traffic route etc.

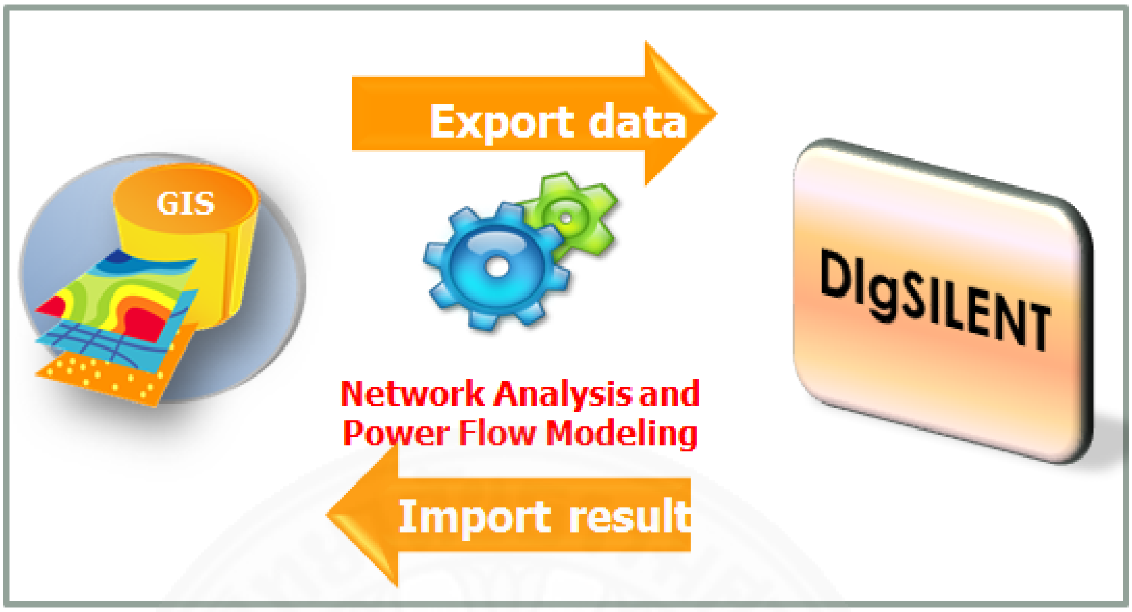


Figure3.6 PEA’s network analyzing systems

From PEA GIS data base, there are many distribution data, so that author will specify only the best of 10 locations that refer to the charging station location to export into file.dz for calculating the power flow in DigSILENT PowerFactory software. As illustrated following figure3.6.

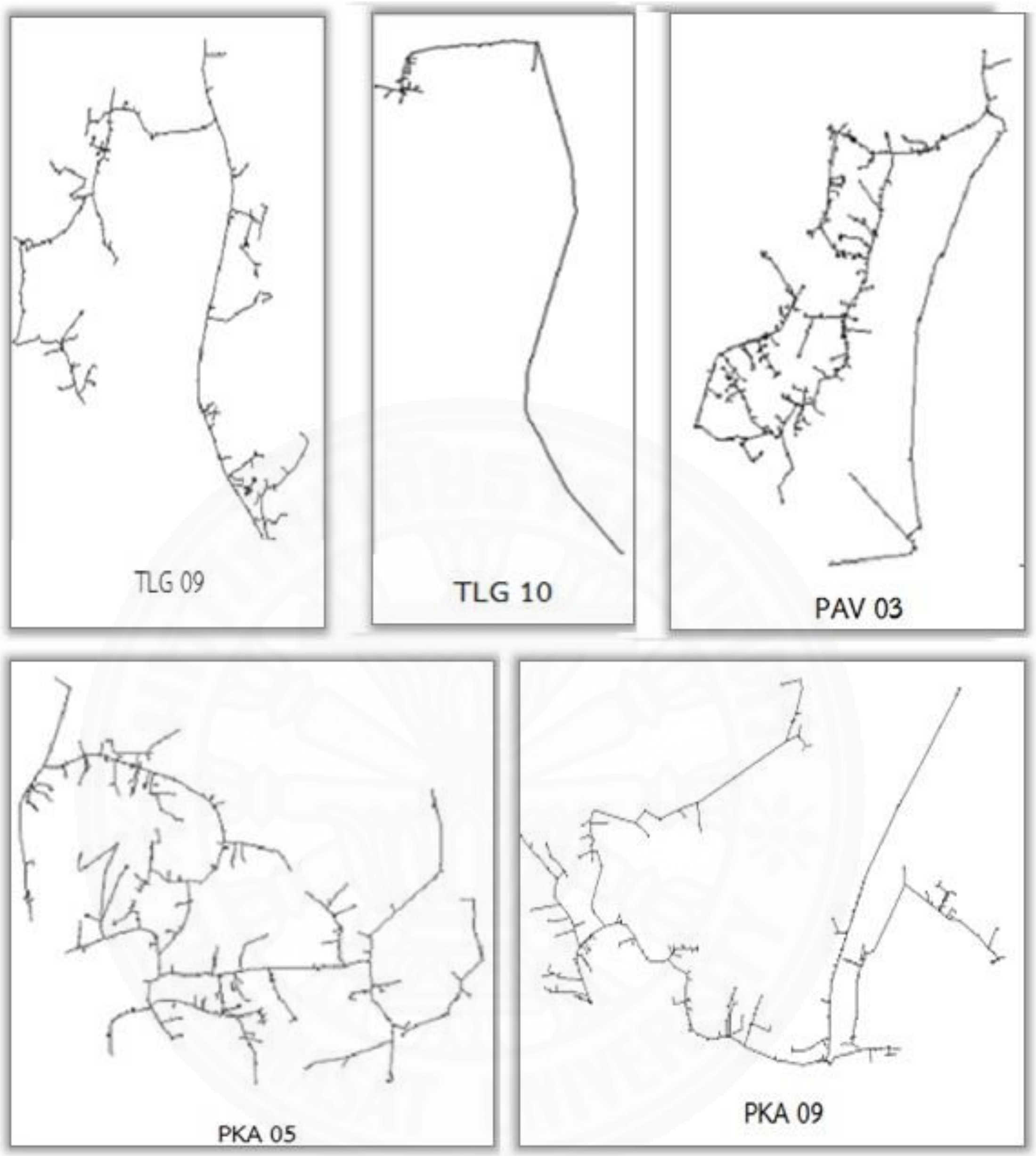


Figure3.7 Phuket distribution systems

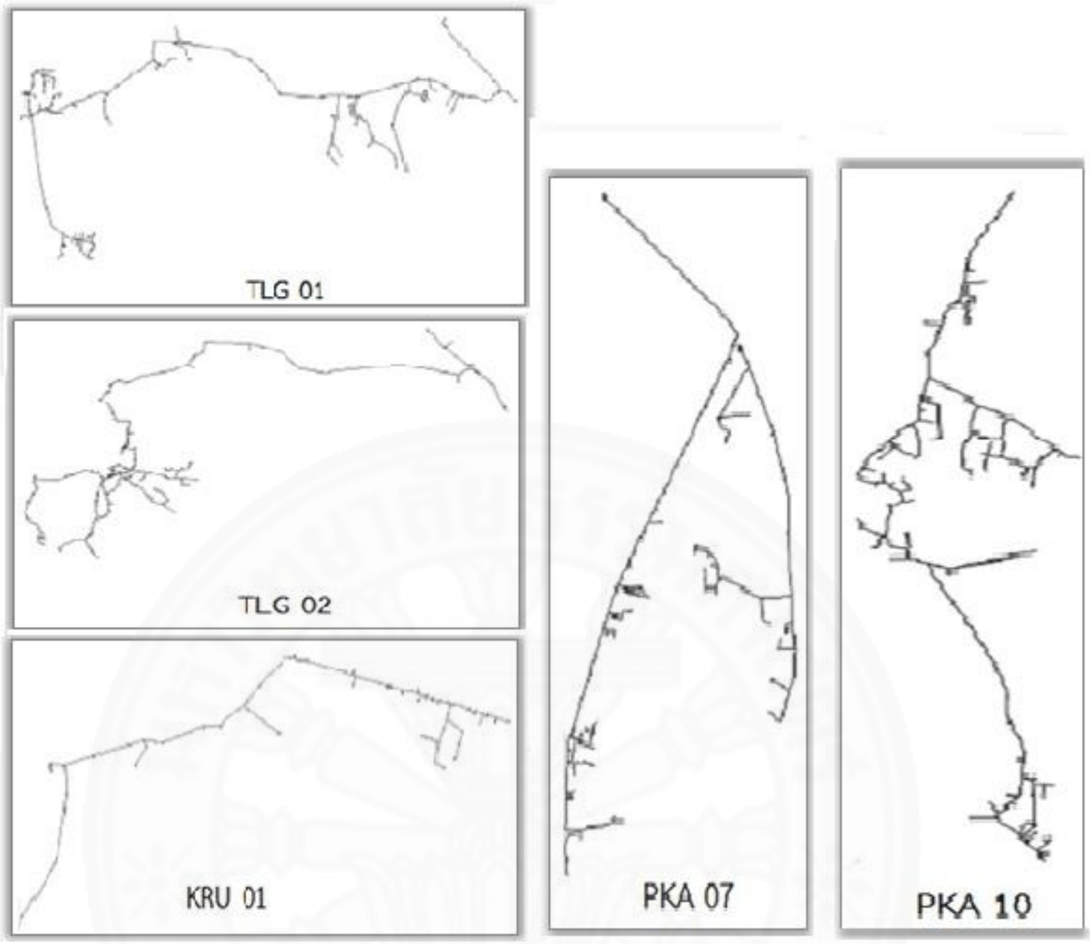


Figure 3.8 Phuket distribution systems (cont.)

3.2.4.3 Load Profile in Phuket

Due to Phuket is traveling city, there are many establishment at night time, so that almost daily load profile have peak demand at night time in Phuket. This thesis is selected TLG02 daily profile to use like a base load profile as shown in figure 3.9 and table 3.2.

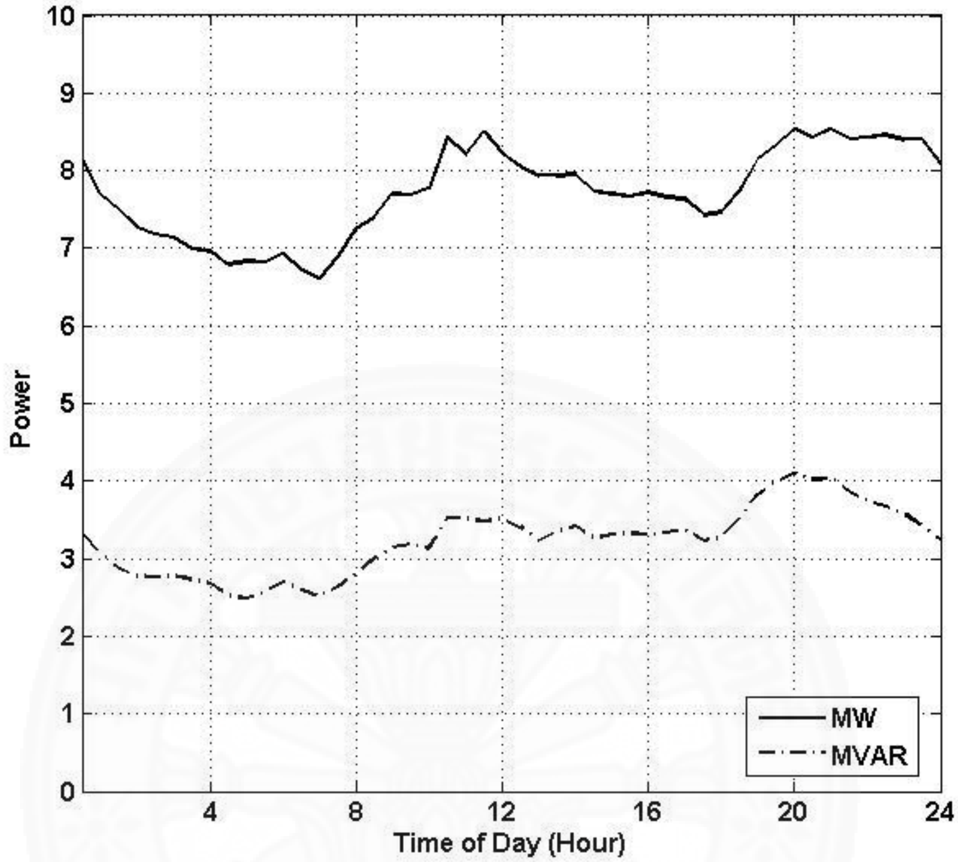


Figure3.9 Daily load profile in Phuket

Table3.2: Daily load profile of TLG02

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
0:00	8.15	3.32
0:30	7.70	3.07
1:00	7.50	2.87
1:30	7.28	2.78
2:00	7.18	2.76
2:30	7.14	2.78
3:00	6.99	2.73
3:30	6.96	2.68
4:00	6.79	2.52
4:30	6.83	2.49
5:00	6.82	2.57
5:30	6.93	2.70
6:00	6.72	2.61
6:30	6.61	2.52

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
7:00	6.89	2.64
7:30	7.25	2.81
8:00	7.40	2.99
8:30	7.70	3.15
9:00	7.69	3.19
9:30	7.77	3.13
10:00	8.43	3.51
10:30	8.21	3.51
11:00	8.50	3.48
11:30	8.22	3.51
12:00	8.05	3.41
12:30	7.93	3.23
13:00	7.93	3.35
13:30	7.95	3.42
14:00	7.73	3.26
14:30	7.70	3.31
15:00	7.67	3.32
15:30	7.72	3.31
16:00	7.66	3.34
16:30	7.64	3.38
17:00	7.43	3.23
17:30	7.47	3.28
18:00	7.73	3.52
18:30	8.15	3.83
19:00	8.33	4.00
19:30	8.54	4.10
20:00	8.43	4.02
20:30	8.54	4.03
21:00	8.41	3.86
21:30	8.43	3.74
22:00	8.46	3.67
22:30	8.40	3.58
23:00	8.40	3.42
23:30	8.08	3.23

3.2.5 Designed of EV Charging Model

Charging Station model is depended on SOC of Each EVs, arrival time of EVs and the number of charger lots of in charging station which are relate to energy consumption for each charging station. From these variables, author will determine to find the practical EVs Charging Station model which is following these steps.

(1) Set up the work variable limitations

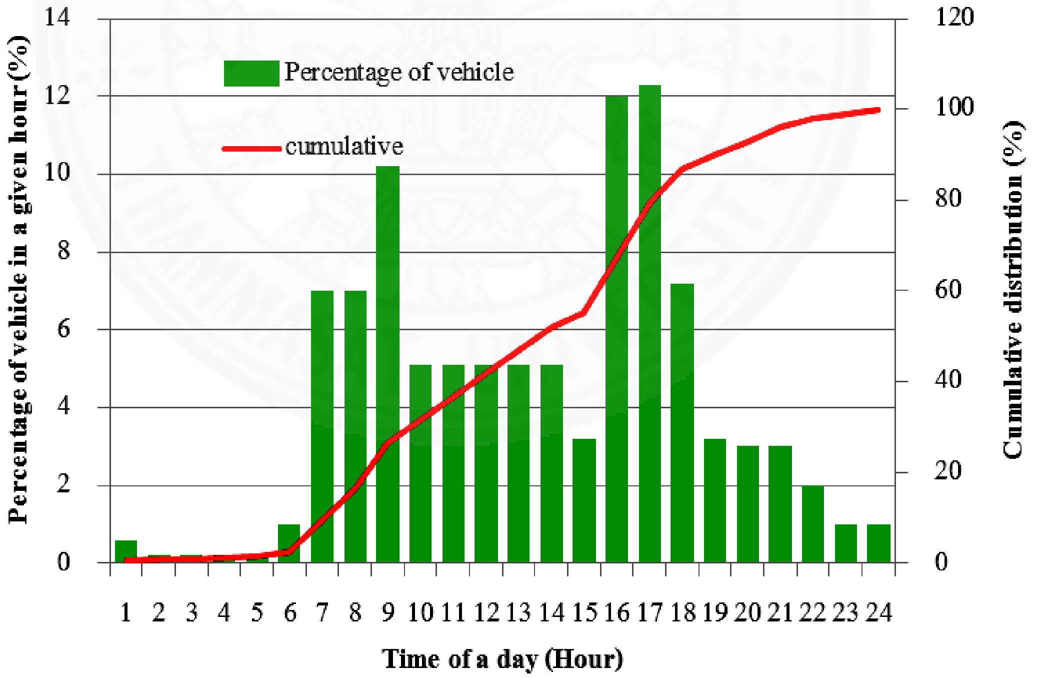
This work we are assumed that the charging station is contained 8 charger lots and energy consumption of each charger lot is 110 kW. There are 16,000 EVs in Phuket area which are using Nissan Leaf for a model of EVs and contained battery size 24 kWh. The EVs SOC will vary on each EV traveling that traveling distance is 100 km of 100% of SOC.

(2) SOC and charging time

SOC and time to charge will relate with the battery remains and traveling distance of each EV when start. This work use random data to determine the SOC of each EV and time to charge are a vary inverse to SOC of each EV.

(3) The EVs arrival time of charging station

The EVs arrival time of charging refers to the demand of EVs go to the charging station in a period of time (Yunus, 2010) which is following the figure 3.10.



Source: Yunus (2010)

Figure3.10 the behavior of EVs arrival time in a day

It shown that the behavior of car users always charge their EVs at 8 a.m. when they are going to work and charge again at 3 p.m. – 4.30 when they are coming back home. This work is using cumulative probability density function to collect the data of EVs arrival time of charging station.

(4) Charger lots power

From the study of charger lots power in fast charging Mode, author will see that the efficiency of charger is about 80-90 percent (Andersson and Carlsson, 2012). This work are determined power consumption output about 100 kW per charger following Table 9. The input power receive AC 380-400 volt 3 phase which could consume input power about 110 kW (at 90 percent efficiency). The loss from charger is about 10 percent.

Table3.3: EV charger Characteristic

Characteristic	**Charging Power**		
	50 kW	**100 kW**	**200 kW**
Power input (AC system)	3 phase 380-480 VAC Current rate 80 Amp/phase	3 phase 380-480 VAC Current rate 160 Amp/phase	3 phase 380-480 VAC Current rate 320 Amp/phase
Power input (DC system)	50- 600 VDC Current rate 125 Amp	50- 600 VDC Current rate 250 Amp	50- 600 VDC Current rate 500 Amp

Source: ABB (2011)

(5) The modeling the EV charging profile

The method for modeling the EV charging profile are applied to use Monte Carlo technic simulation in MATLAB software for generating the EV charging profile of Charging Station. As shown in following step.

(1) Collect data of overall number of EVs charge

To collect all EVs for calculate in software which random amount of EVs demand to charge.

(2) Collect number of charging lots of each EVs and energy consumption for charging

To collect the number of charging lots to calculate the power consumption in each charging station for a day, in this work, author determine that a station could supply to EVs maximum in 8 charger lots and each charger lots consume power about 110 kw per charger (input power).

(3) Random SOC of each EV when start.

(4) Checking SOC of each EV

To check SOC when start of each EV, if EV % SOC less than 40, collect data, calculate time to charge usage and cumulative probability density until 100 percent.

(5) Arrival time to charge in a day.

From the collecting demand charging of EVs arrange time to each EV charging in a day (1440 minute).

(6) Arrange EVs to charger lots

To arrange EVs to charge in maximum of charger lots followed demand of EVs charging in each minute.

(7) Collect charging profile in a day (1440 minute) for 10,000 events.

To collect charging profile of charging station in 1440 minute and collect 10,000 iterations to find a maximum event of charging profile of energy consumption and use to basic data for calculating power flow in DIgSILENT PowerFactory software.

The overall step of modeling charging profile could be shown in the flowchart of Monte Carlo technique simulation for fast charging station. As illustrated in figure 3.11 and figure 3.12.

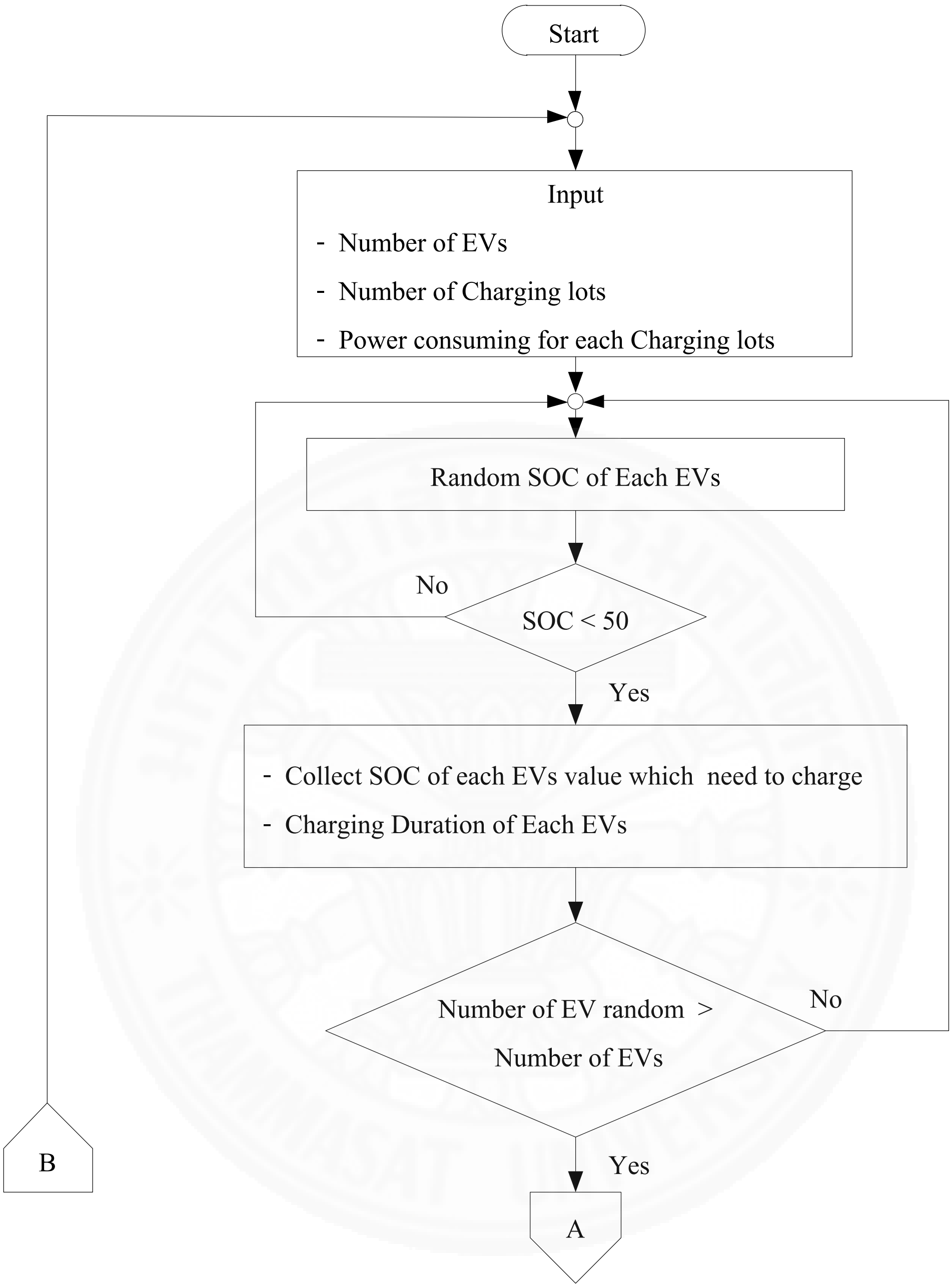


Figure9 charging profile work flow (A)

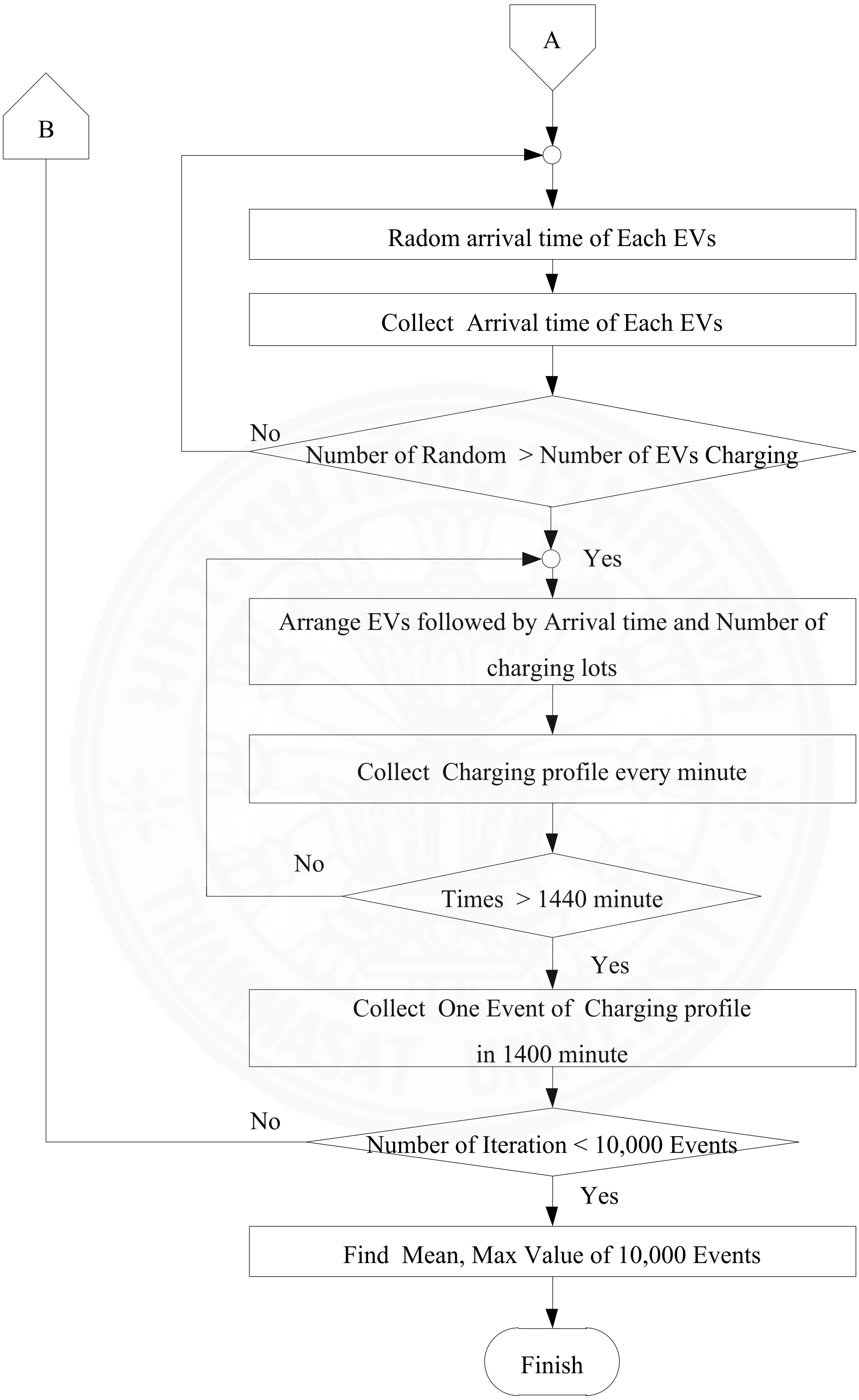


Figure3.12 Charging profile work flow (B)

Author could get the best 10 points from K-mean clustering to find running out point of EVs, distribution line model from PEA GIS data base and the charging load profile of charging station from Monte Carlo model. Therefore we could find power flow while charging EVs to analyst the effect from EVs charge that shown in the figure 3.13.

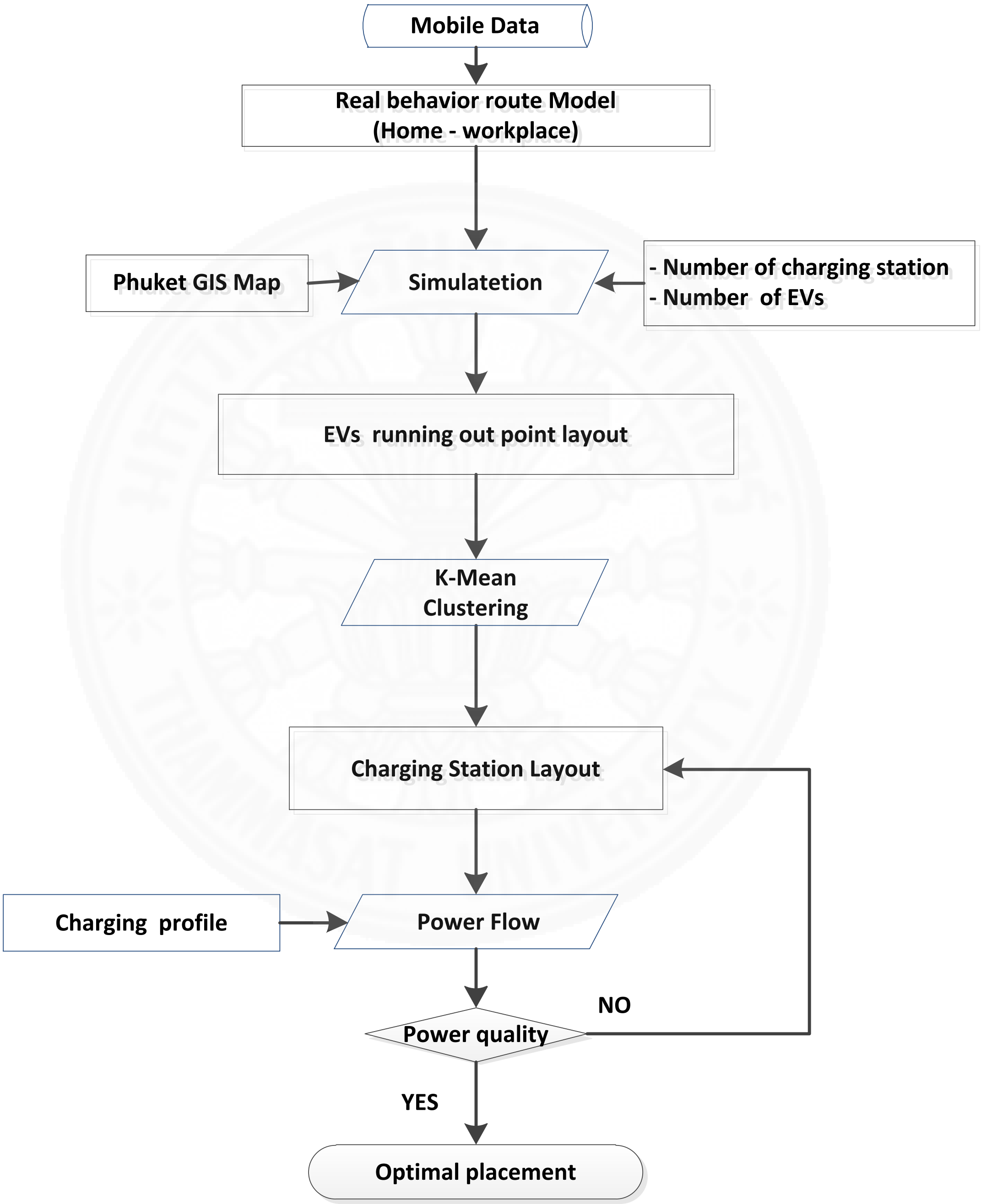


Figure3.1310 Overalls methodology

Chapter 4

Simulation and Result

4.1 The optimal locations results

The result of k-mean clustering algorithm shows the best location of fast charging station considering the running out point of EVs. The optimal location of simulation is shown in Figure 4.1 and Figure 4.2.

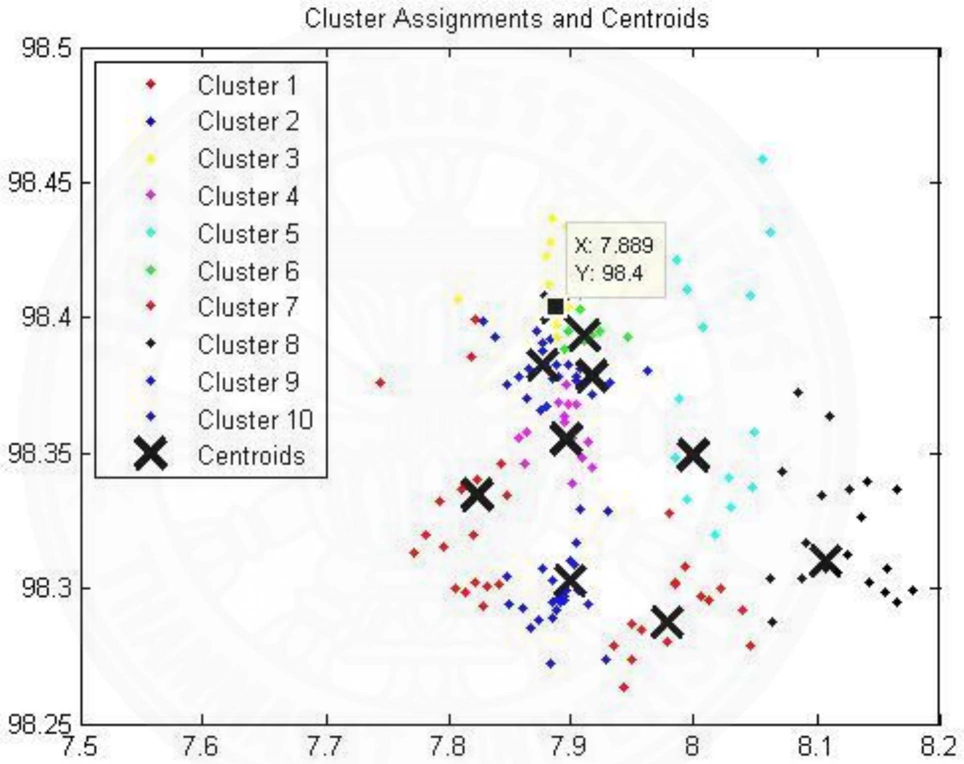


Figure 4.1 Matlab simulation result

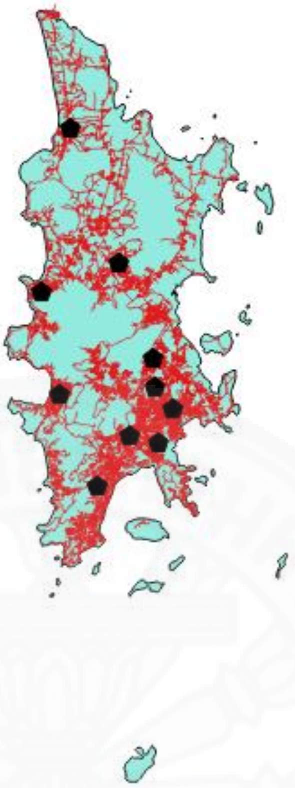


Figure 4.2 The optimal location of charging station layout in Phuket

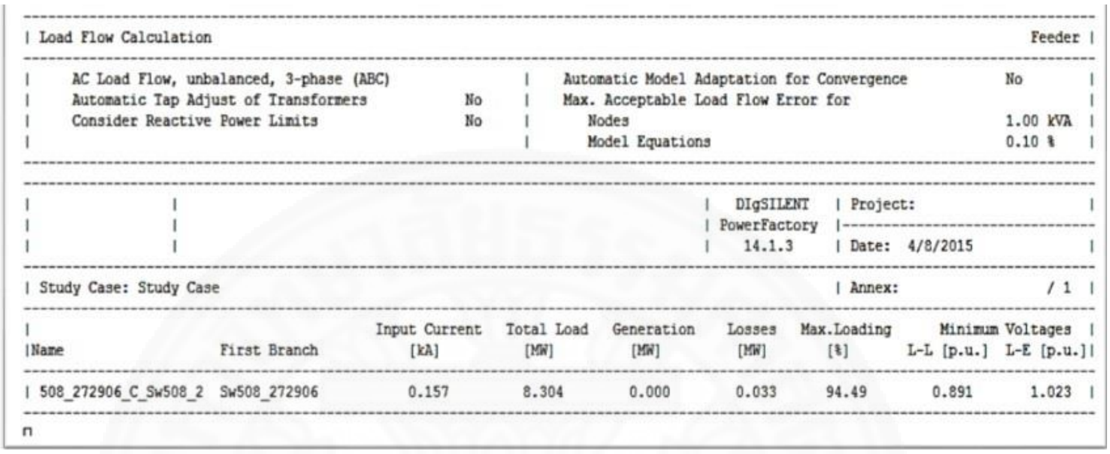
The fast charging station locations are widespread in Phuket and around the Coast of Phuket Island that is provided to the locations installation of fast charging station in Phuket. The 10 best locations are transferred to PEA GIS data such as latitude and longitude to assume as a load add in location of the distribution system. The relationship of station feeder in each load location can be seen in Table 4.1.

Table4.1: The result of the best location of CS

Charging Station	Location [Latitude , Longitude]	Substation Feeder
1	7.9007 , 98.3774	KRU01
2	8.1070 , 98.3102	TLG01
3	7.8229 , 98.3323	TLG02
4	7.8577 , 98.3808	TLG09
5	7.8834 , 98.3919	TLG10
6	7.9240 , 98.3760	PKB01
7	7.8631 , 98.3582	PAV03
8	7.8952 , 98.3022	PKA05
9	7.9999 , 98.3494	PKA09
10	7.9767 , 98.2874	PKA10

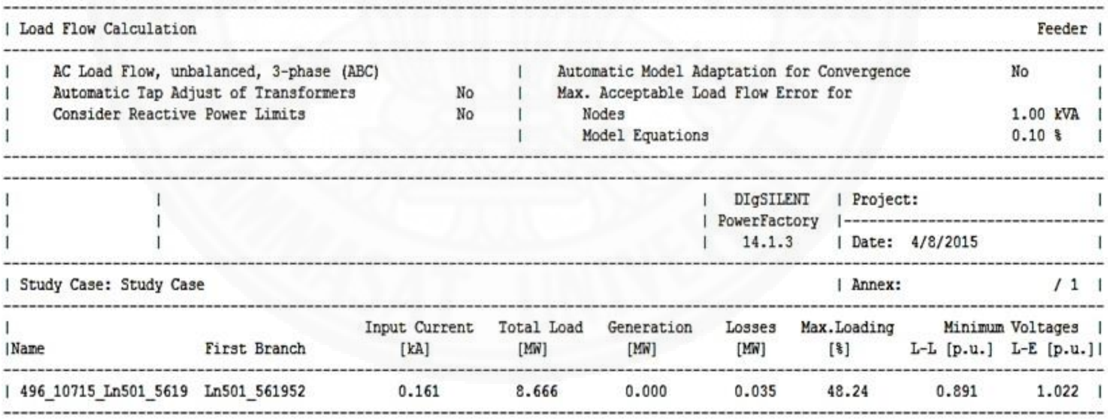
4.2 The 10 locations power flow results

DigSILENT PowerFactory software is used to calculate the power flow of 10 best locations which focus on loading effect and power losses. The result of each feeder after installation fast charging station can be shown following figure 4.3 to figure 4.12.



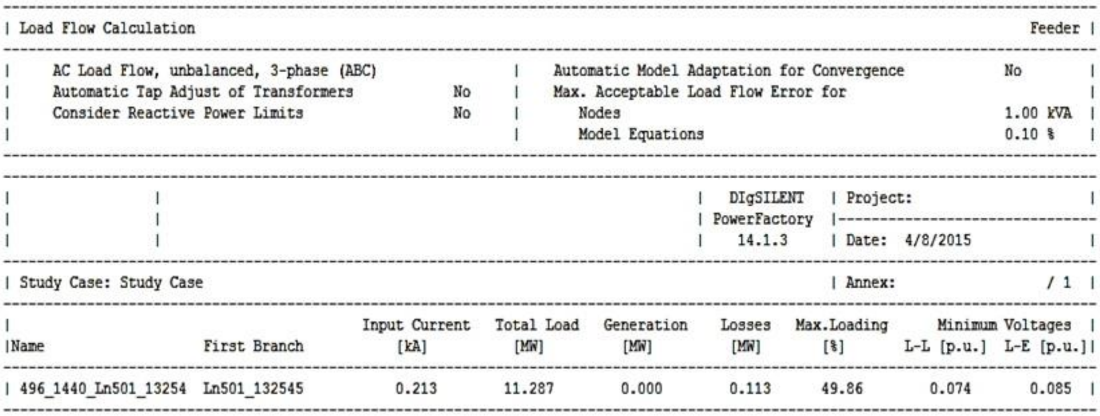
```
-------------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                                                                     Feeder |
-------------------------------------------------------------------------------------------------------------------
|     AC Load Flow, unbalanced, 3-phase (ABC)                |    Automatic Model Adaptation for Convergence    No        |
|     Automatic Tap Adjust of Transformers           No      |    Max. Acceptable Load Flow Error for                     |
|     Consider Reactive Power Limits                 No      |       Nodes                                      1.00 kVA  |
|                                                            |       Model Equations                            0.10 %    |
-------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------------------------
|               |                                                      |   DIgSILENT   | Project:                        |
|               |                                                      | PowerFactory  |---------------------------------
|               |                                                      |    14.1.3     | Date:  4/8/2015                 |
-------------------------------------------------------------------------------------------------------------------
| Study Case: Study Case                                                               | Annex:                   / 1  |
-------------------------------------------------------------------------------------------------------------------
|                                          Input Current  Total Load  Generation    Losses  Max.Loading     Minimum Voltages  |
|Name                  First Branch             [kA]          [MW]        [MW]        [MW]       [%]     L-L [p.u.]  L-E [p.u.]|
-------------------------------------------------------------------------------------------------------------------
| 508_272906_C_Sw508_2  Sw508_272906            0.157         8.304       0.000       0.033      94.49      0.891       1.023  |
-------------------------------------------------------------------------------------------------------------------
n
```

Figure4.3 KRU01 of power flow calculation with installer charging station



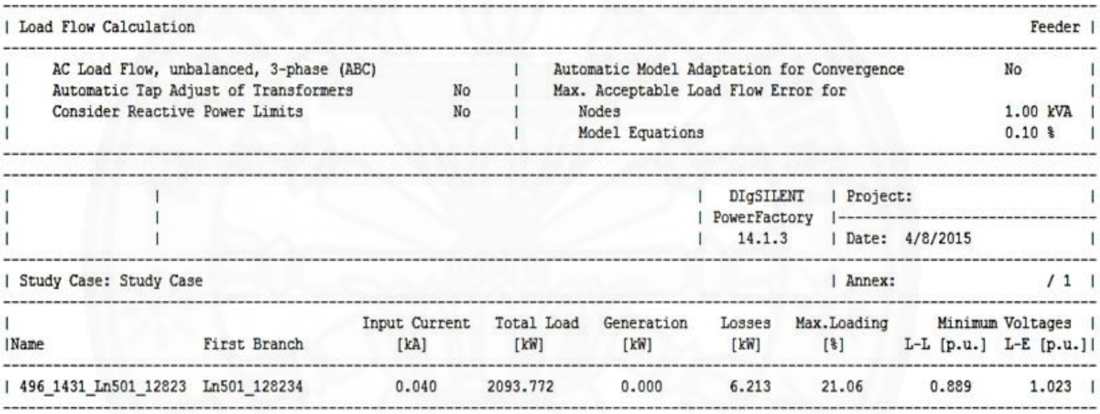
```
-------------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                                                                     Feeder |
-------------------------------------------------------------------------------------------------------------------
|     AC Load Flow, unbalanced, 3-phase (ABC)                |    Automatic Model Adaptation for Convergence    No        |
|     Automatic Tap Adjust of Transformers           No      |    Max. Acceptable Load Flow Error for                     |
|     Consider Reactive Power Limits                 No      |       Nodes                                      1.00 kVA  |
|                                                            |       Model Equations                            0.10 %    |
-------------------------------------------------------------------------------------------------------------------
-------------------------------------------------------------------------------------------------------------------
|               |                                                      |   DIgSILENT   | Project:                        |
|               |                                                      | PowerFactory  |---------------------------------
|               |                                                      |    14.1.3     | Date:  4/8/2015                 |
-------------------------------------------------------------------------------------------------------------------
| Study Case: Study Case                                                               | Annex:                   / 1  |
-------------------------------------------------------------------------------------------------------------------
|                                          Input Current  Total Load  Generation    Losses  Max.Loading     Minimum Voltages  |
|Name                  First Branch             [kA]          [MW]        [MW]        [MW]       [%]     L-L [p.u.]  L-E [p.u.]|
-------------------------------------------------------------------------------------------------------------------
| 496_10715_Ln501_5619  Ln501_561952            0.161         8.666       0.000       0.035      48.24      0.891       1.022  |
-------------------------------------------------------------------------------------------------------------------
```

Figure 4.4 PAV03 of power flow calculation with installer charging station



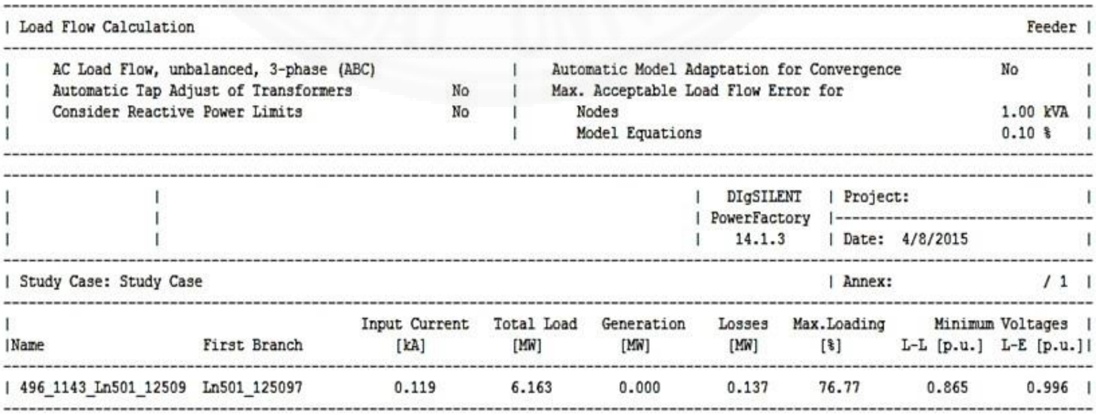
```
---------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                                                                Feeder |
---------------------------------------------------------------------------------------------------------------
|    AC Load Flow, unbalanced, 3-phase (ABC)          |   Automatic Model Adaptation for Convergence       No       |
|    Automatic Tap Adjust of Transformers         No  |   Max. Acceptable Load Flow Error for                       |
|    Consider Reactive Power Limits               No  |      Nodes                                       1.00 kVA |
|                                                     |      Model Equations                             0.10 %   |
---------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------------------------
|              |                                                     |  DIgSILENT   | Project:                  |
|              |                                                     | PowerFactory |------------------------------
|              |                                                     |    14.1.3    | Date:  4/8/2015           |
---------------------------------------------------------------------------------------------------------------
| Study Case: Study Case                                                            | Annex:                / 1  |
---------------------------------------------------------------------------------------------------------------
|                                         Input Current  Total Load  Generation   Losses  Max.Loading     Minimum Voltages  |
|Name                     First Branch        [kA]          [MW]        [MW]       [MW]       [%]      L-L [p.u.]  L-E [p.u.]|
---------------------------------------------------------------------------------------------------------------
| 496_1440_Ln501_13254  Ln501_132545         0.213        11.287       0.000      0.113      49.86       0.074       0.085  |
---------------------------------------------------------------------------------------------------------------
```

Figure 4.5 PKA05 of power flow calculation with installer charging station



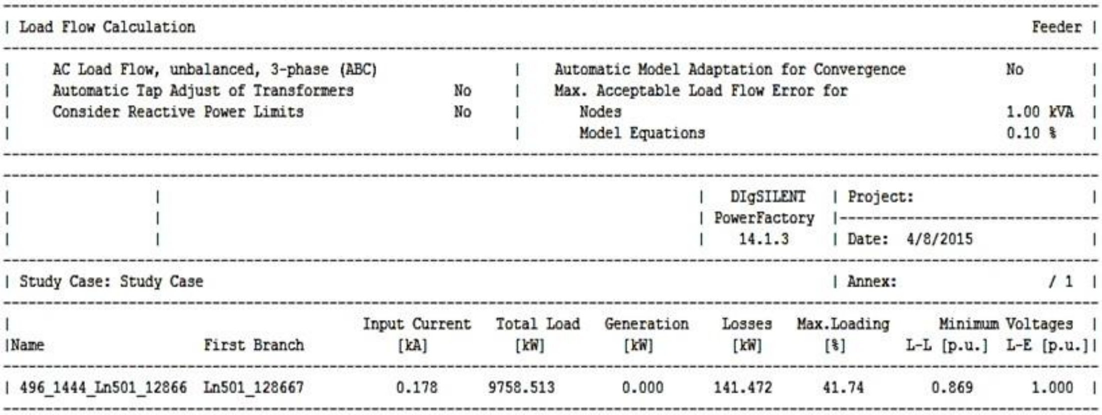
```
---------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                                                                Feeder |
---------------------------------------------------------------------------------------------------------------
|    AC Load Flow, unbalanced, 3-phase (ABC)          |   Automatic Model Adaptation for Convergence       No       |
|    Automatic Tap Adjust of Transformers         No  |   Max. Acceptable Load Flow Error for                       |
|    Consider Reactive Power Limits               No  |      Nodes                                       1.00 kVA |
|                                                     |      Model Equations                             0.10 %   |
---------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------------------------
|              |                                                     |  DIgSILENT   | Project:                  |
|              |                                                     | PowerFactory |------------------------------
|              |                                                     |    14.1.3    | Date:  4/8/2015           |
---------------------------------------------------------------------------------------------------------------
| Study Case: Study Case                                                            | Annex:                / 1  |
---------------------------------------------------------------------------------------------------------------
|                                         Input Current  Total Load  Generation   Losses  Max.Loading     Minimum Voltages  |
|Name                     First Branch        [kA]          [kW]        [kW]       [kW]       [%]      L-L [p.u.]  L-E [p.u.]|
---------------------------------------------------------------------------------------------------------------
| 496_1431_Ln501_12823  Ln501_128234         0.040      2093.772       0.000      6.213      21.06       0.889       1.023  |
---------------------------------------------------------------------------------------------------------------
```

Figure 4.6 PKA09 of power flow calculation with installer charging station



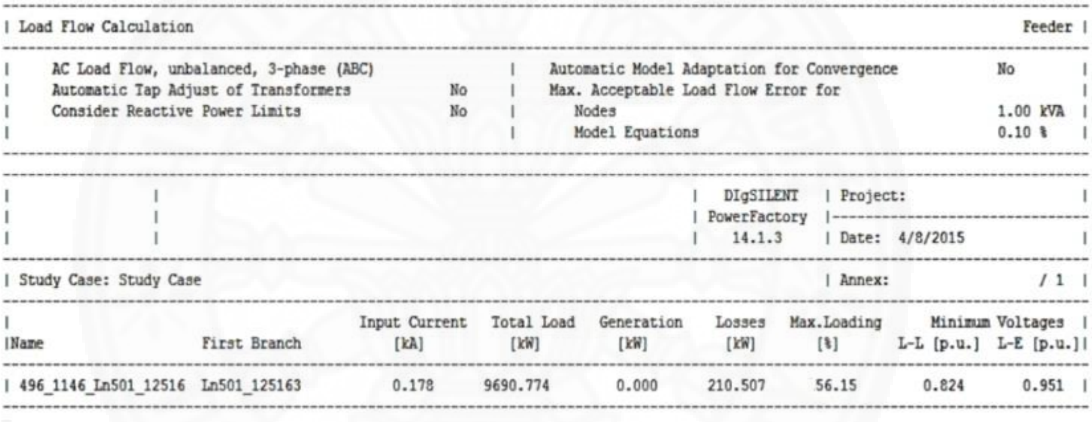
```
---------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                                                                Feeder |
---------------------------------------------------------------------------------------------------------------
|    AC Load Flow, unbalanced, 3-phase (ABC)          |   Automatic Model Adaptation for Convergence       No       |
|    Automatic Tap Adjust of Transformers         No  |   Max. Acceptable Load Flow Error for                       |
|    Consider Reactive Power Limits               No  |      Nodes                                       1.00 kVA |
|                                                     |      Model Equations                             0.10 %   |
---------------------------------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------------------------------
|              |                                                     |  DIgSILENT   | Project:                  |
|              |                                                     | PowerFactory |------------------------------
|              |                                                     |    14.1.3    | Date:  4/8/2015           |
---------------------------------------------------------------------------------------------------------------
| Study Case: Study Case                                                            | Annex:                / 1  |
---------------------------------------------------------------------------------------------------------------
|                                         Input Current  Total Load  Generation   Losses  Max.Loading     Minimum Voltages  |
|Name                     First Branch        [kA]          [MW]        [MW]       [MW]       [%]      L-L [p.u.]  L-E [p.u.]|
---------------------------------------------------------------------------------------------------------------
| 496_1143_Ln501_12509  Ln501_125097         0.119         6.163       0.000      0.137      76.77       0.865       0.996  |
---------------------------------------------------------------------------------------------------------------
```

Figur4.7 PKA10 of power flow calculation with installer charging station



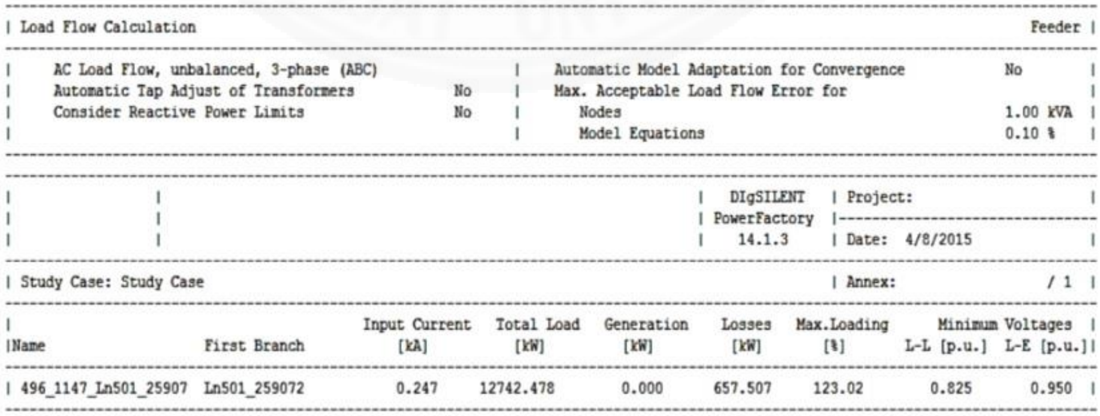
```
-----------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                                                                  Feeder |
-----------------------------------------------------------------------------------------------------------------
|     AC Load Flow, unbalanced, 3-phase (ABC)           |   Automatic Model Adaptation for Convergence          No       |
|     Automatic Tap Adjust of Transformers         No   |   Max. Acceptable Load Flow Error for                          |
|     Consider Reactive Power Limits               No   |      Nodes                                            1.00 kVA |
|                                                       |      Model Equations                                  0.10 %   |
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
|              |                                         |  DIgSILENT   | Project:                          |
|              |                                         | PowerFactory |-----------------------------------
|              |                                         |    14.1.3    | Date:  4/8/2015                   |
-----------------------------------------------------------------------------------------------------------------
| Study Case: Study Case                                                | Annex:                      / 1  |
-----------------------------------------------------------------------------------------------------------------
|                                    Input Current  Total Load  Generation    Losses  Max.Loading    Minimum Voltages  |
|Name                  First Branch       [kA]         [kW]        [kW]        [kW]       [%]      L-L [p.u.]  L-E [p.u.]|
-----------------------------------------------------------------------------------------------------------------
| 496_1444_Ln501_12866  Ln501_128667      0.178     9758.513      0.000     141.472     41.74       0.869       1.000  |
-----------------------------------------------------------------------------------------------------------------
```

Figure4.8 PKB01 of power flow calculation with installer charging station



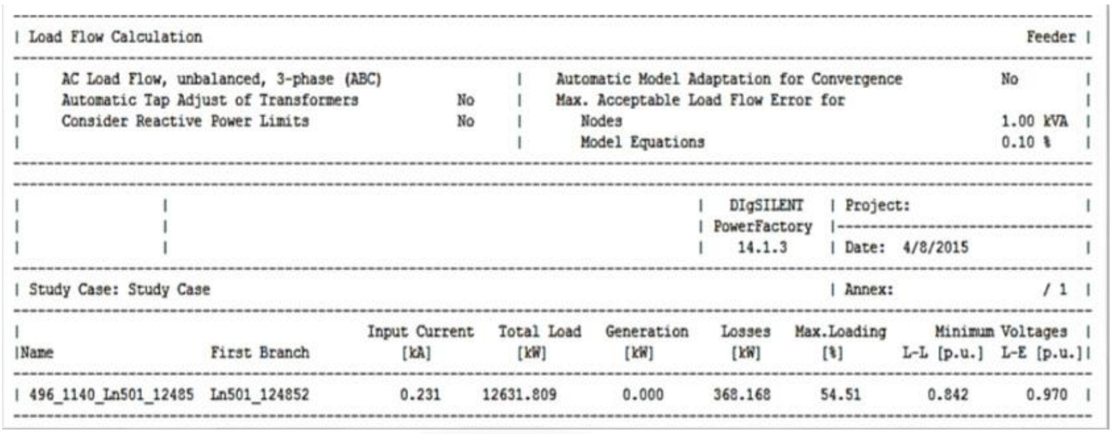
```
-----------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                                                                  Feeder |
-----------------------------------------------------------------------------------------------------------------
|     AC Load Flow, unbalanced, 3-phase (ABC)           |   Automatic Model Adaptation for Convergence          No       |
|     Automatic Tap Adjust of Transformers         No   |   Max. Acceptable Load Flow Error for                          |
|     Consider Reactive Power Limits               No   |      Nodes                                            1.00 kVA |
|                                                       |      Model Equations                                  0.10 %   |
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
|              |                                         |  DIgSILENT   | Project:                          |
|              |                                         | PowerFactory |-----------------------------------
|              |                                         |    14.1.3    | Date:  4/8/2015                   |
-----------------------------------------------------------------------------------------------------------------
| Study Case: Study Case                                                | Annex:                      / 1  |
-----------------------------------------------------------------------------------------------------------------
|                                    Input Current  Total Load  Generation    Losses  Max.Loading    Minimum Voltages  |
|Name                  First Branch       [kA]         [kW]        [kW]        [kW]       [%]      L-L [p.u.]  L-E [p.u.]|
-----------------------------------------------------------------------------------------------------------------
| 496_1146_Ln501_12516  Ln501_125163      0.178     9690.774      0.000     210.507     56.15       0.824       0.951  |
-----------------------------------------------------------------------------------------------------------------
```

Figure4.9 TLG01 of power flow calculation with installer charging station



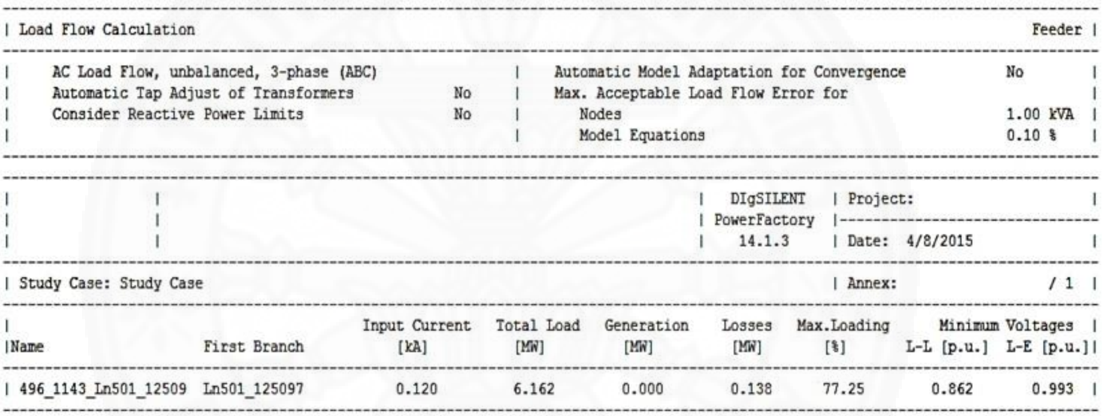
```
-----------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                                                                  Feeder |
-----------------------------------------------------------------------------------------------------------------
|     AC Load Flow, unbalanced, 3-phase (ABC)           |   Automatic Model Adaptation for Convergence          No       |
|     Automatic Tap Adjust of Transformers         No   |   Max. Acceptable Load Flow Error for                          |
|     Consider Reactive Power Limits               No   |      Nodes                                            1.00 kVA |
|                                                       |      Model Equations                                  0.10 %   |
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
|              |                                         |  DIgSILENT   | Project:                          |
|              |                                         | PowerFactory |-----------------------------------
|              |                                         |    14.1.3    | Date:  4/8/2015                   |
-----------------------------------------------------------------------------------------------------------------
| Study Case: Study Case                                                | Annex:                      / 1  |
-----------------------------------------------------------------------------------------------------------------
|                                    Input Current  Total Load  Generation    Losses  Max.Loading    Minimum Voltages  |
|Name                  First Branch       [kA]         [kW]        [kW]        [kW]       [%]      L-L [p.u.]  L-E [p.u.]|
-----------------------------------------------------------------------------------------------------------------
| 496_1147_Ln501_25907  Ln501_259072      0.247    12742.478      0.000     657.507    123.02       0.825       0.950  |
-----------------------------------------------------------------------------------------------------------------
```

Figure4.10 TLG02 of power flow calculation with installer charging station



```
-----------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                                                                  Feeder |
-----------------------------------------------------------------------------------------------------------------
|     AC Load Flow, unbalanced, 3-phase (ABC)             |    Automatic Model Adaptation for Convergence     No      |
|     Automatic Tap Adjust of Transformers        No      |    Max. Acceptable Load Flow Error for                    |
|     Consider Reactive Power Limits              No      |       Nodes                                       1.00 kVA |
|                                                         |       Model Equations                             0.10 %   |
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
|               |                                                  |   DIgSILENT   | Project:                       |
|               |                                                  | PowerFactory  |--------------------------------
|               |                                                  |    14.1.3     | Date:  4/8/2015                |
-----------------------------------------------------------------------------------------------------------------
| Study Case: Study Case                                                           | Annex:                 / 1  |
-----------------------------------------------------------------------------------------------------------------
|                                            Input Current  Total Load  Generation   Losses  Max.Loading    Minimum Voltages |
|Name                   First Branch              [kA]        [kW]        [kW]        [kW]       [%]      L-L [p.u.]  L-E [p.u.]|
-----------------------------------------------------------------------------------------------------------------
| 496_1140_Ln501_12485  Ln501_124852              0.231    12631.809      0.000     368.168     54.51       0.842       0.970  |
-----------------------------------------------------------------------------------------------------------------
```

Figure4.11 TLG09 of power flow calculation with installer charging station



```
-----------------------------------------------------------------------------------------------------------------
| Load Flow Calculation                                                                                  Feeder |
-----------------------------------------------------------------------------------------------------------------
|     AC Load Flow, unbalanced, 3-phase (ABC)             |    Automatic Model Adaptation for Convergence     No      |
|     Automatic Tap Adjust of Transformers        No      |    Max. Acceptable Load Flow Error for                    |
|     Consider Reactive Power Limits              No      |       Nodes                                       1.00 kVA |
|                                                         |       Model Equations                             0.10 %   |
-----------------------------------------------------------------------------------------------------------------
-----------------------------------------------------------------------------------------------------------------
|               |                                                  |   DIgSILENT   | Project:                       |
|               |                                                  | PowerFactory  |--------------------------------
|               |                                                  |    14.1.3     | Date:  4/8/2015                |
-----------------------------------------------------------------------------------------------------------------
| Study Case: Study Case                                                           | Annex:                 / 1  |
-----------------------------------------------------------------------------------------------------------------
|                                            Input Current  Total Load  Generation   Losses  Max.Loading    Minimum Voltages |
|Name                   First Branch              [kA]        [MW]        [MW]        [MW]       [%]      L-L [p.u.]  L-E [p.u.]|
-----------------------------------------------------------------------------------------------------------------
| 496_1143_Ln501_12509  Ln501_125097              0.120       6.162       0.000       0.138     77.25       0.862       0.993  |
-----------------------------------------------------------------------------------------------------------------
```

Figure4.12 TLG10 of power flow calculation with installer charging station

As the result of DigSILENT PowerFactory software power flow calculation can be summed up following Table 4.2.

Table4.2: The result of power flow calculation for each charging station

CS	Location [Latitude , Longitude]	Feeder	Total Loads [MW]	Total Losses [MW]
1	7.9007 , 98.3774	KRU01	8.304	0.033
2	8.1070 , 98.3102	TLG01	9.690	0.210
3	7.8229 , 98.3323	TLG02	12.742	0.657
4	7.8577 , 98.3808	TLG09	12.631	0.368
5	7.8834 , 98.3919	TLG10	6.162	0.138
6	7.9240 , 98.3760	PKB01	9.758	0.141
7	7.8631 , 98.3582	PAV03	8.660	0.035
8	7.8952 , 98.3022	PKA05	11.128	0.113
9	7.9999 , 98.3494	PKA09	2.105	0.007
10	7.9767 , 98.2874	PKA10	6.163	0.176

Form the result of table 4.2, TLG02 feeder has a lot impact to the distribution system that has higher risk in power quality than other feeders. A study is set up for TLG02 feeder to represent voltage impact comparison between condition with and without fast charging station installation which we will talk into the next sequence.

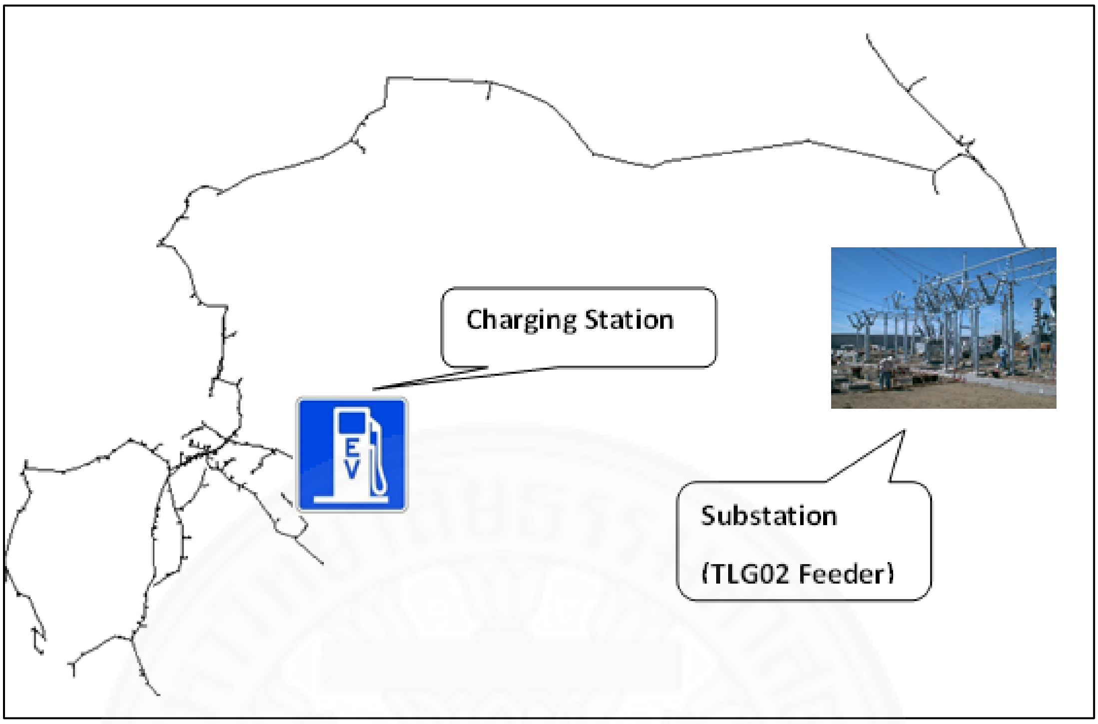


Figure 4.13 The location of charging station in TLG02 distribution line

4.3 EV charging profile result

This work assume that all fast charging station are included 8 charger lots, the input power consume 110 kW per each charger and there are 1600 EVs for this simulate. Matlab software is used to simulate 10,000 events to find base load profile of charging station.

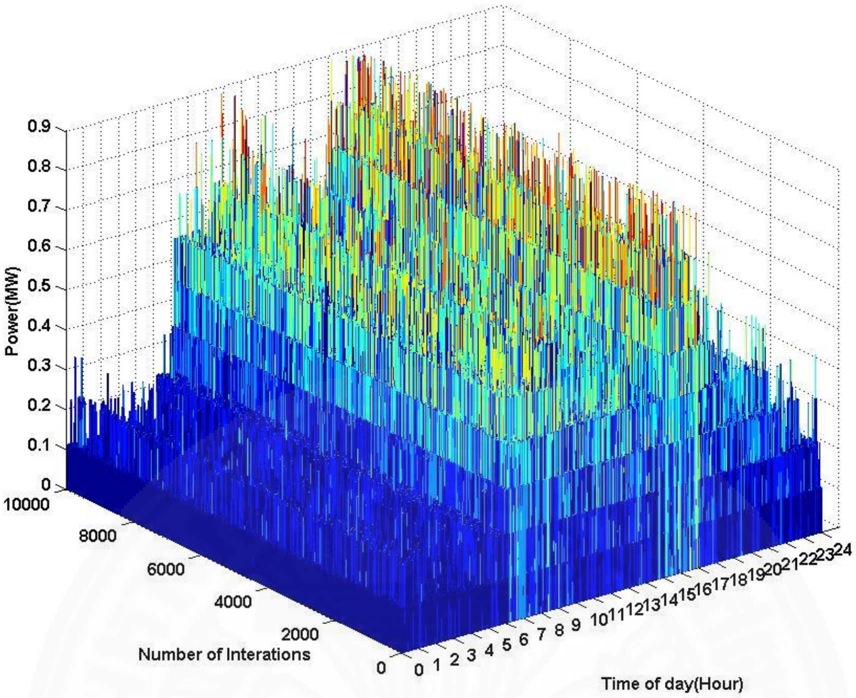


Figure 4.14 The generation of charging profile 10,000 events

4.3.1 The density result of number charging EVs

From the simulation of charging profile of EVs in 10,000 events as shown in figure35, the event of 8856th have the most density number of EVs charging (about 204 EVs), and the mean value of EVs density is about 157 EVs (10 percent of all EVs) which are shown in figure 4.15 and figure 4.16.

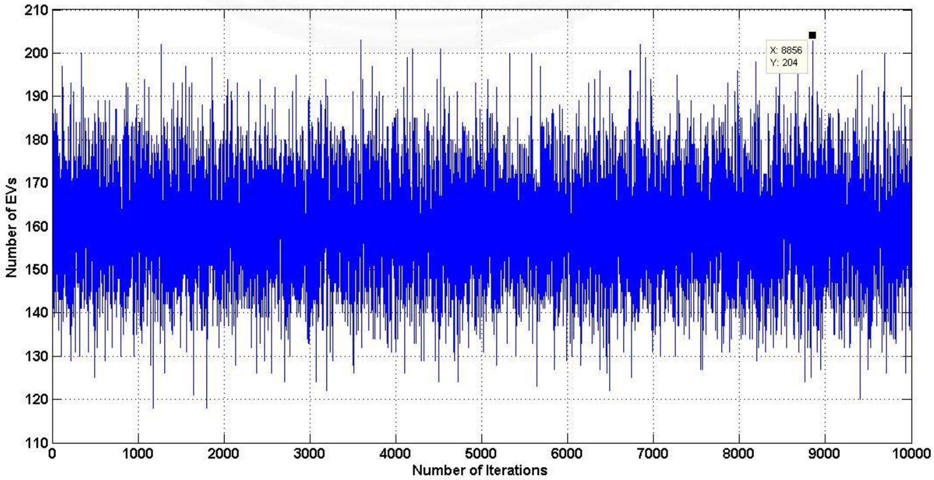


Figure 4.15 The density result of number charging EVs 10,000 events

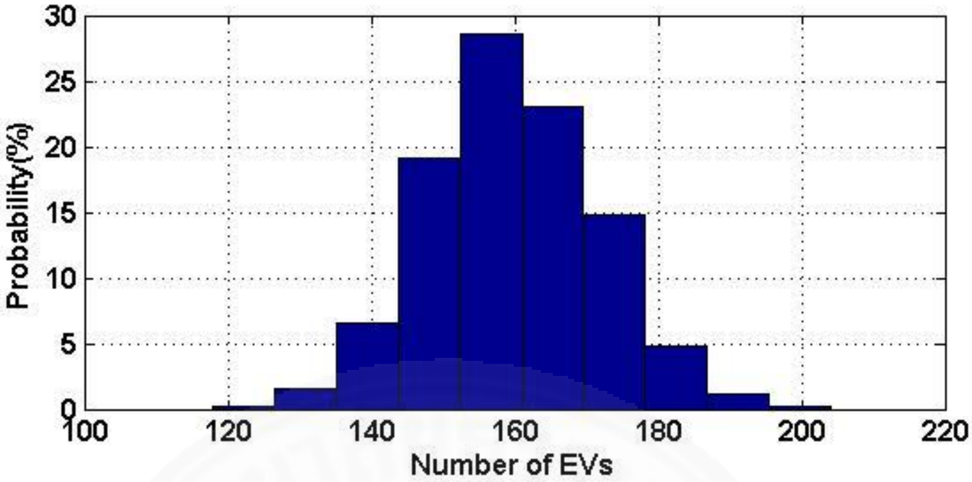


Figure 4.16 The probability of density result of number charging EVs 10,000 events

4.3.2 Result of charging profile of fast charging station

From the result, the maximum demand charging EVs event is illustrated in figure 4.17. There are 8 charger lots to charging EVs which input power energy consumption is about 880 kW at 3.28 p.m. (at 928 min of day). The charging profile is according to the behavior of life cycle of day.

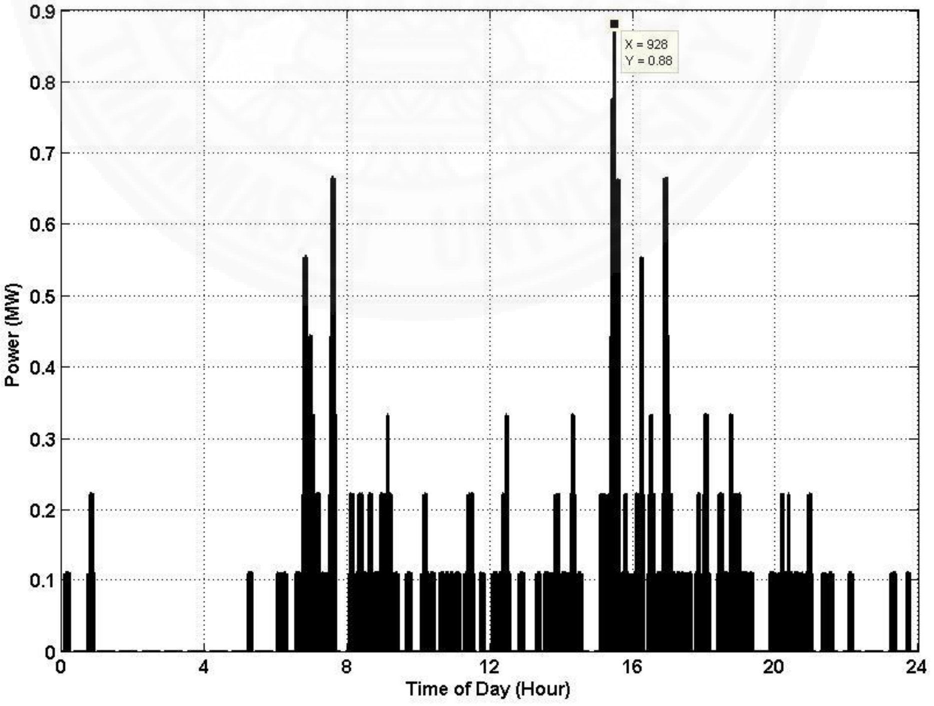


Figure 4.17 The result of maximum energy consumption charging profile

4.4 Comparison result condition with/without charging station in distribution system

4.4.1. Power flow calculation condition without fast charging station

In this case study, the power flow calculation of DigSILENT PowerFactory is used to find the voltage quality in a condition without fast charging station at TLG02 feeder, the simulation show that the substation can supply the voltage level within PEA's voltage standard which the voltage level is not less than 0.95 p.u. The substation voltage level is about 1.03 p.u. and the farther distance from substation is, the bigger voltage drop will be. That can be showed in the figure 4.18.

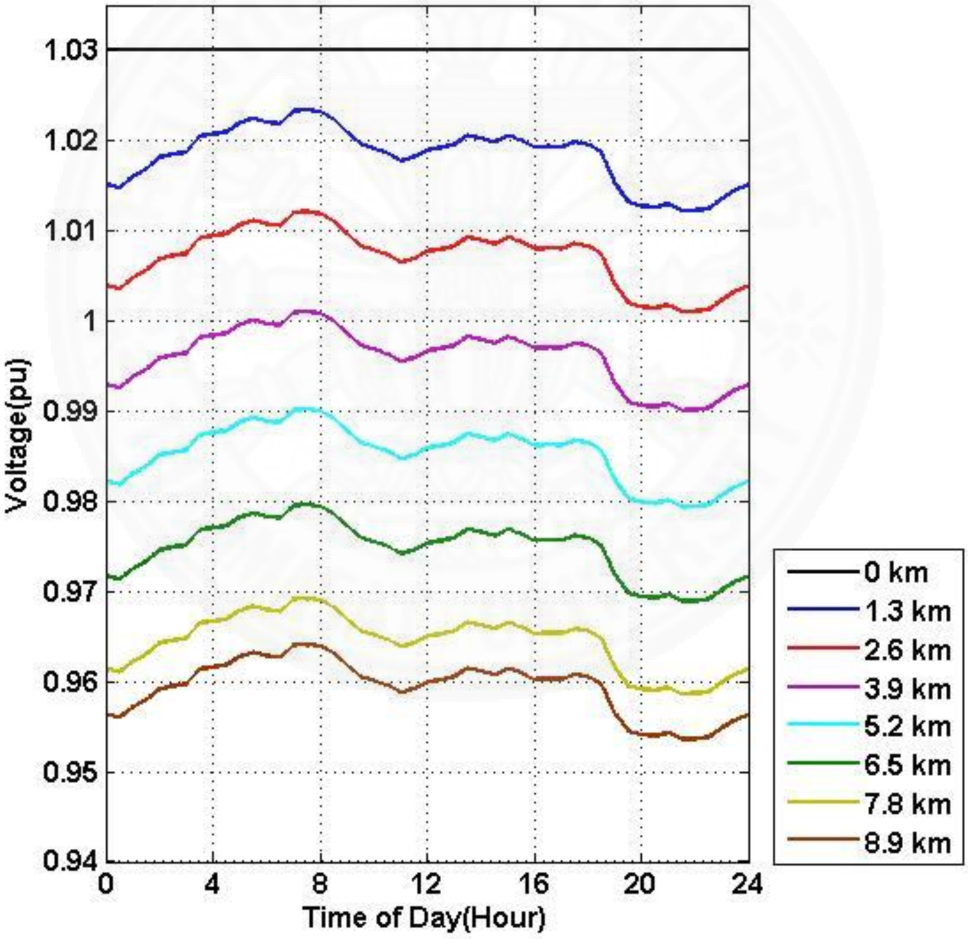


Figure4.18 Voltage drop along distribution line

4.4.2 Power flow calculation condition with installation fast charging station

4.4.2.1 Percent voltage change result

Charging profile is directly impact to distribution systems. From simulation result, a duty time of peak demand charging can be the biggest effect to percent voltage change as shown following figure 4.19 and figure 4.20. At 15.28 of day (928 min of day), there are many demand charge of this work. As the result it can be made a percent voltage change about 0.3%. From this work, the peak charging demand does not same as the peak load demand in distribution. Therefore, the voltage impact can be within voltage level standard. However, if the peak demands of charging same as peak load of distribution, the bigger voltage impact will be occurred and may cause to under voltage quality standard.

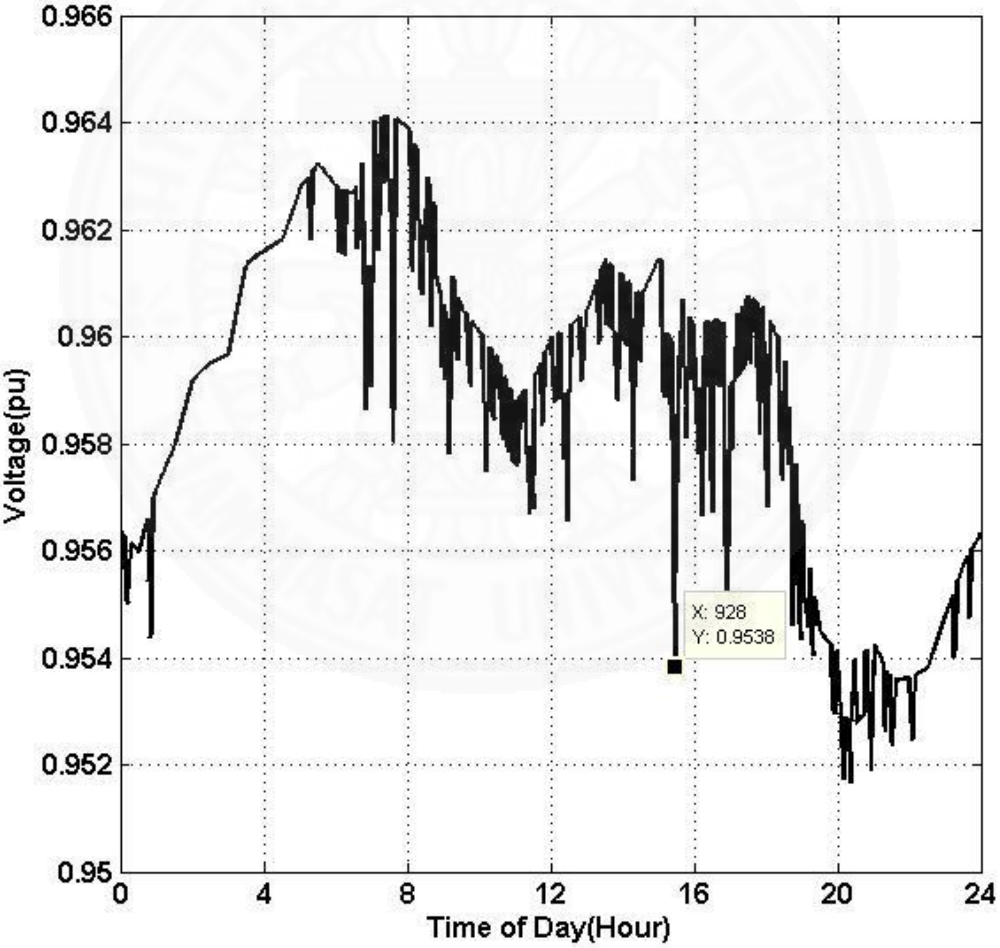


Figure 4.19 Voltage drop condition with charging station installation

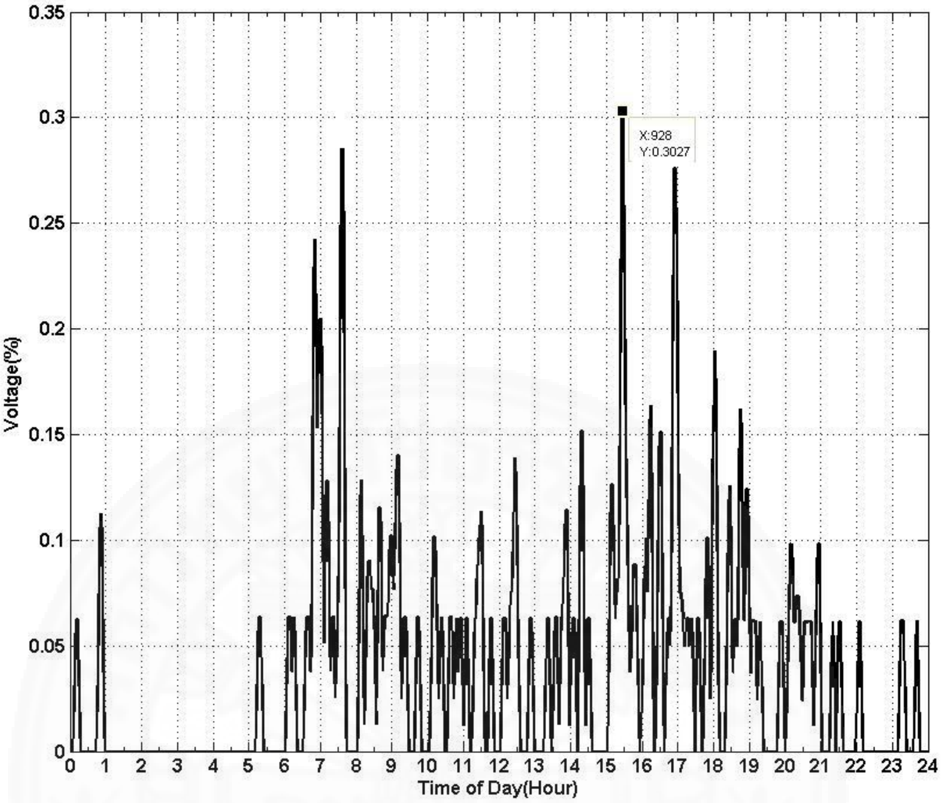


Figure 4.20 Percent Voltage change a day

4.4.2.2 The impact to distribution system result

PEA voltage level standard is within 0.95-1.05p.u. From the result, although, at the time of 928 minutes of day the voltage level is a lot of voltage change, the voltage level is within voltage standard and is not the biggest voltage drop in a day because of the light load period of distribution systems. However, the peak voltage drop period is at 8.21 p.m. (at 1221 minute of day). The voltage quality near the below of voltage stand that may cause power quality problems in distribution system or the bottom end of this distribution line may be risky a bad voltage level quality, as a result from figure 4.21.

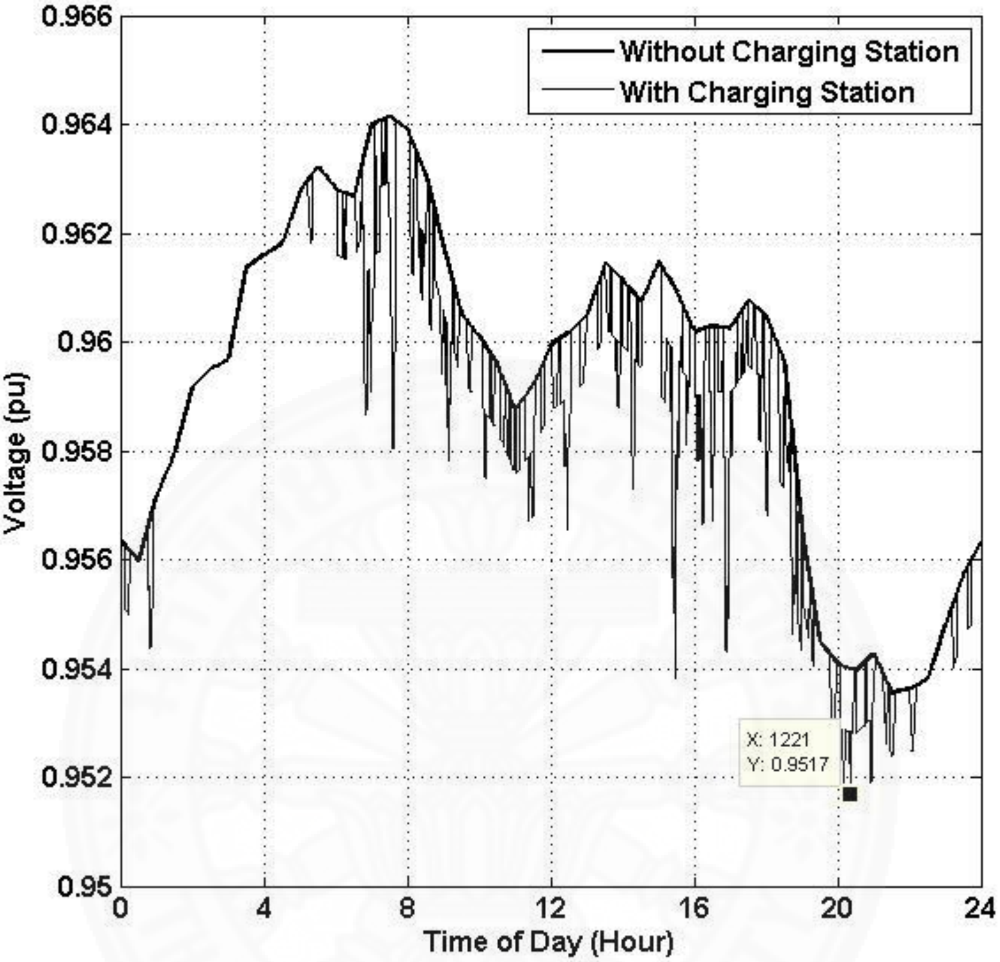


Figure 4.21 the comparison of with/without CS installation

The voltage change profile in distribution system can be affected from charging profile in charging station. As a result the bottom end line could be greatest effect in voltage level which are caputured in figure 4.22

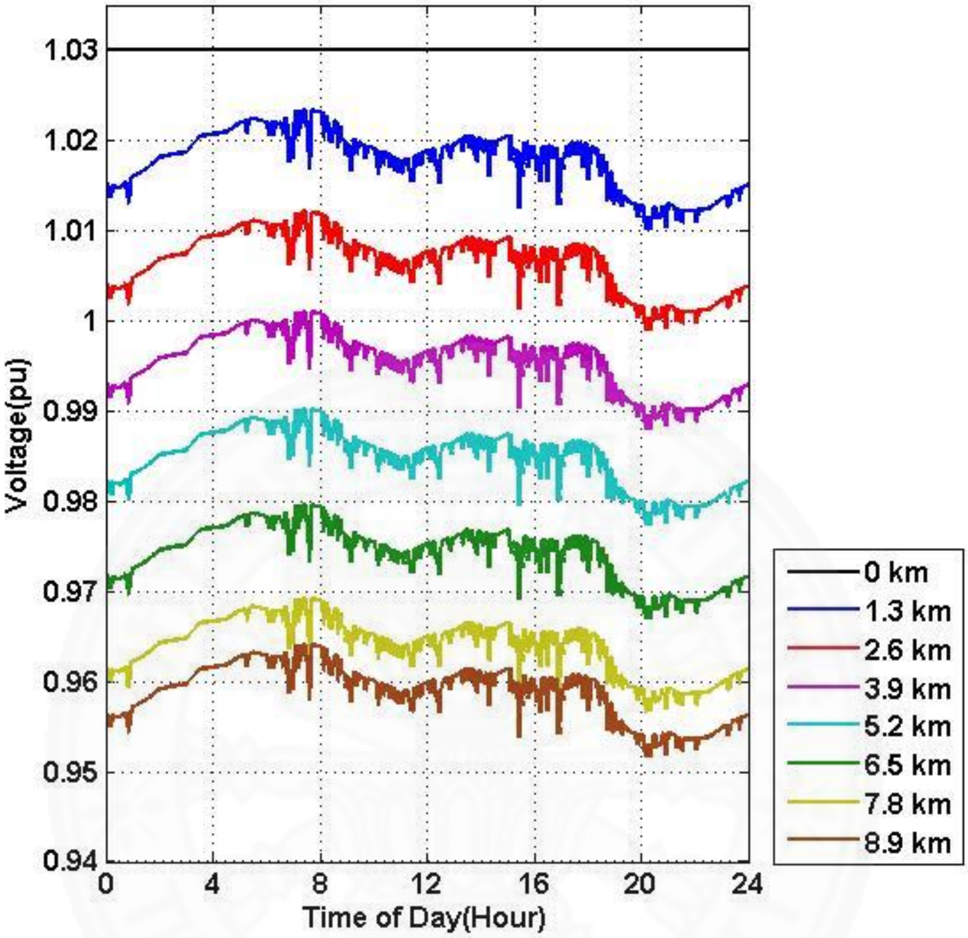


Figure 4.22 the voltage drop impact of fast charging station along distribution line

The voltage impact of fast charging station can be affect directly to distribution systems which is very on the energy consumption in each period time, number of EVs charge and the distance from substation.

Chapter 5

Conclusions and Recommendations

5.1 Conclusion

In conclusion, the optimal placements for supported EVs 16000 EVs are about 10 stations charge. The work result illustrated that the most optimal location of charging station placement in the town and along of the coast of the Phuket Island which deals with the population distribution of Phuket population.

From the result of charging models, there are many factors for supporting the optimal placement of charging station which are affecting to decline the power quality in distribution system. As the result, we can conclude in respectively.

The first factor is the behavior of EVs charging, we found that the behavior of EVs using is about 10 percent all EVs user in Phuket area. The characteristic of charging profile will show that EVs user always start charging their EVs at about 6a.m. to 9a.m. and a peak demand of EVs charging again at 3 p.m. to 6 p.m. which are according with the behavior of life cycle. It’s meaning about, all EVs user also start charging when start go to work and charge again after back home. In this work, a peak demand begins at 9.28 p.m., using 8 charger lots and energy consumption are about 880 kW.

The second factor is the number of EVs, the number of EVs in area is a significant factor to evaluate the maximum of power consumption of each charging station. The more of EVs charge, the more of power consumption will be. The optimal sizing of Charging Station will be modeled to support all number of EVs user in area.

Next, the behavior of EVs arrival time is more one factor which is a significant variable. It’s using to determine the maximum demand of energy consumption in a cycle day to find the optimal number of charger lots which can support the number EVs in a peak duty time of charging station.

The fourth factor is the number of charger lots. The number of charger lots is one more factor that relate to power consumption of charging station effect to distribution systems in a day. In this work, we see that peak time of EVs charging station can take percentage of voltage drop about 0.3 percent (at 1600 EVs/Charging Station in area). Although, the voltage level standard are within the PEA’s standard level. but it’s will be risk in the future, because the trend number of EVs will be increasingly, the number EVs user in area have been grown up too. So the effect of EVs charging will be greater. As the result, the voltage quality will be declined that make chance to face the lower voltage quality of PEA standard level. Thus, it’s a bad sign to risk the distribution system must be improved for support the bigger demand.

The final factor is the location of Charging Station in distribution systems, we found that the location of charging station has a lot effect to voltage profile in distribution systems. We can be captured that a great distance location of charging station can be a lot voltage drop than the closed distance location of charging station from substation. In this work, the result will show up the voltage profile will be decreasing along the distribution line dealing with the distance from substation. As the result TLG02 is a biggest power of the poor power quality. One factor is very far away from Talhang substation (TLG).

From the overall result of this work is a methodology to implement the optimal charging station considering with real behavior of EVs mobility and concerning the impact to distribution system from charging EVs effect. However, implementing the optimal location must be concerned in another factor such as the maximum capacity of distribution system or cost installation of charging station and so on.

5.2 Recommendations

[1]This work is model for one shot planning following in year 2020. The estimates of EVs number are the forecast data and the behavior of EVs user can be changed, so the optimal location will be change following the new data.

[2]This work only sees the effect from voltage profile. In completely, it must add power flow calculation in the P-Q power quality condition, Power Loss and Harmonic from charging station.

[3]In the future, distribution line may change followed the power dispatch. So the result may be change following the new dispatch in power systems

[4]According to the study, 10 CS could be installed in order to maintain the desired power quality condition. However, the CS derives maximum demand together with increasing network power consumption may be risky to power quality problems. One of the methods proposed for handling the peak demand of EVs is installed an Energy Storage Systems (ESS) coupled with CS that can be serve in the peak shaving demand of EVs. Moreover, the evaluation of ESS needs to take into account the optimal sizing of battery storage and energy management systems that is still a challenging problem in next future work.

References

Books and Book Articles

Provincial Electricity Authority (PEA). (2559). *PEA's Regulation of Grid Connection System*. Provincial Electricity Authority Head office, Bangkok.

Andersson, D. and D. Carlsson. (2012). *Measurements of ABB's Prototype Fast Charging Station for Electric Vehicles.* M.E. Thesis, Chalmers University of Technology Gothenburg.

Au, T.K. (2012). *Assessment of Plug-in Electric Vehicles Charging on Distribution Networks.* M.S. Thesis, University of Washington.

Yunus, K.J. (2010). *Probabilistic Modeling of Plug-In Electric Vehicle Charging Impacts on Power Systems.* M.S. Thesis, Chalmers University of Technology Gothenburg.

J. Krumm. (2012). How People Use Their Vehicles: Statistics from the 2009 National Household Travel Survey, *SAE 2012 World Congr. Exhib.*, 1–12.

R. Van Haaren, (2012). Assessment of Electric Cars ' Range Requirements and Usage Patterns based on Driving Behavior , *The National Household Travel Survey of 2009*, vol. 1, no. 917, p. 56.

Articles

Clark, W., Y. Huang and S. Withers. (2003). Does commuting distance matter Commuting tolerance and residential change. *Regional Science and Urban Economics*, 33, 199-221.

Liu, R., L. Dow and E. Liu. 2011. A survey of PEV impacts on electric utilities, *IEEE PES Innovative Smart Grid Technologies Conference, 17-19 January 2011* (pp. 1-8). Institute of Electrical and Electronics Engineers (IEEE) Power & Energy Society (PES), Anaheim, California, United States of America.

Paradopoulos, P., L.M. Clipcican, N. Jenkins and I. Grau. (2009). Distribution networks with electric vehicles, *Proceedings of the 44th International Universities Power Engineering Conference (UPEC), 1-4 September 2009* (pp. 1-5). Institute of Electrical and Electronics Engineers (IEEE), Glasgow, Scotland, United Kingdom.

Shadidinejad, S., S. Filizadeh, and E. Bibeau. (2012). Profile of charging load on the grid due to plug-in vehicles. *IEEE Transactions on Smart Grid*, 3 (1), 135-141.

Veneri, O., L. Ferraro, C. Capasso and D. Iannuzzi. (2012). Charging infrastructures for EV: overview of technologies and issues, *Electrical Systems for Aircraft, Railway and Ship Propulsion (ESARS), 16-18 October 2012* (pp. 1-6). Institute of Electrical and Electronics Engineers (IEEE), Bologna, Italy.

K. Yunus, H. Z. D. La Parra, and M. Reza. (2011). Distribution Grid Impact of Plug-In Electric Vehicles Charging at Fast Charging Stations Using Stochastic Charging Model, *Proceedings of the 2011-14th European Conference 30 August-1 September 2011* (pp.1-11). Power Electronics and Applications (EPE 2011). Birmingham, United Kingdom.

K. J. Yunus, M. Reza, H. Zelaya-De La Parra, and K. Srivastava. (2012). Impacts of stochastic residential plug-in electric vehicle charging on distribution grid, *2012 IEEE PES Innovation. Smart Grid Technol. ISGT 2012*, pp. 1–8.

M. F. Shaaban and E. F. El-Saadany. (2013). Probabilistic modeling of PHEV charging load in distribution systems," *2013 3rd Int. Conf. Electr. Power Energy Convers. Syst. EPECS 2013*, no. July 2010, 0–5.

P. Phonrattanasak and N. Leeprechanon. (2012). *Optimal Location of Fast Charging Station on Residential Distribution Grid*, vol. 3, no. 6.

T. Klayklueng, S. Dechanupaprittha, and P. Kongthong. (2015). Analysis of unbalance Plug-in Electric Vehicle home charging in PEA distribution network by stochastic load model, *Proc. - 2015 Int. Symp. Smart Electr. Distrib. Syst. Technol. EDST 2015*, 394–398.

R. Hiwatari, T. Ikeya, and K. Okano. (2011). A road traffic simulator to analyze layout and effectiveness of rapid charging infrastructure for electric vehicle, *2011 IEEE Vehicle. Power Propuls. Conf.*, 1–6.

Vlilet, O., A. S. Brouwer, T. Kuramochi, M. Broek and A. Faaij. (2011). Energy use, cost and CO_2 emissions of electric cars. *Journal of power sources, 196* (4), 2298-2310.

T. Anegawa. (2010). Development of Quick Charging System for Electric Vehicle Development of Quick Charging System, *Proceeding of World Energy Congress. 11th-16th Sept 2010.*

D. Andersson, (2012). *Measurements of ABB' s Prototype Fast Charging Station for Electric Vehicles A contribution towards standardized models.*

Electronic Media

ABB. (2011). *Electric Vehicle Infrastructure DC Fast Charge Station*. Retrieved from June 1, 2015, http://www05.abb.com/global/scot/scot232.nsf/veritydisplay/19925263c4f5bee0c12578480048c686/$file/dc_fastchargestation_100211.pdf.

Loveday, E. (2010). *Nissan pegs Leaf range between 47 and 138 miles, individual results may vary*. Retrieved from June 14, 2015, http://green.autoblog.com/2013/06/14/nissan-pegs-leaf-range-between-47-and-138-miles-individual-resu/.

Appendices

Appendix A

Source Code

1.MATLAB Source code

1.1 Charging profile by Monte Carlo technic Part I

```
function [p_profile, nc] = Genload

clc;
clear all;
load('cum_sum.mat') % Load cum_SOC
load('Arrival.mat') % Load x,v variable
T = 1:1440;         % Strat from 1 to 1440
kWC= 110;           % Charger Rod per EA
TF = (24/kWC)*60;   % Power for each Time(min/kwc)
n_ev = 1600;        % Number of EV
n_chg = 8;          % Number of charger

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%                                      %%%%
%%              Create SOC Data                 %%
%%| ID | SOC | Arrivaltime | Chargetime | Waittime |      %%
%%| 1  |   2 |     3       |      4     |     5    |      %%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%
%%  random procedure
nc =0;
for i=1:n_ev

    Xprob =rand*100;
    Xtest = floor(Xprob);
    ind = find(Xtest == cum(2,:));
    dis(i)= cum(1,ind);
     EVSOC = ((47-dis(i))/47)*100;

 if EVSOC <= 50
nc= nc+1;
EV(nc,1) = nc;
EV(nc,2) = EVSOC;
EV(nc,3) = floor(interp1(v,x,rand*100));
EV(nc,4) = ceil((80-EV(nc,2))*(TF/100));

     else
     nc = nc;
    end
```

```
end


%% >> Charger

charger_matrix = zeros(n_chg, length(T));


%% >> Charge_Time

for i = 1:1440;%

  y           = find(EV(:,3) == i);%check time
  y_time      = EV(y,4); % find duration

  id          = find(y_time);%find time slot of EV

  z           = find(charger_matrix(:,i) == 0);

  check_slot   = length(z) - length(id);

  if (check_slot < 0)

     tmp_id = id;

     id_now = tmp_id(1:length(z));
     id_later = tmp_id(length(z)+1 : end);

     for k = 1:length(id_later)
        EV(y(id_later(k)), 3) = EV(y(id_later(k)), 3) + 1;

     end
  else
     id_now = id;
  end


  for j = 1:length(id_now)
      charger_matrix(z(j),i:i+y_time(id(j))-1) = y(j);
  end


end
```

```
%% RECHECK
a = zeros(1,length(charger_matrix(1,:)));

for i = 1:length(charger_matrix(1,:))
    [b1, b2] = find(charger_matrix(:,i));
    a(i) = sum(b2);
end
p_profile=a.*(110/1000);

end
```

1.2 Charging profile by Monte Carlo technic Part II

```
clc; clear all;
iter = 10000;
step = 500;
t = step:step:iter;
count_t = 1;
total_nc = zeros(1,iter);
get_profile = zeros(iter, 1440);

tic;

for j=1:iter

    if j==1
        [p_profile, nc_out] = Genload;
        total_nc(1,j) = nc_out;
        get_profile(j,:) = p_profile;
    else
        % ---------------------------------------
            if j == t(1,count_t)

                fprintf('\n iter # %d\n',j);
                count_t = count_t + 1;
                pause(1)
            end
        % ---------------------------------------
                [p_profile, nc_out] = Genload;
        total_nc(1,j) = nc_out;
        get_profile(j,:) = p_profile(1, 1:1440);

        if length(get_profile(1,:)) > 1440
            system('pause')
        end
```

```
    end

end

toc;
```

1.3 K-mean clustering technic source code

```
filename = 'Location.csv';
fid = fopen(filename,'rt');
[data]=textscan(fid, '%f %f',...
        'headerlines', 1,...
        'delimiter',',',...
        'TreatAsEmpty','NA',...
        'EmptyValue', NaN);

 fclose(fid);

 H_W=data{1};
 W_H=data{2};

X = [H_W W_H]

 opts = statset('Display','final');


[idx,ctrs] = kmeans(X,10,...
                    'Distance','city',...
                    'Replicates',5,...
                    'Options',opts);



plot(X(idx==1,1),X(idx==1,2),'r.','MarkerSize',12)
hold on
plot(X(idx==2,1),X(idx==2,2),'b.','MarkerSize',12)
hold on
plot(X(idx==3,1),X(idx==3,2),'y.','MarkerSize',12)
hold on
plot(X(idx==4,1),X(idx==4,2),'m.','MarkerSize',12)
hold on
plot(X(idx==5,1),X(idx==5,2),'c.','MarkerSize',12)
hold on
plot(X(idx==6,1),X(idx==6,2),'g.','MarkerSize',12)
hold on
plot(X(idx==7,1),X(idx==7,2),'r.','MarkerSize',12)
```

```
hold on
plot(X(idx==8,1),X(idx==8,2),'k.','MarkerSize',12)
hold on
plot(X(idx==9,1),X(idx==9,2),'b.','MarkerSize',12)
hold on
plot(X(idx==10,1),X(idx==10,2),'b.','MarkerSize',12)

plot(ctrs(:,1),ctrs(:,2),'kx',...
     'MarkerSize',12,'LineWidth',2)
plot(ctrs(:,1),ctrs(:,2),'ko',...
     'MarkerSize',12,'LineWidth',2)



legend('Cluster 1','Cluster 2','Cluster 3','Cluster 4','Cluster 5','Cluster 6','Cluster
7','Cluster 8','Cluster 9','Cluster 10','Centroids',...
       'Location','NW')
```

2.Python Source Source code

2.1 Simulator of the estimation Phuket OD Location

```
import psycopg2
from multiprocessing import Pool
from itertools import zip_longest

connection_string = "host=localhost dbname=smartroute user=postgres
password=letmein connect_timeout=5"

def process_chunk(line):
    if line is not None:
        imei, h_cid, w_cid, h_lat, h_lon, w_lat, w_lon = line.strip().split(",")
        if (h_lon, h_lat) != (w_lon, w_lat):
            with psycopg2.connect(connection_string) as conn:
                with conn.cursor() as cursor:
                    path = [h_lon, h_lat, w_lon, w_lat]
                    cursor.execute("SELECT SUM(cost) FROM
pongpgr_fromAtoB('hh_2po_4pgr', %s, %s, %s, %s)", path)
                    cost = str(cursor.fetchone()[0])
                    return ','.join([imei, h_cid, w_cid, h_lat, h_lon, w_lat, w_lon, cost])

def grouper(n, iterable, padvalue=None):
    return zip_longest(*[iter(iterable)]*n, fillvalue=padvalue)

if __name__ == "__main__":
    pool = Pool(4)
    with open("phuket_home_work2.csv", "r") as input_file:
        with open("result.csv", "w") as output_file:
            output_file.write("imei,h_cid,w_cid,h_lat,h_lon,w_lat,w_lon,cost")
        for chunk in grouper(1000, input_file):
            results = pool.map(process_chunk, chunk)
            with open("result.csv", "a") as output_file:
                for r in filter(None, results):
                    output_file.write("\n" + r)
```

3.DigSILENT PowerFactory Source Source code

3.1 Load Flow Calculation by DPL script

```
set sBus;
set sLoad;
set Line;
object oBus,oLoad,oLine,O,SumGrid,pLoad,Ldfw;
int NoBus,NoLine,NoLoad,i,j,ii,pCount;
int Nr,Nc,nn,kk,jj,chk,chk1,chk2,chk3,chk4,chk5,chk6,chk7,chk8;
double  Ul,Bus_PU,P_Bus,Q_Bus,MW,MVar;
string s1,s2,s3,s4,w;

ClearOutput();
sBus = AllRelevant('*.ElmTerm');
sLoad = AllRelevant('*.ElmLod');
!Line = AllRelevant('*.ElmLne');


NoBus = sBus.Count();
!NoLine = Line.Count();
!NoLoad = sLoad.Count();

!printf('Number of Bus = %d',NoBus);
!printf('Number of Line = %d',NoLine);
!printf('Nunber of Switch = %d',NoLoad);

!Check size Input Matrix
Nr = Loaddata.NRow();
Nc = Loaddata.NCol();

printf('Nunber of Row = %d',Nr);
printf('Nunber of Columr = %d',Nc);
printf('Nunber of bus = %d',NoBus);


!Form Matrix for get values after Load Flow Execute
Bus.Init(Nr*sData,NoBus);
!nn=1;
!for(oBus = sBus.First();oBus; oBus = sBus.Next()){

   !s1 = sprintf('%s',oBus:loc_name);
   !Bus.ColLbl(s1,nn);
   !nn=nn+1;
!}
              kk=2;
for(i=1;i<=Nr;i+=1){
```

```
        if(i=1){
   s1 = sprintf('P_Flow%d',i);
   s2 = sprintf('Q_Flow%d',i);
   s3 = sprintf('V_Magnitude%d',i);
   Bus.RowLbl(s1,i);
   Bus.RowLbl(s2,i+1);
   Bus.RowLbl(s3,sData);
    }
    else{
    s1 = sprintf('P_Flow%d',i);
    s2 = sprintf('Q_Flow%d',i);
    s3 = sprintf('V_Magnitude%d',i);
    Bus.RowLbl(s1,i+kk);
    Bus.RowLbl(s2,i+kk+1);
    Bus.RowLbl(s3,i+kk+2);
    kk=kk+2;
    }
  }

     kk=2;
    for (i=1;i<=Nr;i+=1)
        {

             for(oLoad = sLoad.First();oLoad;oLoad=sLoad.Next())
             {
                 printf('Name of Load = %s',oLoad:loc_name);

                 s4 = oLoad:loc_name;

!                 sprintf('S4 = %s',s4);

                 !chk = strcmp(s4,'F1'); !compare fix load
                 !chk1 = strcmp(s4,'F2');
                 !chk2 = strcmp(s4,'F3');
                 !chk3 = strcmp(s4,'F4');
                 chk4 = strcmp(s4,'S1');
                 chk5 = strcmp(s4,'S2');  !*****
                 !chk6 = strcmp(s4,'L2');
                 !chk7 = strcmp(s4,'L3');
                 !chk8 = strcmp(s4,'L4');
                if (chk4 =0){
                    oLoad:plini = Load1.Get(i,1);
                    oLoad:qlini = Load1.Get(i,2);
                    }
                else if (chk5 =0) {
                      oLoad:plini = Load2.Get(i,1);
                      oLoad:qlini = Load2.Get(i,2);
```

```
            }


      }

       Ldfw = GetCaseCommand('ComLdf');
       Ldfw:iopt_net = 1;
       Ldfw.Execute();
       Results_1.WriteDraw();
           nn=1;
           for(oBus = sBus.First();oBus; oBus = sBus.Next())
              {

               Bus.ColLbl(oBus:loc_name,nn);

                   Ul = oBus:m:u1; !Voltage Magnitude in pu. at Bus
                   !P_Bus = oBus:m:Pflow;
                   !Q_Bus = oBus:m:Qflow;

                     if(i=1){
                        Bus.Set(i,nn,P_Bus);
                        Bus.Set(i+1,nn,Q_Bus);
                        Bus.Set(sData,nn,Ul);
                             }

                      else{
                        Bus.Set(i+kk-2,nn,P_Bus);
                        Bus.Set(i+kk+1-2,nn,Q_Bus);
                        Bus.Set(i+kk,nn,Ul);

                            }

                         nn=nn+1;
                }

       kk=kk+2;

}
```

Appendix B
Related Data

Phuket Load data

(1)TLG01's Feeder

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
0:00	5.2	2.0
0:30	5.2	2.0
1:00	4.9	1.9
1:30	4.8	1.8
2:00	4.6	1.8
2:30	4.5	1.7
3:00	4.5	1.7
3:30	4.3	1.6
4:00	4.3	1.6
4:30	4.1	1.6
5:00	4.2	1.6
5:30	4.3	1.6
6:00	4.5	1.7
6:30	4.6	1.8
7:00	4.8	1.8
7:30	5.1	2.0
8:00	5.5	2.1
8:30	5.8	2.2
9:00	6.4	2.5
9:30	6.6	2.5
10:00	7.1	2.7
10:30	7.4	2.8
11:00	7.6	2.9
11:30	7.7	2.9
12:00	7.7	2.9
12:30	7.5	2.9
13:00	7.4	2.8
13:30	7.3	2.8
14:00	7.5	2.9
14:30	7.6	2.9
15:00	7.7	2.9
15:30	7.7	2.9
16:00	7.4	2.8

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
16:30	7.4	2.8
17:00	7.5	2.9
17:30	7.2	2.8
18:00	7.4	2.8
18:30	7.0	2.7
19:00	7.4	2.8
19:30	8.1	3.1
20:00	7.9	3.0
20:30	7.6	2.9
21:00	7.4	2.8
21:30	7.2	2.8
22:00	6.9	2.6
22:30	6.9	2.6
23:00	6.7	2.6
23:30	6.1	2.3

(2)TLG09's Feeder

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
0:00	2.2	0.8
0:30	2.2	0.8
1:00	2.1	0.8
1:30	2.2	0.8
2:00	2.1	0.8
2:30	2.1	0.8
3:00	2.0	0.8
3:30	2.0	0.8
4:00	2.0	0.8
4:30	2.0	0.8
5:00	2.1	0.8
5:30	2.1	0.8
6:00	2.2	0.8
6:30	2.3	0.9
7:00	2.8	1.1
7:30	2.7	1.0
8:00	3.0	1.1
8:30	3.5	1.3
9:00	3.4	1.3
9:30	3.5	1.3

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
10:00	3.7	1.4
10:30	3.8	1.5
11:00	3.8	1.5
11:30	3.8	1.5
12:00	3.8	1.5
12:30	3.6	1.4
13:00	3.6	1.4
13:30	3.6	1.4
14:00	3.7	1.4
14:30	3.8	1.5
15:00	3.7	1.4
15:30	3.9	1.5
16:00	3.8	1.5
16:30	3.7	1.4
17:00	3.7	1.4
17:30	3.5	1.3
18:00	3.3	1.3
18:30	3.3	1.3
19:00	3.3	1.3
19:30	3.6	1.4
20:00	3.5	1.3
20:30	3.4	1.3
21:00	3.2	1.2
21:30	2.6	1.0
22:00	2.5	1.0
22:30	2.4	0.9
23:00	2.7	1.0
23:30	2.5	1.0

(3)TLG10’s Feeder

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
0:00	7.2	2.8
0:30	7.0	2.7
1:00	6.8	2.6
1:30	6.7	2.6
2:00	6.4	2.5
2:30	6.3	2.4
3:00	6.2	2.4

Time of Day(Hour)	**Real Power (MW)**	**Reactive Power (MVAR)**
3:30	6.2	2.4
4:00	6.2	2.4
4:30	6.3	2.4
5:00	6.4	2.5
5:30	6.7	2.6
6:00	7.0	2.7
6:30	7.1	2.7
7:00	6.7	2.6
7:30	6.6	2.5
8:00	6.8	2.6
8:30	7.1	2.7
9:00	7.3	2.8
9:30	7.5	2.9
10:00	7.6	2.9
10:30	7.7	2.9
11:00	7.7	2.9
11:30	7.8	3.0
12:00	7.4	2.8
12:30	7.3	2.8
13:00	7.3	2.8
13:30	7.2	2.8
14:00	7.3	2.8
14:30	7.4	2.8
15:00	7.4	2.8
15:30	7.5	2.9
16:00	7.5	2.9
16:30	7.7	2.9
17:00	7.6	2.9
17:30	7.5	2.9
18:00	7.5	2.9
18:30	7.5	2.9
19:00	8.1	3.1
19:30	9.6	3.7
20:00	9.5	3.6
20:30	9.2	3.5
21:00	9.0	3.4
21:30	9.0	3.4
22:00	8.9	3.4
22:30	8.7	3.3
23:00	8.4	3.2
23:30	8.0	3.1

(4)PKA05's Feeder

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
0:00	8.63	3.31
0:30	8.63	3.31
1:00	8.29	3.18
1:30	7.94	3.04
2:00	7.94	3.04
2:30	7.6	2.91
3:00	7.6	2.91
3:30	7.25	2.78
4:00	7.25	2.78
4:30	7.25	2.78
5:00	7.25	2.78
5:30	7.6	2.91
6:00	7.6	2.91
6:30	7.94	3.04
7:00	7.6	2.91
7:30	7.6	2.91
8:00	7.94	3.04
8:30	8.63	3.31
9:00	8.63	3.31
9:30	8.98	3.44
10:00	8.98	3.44
10:30	9.67	3.70
11:00	9.67	3.70
11:30	9.67	3.70
12:00	9.32	3.57
12:30	8.98	3.44
13:00	8.98	3.44
13:30	9.67	3.70
14:00	9.32	3.57
14:30	9.32	3.57
15:00	9.32	3.57
15:30	9.32	3.57
16:00	9.32	3.57
16:30	8.98	3.44
17:00	8.63	3.31
17:30	8.63	3.31
18:00	8.63	3.31
18:30	8.98	3.44

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
19:00	10.01	3.83
19:30	10.36	3.97
20:00	10.36	3.97
20:30	10.01	3.83
21:00	10.36	3.97
21:30	10.01	3.83
22:00	10.36	3.97
22:30	10.01	3.83
23:00	9.67	3.70
23:30	9.32	3.57

(5)PKA09's Feeder

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
0:00	7.60	2.91
0:30	7.60	2.91
1:00	7.25	2.78
1:30	6.91	2.65
2:00	6.91	2.65
2:30	6.57	2.52
3:00	6.22	2.38
3:30	6.22	2.38
4:00	6.22	2.38
4:30	6.22	2.38
5:00	6.22	2.38
5:30	6.22	2.38
6:00	6.57	2.52
6:30	6.91	2.65
7:00	6.57	2.52
7:30	6.91	2.65
8:00	7.25	2.78
8:30	8.29	3.18
9:00	8.98	3.44
9:30	9.32	3.57
10:00	9.32	3.57
10:30	1.03	0.39
11:00	1.72	0.66
11:30	3.10	1.19
12:00	9.32	3.57

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
12:30	9.32	3.57
13:00	9.32	3.57
13:30	10.01	3.83
14:00	8.63	3.31
14:30	9.67	3.70
15:00	9.67	3.70
15:30	9.32	3.57
16:00	9.32	3.57
16:30	8.98	3.44
17:00	8.63	3.31
17:30	8.29	3.18
18:00	8.29	3.18
18:30	8.63	3.31
19:00	9.67	3.70
19:30	9.67	3.70
20:00	10.01	3.83
20:30	10.01	3.83
21:00	9.67	3.70
21:30	9.67	3.70
22:00	9.32	3.57
22:30	9.32	3.57
23:00	8.98	3.44
23:30	8.63	3.31

(6)PKA10’s Feeder

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
0:00	5.53	2.12
0:30	5.17	1.98
1:00	5.17	1.98
1:30	4.82	1.85
2:00	4.82	1.85
2:30	4.82	1.85
3:00	4.48	1.72
3:30	4.48	1.72
4:00	4.13	1.58
4:30	4.13	1.58
5:00	4.13	1.58
5:30	4.13	1.58

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
6:00	4.48	1.72
6:30	4.48	1.72
7:00	4.48	1.72
7:30	4.48	1.72
8:00	4.82	1.85
8:30	5.53	2.12
9:00	5.53	2.12
9:30	5.53	2.12
10:00	5.88	2.25
10:30	6.22	2.38
11:00	6.22	2.38
11:30	6.22	2.38
12:00	5.88	2.25
12:30	5.88	2.25
13:00	5.88	2.25
13:30	6.57	2.52
14:00	5.53	2.12
14:30	5.88	2.25
15:00	5.88	2.25
15:30	5.88	2.25
16:00	5.88	2.25
16:30	5.53	2.12
17:00	5.53	2.12
17:30	5.17	1.98
18:00	5.17	1.98
18:30	5.53	2.12
19:00	5.88	2.25
19:30	5.88	2.25
20:00	5.88	2.25
20:30	5.88	2.25
21:00	5.88	2.25
21:30	5.88	2.25
22:00	5.88	2.25
22:30	5.88	2.25
23:00	6.57	2.52
23:30	6.57	2.52

(7)PKB01’s Feeder

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
0:00	4.82	1.85
0:30	4.82	1.85
1:00	4.48	1.72
1:30	4.48	1.72
2:00	4.48	1.72
2:30	4.13	1.58
3:00	4.13	1.58
3:30	4.13	1.58
4:00	4.13	1.58
4:30	4.13	1.58
5:00	4.13	1.58
5:30	4.13	1.58
6:00	4.48	1.72
6:30	4.13	1.58
7:00	4.48	1.72
7:30	4.82	1.85
8:00	5.53	2.12
8:30	6.22	2.38
9:00	6.91	2.65
9:30	7.25	2.78
10:00	7.25	2.78
10:30	7.60	2.91
11:00	7.60	2.91
11:30	7.60	2.91
12:00	7.60	2.91
12:30	7.25	2.78
13:00	7.25	2.78
13:30	7.94	3.04
14:00	7.94	3.04
14:30	7.60	2.91
15:00	7.94	3.04
15:30	7.60	2.91
16:00	7.60	2.91
16:30	7.60	2.91
17:00	6.91	2.65
17:30	6.57	2.52
18:00	6.22	2.38
18:30	6.57	2.52
19:00	6.91	2.65

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
19:30	6.57	2.52
20:00	6.57	2.52
20:30	6.22	2.38
21:00	6.22	2.38
21:30	6.22	2.38
22:00	5.88	2.25
22:30	5.88	2.25
23:00	5.53	2.12
23:30	5.17	1.98

(8)KRU01's Feeder

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
0:00	4.48	1.72
0:30	4.48	1.72
1:00	4.13	1.58
1:30	4.13	1.58
2:00	3.79	1.45
2:30	3.79	1.45
3:00	3.44	1.32
3:30	3.44	1.32
4:00	3.44	1.32
4:30	3.44	1.32
5:00	3.44	1.32
5:30	3.44	1.32
6:00	3.79	1.45
6:30	3.79	1.45
7:00	3.79	1.45
7:30	4.13	1.58
8:00	4.82	1.85
8:30	5.53	2.12
9:00	6.57	2.52
9:30	6.91	2.65
10:00	7.60	2.91
10:30	7.94	3.04
11:00	8.29	3.18
11:30	8.29	3.18
12:00	7.94	3.04
12:30	7.94	3.04

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
13:00	7.94	3.04
13:30	8.29	3.18
14:00	7.94	3.04
14:30	7.94	3.04
15:00	7.94	3.04
15:30	7.94	3.04
16:00	7.94	3.04
16:30	7.94	3.04
17:00	7.60	2.91
17:30	7.25	2.78
18:00	7.25	2.78
18:30	6.91	2.65
19:00	6.91	2.65
19:30	7.25	2.78
20:00	7.25	2.78
20:30	6.57	2.52
21:00	6.57	2.52
21:30	5.88	2.25
22:00	5.53	2.12
22:30	5.17	1.98
23:00	5.53	2.12
23:30	5.17	1.98

(9)PAV03's Feeder

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
0:00	7.60	2.91
0:30	7.25	2.78
1:00	7.25	2.78
1:30	6.91	2.65
2:00	6.91	2.65
2:30	6.57	2.52
3:00	6.57	2.52
3:30	6.57	2.52
4:00	5.53	2.12
4:30	5.53	2.12
5:00	5.53	2.12
5:30	6.57	2.52
6:00	6.57	2.52

Time of Day(Hour)	Real Power (MW)	Reactive Power (MVAR)
6:30	6.57	2.52
7:00	6.57	2.52
7:30	6.91	2.65
8:00	7.25	2.78
8:30	7.60	2.91
9:00	7.94	3.04
9:30	7.94	3.04
10:00	8.63	3.31
10:30	8.63	3.31
11:00	8.98	3.44
11:30	8.63	3.31
12:00	8.29	3.18
12:30	7.94	3.04
13:00	8.29	3.18
13:30	8.63	3.31
14:00	8.63	3.31
14:30	8.29	3.18
15:00	8.29	3.18
15:30	8.29	3.18
16:00	7.94	3.04
16:30	7.94	3.04
17:00	7.60	2.91
17:30	7.25	2.78
18:00	6.57	2.52
18:30	6.91	2.65
19:00	7.60	2.91
19:30	7.60	2.91
20:00	7.60	2.91
20:30	7.60	2.91
21:00	7.60	2.91
21:30	7.60	2.91
22:00	7.25	2.78
22:30	8.63	3.31
23:00	8.29	3.18
23:30	7.94	3.04