Optimal Placement of EV Charging Station Considering the Road Traffic Volume and EV Running Distance

Surat Saelee and Teerayut Horanont
Sirindhorn International Institute of Technology, Thammasat University, Bangkok Thailand
Email: surat.saelee@studentmail.siit.tu.ac.th, teerayut@siit.tu.ac.th

***Abstract*—The number of the Electric Vehicles (EVs) has been increasing rapidly due to environmental friendliness. However, there is a need to prepare an effective Charging Station (CS) infrastructures to charge battery for daily energy consumption. Then the electric vehicle charging station must be extensively installed to sufficiently serve a number of EVs. In this work, we propose a new approach to select the location of CS by using road traffic volume and driving range from real mobile data log. The proposed algorithm is used to determine the effective layout of CS based on running out point of electricity. Especially, voltage impact and power losses in distribution line affected by EV charging behavior is a serious problem of power quality. From this reason, the power flow analysis is simulated for power quality of location selection that suggest basic guide-line for alleviating the problem.**

***Index Terms*—electric vehicle charging station selection, route optimization, spatial analysis**

I. Introduction

Smart Grids (SG) provide energy greener than the traditional grids do, while EVs are more environmentally friendly than gas vehicle, and hence the combination of smart grids and EVs would bring huge benefits to 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 charging station infrastructure throughout Thailand.

Recently, the increasing of fuel cost and environmental concerns have stimulate recent take-off of EVs market. However, the capacity and size of EV battery is still bottle-neck of EVs technology that can take a short driving range amount 50-200 km. So public recharging or Public CS will be necessary for short drive range in today technology [1] and [2]. Since the installation cost of CS is very expensive, the selecting the optimal placement will be one of the key issue that can deal with demand response in the EVs user in transportation systems. In this work, we propose a new approach to selecting the location of CS station by using the real behavior from person who carry mobile phone in Phuket. The proposed method is used mobile phone log data to determine the real driving range (from home to work, and work to home) and simulate running out point of EVs. Finally we apply clustering algorithm to estimate the optimal location of CS based on group of location that determine the EVs running out of energy.

Manuscript received April 12, 2015; revised August 15, 2015.

II. Problem Formulation

A. The Estimation Number of CS

TABLE I. 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)	500	kVA
Power factor ($cos\O$)	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

In this work, we set up scenario for implementing CS in year 2020. According to the Department of Land Transport of Thailand (DLT), the number of vehicle registered in Thailand as of 31 March 2015 in Phuket is about 441,120 cars. Furthermore, Thailand Automotive Institute (TAI) forecast 5% increasing of cars by 2020. Asia Pacific Automotive Forecasting expected EV market share is 3.5% of all vehicles. So the number of EV in Phuket is about 16000 vehicles in years 2020.According to equation from [3], we will find the number of charging station using the following equation;

$$N = \frac{P \times E \times l_{fv} \times chg\_time}{s \times f \times q \times Cap \times l_f \times \cos\theta} \tag{1}$$

doi: 10.18178/jtle.4.1.19-23

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, and *cosØ* is the power factor of charging station.

Finally, by using the parameter in Table I to solve following to equation 1, we get the optimal number of CS in Phuket is 10 station. In this research, we set up experiment to find the best location of 10 electric vehicle charging station placement.

B. Charging Model and Arrival Time of EVs Charging

Regarding the method for charging systems, it is used a single-phase 200V or 400 VAC for night time charging at home that normally take a long time to charge. However, during day time, we expected a shorter time to fill up their battery. Fast charging method will be very significant. From this reason, we focus to use a fast charge method by using three phases 400 VAC, 250 A, 50 Hz, and 100 kVA. In this work, please note that one CS also contains 5 charging circuits or 500 kVA.

According to the charging behavior of EVs, almost EVs always charge in the day time. Especially, the time between 4-6 p.m., we captured of a lot demand energy consumption for charging EVs that is one of the main issue affecting to distribution systems. In this research, 1600 EVs are conducted 10,000 events for charging load profile by using Monte Carlo simulation [4], and find the peak load profile event as the base of load profile of CS.

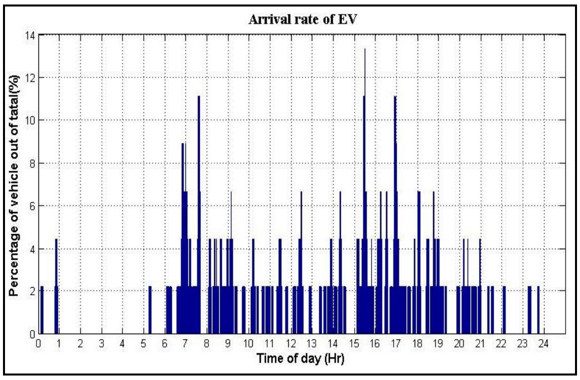


Figure 1. Arrival rate of EVs charging during a day.

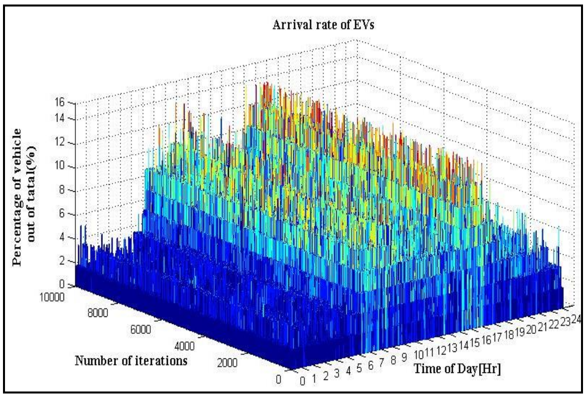


Figure 2. Arrival-time of EV charging 10000 events.

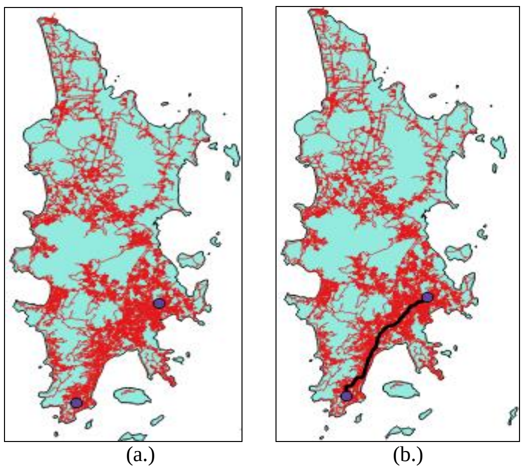
The algorithm exploits the statistical data which is considered as the key factor to get the CS load profile. The Matlab software is used to generate as shown in Fig. 1 and Fig. 2.

III. Methodology and Model

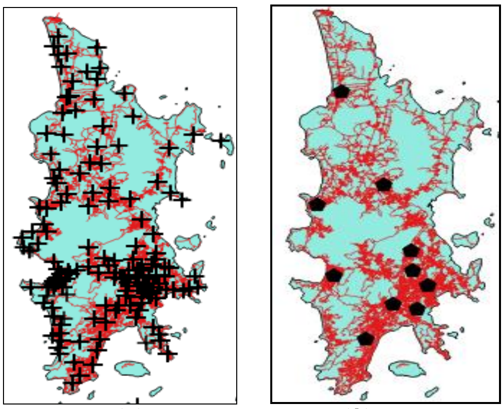
We propose a new approach using mobile usage data to select the optimal place of CS. By collecting a long-term mobile data log in Phuket, we could estimate home and work locations and use them to simulate the real mobility for each EV running path in a day. The open source routing software, pg routing, is used to calculate distance of energy running out points. We assume all EVs is fully charged at night (100 percent SOC). Then, in the day time everyone go around home and work place, and start using their EVs. The SOC of each EVs will decrease based on driving range until the energy remains 40 percent of SOC that is the running out point of electricity considered in this work. After that, we use k-mean algorithm to find the optimal location of CS from a cluster of running out point.

In addition, we utilize GIS map to create the effective layout of CS. The QGIS software is used to illustrate the map by following these steps.

- We use the raw mobile log to simulate the real mobility of population living in Phuket. The result estimate individual home-work location as shown in Fig. 3a.
- The simulation of daily travel pattern is used to determine the point of EVs running out. EVs traveling path for each EVs is calculate base on the assumption of trip traveling between home and work by using the dijktra's shortest path algorithm as can be seen in Fig. 3b.
- The simulation result of running out point of electricity is used to determine the selection point of CS by using K-mean algorithm as following to Fig. 3c and Fig. 3d.
- The Power flow analysis is formulated by exporting GIS database to DigSILENT software to analyze the power quality in MV distribution system (33 kV) in Phuket as shown in Fig. 4. We focus on voltage drop along distribution line and power losses after installing CS in MV distribution systems.



(a.) (b.)



(c.) (d.)

Figure 3. The GIS effective lay out of EV running out a.) Estimated Home-Work location, b.)Shortest path of EV, c.) Running out point of electricity 10000 point, d.)The optimal location of CS.

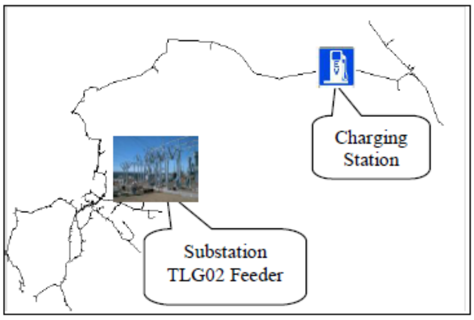


Figure 4. DigSILENT software model of MV distribution line in Phuket (Feeder TLG02).

IV. Simulation and Result

The result of k-mean clustering algorithm shows the best location of CS considering the estimated running out point. The optimal location of result is shown in Fig. 5.

The CS locations spreaded in Phuket province and the edge of the Phuket Island. We select the optimal point from simulation result to be the place of installation CS in MV distribution systems. We use load profile data from [5] and base load for each CS to run load flow calculation of power losses and voltage drop of each feeder when CS installer as can be seen in Table II.

Form Table II, we can see that the TLG02 feeder has a lot impact to the distribution system. Thus we setup a case study for TLG02 feeder to present a per minute load file, per minute voltage profile and voltage impact comparison between with and without CS installation.

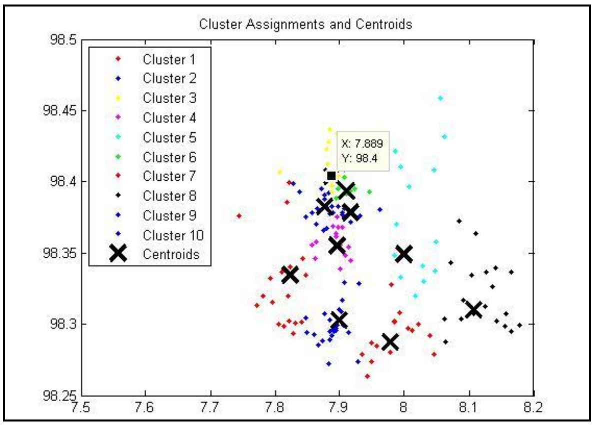
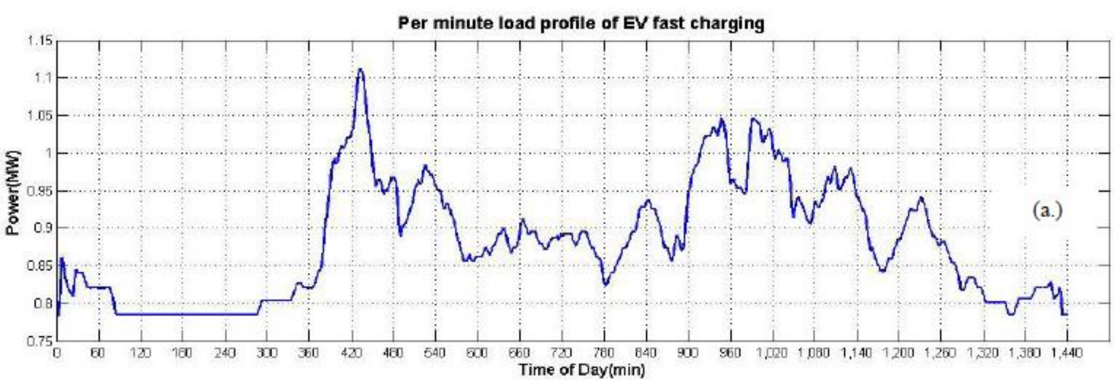


Figure 5. Matlab simulation result of the best CS location in Phuket.

TABLE II. The Result of the Best Location of CS and Power Flow Calculation for Each CS

CS No.	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

PEA voltage level standard is within 0.95-1.05p.u. From the result, at the time of 920 minutes of day, with CS installation, the voltage level change so much when comparing with no CS installation. However, at the peak period (1210 minutes of day), there is the greatest drop in voltage level that may cause power quality problems in distribution system if the demand of energy consumption also increase at this time. The changing of voltage level directly relate with the energy consume of CS in a day. As can be seen from Fig. 6, voltage drop is almost 5% from standard level that will be risky to cause power quality problem in distribution systems.



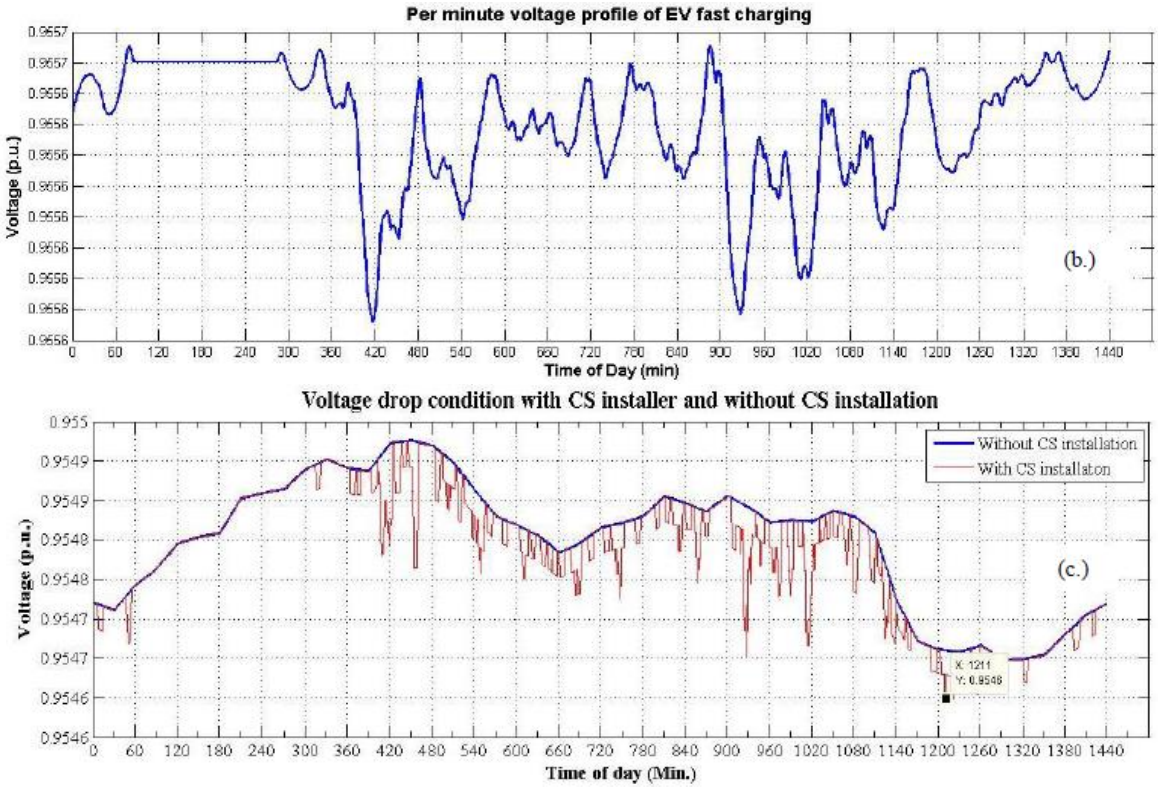


Figure 6. TLG02 load flow simulation result a.) Per minute voltage profile of EV fast charging b.) Per minute load profile of EV fast charging c.)The comparison of voltage drop condition with CS installation and without CS installation.

V. Conclusion

In conclusion, this work illustrates the most optimal location of CS placement in the town and along of the coast of the Phuket Island that deals with the population distribution. In power quality case, the location of CS placement affect the power quality by charging EVs. Especially, the arrival of time of EVs charging and the number of EV charging affect to power quality in the distribution systems. Although the voltage level of this research are within standard range, the energy consumptions will be increasing in the future. If we do not have a controlling of EVs charging or the energy supported in the peak demand period, it may cause the power quality problem to the distribution systems.

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.

Acknowledgment

The authors wish to thank 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.

References

[1] R. Hiwatari, T. Ikeya, and K. Okano, “A road traffic simulator to analyze layout and effectiveness of rapid charging infrastructure for electric vehicle,” in *Proc. IEEE Veh. Power Propuls. Conf.*, Sep. 2011, pp. 1-6.

[2] T. Anegawa, “Development of quick charging system for electric vehicle development of quick charging system,” presented at the World Energy Congress, Montreal, Canada, Sept. 11-16, 2010.

[3] P. Phonrattanasak and N. Leeprechanon, “Optimal location of fast charging station on residential distribution grid,” *International Journal of Innovation, Management and Technology*, vol. 3, no. 6, pp. 675-681, Dec. 2012.

[4] K. Yunus, H. Z. D. La Parra, and M. Reza, “Distribution grid impact of plug-in electric vehicles charging at fast charging stations using stochastic charging model,” in *Proc. 14th Eur. Conf. Power Electron. Appl.*, 2011, pp. 1-11.

[5] PEA Load Research - Enquiry by Estimated Population. [Online]. Available: http://pastpea.pea.co.th//th/loadprofile_t/show.php

Surat Saelee was born in 1987 and received his B.Eng. in Engineering from King Mungkut’s University of Technology Thonburi, Thailand in years 2008 respectively. Currently, he works at Provincial Electricity Authority (PEA), and received a scholarship to study at SIIT in Thailand while pursuing his master in Engineering at the School of Information, Computer, and Communication Technology (ICT), Thammasat University. His research interests are in the area of power system analysis, renewable energy and smart grid development issues.

Teerayut Horanont is currently an assistant professor at Sirindhorn International Institute of Technology (SIIT), Thammasat University. His recent work focuses on human mobility analysis using geo-location traced from mobile devices and mining big geo-spatial data. Dr. Horanont got his Ph.D. in civil engineering from the University of Tokyo. Before joining SIIT, he was a project assistant professor at the University of Tokyo and had working with several open source GIS firms in Japan..