Optimal Fast Charging Station for Electric Vehicles (EVs) in Muang District, Nakhon Ratchasima, Thailand

Nuttapol Chartsuk and Boonruang Marungsri*

***Abstract*— *Recently, Electric Vehicles (EVs) have been encouraging for a less carbon-intensive in the city. The key to charging EV is a fast charging station. The fast-charging stations are connected to the power distribution system and recharging the EV batteries before they are depleted. The recharging of EV takes approximately 15 minutes. The location of the fast charging station is essential because EV users can access the station within their appropriate driving range. This paper presents a simple analytical method, five scenarios were proposed for a case study, for identification of the optimal location and size of the fast-charging stations in a given Muang district, Nakhon Ratchasima, Thailand. By considering the minimal total cost, the total cost consists of the station's development cost, the electrification cost of the fast-charging stations, the traveling cost of EV users, and the energy loss of the power distribution system. The need of fast-charging stations considering the traveling convenience of EV users has been discussed. Simulation results of a cases study show that planning method can determine the most suitable locations and size of the fast charging stations.*

***Keywords*— Electric vehicles, Monte Carlo method, optimal fast-charging stations.**

1. INTRODUCTION

In the future, there is a high probability that a large number of EVs will dominate the transportation. EV did not have any of the issues associated with greenhouse gas emissions and air pollution globally, which is the major problem of internal combustion engines. The battery of EV can be recycled.

The key to charging EV is a fast charging station. The availability of fast charging station such as the appropriate location of fast charging stations and a time of less than half an hour for recharge will be an indicator of EV users convenience. The fast-charging stations need to consider investment costs such as the cost of establishing fast charging station and cost of overhead power lines, as well as energy loss cost of power distribution system and EV energy loss cost for EV moving to the fast charging station to recharge. The basic structure of fast charging station is shown in Fig. 1 [1], [2].

In recent years, have several methods were proposed associated with fast charging, [3]-[5] proposed application of electrical storage systems in fast charging stations which help to reduce operational costs of the station to minimize cost and mitigate impacts of station operation on the power distribution system. [6] proposed a control the charging of EVs to maximize the utilization of the capacity of the distributed power system and reduces long a queuing time of EVs as well as the length of the queue. [7] proposed the optimal location and capacity of fast charging stations by considering investment cost.

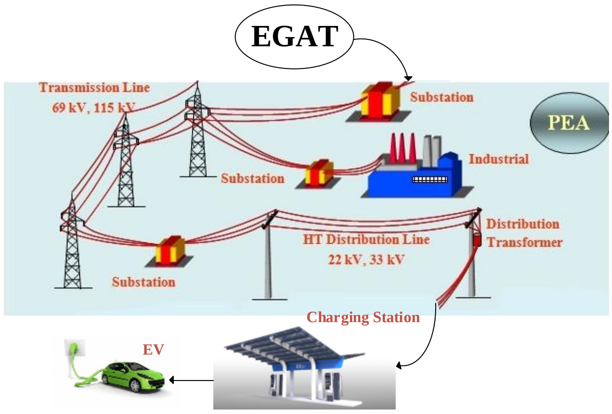

Fig.1. The basic structure of the fast charging station.

This paper presents a simple analytical method, five scenarios were proposed for a case study, for identification of the optimal location and size of the fast-charging stations in a given Muang district, Nakhon Ratchasima, Thailand. By considering the minimal total cost, the total cost consists of the station's development cost, the electrification cost of the fast-charging stations, the traveling cost of EV users, and the energy loss of the power distribution system. The need of fast-charging stations considering the traveling convenience of EV users has been discussed.

This paper is organized as follows. Section II describes the basic models and methodology. The identification of the optimal location and size of the fast charging stations were discussed in Section III. System description in Section IV. Section V gives simulation results and discussion. The conclusion is in Section VI.

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2. THE BASIC MODELS AND METHODOLOGY

Optimal Load Design of Charging Demand

The confidence interval is a range of values calculated by statistical methods with a probability defined in advance. The confidence interval is used for optimal load design of charging demand in this paper. The confidence level of 95% is usually selected, critical value (z) equal to 1.96 [8]. The size of the confidence interval depends on the average and the standard deviation of the study groups. The study groups in this paper are the model of EVs in 2015 to 2017, a model of EV has a size of battery given by the manufacturers in which the capacity of battery demonstrates an amount of km of each model [9]. Assumed that EV needs to charge when the state of charge (SOC) of EV battery is 25% of SOC. Therefore, the energy demand for EVs is between 7.92 kWh and 39.6 kWh (recharge EVs up to 80% of SOC) as illustrated in Table 1.

The average: $$\overline{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \quad (1)$$

The variance: $$s^2 = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \overline{X})^2 \quad (2)$$

where X_i is the energy demand of the EV model *(i)*. n is a number of EV models.

The confidence interval of the study groups can be calculated by [8],

$$Confidence \quad Interval = \overline{x} \pm (z\frac{s}{\sqrt{n}}) \quad (3)$$

From equation (3), the confidence interval is a range of the energy demand of EVs. The total distance of EV after recharge can be calculated by,

$$T_{Dist} = (E_{DC} \times EVC) + D_{SOC25\%} \quad (4)$$

where E_{DC} is the energy demand of EV in kWh. EVC is the energy consumption of EV in km/kWh. $D_{SOC25\%}$ is the distance of EV can travel with SOC equal to 25% in km.

The Fast Charging Model

The fast charging model of EV has used a battery based on a battery charging characteristic. The typical Li-ion battery charging characteristics is shown in Fig. 2 [10]. From Fig. 2, demonstrate that the interval 0 - T_1 is constant current charging and charging float voltage increases and the interval T_1 – T_2 are constant voltage charging and charging float current decreases. The approximate models of battery charging in the interval 0-T_1 are,

$$v(t) = V_n(1 - e^{\frac{-t}{\tau_v}}) \quad (5)$$

$$i(t) = I_n \quad (6)$$

Table 1. Model of Commercial EVs [9]

Models (2015-2017)	Range [km]	Battery [kWh]	Usable battery [kWh]	Δload (SOC 25%-80%) [kWh]
Mitsbuishi i-MiEV	100	16	14.4	7.92
Smart Electric	110	17	15.3	8.42
Chevy Spark EV	130	20	18.0	9.90
BMW i3	130	22	19.8	10.89
Ford Focus EV	130	23	20.7	11.39
Fiat 500e	140	24	21.6	11.88
Leaf 24k Wh	130	24	21.6	11.88
Leaf 30k Wh	165	30	27.0	14.85
Kia Soul EV	150	30	27.0	14.85
Mercedes BClassEV	170	36	32.4	17.82
VW eGolf	300	37	33.3	18.32
Tesla S 60	340	60	54.0	29.70
Tesla model 3	350	60	54.0	29.70
Tesla modelS80	450	80	72.0	39.60

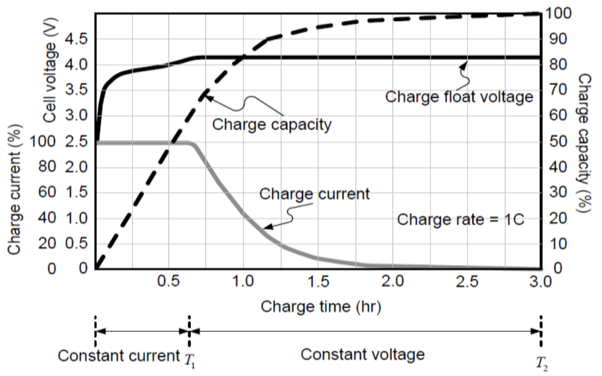

Fig.2. Typical Li-ion battery charging characteristics [10].

The approximate models of battery charging in the interval T_1-T_2 are,

$$v(t) = V_n \quad (7)$$

$$i(t) = I_n e^{\frac{-t}{\tau_i}} \quad (8)$$

where V_n is the nominal voltage of the EV battery. τ_v and τ_i are the time constant determined from the charging voltage and charging current curves. The constant current I_n decreases until the battery reaches the full charging status.

The instantaneous power of the EV battery during the charging process can be calculated by,

$$P(t) = v(t) \cdot i(t) = \begin{cases} V_n I_n (1 - e^{\frac{-t}{\tau_v}}) & ; 0 \le t \le T_1 \\ V_n I_n e^{\frac{-t}{\tau_v}} & ; T_1 < t < T_2 \end{cases} \quad (9)$$

The total energy of EV charging is,

$$W = \int P(t)dt = \int_{T_0}^{T_1} V_n I_n (1 - e^{\frac{-t}{\tau_v}})dt + \int_{T_1}^{T_2} V_n I_n e^{\frac{-t}{\tau_v}} dt = KI_n \quad (10)$$

The nominal value of charging current of EV battery can be calculated by,

$$I_n = \frac{kWh \times 10^3 \times 3600}{K} \quad (11)$$

The constant kWh is the energy demand of EV in kilowatt-hour.

Design an electrical system by considering the full load current (which the safety factor was defined as 25%) can be calculated by,

$$I_{fl} = I_n \times 1.25 \quad (12)$$

Monte Carlo Method

Monte Carlo method simulates problems by using a random number or generate a random number. Monte Carlo method involves following steps [11],

1. Determination of the statistical properties or outcome of possible inputs.
2. Determination of possible inputs which follow the outcome in step 1.
3. Determination of the range of numbers refers to possible outcomes which follow the possible inputs in step 2.
4. Generation of random numbers based on possible outcomes.
5. Analysing the results statistically.

Station Development Cost

Station development cost consists of two main components as follow, station equipment cost and land cost. The station equipment cost depends on the station capacity, the rated power charger, and the number of the charger installed in the fast charging station. The land cost depends on the area of each charger, Fig. 3 shows the charging station layout; station requires a 4.9 × 2.75 m^2 area per charger [12]. In this paper, single charger area is assumed as 25 m^2, and the land cost of the fast charging station was considered for 5 years rental cost. The development cost can be calculated as [2], [7],

$$DC_i = C_{initial} + (A \times C_{land} \times N_{charger}) + (PC \times C_{charger} \times (N_{charger} - 1)) \quad (13)$$

where $C_{initial}$ is station fixed cost in \$. A is a single charger area in m^2. C_{land} is the area rental cost for 5 years in \$/m^2. PC is the rated power charger in kW. $C_{charger}$ is the charger development cost in \$/kW. $N_{charger}$ is number of chargers in the charging station *(i)*.

The station fixed cost ($C_{initial}$), is the cost regarding equipment and facilities for an establishing the fast charging station. The area rental cost (C_{land}), highly depends on the prosperity of the land in different locations of the city. The charger development cost ($C_{charger}$), highly depends on the rated power of the charger. The capacity of the charging station can be calculated by,

$$SC_i = PC \times N_{charger} \quad [\text{kW}] \quad (14)$$

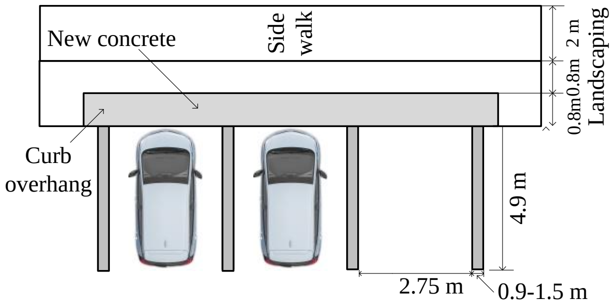

Fig.3. Charging station layout [12].

Electrification Cost of Fast Charging Station

Electrification cost of fast charging station depends on the overhead lines cost. The overhead lines cost depends on the rated current of the overhead lines, the length of overhead lines and the connection technology. In this paper, assumed that the fast charging station was directly connected to the substation via overhead line. Table 2 shows the rated current of overhead line types [13]. Therefore, the application cost of overhead line is the function of cross-section area of the overhead line. Which can be calculated by [2], [7],

$$AC_i = 8000 + 65.7CS_i \quad [\$/\text{km}] \quad (15)$$

where CS_i is the cross-section area of overhead line conductor in mm^2.

Table 2. Conductors for Type of Overhead Lines [13]

Type name	FOX	MINK	DOG	PARTRIDGE
Cross section area (mm^2)	42.77	73.60	118.50	156.90
Rated current (A)	192	288	380	460

And the electrification cost of the fast charging station can be calculated by,

$$EC_i = AC_i \times L_i \times N_{charger} \quad (16)$$

where L_i is the length of the overhead line from the fast charging station *(i)* to a substation in km.

Loss Cost of EV Users

Loss cost of EV users depends on the traveling distance of EV to the nearest fast charging station for charging EV battery. The loss cost of EV users can be calculated by,

$$EVL_j = T_{day} \times EP \times AEVC \times D_j \quad (17)$$

where T_{day} is a total number of the days in 5 years. *EP* is electricity price in \$/kWh. *AEVC* is the average energy consumption of EVs (models 2015-2017). D_j is the traveling distance from EV location *(j)* to the nearest fast charging station.

Loss Cost of Power Distribution System

The fast charging EVs are the load of the power distribution system. The large-sized fast charging can bring an effect on the power distribution system. The effect on the power distribution system may be increased energy loss in the power distribution system. Added power loss in the power distribution system after connecting the fast charging stations with fast charging EVs can be calculated by,

$$APL_n = TPL_n - GPL \quad [\text{kW}] \quad (18)$$

where TPL_n is total power loss with fast charging EVs in kW. *GPL* is total power loss without fast charging EV in kW.

The added energy loss depends on the operating hours of the fast charging stations. The operating hours can be calculated by,

$$H_n = \frac{TEV_n}{TC_n} \times \frac{t}{60} \quad [\text{h}] \quad (19)$$

where TEV_n is a total number of EVs recharged on the substation (*n*). TC_n is a total number of the chargers connected to the substation (*n*). *'t'* is recharge time in min.

Therefore, the added energy loss can be calculated by,

$$AEL_n = APL_n \times H_n \quad [\text{kWh}] \quad (20)$$

Finally, the added energy loss cost for 5 years of the power distribution system can be calculated by,

$$ELC_n = AEL_n \times EP \times T_{day} \quad (21)$$

3. IDENTIFICATION OF THE OPTIMAL LOCATION AND SIZE OF THE FAST CHARGING STATIONS

Total cost

In this paper, five scenarios were proposed for a case study. These scenarios were described in section 4. The cost depends upon the minimal total cost of the fast-charging stations, EV users, and the power distribution system. The total minimal cost is given in (22) [1], [2], [7].

$$Min\ C_{totat} = \sum_{i=1}^{NC}(DC_i + EC_i) + \sum_{j=1}^{NEV} EVL_j + \sum_{n=1}^{NB} ELC_n \quad (22)$$

where *NC* is a number of fast charging stations were selected. *NEV* is a number of EVs has been assumed to be recharged in a day. *NB* is a number of bus of the power distribution system.

Operation constraints

In this paper, simulated by using calculation on MATLAB R2014a software, so, necessary to assumed that the traveling distance from EV location *(j)* to the fast charging station *(i)* and the length of overhead lines could be calculated by,

$$d_{j,i} = v_{j,i} \times 1.30 \quad (23)$$

$$l_{i,n} = v_{i,n} \times 1.30 \quad (24)$$

where $v_{j,i}$ is a displacement of the traveling distance from EV location *(j)* to the fast charging station *(i)* in km. $v_{i,n}$ is a displacement of the length of overhead lines from the fast charging station *(i)* to the substation *(n)* in km.

The traveling distance from EV location *(j)* to the fast charging station *(i)* is $d_{j,i}$, the traveling distance of EV was considered by EV traveling to the nearest fast charging station. The traling distance of EV is expressed by,

$$D_j = Min(d_{j,i}),\ j = 1,2,...,NEV \ ,i = 1,2,...,NC \quad [\text{km}] \quad (25)$$

A number of chargers were installed in a fast charging station depending upon the number of EVs selected to recharge the battery at the fast charging station in a day. In this paper, assumed that the maximum number of chargers installed in the fast charging station is 8 chargers. The range of a number of EVs to indicating the optimal number of chargers was defined in this paper, which can be expressed by,

$$\text{N}_{charger,i} \begin{cases} = 1 & ;0 < NEV_i \le 10 \\ = 2 & ;10 < NEV_i \le 20 \\ = 3 & ;20 < NEV_i \le 30 \\ = 4 & ;30 < NEV_i \le 40 \\ = 5 & ;40 < NEV_i \le 50 \\ = 6 & ;50 < NEV_i \le 60 \\ = 7 & ;60 < NEV_i \le 70 \\ = 8 & ;NEV_i > 70 \end{cases} \quad (26)$$

The length of the overhead line from the fast charging station (*i*) to the substation (*n*) was considered the length from the fast charging station to the nearest substation. The shortest length of the overhead line is expressed by,

$$L_i = Min(l_{i,n}), i = 1,2,...,NC \quad ,n = 1,2,...,NB \quad [\text{km}] \quad (27)$$

4. SYSTEM DESCRIPTION

In this section, showing the details of the system which consists of the power distribution system, road networks, and the procedures of operation. The parameters used to study in this paper are shown in Table 3. The system simulated by using calculation on MATLAB R2014a software.

Table 3. The Study Parameters

Name	Parameter	Value	Unit
Station fixed cost	$C_{initial}$	70000.0 [14]	$
Area rental cost for 5 years	C_{land}	4000.0 [2]	$/m^2
Charger development cost	$C_{charger}$	208.3 [14]	$/kW
Rated power of Charger	*PC*	96.0 [15]	kW
Total number of the days in 5 years	T_{day}	1825.0	day
Electricity prices	*EP*	87.7 [2]	$/MWh
Average energy consumption of EVs (models 2015-2017)	*AEVC*	5.9	km/kWh
Recharge time	*t*	15.0	min

Power Distribution System

The data of the 5-bus power distribution system, whose single line diagram is illustrated in Fig. 4 and the detail is illustrated in [16]. In this paper, Newton Raphson power flow method was applied to calculate power loss. For the simulation to calculate power loss, essential data were defined. The bus 2 was defined as SUT substation. The bus 3 was defined as Nakhon Ratchasima High Voltage 2 substation. The bus 4 was defined as Nakhon Ratchasima 4 substation. The bus 5 was defined as Nakhon Ratchasima High Voltage 1 substation.

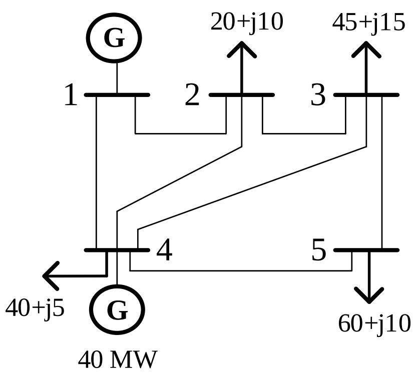

Fig.4. Single-line diagram for the 5-bus system.

Road Networks

The area of 755.6 km^2 in Muang District, Nakhon Ratchasima, Thailand was applied to study in this paper as shown in Fig 5. The area consists of four corners as shown in Table 4. Fig. 5 shows EVs location, charging station, and substation in the area. The redpoints of charging station was not considered in this paper because it's not a fast charging station. But the green points of charging station were considered in this paper because these points are fast charging station. The distance between two fast-charging stations is 4 km on main roads was assumed in this paper. The results of simulation of Muang District, Nakhon Ratchasima map via MATLAB programming are shown in Fig. 6.

Table 5 shows the vehicle's sales from 2013-2016 of Nakhon Ratchasima province [17]. From Table 5, it is clear that the vehicle's sales have grown an average of 16205 cars per year from 2012-2016 of Nakhon Ratchasima province. Seventeen percents of total number of vehicles were assumed to EVs in the area. Which means 2755 EVs. Twenty percents of EVs in the area were assumed to recharge in a day as 551 EVs. The locations of 551 EVs were generated on the basis of population density of each sub-district in the area by using Monte Carlo method.

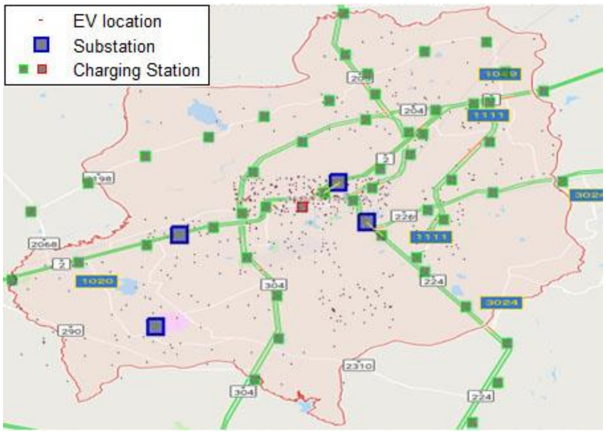

Fig.5. Road network of Muang District, Nakhon Ratchasima, Thailand.

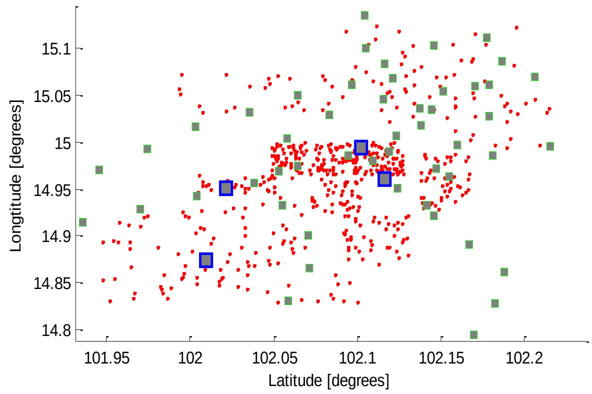

Fig.6. Simulation Muang District, Nakhon Ratchasima via MATLAB Programming.

Table 4. The Boundary of Muang District, Nakhon Ratchasima area

Corner	Decimal degrees
Upper left	101.931215,15.144647
Upper right	102.236772,15.144647
Lower left	101.931215,14.786372
Lower right	102.236772,14.786372

Table 5. The Vehicles Sales from 2013-2016 of Nakhon Ratchasima Province

Years	Number of vehicles
2012	20577
2013	19609
2014	15631
2015	12134
2016	13078

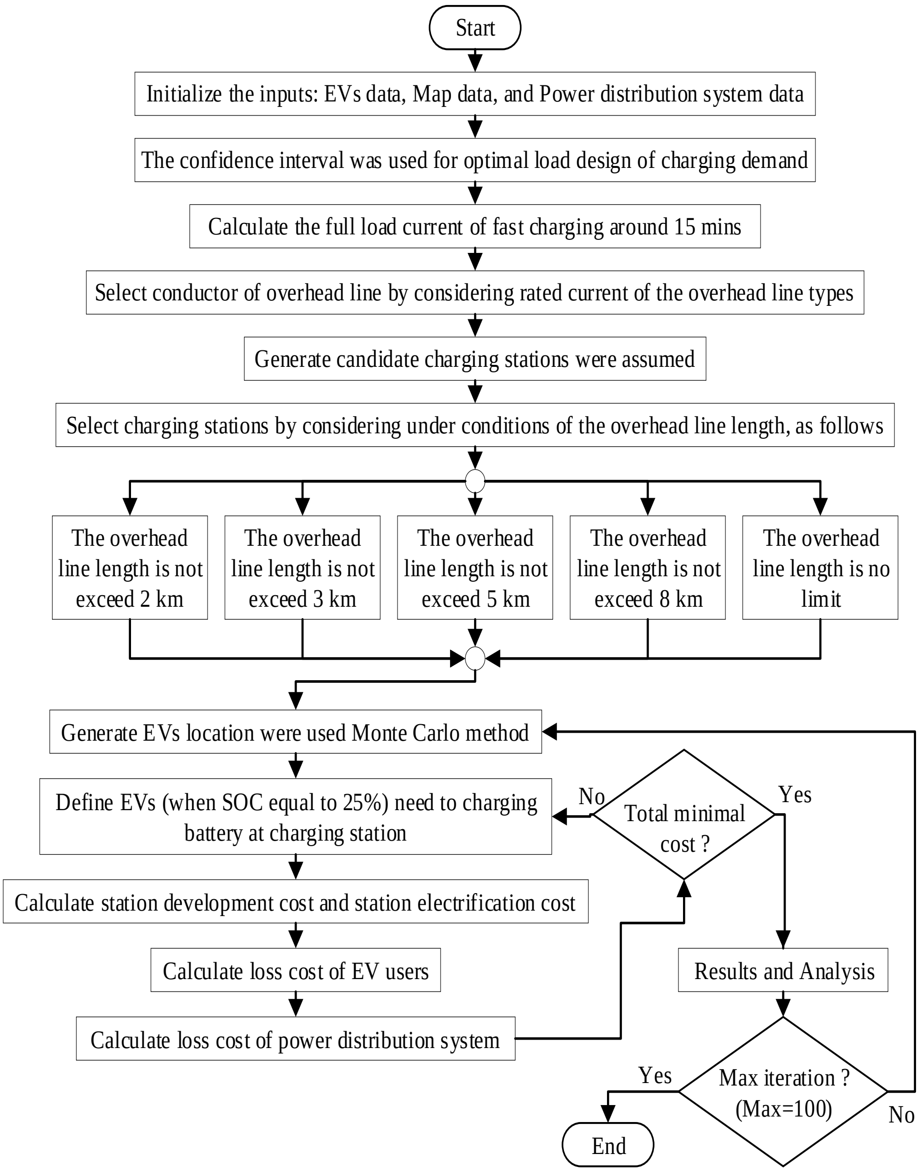

Fig.7. Flowchart for identification of the optimal location and size of the fast charging stations.

The procedures of operation are shown in Fig. 7. The first step, initialize the data inputs. After that, the confidence interval method is calculated and obtained a range of the energy demand of EVs, then the optimal load of charging demand was selected from a range of energy demand of EVs. After the fast charging for around 15 mins, calculate the full load current for *kWh* is the energy demand. After that, select conductor of overhead line by considering rated current of the overhead line types and assess the cost of the overhead line as a function of the cross-section area of the line. After that, generate candidate charging stations were assumed that the distance between two charging stations as 4 km on main roads as shown in Fig. 5. Next, select charging stations by considering under conditions of the overhead line length, as follows, the overhead line length are not exceed 2 km, not exceed 3 km, not exceed 5 km, not exceed 8 km, and no limits, respectively. The locations of 551 EVs were generated the basis of population density of each sub-district in the area by using Monte Carlo method as shown in Fig. 5. After that, define EVs need to charge the battery at charging station when SOC equal to 25% (the under the condition that the traveling distance of the EVs to the nearest charging station are the minimal loss cost of EV users). Next, Calculate all costs to investigate the minimal total cost.

Table 6. Model of Commercial EVs with Recharged

Models (2015-2017)	Range [km]	Average [km] of EV with SOC25%	Average [km] of EV with charge 1 time	Total distance [km]
Mitsbuishi i-MiEV	100	25.0	75.0	100.0
Smart Electric	110	27.5	82.5	110.0
Chevy Spark EV	130	32.5	97.5	130.0
BMW i3	130	32.5	97.5	130.0
Ford Focus EV	130	32.5	96.0	128.0
Fiat 500e	140	35.0	99.0	134.0
Leaf 24k Wh	130	32.5	92.0	124.5
Leaf 30k Wh	165	41.2	93.5	134.7
Kia Soul EV	150	37.5	85.0	122.5
Mercedes BClassEV	170	42.5	80.2	122.7
VW eGolf	300	75.0	137.8	212.8
Tesla S 60	340	85.0	96.3	181.3
Tesla model 3	350	87.5	99.0	186.5
Tesla modelS80	450	112.5	95.5	208.0

Finally, runs 100 iterations of the minimal total cost to analyze the average minimal total cost because the uncertain location of EVs by using Monte Carlo method need to runs several times to investigate preciseness.

5. SIMULATION RESULTS AND DISCUSSION

From equation (3), the calculated results show that the confidence interval is a range of the energy demand of EVs (models 2015-2017) should be size around 11.45 to 22.42 kWh. To satisfy the energy demand of EVs, the optimal load of charging demand from the fast charging station is 17 kWh was selected in this paper from the confidence interval because the total distances more than 100 km after charging EVs were calculated from equation (4) as shown in Table 6, which are adequate for driving in the city and outside. In this paper, the fast charging was defined as 15 min in which EV consumes 17 kWh of energy. The small EVs battery packs such as Mitsubishi i-MiEV, Smart Electric, Chevy Spark EV, and BMW i3, the fast charging station can recharge them in less than 15 min as the battery reaches its full charge status. For large EVs battery packs such as VW eGolf, Tesla models of S 60, Model 3 and ModelS80, the fast charging station can recharge them with more than 180 km of driving. If the users need more driving kilometers or they want to reach 80% of the SOC, the EVs can be recharged twice with a charging time for around 30 min.

The simulation in this paper, essential data were defined as follows, the interval times of constant current and constant voltage charging were defined equal to 5 times time constant [10]. The power factor of the EV battery was set equal to 0.9. Recharge time for around 15 mins for the energy demand equal to 17 kWh, the calculated results, the full load current for fast charging equal to 430.33 A.

In achieving this goal, five scenarios were proposed for a case study. These scenarios are as follows, Scenario 1-5: the overhead line length are, not exceed 2 km, not exceed 3 km, not exceed 5 km, not exceed 8 km, and no limits, respectively. Table 7, shows results of the total number of fast charging stations and the total number of chargers for the five scenarios.

Table 7. The Results for the five scenarios

Number of	Scenarios				
	1	2	3	4	5
Fast charging stations	2	6	8	21	44
Chargers	16	45	53	63	76

As shown in Table 8-11, showing the results of the optimal charging stations for the five scenarios without scenario 5, the result consists of a number of chargers were installed in the fast charging station, the capacity of the fast charging station, and the total number of EV charging at the fast charging station in a day and Fig. 8-12, showing the fast charging stations were connected to substations (represented by yellow lines) and the fast charging stations were selected from EVs for charging the battery (represented by black lines).

Table 12, show results of the cost for the five analyzed scenarios and also comparative results of the cost as shown in Fig. 13. The traveling distances of EV users indicate the convenience of EV users for the five scenarios as shown in Table 13.

Results obtained for Scenario 1 shows that this is the best choice to the minimal total cost of the investor but affect the convenience of EV users. As the average and maximum travel of EV users are 8.3 and 29.1 km, respectively. The arrival of maximum EVs at the charging station during hour is around twelve percents of the total of EVs charging at the charging station in a day [18], From Table 8, the twelve percents of EVs charging at charging station (*1*) and charging station (*2*) are equal to 0.12×354=43 EVs and 0.12×197=24 EVs, respectively. The fast charging for 15 mins can charge EVs within an hour as 4 times, so, 8 chargers can charge 8×4=24 EVs at maximum in an hour. Therefore, The twelve percents of EVs charging at charging station (*1*) is 43 EVs more than the 24 EVs which could be charged by 8 chargers at maximum, the chargers in this scenario are not enough to recharge EVs.

Scenario 2, the best choice to suit the total cost of the investor and EV users obtain convenience due to the average and maximum travel of EV users decrease about 28% of scenario 1. For analysis of chargers in this scenario has been analyzed similar to scenario 1, the chargers in this scenario are enough to recharge EVs.

Scenario 3, a high total cost of the investor can be the plan to develop scenario 2, however, it has better degree of user convenience for EV users.

Table 8. Optimal Fast Charging Stations for Scenario 1

Stations	Number of chargers	The capacity of stations [kW]	Number of EVs
1	8	768	354
2	8	768	197
Total	16	1536	551

Table 9. Optimal Fast Charging Stations for Scenario 2

Stations	Number of chargers	The capacity of stations [kW]	Number of EVs
1	7	672	70
2	8	768	83
3	8	768	146
4	8	768	107
5	6	576	55
6	8	768	90
Total	45	4320	551

Scenario 4, a high total cost of the investor can be the plan to develop scenario 3, user convenience is higher than the previous 3 so it may be more suitable in future if the number of EVs increased.

Scenario 5, the most convenient for EV users but has highest total cost which unnecessary for investment in this paper.

Table 10. Optimal Fast Charging Stations for Scenario 3

Stations	Number of chargers	The capacity of stations [kW]	Number of EVs
1	8	768	89
2	8	768	83
3	8	768	124
4	8	768	73
5	4	384	33
6	5	480	41
7	8	768	73
8	4	384	35
Total	53	5088	551

Table 11. Optimal Fast Charging Stations for Scenario 4

Stations	Number of chargers	The capacity of stations [kW]	Number of EVs
1	4	384	33
2	2	192	17
3	2	192	17
4	5	480	48
5	5	480	62
6	1	96	3
7	3	288	28
8	1	96	3
9	4	384	33
10	4	384	33
11	2	192	15
12	5	480	42
13	5	480	54
14	2	192	17
15	4	384	36
16	1	96	8
17	4	384	31
18	2	192	13
19	3	288	25
20	2	192	18
21	2	192	15
Total	63	6048	551

Table 12. The Results of the minimal total cost

Cost	Scenarios				
	1	2	3	4	5
Station development cost (M$)	2.02	5.56	6.57	8.35	11.34
Electrification cost of fast charging station (M$)	0.50	1.77	2.42	5.62	10.29
Loss cost of EVs (M$)	0.12	0.09	0.08	0.05	0.04
Loss cost of power distribution system (M$)	0.17	0.16	0.16	0.17	0.17
Total cost (M$)	2.81	7.58	9.23	14.19	21.84

Table 13. The travelling distances of EV users indicate to the convenience of EV Users

The traveling distances of EV users	Scenarios				
	1	2	3	4	5
Average (km)	8.3	6.0	5.5	3.7	2.5
Maximum (km)	29.1	20.7	18.6	14.8	11.6

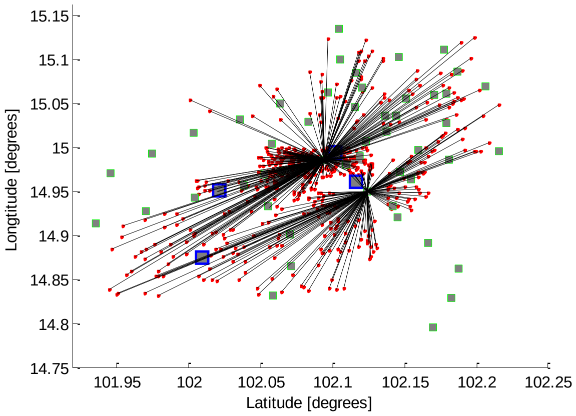

Fig.8. Optimal fast charging stations for Scenario 1.

6. CONCLUSION

This paper presented a method to design appropriate energy demand of EVs (model 2015-2017) and fast recharge time was defined for around 15 mins. The location and size of the fast charging stations are significant problem in planning and development of the city of Nakhon Ratchasima, Thailand. This paper presented a simple analytical method, five scenarios were proposed for a case study, including the total cost based on the cost of station development cost, traveling cost of EV users, and cost of the energy loss of the power distribution system. The results of these scenarios showed that scenario 1, is the best choice to the minimal total cost of the investor but affect the convenience of EV users due to the fact that, the average and maximum travel of EV users are 8.3 and 29.1 km respectively. Which is very high among other options? The chargers in this scenario are not enough to recharge EVs. Scenario 2, the best choice to suite the total cost of the investor and EV users obtain convenience because the average, and maximum travel of EV users may decrease about 28% of scenario 1. The chargers in this scenario are enough to recharge EVs. Scenario 3, high total cost of the investor can be the plan to develop scenario 2, but increased convenience to EV users. Scenario 4, high total cost of the investor can be the plan to develop scenario 3, it has more convenience than scenario 3 to EV users and suitable for an increment of the number of EVs in the future. Scenario 5, the most convenient to EV users but the highest total cost which unnecessary for investment in this paper.

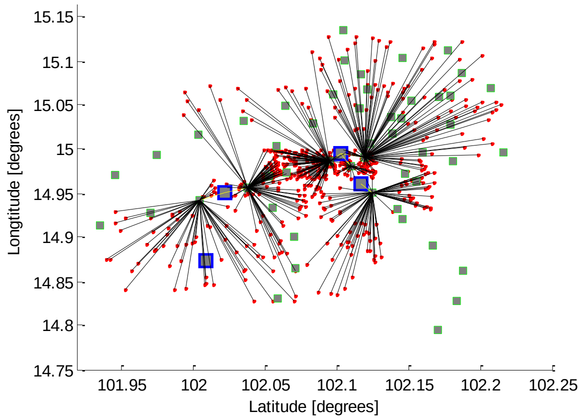

Fig.9. Optimal fast charging stations for Scenario 2.

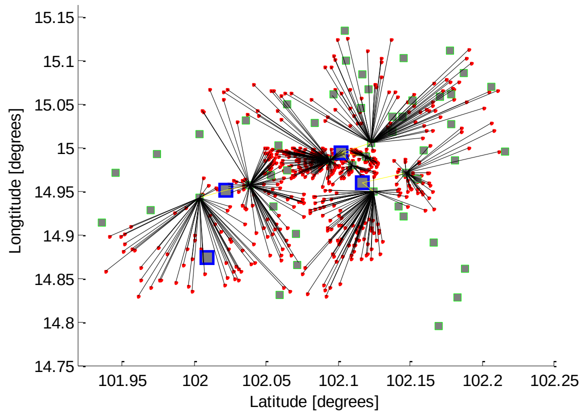

Fig.10. Optimal fast charging stations for Scenario 3.

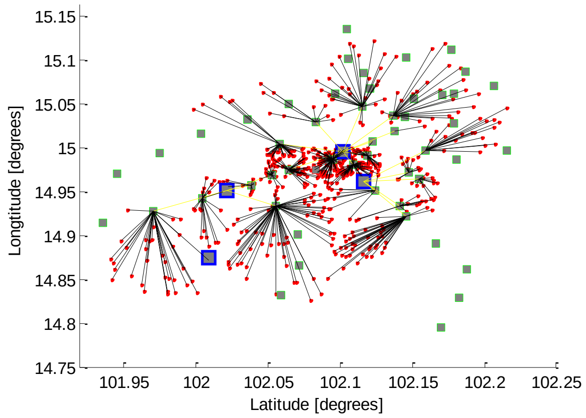

Fig.11. Optimal Fast Charging Stations for Scenario 4

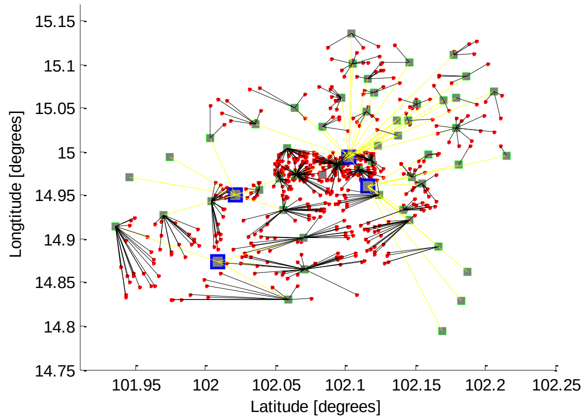

Fig.12. Optimal fast charging stations for Scenario 5.

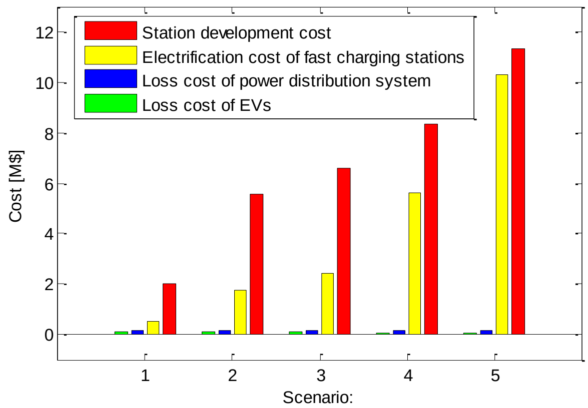

Fig.13. The results of the minimal total cost.

The numerical results show that station development cost and electrification cost of the fast charging stations are the major of the total cost of build up fast-charging stations. The energy loss cost of the power distribution system and the traveling cost of EV users are the next important parameter of the total cost. The traveling cost of EV users is important to consider ensuring a suitable distance between EV and charging station, which is the measure of user convenience. The case study showed that this method could be beneficial to develop location and size of fast-charging stations in the future.

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