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Impact of electric bus charging in power distribution systems

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ABSTRACT

This paper introduces a simple model for electric vehicles suitable for load flow studies of electric bus charging. The electric bus demand system is analyzed from the Li-ion charging characteristics. The charging PQ is given by closed formulas as a function of charging time. A specific manufacturer model of electric vehicles is used as a study case. The simulation results shown the impact of electric bus charging in power distribution systems. The power loss and voltage profile are the selected parameters for the investigation of this work.

1. INTRODUCTION

The global warming since the late 19th century is the urgent issue of the world. The CO_2 emission is the main causes of the greenhouse effect and global warming. The one major source of emission is the petrol burning in the combustion engine of the vehicle. A good rule of thumb to solve this problem is changing combustion vehicles to electric vehicles (EVs). (Chan, Chau, & Chan 1998) have noted that EVs offer high energy efficiency and zero emission. The Batteries of EV can be charged with various types of electric sources such as utility, wind power, solar power and biomass. The optimal schedule of EVs charging enables load equalization of power system. Furthermore, the electric drive system of EV operates quietly and almost vibration-free. The integrating more electric vehicles, utilities must analyze the related impacts on the distribution system operation. The different charging capacities effects on voltages, line drops, line losses, and operation cost. Thus, the impact of electric charging in electric distribution is a very important issue.

The investigation into the impact of electric vehicle load on the electric utility distribution system is found in Rahman & Shrestha (1993). This work described problems and requirements which assure the utility's providing enough charging facilities. Unfortunly, the utility's load may excess energy available during off-peak hours to charge EV batteries at various locations. The effect of harmonic distortion in

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the distribution system resulting of EV battery chargers is found in Gomez & Morcos (2003). The optimum charging time is scheduled as a function of the existing load, ambient temperature, and time of day. This function is a quadratic relationship between the transformer life consumption and the total harmonic distortion of the battery charging current. The impact of battery charging of electric vehicles on the power distribution system which integrate the renewable energy systems is found in Shortt & O'Malley (2009). This work considered the power systems impact of different vehicle charging schemes. Charging profiles were developed for slow, fast and controlled optimal charging. Moreover, the optimal generation portfolios were proposed using a least-cost optimization algorithm.

The other important issue of EV charging study is the model development. The electric vehicle demand model for load flow studies is found in García-Valle & Vlachogiannis (2008). This work proposed a specific and simple model for EVs suitable for load flow studies. The demand system is modeled as a PQ bus with stochastic characteristics based on the concept of the queuing theory. All appropriate variables of stochastic PQ buses are given by closed formulas as a function of charging time. The other method of load demand due to EV battery charging is found in Qian, Zhou, Allan, & Yuan (2011). The method is stochastically formulated so as to account for the stochastic nature of the start time of individual battery charging and the initial battery state-of-charge. A comparative study is carried out by simulating four EV charging scenarios. The proposed four EVs charging scenarios take into account the expected future changes to the electricity tariffs in the electricity marketplace and appropriate regulation of EVs battery charging loads.

According to the literature review, this work proposes the impact of electric bus charging in power distribution systems The first part of the paper describe the EV model for load flow studies. The charging demand model is analyzed from the typical Li-ion charging characteristics which using in K9-electric bus of BYD. The equivalent model of EVs charging station is set the PF and efficiency of the power converter. The second part of the paper shows the simulation results which consist of voltage profile and power losses. The simulation results and impacts of electric bus charging due to power distribution system is summarized in the final part of the paper.

2. EV MODEL FOR LOAD FLOW STUDIES

Load flow modeling consist of the active power of EV, VSC model, and the equivalent model of charging center. The optimal active power of EV during charging is effective to all models. The fitness values of optimal solutions are evaluated at each iteration and verified by using the load flow calculation.

2.1 The Charging Demand Model

The charging demand model of EVs is based on battery charging characteristic.

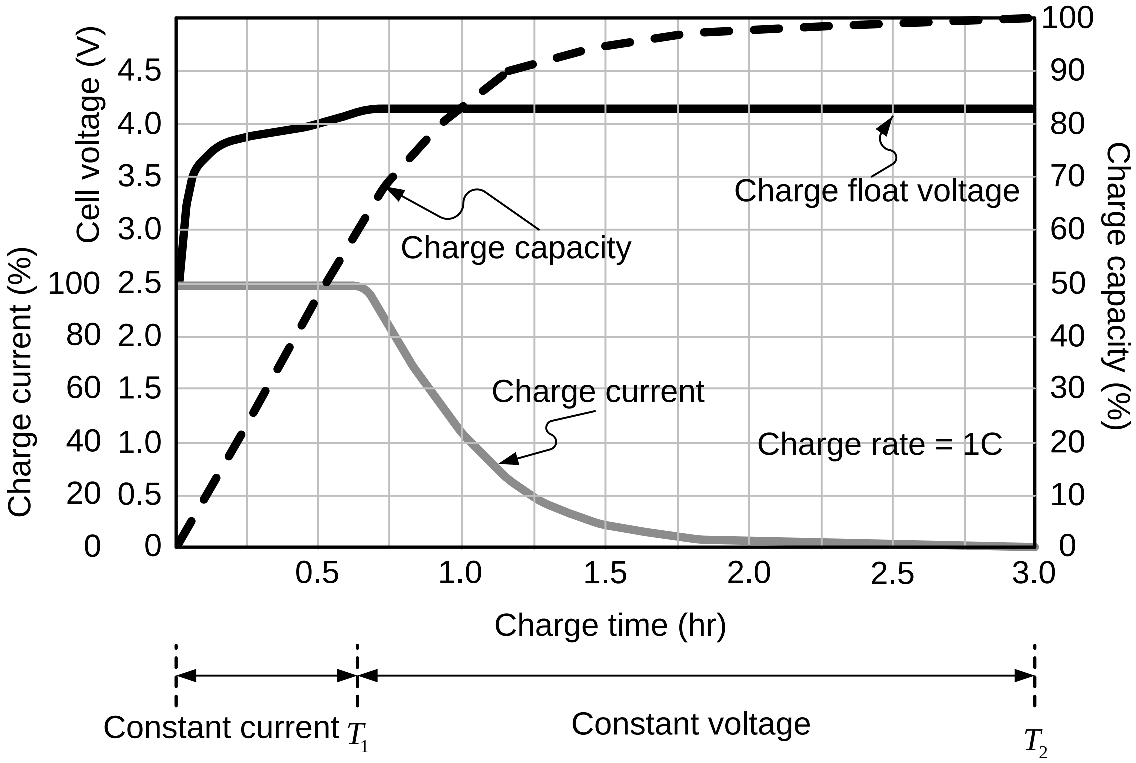


Fig. 1 The typical Li-ion charging characteristics

According to the typical Li-ion charging characteristics in Fig. 1, the approximate models of battery charging in the interval 0 - T_1 are,

$$v(t) = V_n\left(1 - e^{-t/\tau_v}\right) \tag{1}$$

$$i(t) = I_n \tag{2}$$

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

$$v(t) = V_n \tag{3}$$

$$i(t) = I_n e^{-t/\tau_i} \tag{4}$$

The constant voltage V_n is the nominal voltage of EVs battery. The time constant τ_v and τ_i are determined from the charge voltage and charge current curve. The constant current I_s change to exponential decay until battery reach the full charge status. The instantaneous power of EV battery during the charge process can be calculated by,

$$p(t) = i(t)v(t) = \begin{cases} V_n I_n \left(1 - e^{-t/\tau_v}\right) & 0 \le t \le T_1 \\ V_n I_n e^{-t/\tau_i} & T_1 < t \le T_2 \end{cases} \quad (5)$$

The total energy delivers to the battery through the charging process is,

$$w = \int p(t)dt = \int_0^{T_1} V_n I_n \left(1 - e^{-t/\tau_v}\right)dt + \int_{T_1}^{T_2} V_n I_n e^{-t/\tau_i} dt = KI_n \quad (6)$$

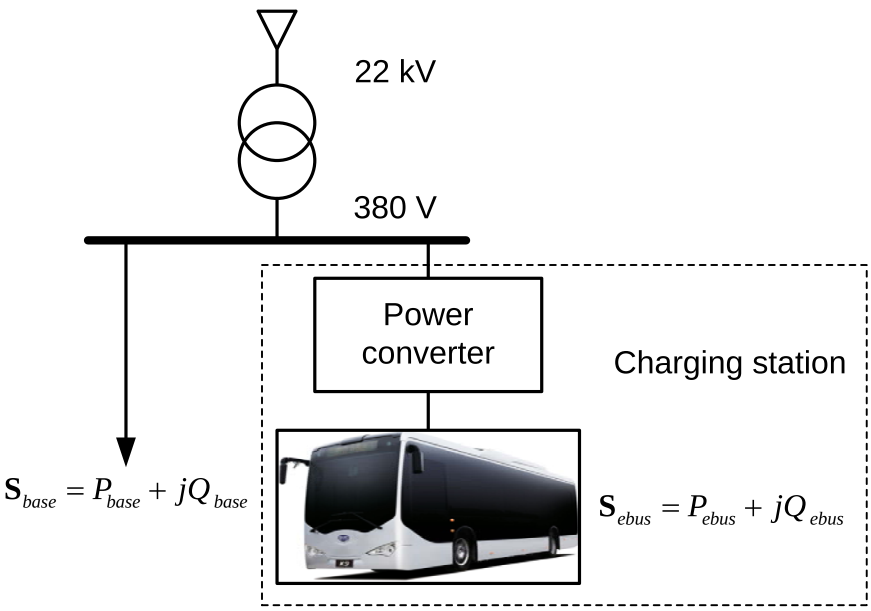
The nominal value of charging current of EV can be calculated by,

$$\begin{aligned} KI_n &= kWh \times 10^3 \times 3{,}600 \\ I_n &= \frac{3.6 \times 10^6 \times kWh}{K} \end{aligned} \quad (7)$$

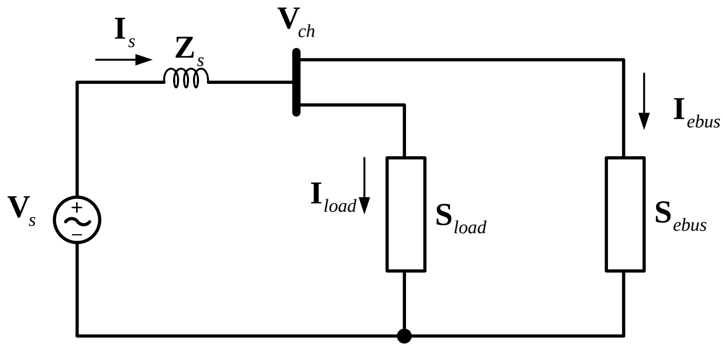
The constant kWh is EV battery capacity in kilo-watt-hour.

2.2 Equivalent Model of EV Charging Station

The schematic diagram and equivalent circuit of the EV charging station are presented in Fig. 2. The equivalent circuit for power flow studies can be represented as shown in Fig. 2(b).



(a)



(b)

Fig. 2 The charging station (a) The schematic diagram (b) The equivalent circuit

The supply current of the bus which installed charging station is

$$\mathbf{I}_s = \mathbf{I}_{load} + \mathbf{I}_{ebus} = \left(\frac{P_{ebus} + jQ_{ebus}}{\mathbf{V}_{ch}}\right)^* + \left(\frac{P_{load} + jQ_{load}}{\mathbf{V}_{ch}}\right)^* \quad (8)$$

The charging voltage of the electric buses is

$$\mathbf{V}_{ch} = \mathbf{V}_s - \left(R_s + jX_s\right)\mathbf{I}_s$$

$$\mathbf{V}_{ch} = \mathbf{V}_s - \left(R_s + jX_s\right)\left\{\left(\frac{P_{ebus} + jQ_{ebus}}{\mathbf{V}_{ch}}\right)^* + \left(\frac{P_{load} + jQ_{load}}{\mathbf{V}_{ch}}\right)\right\}^* \quad (9)$$

The Eq. (9) is the power flow equation which can be solved by the iteration method. The power flow solutions describe the impact of electric bus charging in power distribution systems.

3. CASE STUDIES AND SIMULATIONS

This work is performed extensive simulations to demonstrate the impact of electric bus charging in power distribution systems. The electric bus of case study is K9-BYD. The system data of power distribution system were evaluated from the 10th circuit of Nakhon Ratchsima station, Thailand. The Thevenin's equivalent circuit was analyzed at bus 54 by the load transformation method.

3.1 Simulation Setting

According to the electric bus specification, the power capacity of Li-ion battery is 100 kWh. The battery takes 3 hours to reach a fully charged state with the quick charge mode. This work supposes that the time interval of constant current and constant voltage charging is equal to 5 times time constant as,

$$t_{con} = 5\tau \tag{10}$$

The time constants of voltage and current curve can be calculated from the 2 hours of constant charging voltage and 1 hours of constant charging current as follows

$$\tau_v = \frac{t}{5} = \frac{2 \times 60 \times 60}{5} = 1,440 \text{ s} \tag{11}$$

$$\tau_i = \frac{t}{5} = \frac{1 \times 60 \times 60}{5} = 720 \text{ s} \tag{12}$$

The nominal phase voltage of the test system is 380 V and the capacity of K9-BYD electric bus is 100 kWh. Thus, the total charging energy equation corresponds to Eq. (6) and nominal charging current are

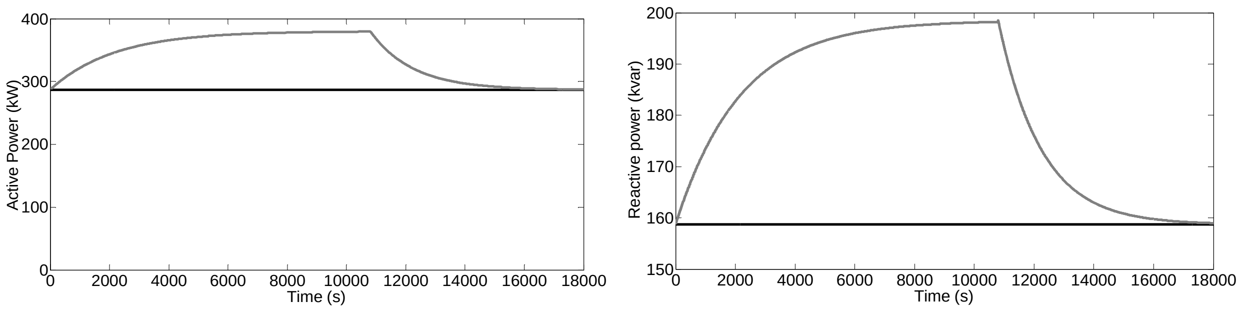
$$100 \times 10^3 \times 3,600 = \int_0^{3,600} 380 I_n \left(1 - e^{-t/1,400}\right) dt + \int_{3,600}^{10,800} 380 I_n e^{-t/720} dt = 878.5 \times 10^5 I_n \tag{13}$$

$$I_n = \frac{100 \times 10^3 \times 3,600}{878.5 \times 10^5} = 409.79 \text{ A} \tag{14}$$

The simulation supposes that the efficiency of power converter is equal to 80% and power factor of of electric bus is equal to 0.90. The Thevenin's equivalent impedance of the test system is $0.0165 + j0.0310\ \Omega$. The base load without the electric bus charging is equal to $286.806 + j158.685\ \text{kVA}$. The number of electric buses is the random variant and for each iteration calculation of power flow analysis to verify the voltage profile and power losses.

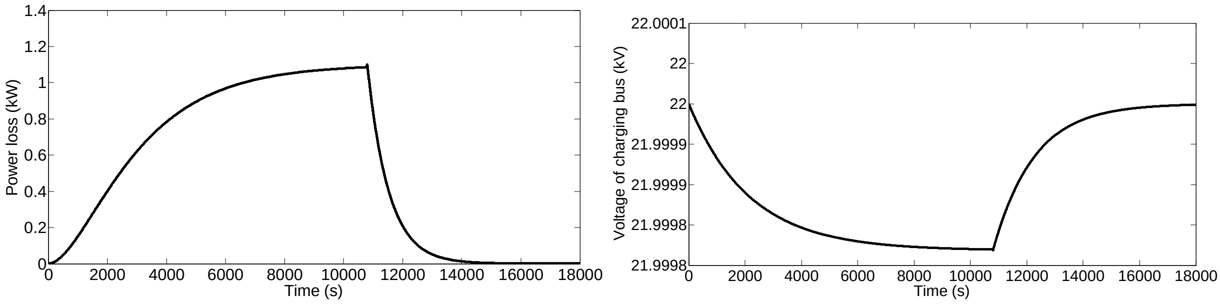
3.2 Simulation Results

The charging loads for 20% EV penetration level under the base equivalent load are computed by the Eq. (5). The comparison between base demand load and the total demand load which include the charging power of electric bus is shown in Fig. 3.



(a) (b)

Fig. 3 (a) The active demand load (b) The reactive demand load



(a) (b)

Fig. 4 (a) The power loss (b) The voltage profile

According to Fig. 3., the active power increase about 100 kW during the period of charging while the reactive power increase about 40 kvar. The increasing of total load demand resulting of electric bus charging effect both of power loss and voltage profile of charging bus as shown in Fig. 4. The increasing of power loss is the function as same as charging power of electric bus. Thus, the control of charging power is the control of power loss too. The voltage profile as shown in Fig. 4(b) fall by the decay exponential function. The high penetration level of electric bus is the more effect to the voltage profile and voltage regulation of power distribution system. Therefore, the design of the optimal schedule and a penetration level of electric bus charging are needed.

4. CONCLUSIONS

This paper proposes the electric bus charging modeling and simulation results about the impact of electric bus charging in power distribution systems. The simulation results show that the charging with high energy level increases the total load demand of power distribution system. The consequence effects are the increasing of power loss and degrade the voltage regulation of over all system. According to this work, it is clear that the optimal schedule charging is the most important for the future operation with the electric vehicles.

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