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Improved of Active-Reactive power Dispatch with Charge Stations

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Abstract: *In this paper, a distribution test-network model is described. A new analytical method is proposed, using the stations' cooperation in terms of optimal active and reactive power dispatch as well as power flow analysis for locating the optimal placement of charge stations, so as to reduce power losses. This method is compared with the previously developed current density method for single charge stations using system simulation results.*

Key words: *distribution network, charge stations, Electric Vehicles, active and reactive power.*

INTRODUCTION

The state-of-the-art of batteries is restricted by material science and physics. The charge station is a relatively mature technology and with an increasing number of EVs will become an essential part of the commercial chain. In Ref. [3] the researchers concentrated on designing multi-charge stations for vehicles together with their utilization in the grid by considering battery replacement, charging and vehicle to grid. In Refs. [4,5] the authors considered both EV arrival time, departure time, energy demands, and real world parking statistics. Based on these data the papers provided charge station scheduling strategies. Refs. [6-8] concentrated more on the optimal planning and economic aspects of a charge station for EV; by considering various costs, to achieve comprehensive cost and energy loss minimization. As an alternative, Refs. [9,10] focused on optimization of EV charge station location by using the conservation theory of regional traffic flows, taking EVs as fixed load points for the charge station. The maintenance and capital cost minimization for a charge station was considered in this work. *In addition, 27% of the average active power loss was saved by installing two charge stations rather than no charge stations in the test-line. It is shown that this could represent a 2.6% annual yield above inflation for investing in installing and running such charge stations.* In order to reduce CO2 emissions, more attention is being paid to Electric Vehicles (EV) than before. However, the driving range limitation is still a big concern for all EV drivers. This problem can be solved either by improving the state-of-the-art of EV batteries or by building charge stations into Distribution Networks (DN) and Transmission Networks (TN) [1,2].

In [11] the Battery Energy Storage System (BESS) was considered as a design criteria in charge stations. By using this criteria the EV charge efficiency and time was improved. In [12] the concept of combined photovoltaic systems and battery unit multi-\supply systems was mentioned. In [13] the BESS was installed in fast charge stations as an energy supplier. The daily operating cost was minimized by optimizing the active power of the BESS. Mean-while, charging loads were smoothed and high-price electricity absorption from the grid was avoided. The common drawback of these papers is that no matter what type of method were used to optimize the size and location, and to minimize the various costs of those stations, the energy transfer between charge stations was not considered. For example, com-binned BESSs in charge stations can store off-peak energy and use it to provide energy to EVs during peak-time. But these charge stations do not provide energy to each other. In this paper cooperation between two charge stations, in terms of transferring energy to each other, is specified and tested for four different operation scenarios. This cooperation makes charge stations able to support each other, reduce losses further and provide energy to customers.

Installing combined BESS charge stations brings some additional problems, one of which is where to install these charge stations in the power system. In existing literature the optimal location problem has been treated in the following ways. In [14] the author proposed a maximization of the wind energy method based on Ontario's standard offer program for locating a BESS in a DN with high penetration of wind energy. In [15] the author used a hybrid Genetic Algorithm (GA) combined with quadratic programming to size and site the BESS, so as to reduce network losses and cost. In [16] a hybrid method relying on dynamic programming with a GA was described. Through this method the location, rating and control strategy of the BESS were found, and overall investments and network costs were minimized. A methodology proposed in [17] was to optimize the location of the BESS in DNs and also to mitigate problems created by high penetration of renewable Distribution Generation (DG). A two segment current density integration method was used in [18] for choosing the optimal location of DG in a single-DG system. The method was tested and proved using an 11-bus distribution line network.

However, these methods did not consider the active and reactive power transferring between two BESSs when choosing the location. The research described by the authors of this paper expands on the current density integration method for a two charge station system. The new method identifies the optimal location for the second charge station given the optimal location of the first charge station. The developed method was tested in the same system as [18] using four different operational scenarios. It was found that the current density method was accurate for the system with one charge station, but it could not be applied to a system that had two charge stations, under several different operational scenarios, because it only considered one current component from the BESSs. Therefore, an analytical cooperation approach, combining active and reactive power optimization methods, was proposed to address this. This method was more accurate than the current density method. The results were compared with the current density method not only as a mathematical model, but also considering the cost of power loss.

After finding the locations of charge stations, the costs and profits of the charge stations were analyzed. From the results, the owners of the charge stations can earn 0.84 million dollars over15 years'. Further benefits, for example by providing voltage sup-port and load peak shaving services to the DN could be obtained from operation.

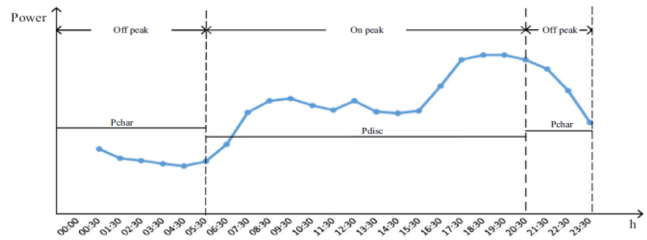
System modelling

System load modelling

It can be seen from Fig. 1 that during the first and second off-peak periods the BESS can store energy from the TN, This energy can be purchased at a low price, whereas during the on-peak period the BESS can dispatch the stored energy to customers. This will not only save money on their electricity bill, but also enhance sys-tem stability [20]. In order to test the proposed method three load periods, two off-peak (00:30-05:30 h and 05:30-20:30 h) and one peak (20:30-23:30 h), for a typical day [19] were chosen to separate each 24 h into three power demand periods. These can be seen in Fig. 1. The 11-bus distribution test-line with three different types of load profile, which can illustrate the majority of load patterns in such power systems, was used in this paper for identifying the optimal location of the charge stations [18].

Specifications and modelling of Evs

According to recent EV market surveys [21-23], the Chevrolet Volt plug-in hybrid occupied 41% of the whole electric vehicle market, the Nissan Leaf all-electric car accounted for 30%, the Toyota Prius Plug-in Hybrid took up 17%, while the Tesla Model S had the remaining 12% of the market. Therefore, an assumption was made that, for a mid-sized city there are 100 EV owners [24], 41 used Chevrolet Volt Plug-in Hybrid cars, 30 used Nissan Leaf all-electric cars, 17 used Toyota Prius Plug-in Hybrid cars, and 12 used the Tesla Model S.



Fige.1. *Three periods of daily electricity demand [15].*

The power demand of each type of EV in one timeslot can be calculated by using Eq. (1) [27].

$$Pi(t) = \frac{[bi-xi]\times Ci}{EiHaver} \quad \forall_{i,t} \qquad (1)$$

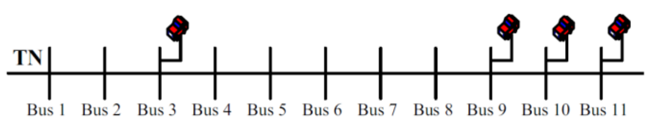
Where P i (t) is the power demand of the EV at any timeslot t. bi is the desired State of Charge (SOC). Xi is the SOC at the beginning of t. Ci is the capacity of the EV. Ei is the battery charging efficiency of the EV, Haver is the EV's average charge time.The total power demand of all EVs can be express as shown in Eq. (2).

$$PT\,(t) = \sum_{i=1}^{41} Pi(t)c + \sum_{i=1}^{30} Pi(t)n + \sum_{i=1}^{17} Pi(t)p + \sum_{i=1}^{12} Pi(t)t \quad (2)$$

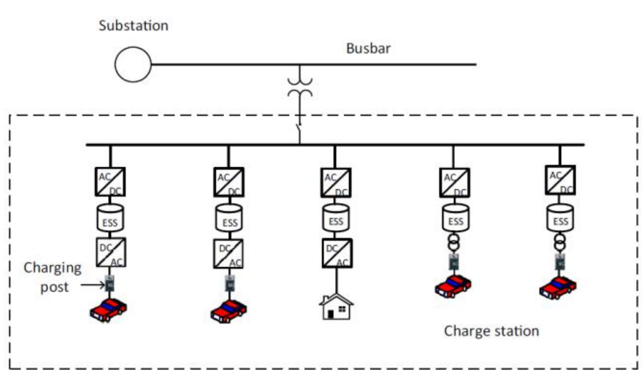
Where PT (t) are the total power demands of all types of EVs. Pi(t)c; Pi(t)n; Pi(t)p, and Pi(t)t are the power demand for each type, i.e. Chevrolet, Nissan Leaf, Prius, and Tesla.These EVs were added into the test-line at the locations seen in Fig. 2.

The modelling of combined BESS charge station

The combined BESS charge station is different compare with the traditional charge station. Traditional stations are not able to store off-peak energy and sell it to EVs and local residents at any time. Whereas, BESS can make the profits by utilizing electricity price Differences between peak and off-peak times. The configuration of the stations can be seen in Fig. 3.

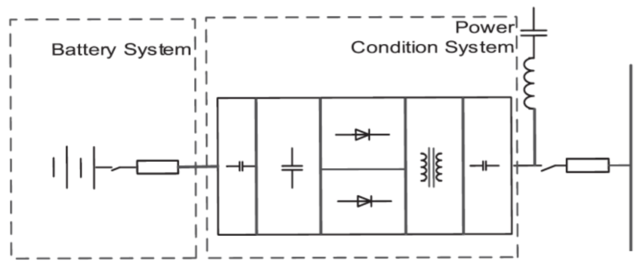


Fige.2. *A test-line with EVs.*

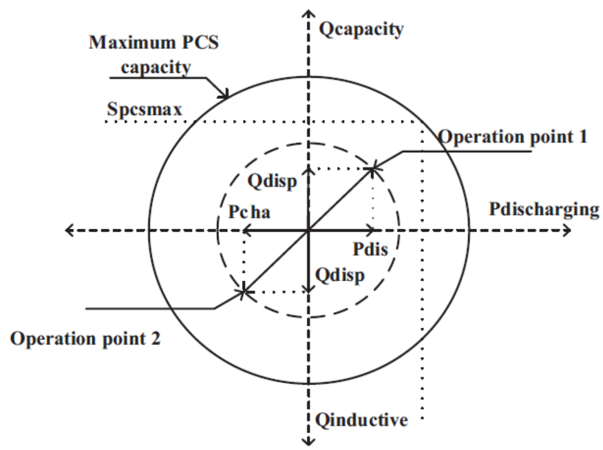


Fige.3. *Charge station's configuration*

The charge station consists of BESSs, normal charging points and relevant charging facilities such as transformers, active and reactive compensators, inverters and converters, and charging spaces. The BESS consists of batteries and Power Conditioning Systems (PCS) [20,28]. A simple PCS consists of electronic devices such as capacitors, diodes and transformers, the structure can be seen in Fig. 4. The PCS capability is show in Fig. 5.



Fige.4. *The structure of BESS*



Fige.5. *Active and reactive power capability [29].*

The active and reactive power discharge of BESS should not exceed the maximum apparent power $S_{BESSmax}$ of the BESS [30].

$$P_{dis}^2 + Q_{dis}^2 \leq S_{BESSmax}^2 \quad (3)$$

$$P_{char}^2 + Q_{dis}^2 \leq S_{BESSmax}^2 \quad (4)$$

The active power for charging and discharging must be positive values

$$P_{char(k,h)} \geq 0 \text{ , } P_{dis(k,h)} \quad (5)$$

$$-S_{BESSmax(k,h)}^2 \leq Q_{dis}^2(k,h) \quad (6)$$

Moreover the upper and lower bound of the storage capacity should satisfy.

$$E_{min\leq}\ E_{LOW} \text{ , } E_{UP\leq}\ E_{max} \quad (7)$$

The EV's impact modelling and four operation scenarios

For the sake of modelling the EV's impact in terms of active and reactive power losses, and observing the power losses for the test- line without a charge station, with one charge station and with two charge stations, power flow analysis was used.Four different operation scenarios, in terms of the cooperation between two charge stations, are listed below. The first scenario is for normal EV charge requirements, where a regular amount of drivers charge their EVs at the charge station. The second and the third scenario are designed for some exceptional events, where one charge station runs out of energy and needs to borrow it from other sources. The last scenario is where the EV's energy requirements exceed both charge stations' designed capacity; this time both stations need external energy from the TN.

(1) The first scenario is the most common one, both charge stations used their full charged capacity to charge EVs without any optimized power charge and discharge.

(2) The second scenario considers both charge and discharge processes as charge station two runs out of rated energy. Charge station one needs to transfer energy to charge station two. The active and reactive discharge power from station one will be optimized.

(3) The third scenario also considers both charge and discharge processes, but here charge station one runs out of rated energy. Charge station two needs to transfer energy to charge station one. The active discharge and reactive dis- patch power from station two will be optimized.

(4) The fourth scenario is where both charge stations one and two cannot supply the EVs and loads. External energy from the TN is used to charge stations one and two. The active and reactive power from the TN will be optimized to charge both stations. Tables 2–4 show comparisons of active and reactive power losses without charge stations, with one charge station and with two charge stations in 11-bus distribution test-line.

Theoretical analysis

The main focus of this paper is to identify charge station two's optimal location. In practice, there are many additional constrains for the optimization of charge station's location, such as different countries' energy policies and geographic factors. This paper does not consider these factors.

Analytical approach for optimal location

In order to reduce the power loss caused by EV penetration, a distribution network with charge stations one and two and the p line model [31] was created and developed for analyzing the location of station two for loss reduction. The active, reactive power flow, bus voltage and current of p line model are given by Eqs. (8)-(13). P_i and $Q_i$are the sending-end active and reactive power through bus S_1 and S_2

$$P_{I}= \acute{p}_i + R_I \frac{P_I^2+\bar{Q}_i^2}{V_{S2}^2} \qquad (8)$$

$$Q_{i}= Q_i'' - V_{S1}^2 \frac{Y_I}{2} = \acute{Q}_i + X_i \frac{\acute{p}_i^2}{V_{S2}^2} - V_{S1}^2 \frac{Y_i}{2} \qquad (9)$$

$\acute{p}_i$ and $\acute{Q}_i$ are the injection active power and reactive power to bus S_2 respectively

$$\acute{p}_i = P_{dis2+} P_{load2+} P_{m2F-} P_{grid-} P_{dis1} \qquad (10)$$

$$\acute{Q}_i = Q_{dis2+} Q_{load2+} Q_{m2F+} Q_{grid-} Q_{dis1-} V_{S2}^2 \frac{Y_i}{2} \qquad (11)$$

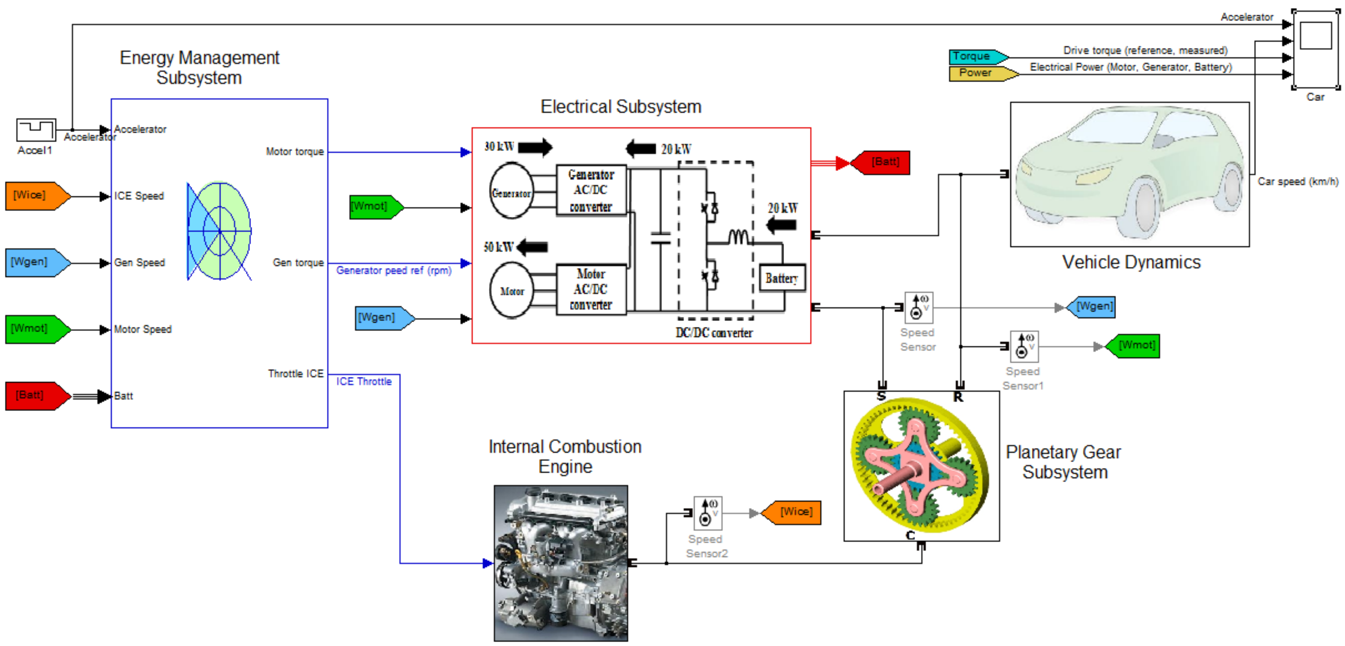
The voltage at bus S_2 is

$$V_{s2=} V_{s1-} I_i Z_i = V_{s1-} \frac{S_i''^*}{V_{s1}^*} (R_{i+jX_i}) \qquad (12)$$

$$V_{s2}=V_{s1}-\frac{P_i''-jQ_i''}{V_{s1}}(R_i+jX_i)=\left(V_{s1}-\frac{P_i''R_i+Q_i''X_i}{V_{s1}}\right)-j\left(\frac{P_i''X_i-Q_i''R_i}{V_{s1}}\right) \quad (13)$$

MATLAB/SIMULINK SIMULATION RESULT

For study the stability of the system and to validate the proposed a new analytical method is proposed, using the stations' cooperation in terms of optimal active and reactive power dispatch as well as power flow analysis for locating the optimal placement of charge stations, so as to reduce power losses. For this purpose a test operating scenario is simulated. Operations EV are in Fig. 6.



Fige.6. *Active and reactive power capability [29].*

Table 1 shows the P, Q station two at different locations for uniformly load and Table 2 shows the Pgrid, Qgrid from TN at different locations for uniformly load. Also optimal locations for charge station two in the test-line for power loss reduction. From the system operating view point, four different operation scenarios have different station two's locations. They give system operators suggestions for power loss reduction operations.

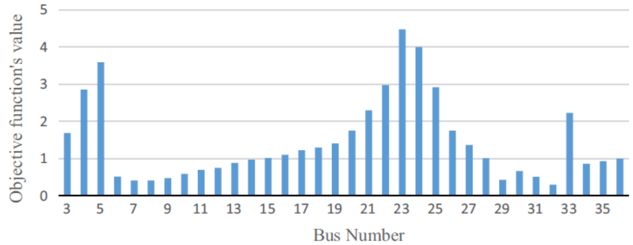
TABLE 1. P, Q station two at different locations for uniformly load.

P, Q	No	No	No	No	No	No	No	No	No
	3	4	5	6	7	8	9	10	11
P_{dis}	3.81	3.79	3.77	3.63	3.20	2.68	2.03	1.09	1.58
Q_{dis}	1.47	1.50	1.56	1.29	1.19	0.93	0.61	0.48	0.27

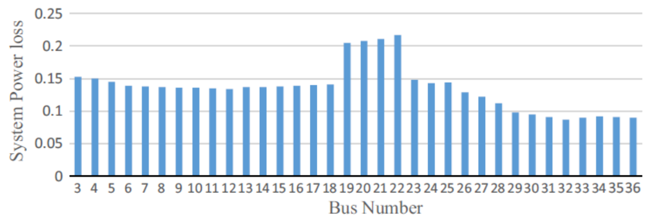
TABLE 2. Pgrid, Qgrid from TN at different locations for uniformly load

P, Q	No								
	3	4	5	6	7	8	9	10	11
P_{dis}	9.45	9.51	9.56	9.62	9.67	9.72	9.77	9.83	9.85
Q_{dis}	2.95	3.00	3.04	3.09	3.14	3.18	3.22	3.25	3.27

The proposed method was also tested in a 36-bus distribution networks [32]. The simulation results prove the accuracy of the proposed method. The objective function values and the simulation results can be seen in Figs. 7 and 8.

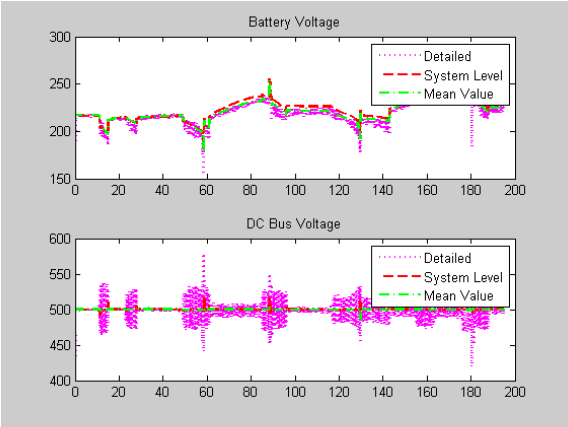


Fige.7. *Objective function's values of 36-bus test distribution network*

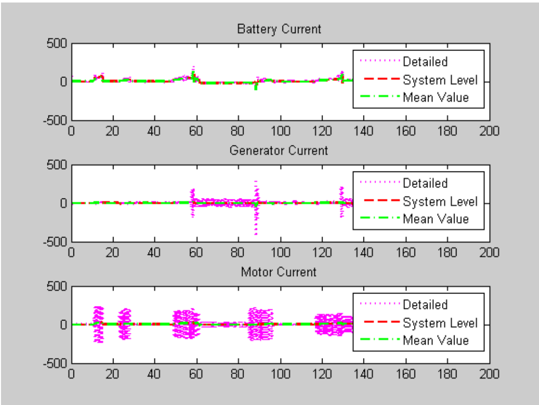


Fige.8. *The power loss of the 36-bus test distribution network*

The   battery voltage and current obtained by using the already proposed method and are shown in Fig. 9 and 10.



Fige.9. *The voltage EV*



Fige.10. *The current EV*

Conclusion

In this paper, a new analytical method is proposed, using the stations' cooperation in terms of optimal active and reactive power dispatch as well as power flow analysis for locating the optimal placement of charge stations, so as to reduce power losses. As a results it was shown that 27% of average active power loss can be saved by installing two charge stations rather than no charge stations. From the power flow analysis, it was proved that the current density method is not accurate for choosing charge stations two's location.

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