Proc. XXVII International Scientific Conference Electronics - ET2018, September 13 - 15, 2018, Sozopol, Bulgaria

Strategy for dispatching of multiple electric vehicles recharging in a microgrid

Hristiyan Chavdarov Kanchev[1], Vasil Aleksandrov Shterev[2]
and Nikolay Lyuboslavov Hinov[1]
[1]Faculty of Electronic Engineering and Technologies, Department of Power Electronics
[2] Faculty of Telecommunications, Department of Communication Networks
Technical University of Sofia
8 Kliment Ohridski blvd., 1000 Sofia, Bulgaria
{hkanchev, vas, hinov}@tu-sofia.bg

Abstract – **Simultaneous recharging of a large number of electric vehicles in addition to the daily peak of consumption can have a significant impact on the stability of distribution grids. If electric vehicles are expected to outnumber those driven by internal combustion engines in the near future, recharging of their batteries has to be coordinated in order to avoid a negative impact on grid stability. An approach for dispatching of multiple electric vehicle chargers is presented in this paper. A model of the studied grid is implemented in the MATLAB/Simulink environment. The dispatching problem is formulated as a discrete optimization with constraints and a numerical example is used for assessment of the influence of electric vehicle charging on the load curve. Simulation results demonstrate that coordinated recharging of electric vehicles decreases the load peaks and the potential risks associated with them while guaranteeing that each vehicle is recharged before the deadline set by their users.**

Keywords – **Microgrid, power system, dispatching, electric vehicle, charging, optimization**

I. INTRODUCTION

Due to the increased penetration of Electric Vehicles (EV) the energy consumed for recharging their batteries is expected to account for 10-15% of the average daily consumption by 2030 [1]. Although this may not seem a huge percentage, the problem arises due to the fact that daily curves of power consumption are strictly correlated to the daily population activity: in large metropolitan areas usually people go to work and return back home simultaneously, in the range of a few hours in the morning and evening. In standard charging mode EV battery chargers have a rated power of 1,5 up to 4 *kW* and in fast charge some models consume up to 40kW. In addition to the repetitive daily load peak in distribution grids EV recharging could have a significant impact on distribution grid stability and power quality. In particular, the impact in residential areas can be substantial, especially in cases of high penetration levels of EV. According to some sources, EVs could even double the evening peak load of low voltage grid feeders. In order to avoid the negative impacts on distribution grids, coordination and dispatching of electric and plug-in hybrid electric vehicles recharging should be implemented. Furthermore in the context of the Smart Grid, EV batteries can be locally aggregated in order to play a role of distributed energy storage and provide grid support for peak load shaving [2-6].

Two major approaches for control of EV recharging are subject to researchers [2-9]: the first one is often referred to as centralized microgrid control (fig.1) where local communities of loads and Distributed Energy Ressources (DER) coupled to the same low voltage feeder form microgrids and are dispatched by their corresponding Microgrid Central Energy Management Systems (MCEMS) which communicate with the Distribution System Operators (DSO). The second approach is a Multi-Agent System (MAS), a market approach where electricity prices are communicated in real time and the algorithms implemented in each device (load or DER) take decisions and adapt their consumption or generation. Although it can lead to convergence, this approach has its disadvantages. Apart from the large amounts of information that has to be exchanged in real time, the multi agent approach could lead to periodic oscillations in the consumption [4, 5] or unusual volatility in the grid load which is undesirable for the long-term dispatching of the power system. Also, the acceptance of real-time electricity pricing is still subject to discussions. Therefore in the present paper authors have chosen to focus on the centralized microgrid dispatching approach.

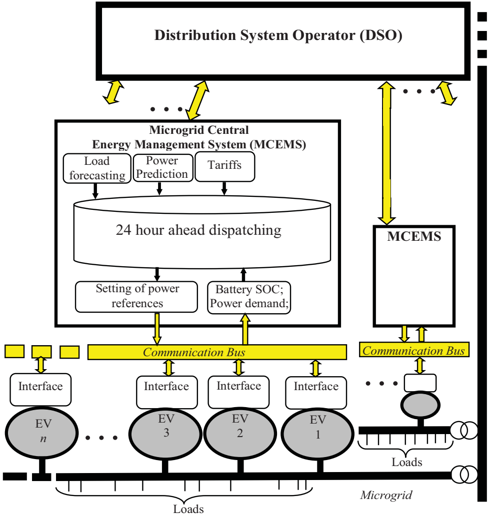

Fig. 1. Communication and power infrastructure for centralized dispatching of loads in a microgrid

From the point of view of EV owners, their main concern is to have their batteries charged at the time they need their vehicle. Therefore each user can set a deadline and the dispatching algorithm should guarantee that vehicles are

978-1-5386-6692-0/18/$31.00 ©2018 IEEE

charged not later than their respective deadlines. A certain degree of flexibility is available, because vehicles are often parked for periods of time longer than the time required to charge their batteries, for example during the whole night. This flexibility can be used to shift EV recharging to a time range of lower demand (during the night). Therefore the development of intelligent charging algorithms that utilize this flexibility to avoid issues in the distribution grid is an interesting topic. These algorithms will decide on when and which vehicle to charge and potentially at what charging rate (if the corresponding vehicle has fast and ordinary charging options) to achieve a certain objective (e.g., peak shaving or maximum use of the available power from renewable energy sources). Such an approach is often referred to as demand side management (DSM) or demand response (DR). Instead of adapting generation to power demand, the demand is adapted and vice versa in order to support optimal operation of the power system (fig.1). In this paper are presented simulations of the load curve in a microgrid comprising 50 EV in a residential neighborhood consisting of 50 households. The objective of the proposed dispatching strategy is to avoid reinforcement of the evening peak of consumption, to shift EV charging during the night and guarantee that each vehicle is charged at the corresponding deadline and the morning.

II. MODELLING OF THE CONSUMER BEHAVIOR

One of the main problems related to EV integration into distribution grids is prediction of the individual EV owner behavior [6], [7]. To meet the total EV charging demand in a way that enhances the load profile, it is necessary to deduce and forecast the parking availability pattern (schedule) that the local controller (aggregator) will use to determine the possibilities for scheduling the EV recharging.

Statistical data of the EV user behavior synthetized described in [6] is used in this paper to model the parking availability pattern in a residential area (fig. 2 and fig. 3). Based on the information about the type of trip (trips to work, for shopping, leisure, etc.) and the duration of the trip is deduced the hourly distribution of EV's in the parking (fig.3). For the goals of dispatching, the following data has to be available to the microgrid aggregator: estimated time and battery State of charge (SOC) upon arrival of each vehicle and the deadline (set by each user individually) when the vehicle should be fully charged. The forecasted load profile of the microgrid (fig. 4) is also necessary in order to elaborate the EV dispatching plan.

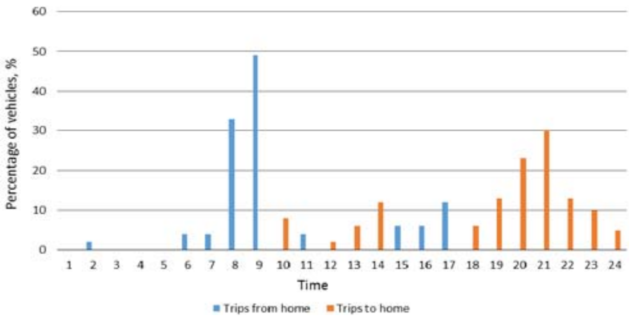

Fig. 2. Hourly distribution of the trips to and from home during workdays

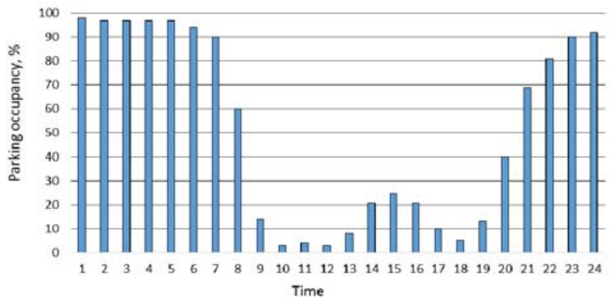

Fig. 3. Hourly distribution of the EV's in the parking

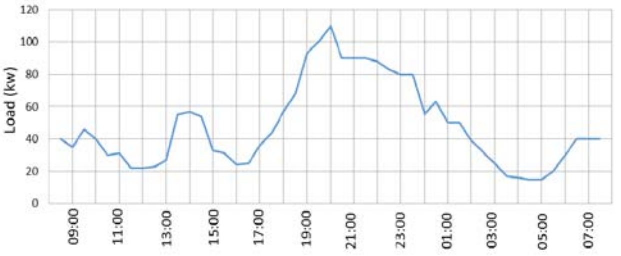

Fig. 4. 24-hour load profile of the examined microgrid, without EV charging

III. MATHEMATICAL DESCRIPTION OF THE PROBLEM

The 24 hour interval is sampled in 48 timesteps of 30 minutes each (as depicted in fig. 4).

$$t \in [1,48] \tag{1}$$

At each timestep t the microgrid resultant load at the point of common coupling (the low voltage feeder) P_{LOAD_PCC} is the sum of the non-dispatchable loads in the grid P_{LOAD} and the power consumption of the EVs that are being charged:

$$P_{LOAD\_PCC}(t) = P_{LOAD}(t) + \sum_{j=1}^{50} P_{EV\_j}(t) \tag{2}$$

Where $P_{EV\_j}(t)=0$ if the j-th vehicle is not being charged in timestep t.

The ratio of simultaneous EV charging in timestep t is given by the following equation:

$$c(t) = \frac{n(t)}{N(t)} \tag{3}$$

Where n is the number of vehicles being charged and $N(t)$ is the total number of EV in the parking.

The following equation describes the load control variable. It actually represents the amount of 30-minute intervals

$$M_i = floor\frac{\left((T_{i\_end} - T_{i\_beg})\right)}{\Delta T_i} \tag{4}$$

Where T_{i_end} – the timestep in which the vehicle has to be fully charged (set by the user), T_{i_beg} – initial time, ΔT- equal time intervals of 30 minutes, M – the number of timesteps time and *floor* is a function for rounding to an entire number. With the aid of the variable x_{jt} is defined the state of the j-th vehicle at timestep t. If the vehicle is being charged x_{jt}=1, else x_{jt}=0.

$$x_{jt} \in \{0,1\} \tag{5}$$

In this case the power consumed by the respective EV is equal to:

$$P_{EV\_j}(t) = P_{LOAD\_j}.x_{jt} \tag{6}$$

Where Pcharge_j is the rated charging power of the j-th EV. The time for fully charging of an EV is:

$$T = \frac{(100 - SOC_j)}{100} \cdot \frac{E_{\max\_j}}{P_{charge\_j}} \tag{7}$$

Where SOC_j is the battery state of charge (in percent), $E_{max\ j}$ is the battery capacity (in kWh). The upper limit ot the EV battery state of charge SOC_{j_max} is 100% and the lower limit SOC_{j_min} is set to 10% (supposing that the battery would not be fully discharged upon arrival at the parking):

$$SOC_{j\_min} \leq SOC_j \leq SOC_{j\_max} \tag{8}$$

Further, instead of time measured in the SI system, we will measure the time required for charging a vehicle in timesteps of 30 minutes (which is the sampling interval adpoted in this study). The time required for fully charging the vehicle j is expressed by:

$$T_{\max\_j} = floor(T_j / \Delta T_j) \tag{9}$$

And for the battery of j-th EV, the following equation is defined:

$$\sum_{j=1}^{N_e} x_j = T_{\max j} \tag{10}$$

where N_e is the maximum number of timesteps until the battery is fully charged.

The total power of all EV's for the t^{th} sample is:

$$P_{EV\_total}(t) = \sum_{j=1}^{N_t} P_{charge\_j}.x_{jt} \tag{11}$$

where N_t is the number of EV's being charged at the t-th timestep.

Definition of the optimization problem

This problem can be defined as discrete optimization with constraints. First the dispatcher (the microgrid central energy management system) has to determine a schedule for charging of each electric vehicle with main purpose to flattern the power consumption from the distribution grid – at the point of common coupling. Accordingly the objective function is:

$$\min\left(\sum_{j=1}^{N_t}\sum_{i=1}^{N_e} P_i.x_{ij}\right) \tag{12}$$

With constraints:

$$\sum_{j=1}^{N_t} x_{jt} \leq T_{\max,j} \tag{13}$$

$$P_{EV\_\max}(t) \leq P_{PCC\_\max}(t) - P_{LOAD}(t) \tag{14}$$

In the former equation is described the maximum power that can be consumed for charging the vehicles, obtained as the difference between the maximum power at the point of common coupling (the allowed power consumption for the whole microgrid, imposed by the distribution system operator) and the power consumption of the other loads in the system.

A second optimization problem arises as a subproblem of the first one: it is to define a schedule for charging each electric vehicle with main purpose to minimize the required power from the distribution network for the certain cycle where the required power is higher than the average for the past 24 hours. The corresponding objective function can be expressed as:

$$\min\left(\max_{j\in\{1,\ldots,N_t\}} \sum_{i=1}^{N_e} P_i.x_{ij}\right) \tag{15}$$

With the same constraints like the former: (13) and (14).

IV. NUMERICAL EXAMPLE AND SIMULATION RESULTS

In the current paper a forecast model with the presence of 50 electric vehicles are studied. A set of random variables (with a distribution according to fig.2 and fig.3) is generated for their time of arrival, time of departure and state of charge upon arrival (between 20% and 60%). The values for the first 7 vehicles are presented in table 1. The power consumption for charging the vehicles in this study is considered equal to 2kW for all the vehicles, corresponding to an ordinary charge process of an EV (fast charging requires a power of up to 15kW for one vehicle and will be included in future works).

- Number of electric vehicles : 50
- Time of arrival: between 16:30 and 20:00
- Time of departure – deadline: between 05:30 and 09:00
- Initial state of charge : 20% and 70%

TABLE 1. TIME OF ARRIVAL (T_{beg}), DEPARTURE DEADLINE (T_{end}) AND STATE OF CHARGE UPON ARRIVAL SOC_{j_0} OF THE FIRST 7 VEHICLES.

Number of electric vehicle (*j*)	**T_{beg}**	**T_{end}**	**SoC_{j_0} [%]**
1	17:30	6:30	30
2	17:00	7:00	45
3	17:00	8:00	55
4	18:30	7:30	40
5	19:00	8:30	80
6	18:30	7:00	30
7	19:30	8:00	60
…		…..	….

The proposed dispatching procedure is implemented in MATLAB. The algorithm groups the vehicles based on their time of departure (the deadline when the battery should be already charged). After this the number of time slots for charging each group is calculated. Then the vehicles are prioritized based on their initial SOC. This ensures that the batteries with smaller initial SOC will start charging earlier.

A depiction of the dispatching plan for charging of several electric vehicles is presented in fig. 6. The dispatching results can also be presented by a timetable showing which EV is being recharged at the timestep t by its control variable x_{jt}. The resultant load of the microgrid for the studied 24 hour period is presented in figure 7. The scenario without coordination of the EV recharging is traced with a dashed line and the resultant load with coordinated recharging is traced with a solid line. The developed algorithm decreases the peaks of consumption and the risk of potential overloads of the power infrastructure.

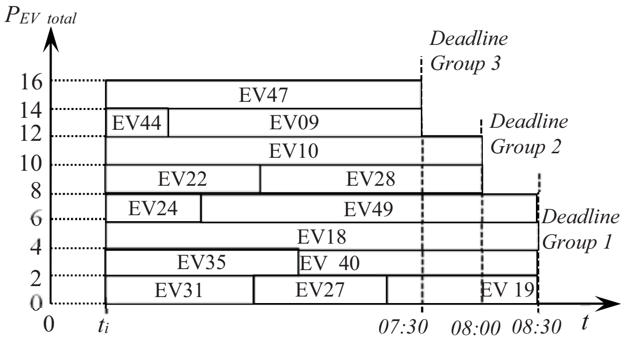

Fig. 6. Depiction of the proposed dispatching strategy

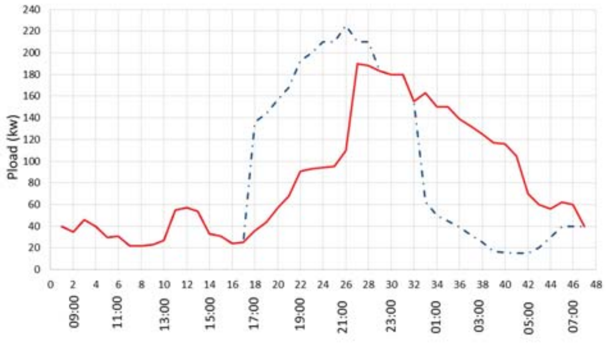

Fig. 7. Resulting load curve of the microgrid for the studied 24-hour period with optimnization (solid line) and without optimization - by simultaneous recharging of all the electric vehicles (dashed line)

TABLE 2. DISPATCHING PLAN FOR THE FINAL TIMESTEPS OF RECHARGING OF THE EV'S 11 TO 17

Timestep	**EV number (*j*)**						
	11	12	13	14	15	16	17
42	1	1	1	0	0	0	0
43	1	1	1	0	0	0	1
44	1	1	1	1	0	0	0
45	1	1	1	1	0	0	0
46	1	1	1	1	1	0	0
47	1	1	1	1	1	0	0
48	1	1	1	1	1	0	0

V. CONCLUSION

In this paper is presented a dispatching approach for coordinated recharging of a fleet of electric vehicles in a residential microgrid. The system model is implemented in MATLAB and a numerical example of dispatching a microgrid comprising 50 electric vehicles and the same number of households is solved. Simulation results demonstrate proper operation of the proposed approach: the resultant load curve does not contain a peak due to simultaneous recharging of all the vehicles and the consumption is equally distributed during the night, while all vehicles are recharged before the deadline set by their owners. The coordinated recharging of electric vehicle batteries decreases the peaks of consumption and the risk of potential overload of the power infrastructure. The presented mathematical model can be further developed for coordination of the energy flows in microgrids comprising not only loads but also small-scale distributed generation and storage.

ACKNOWLEDGEMENT

This research is realized in the framework of the project "Optimization of energy flows management and the interaction between electric vehicles and intelligent grids", funded by the Research and Development sector of the Technical University of Sofia, contract 181ПР0015-03.

REFERENCES

[1] O. Marcincin, Z. Medvec and P. Moldrik, "The impact of electric vehicles on distribution network", Proceedings of the 18th International Scientific Conference on Electric Power Engineering (EPE 2017), Kouty nad Desnou, Czech Republic, 17-19 May 2017, DOI: 10.1109/EPE.2017.7967344

[2] F. Josi, K. Mazlumi and H. Hosseini, Charging and discharging coordination of electric vehicles in a parking lot considering the limitation of power exchange with the distribution system, Proceedings of the 2017 IEEE 4th International Conference on Knowledge-Based Engineering and Innovation (KBEI), Tehran, Iran, 22 Dec. 2017, DOI: 10.1109/KBEI.2017.8324933

[3] M. Shafie-Khah, E. Heydarian-Forushani, G. Osório et al., "Optimal Behavior of Electric Vehicle Parking Lots as Demand Response Aggregation Agents", IEEE Transactions on Smart Grid Volume: 7 , Issue: 6 , pp. 2654 – 2665, 2016, DOI: 10.1109/TSG.2015.2496796

[4] V. L. Nguyen, T. T. Quoc, S. Bacha, B. Nguyen, "Charging Strategies to Minimize the Peak Load for an Electric Vehicle Fleet", in IEEE IECON, Texas, USA, 2014

[5] Z.Yang, K. Li, A. Foley, C. Zhang, "Optimal Scheduling Methods to Integrate Plug-in Electric Vehicles with the Power System: A Review", Proceedings of the 19th World Congress The International Federation of Automatic Control Cape Town, South Africa. August 24-29, 2014, pp. 8594-8603.

[6] M. Yazdani-Damavandi, M. Moghaddam, M. Haghifam et al., "Modeling operational behavior of plug-in electric vehicles' parking lot in multi-energy systems", Proceedings of the 2016 IEEE/PES Transmission and Distribution Conference and Exposition (T&D), Dallas, TX, USA, 3-5 May, 2016, DOI: 10.1109/TDC.2016.7519991

[7] J. Tao, D. Huang, D. Li et al., "Pricing strategy and charging management for PV-assisted electric vehicle charging station", Proceedings of the 13th IEEE Conference on Industrial Electronics and Applications (ICIEA), Wuhan, China, 31 May-2 June 2018, DOI: 10.1109/ICIEA.2018.8397782

[8] S. Khatiri-Doost and M. Amirahmadi, "Peak shaving and power losses minimization by coordination of plug-in electric vehicles charging and discharging in smart grids", Proceedings of the IEEE International Conference on Environment and Electrical Engineering and IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Milan, Italy, 6-9 June, 2017, DOI: 10.1109/EEEIC.2017.7977547

[9] Ch. Ch. Chan, L. Jian, D. Tu, "Smart charging of electric vehicles – integration of energy and information", IET Electrical Systems in Transportation, 2014, pp. 1-8

[10] S. Hensel, T. Strauss and M. Marinov, Eddy Current Sensor Based Velocity and Distance Estimation in Rail Vehicles, IET Science, Measurement & Technology, Vol. 9, Issue 7, October 2015, p. 875 – 881, DOI: 10.1049/iet-smt.2014.0302, Print ISSN 1751-8822, Online ISSN 1751-8830