Demand Side Management for Charging Plug-In Hybrid Electric Vehicles

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Abstract - In future the usage of Plug-in hybrid electric vehicles (PHEV) will be in wide range, which will impose huge burden to the distributive system. The peak load at the distribution system can be controlled by Demand Side Management (DSM) strategy. In the proposed study, the load curve of Low-voltage Transformers (LVTs) is made to be flatten, on satisfying the requirement of charging PHEV at given time to the required level. The proposed problem statement is formulated as convex optimization problem, and then the random arrival of PHEV is handled by introducing the moving horizon strategy. Based on this, the PHEV are being disconnected from the LVTs beyond their respective exit times. Such that the demand curve of the LVTs is flattened. This problem is solved using MATLAB and the power demand curves of the LVTs, power curves of the PHEVs and non- PHEV load are compared over a time of 24 hours to show that the power curve is flattened with the penetration of PHEV.

Keywords - Demand Side Management (DSM), Convex optimization, Moving Horizon Approach.

1. Introduction

The usage of petroleum products will no longer exist in future, so the growth of electric vehicles has been increasing day by day. In the situation of long distance travelling the plug-in hybrid electric vehicles (PHEVs) is more desirable to employ. In PHEV the batteries and combustion engines are employed together and the batteries can be charged at available charging stations. When a number of PHEVs are connected into the distribution grid, a current peak load or a new peak load is created which causes serious deviation in voltage and impose huge current burden to transformers. The overloading will damage the transformers; the connected appliances Excessive deviation in voltage will damage the components connected in the power transmission network, which may result in a blackout.

These problems can be addressed by development of advanced metering and communication strategies, the problems associated with the distribution system during PHEV charging can be handled. So, the demand side management techniques basically employed to balance the load side demand and generation, which is responsible for economical and reliable operation of the grid.

2. Literature Review

Numerous studies have been carried out on demand side management for PHEV. The following are some of the studies related to DSM for PHEV. The Korean government has proposed plans for electrification of transportation including subsidies to buy EV and for improvement of charge structure, [1]. This case study analyzes the consumer preferences on electric vehicle using discrete choice experiment (DCE). The national and individual economic benefit of vehicle to power grid supply was estimated with the amount of electricity supplied by the vehicle owners. This estimation accounts for about 560,000 units of power which will reach 1.81GW by 2030 in South Korea. The consumer’s preference structure is estimated in [2] and the interest for paying the future residential electric power services. A quantitative estimation of the individual utility functions for certain features like E- procurer groups, grid integration with renewable energy generation, type of service – providing company, smart metering equipment, relaxation on progressive electrical billing system is done by using a choice experiment based on conjoint survey conducted. This estimation is done by employing a mixed logit model. Reference [3], Optimal load management of PHEV with DSM in vehicle to grid application proposes a scheduling vector for charging and discharging of PHEV by satisfying the utility aim to reduce the peak to average demand ratio and also the overall energy cost using multi objective optimization technique. Reference [4], in the circumstance of energy hubs, a new framework is proposed for the coordination in charging of Plug – in Hybrid Electric Vehicles (PHEVs). To obtain a optimal charging of PHEVs in the view of vehicle owners’ and system operator a Multi objective Optimization framework is employed by the PHEVs Coordinator Agent (PCA). This framework is applied to the modified IEEE 34 – node test system and the results are obtained which exhibits the efficiency and applicability of the proposed approach. Reference [5], a stochastic planning or resources of the PHEV Charging station with the consideration of the contracted controllable fleets and the price – responsive commercial charging customers. Based on the demand side on charging service pricing and controllable demands allocation, optimized energy supply decisions are made which includes procurement and internal generation. A portfolio is achieved for the PHEV charging station for resource planning and the uncertainties of renewable generation and spot market price forecasting are handled by SAA method. Reference [6], An algorithm to maximize the profit in charging stations is proposed which includes the scheduling the various types of
vehicles by proper energy management. The proposed algorithm, close-to-optimal algorithm, achieves optimal conditions by controlling the price for charging, and effective charging and discharging of PHEVs and also profit maximization. This paper concentrates on the reduction of energy loss at the micro grid by employing two – stage optimization with different penetration of PHEVs. This methodology, a convex quadratic objective function is formulated for active power management of PHEVs and their daily consumption is calculated approximately based on the PHEVs owner’s behavior [7]. With this, smart charging strategies are employed to minimize the network energy loss. Without employing smart charging strategies minimization of energy loss in the network is not possible. Monte Carlo Simulation (MCS) is used to analyze the data numerically. Reference [8], Synergistic control of Plug-in vehicle charging and wind power scheduling presents a hierarchical control algorithm to realize the synergy between Plug-in Electric Vehicles (PEV) and wind energy by integrating the PEV charging and wind power scheduling. The three level controllers utilize PHEV charge to compensate for the wind power fluctuations and this regulates the grid frequency. Reference [9], Demand response a load shaping tool in an intelligent grid with electric vehicles presents t he impacts of charging Electric vehicles (EVs) on residential distribution networks including the transformer and a demand response strategy is proposed as a load shaping tool. This strategy improves the distribution transformer utilization and prevents overloading of the transformer by peak load shedding with the consideration of consumer preferences and load Priorities. In the reference [10], Optimal decentralized protocol for electric vehicle charging, the utility company’s control signal is altered to guide the updates of PHEVs’ charging profiles. The algorithm proposed converges for both homogeneous and non-homogeneous cases to optimal charging profiles. The reference [11], Demand response and economic dispatch of power systems considering Large-Scale Plug-in Hybrid Electric/Electric Vehicles (PHEVs / EVs): A review discusses on the usage of PHEVs/ EVs as a new tool for system operation and regulation from a review of recent studies and mainly considers demand response and economic dispatch. In reference [12], Optimal charging of electric vehicles in smart grid: characterization and valley filling algorithms, a joint optimal power flow (OPF) and electric vehicle charging problem the augments the OPF problem with charging EVs overtime is studied and an online program optimally minimizes the power loss.

3. Objective of The Proposed System

The objective of the Proposed System is to flatten the load curve of LVTs, while satisfying consumer’s requirement for charging the PHEVs to the required level in their respective charging times. This is formulated as a convex optimization problem and a power allocation algorithm is proposed to solve it. The random arrival of PHEV is managed using a moving horizon approach. Our algorithm is being demonstrated using numerical simulations with practical examples to show the effectiveness of our algorithm for DSM.

4. Problem Formulation

A radial structure of the power distribution system is the most common structure. In this proposed system we consider the distribution grid as given in the Figure 1. The structure is hierarchical involving a high voltage transformer connecting to a number of LVTs. Each LVTs are connected to a number of households having PHEV chargers.

The objective is to apply Demand side management on PHEV chargers to reduce demand maximally such the demand curve of transformer is flattened and also, the consumer’s requirement of charging the PHEV to the required level in the prescribed time is satisfied.

Here we consider only single phase LVTs since power supply to residential and small commercial customers is single-phase and the PHEV chargers are also single-phase. The single-phase supply may be from a one phase of a two or three phase LVT. In this case the load balancing of different phase is managed with the help of distribution planner. The Flattening of load curve at different phase results in load balancing. DSM for different phases creates extra difficulties because it may be supplied from different residential or commercial areas. So, DSM for three-phase power supplies is treated as three separate problems with single phase LVTs.
It is assumed in the study that the considered DSM has enough power capacity, the power line flow limit does not exceed, and the load is assumed as pure resistive.

The PHEV problem is formulated for the given time interval 1 to 1440 (duration of 24 hours in minutes). The forecast of non-PHEV power consumption of each household is known. The objective function of the proposed DSM is formulated as follows:

\[
\min f(p) = \sum_{i=1}^{1440} \left( \sum_{k=1}^{5} (p(i)(k) + q(i)(k) - \eta) \right)^2
\]

subject to

\[
0 \leq p(i)(k) \leq \text{pimax}(k)
\]

Here \( p \) is the charging power of PHEV, \( b \) is the energy need of the PHEV, \( q \) is the non-PHEV power consumption. This problem is solved using a power allocating algorithm which is explained in the next section.

5. Proposed Algorithm

This algorithm helps in allocating power to the PHEV dynamically such that the peak load occurrence at the LVTs is reduced and thus finally the demand curve of the LVTs is flattened. The algorithm is given below.

Input: \( e, p_{\text{max}}, b, q(k), k=1 \) to 1440
Output: alpha and \( p(k), k=1 \) to 1440

Initialize

\[\alpha_{\text{min}} = \min (q)\]
\[\alpha_{\text{max}} = \max (q) + p_{\text{max}}\]

while \( \alpha_{\text{min}} - \alpha_{\text{max}} > e \) do

Choose

\[\alpha = (\alpha_{\text{min}} + \alpha_{\text{max}})/2\]

Evaluate

\[p(k) = \alpha - q(k), k = 1 \) to 1440\]

if \( k = \) entry time to exit time \{\n
\[\sum p(k) > b \text{ for } k \) 1 to 1440\]

Then

\[\alpha_{\text{max}} = \alpha\]

else if

\[\sum p(k) < b \text{ then}\]

\[\alpha_{\text{min}} = \alpha\]

}\}

for \( k = 1 \) to 1440

if \((k=\) entry time \&\& \( k=\) exit time)\n
compute the \( p(k) \) (power of PHEV)

end if

end for

if \( p(k) > \) transformer power

disconnect the respective PHEV

First the range of power that can be used by PHEV is allocated by \( \alpha \) considering the non-PHEV power consumption. With this the charging power of PHEV is computed whose summation is checked whether it exceeds the energy need of the PHEV. If it exceeds the then \( \alpha_{\text{max}} \) is set as \( \alpha \) so the range is being increased. And if it is less than the energy needs then \( \alpha_{\text{min}} \) is set as \( \alpha \). Thus, the charging power range required is set. Then the total power is calculated for each PHEV within their respective time and it is compared with the transformer power for checking whether the transformer is overloaded. If so the PHEV responsible for overloading is not allocated power such that it is disconnected and it is being shifted to time when \( q \) is minimum.

6. Numerical Simulation Results

For case study five households having a different PHEV is simulated. The numerical simulations of the proposed algorithm are done in MATLAB. The required parameters of the PHEV are given the table below.

| Table 1: PHEV parameters |
|---------------------------|
| No. | Model       | Size of the Battery (kWh) | Energy Required (kW) | Maximum Power (kW) |
|-----|-------------|-----------------------------|-----------------------|---------------------|
| 1   | GM Chevy vol | 16                          | 8                     | 3.84                |
| 2   | Nissan Leaf | 24                          | 12                    | 6.6                 |
| 3   | Tesla MODEL S | 60                         | 30                    | 10                  |
| 4   | Volvo C30   | 24                          | 12                    | 3.52                |
| 5   | BMW Mini E  | 35                          | 17                    | 11.52               |

| Table 2: Entry time and Exit time of PHEV |
|------------------------------------------|
| No. | PHEV Model       | Charging time(hrs) | Entry time (minute) | Exit time (minute) |
|-----|------------------|--------------------|---------------------|--------------------|
| 1   | GM Chevy volt    | 12-19              | 0                   | 720                |
| 2   | Nissan Leaf      | 12-15              | 200                 | 1040               |
| 3   | Tesla MODEL S    | 14-20              | 420                 | 1260               |
| 4   | Volvo C30        | 8-10               | 945                 | 1425               |
| 5   | BMW Mini E       | 15-20              | 333                 | 1353               |

The power allocated to each PHEV is obtained from the simulation with the data from Table 1 and Table 2. This is represented in the following graph in which the power is given for 24hrs with a sample time of 1 min, so it is for 1440 min.

Fig. 2: Power of non-PHEV load
Fig. 3: Power Required by PHEV1

Fig. 4: Reduced Power Allocated to PHEV1

Fig. 5: Power Required by PHEV2

Fig. 6: Reduced Power Allocated to PHEV2

Fig. 7: Power Required by PHEV3

Fig. 8: Reduced Power Allocated to PHEV3

Fig. 9: Power Required by PHEV4

Fig. 10: Reduced Power Allocated to PHEV4
From above Figures 2-16 it is clearly shown that the power allocated to each PHEV is reduced by the algorithm. We can infer that the total PHEV load at the transformer is being reduced such that the demand of the PHEV from the LVT gets reduced.

Table 3: Power Reduction

| k (min) | Total PHEV power (kW) | Reduced PHEV power (kW) | Total Demand of LVT (kW) | Reduced Total Demand of LVT (kW) |
|---------|-----------------------|-------------------------|--------------------------|---------------------------------|
| 600     | 10.65                 | 6.75                    | 15.83                    | 11.94                           |
| 800     | 9.36                  | 9.36                    | 12.44                    | 12.44                           |

7. Conclusion
The Demand side management is necessary to reduce the peak load as there is increase in the penetration of PHEVs. Thus, by reducing the Demand of the LVTs overloading of Transformers is avoided. In this paper this problem is being solved using a power allocation algorithm and the results of simulation shows that the peak demand occurred due to PHEV is reduced which avoids overloading of transformer. This power reduction is shown in the Table 3 for two instances of time in minutes.
8. Future Work

The future work of the proposed system is the implementation of the power allocation techniques in hardware such that the scheduling of PHEV dynamically can be done effectively.

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