Switching Signal Reduction of Load Aggregator with Optimal Dispatch of Electric Vehicle Performing V2G Regulation Service

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Abstract—**Environmental concerns over the production of greenhouse gas have led to the development of environmental friendly transportation such as electric vehicle (EV). As the number of EVs is increasing day by day, it will have a great impact on grid operation and electricity market. Significant amount of EV charging during peak hour will cause branch congestions and low voltage. Moreover, high penetration of EVs plays an important role in altering electricity price. Thus, optimal scheduling of EVs charging is inevitable from the perspective of both system reliability and market. Load aggregators can combine the capacities of many EVs to participate in wholesale energy market. In this paper, optimal dispatch algorithm of EVs is developed and tested on a system consisting 1000 EVs. The advantage of the algorithm is that it requires less number of communication signals and less expensive infrastructure. EVs are turned on and turned off in binary fashion based on priority to follow the regulation signal.**

Index Terms— **Dispatch algorithm; Electric vehicle; Greenhouse gas; Load aggregator; Regulation up; Regulation down; Switching signal.**

I. INTRODUCTION

In many recent works, several techniques have been proposed for scheduling EVs. In [1], discrete dispatch algorithm for EVs has been proposed to perform frequency regulation. In this work, regulation signal is discretized into increments that can be met by turning on and off of different EVs based on priority. Coordination algorithm for managing the EVs charging has been proposed in [2] and compared with an uncoordinated strategy. Heuristic technique dispatches EVs at each time interval separately and optimization technique dispatches EVs at all the time intervals. Controlling load with Plug-in Hybrid Electric Vehicle (PHEVs) can solve peak charging load demand due to large scale PHEVs charging as well as PHEV can be treated as mobile energy storage device which can provide ancillary services such as regulation, load shifting, emergency security, and spinning reserve with their optimal charging strategies [3-4]. An algorithm for unidirectional regulation has been developed and aggregator profit maximizing set point selection has been formulated with constraints that are analogous to conditions in the smart charging algorithms [4]. A new algorithm for economic dispatch of plug-in electric vehicles (PEVs) is proposed in [5] considering uncertainties both in PEV and wind power. The algorithm is based on the integration of interior point method and particle swarm optimization (PSO). Generation cost of wind power and V2G power is derived analytically. The authors assume that each type of PEVs has specific charging period and it follows uniform charging pattern within that specified time. The main drawback of the proposed algorithm is that it will give uncertain profit if the mentioned assumptions do not hold. Y. Weifeng *et. al.* [6] have presented a hierarchical and zonal architecture for dispatching PEVs. The authors establish upper-level and lower-level model in their decomposition approach. The goal of upper-level decomposition is to minimize system operation cost through proper dispatch of generators and PEVs while the objective of the lower-level is to strictly follow the dispatching instructions form the upper-level through designing of appropriate charging and discharging strategies of each PEVs for the specified period. Risk of load mismatch between forecast and actual EVs load and charging cost reduction algorithm have been proposed in [7]. Non-convex of risk-aware day-ahead has been converted to convex one by using hidden convex structure which can be remodeled as two state stochastic linear program. Integration of PEVs and renewable energy resources (REV) has been studied [8] for energy cost saving and emission reduction through smart vehicle charges strategy. Simulation has been performed with real Spanish power system with a detailed hydro-thermal unit commitment (UC) model for energy and reserve. In [9], X. Xiaomin and S. Ramteen presented decentralized PEVs charging control. The technique conveys price and quantity to the load aggregator and compares to price only method and it shows superiority over price only scheme. Moreover, this method does not depend on regularization term to warrant convergence. The drawback of the proposed technique is that it is not as easy implementable as centralized technique. A multilevel architecture for bidirectional vehicle to grid regulation is proposed through appropriate

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coordination of charging and discharging of electric vehicle [10]. To guarantee adequate charging of EVs, scheduling problem is formulated as convex optimization problem. The drawback is that proposed techniques does not consider centralized algorithm [11].

Continuous switching of load has great negative impact on system stability [12-13]. However, high penetration levels of renewable energy sources and microgrid flexibility offer more opportunities for the interaction between EVs and microgrid and increase system stability. EVs and battery swapping station (BSS) can mitigate load variability and improve microgrid economics also system reliability can be improved utilizing the advantage of V2G technology [14]–[18] through proper optimization approach in the day-ahead energy market. A couple of literatures [19]-[22] discussed promising strategies for energy management through optimized operation of EVs considering the impact of EVs' deep penetration on the electric grid with utilization of price-incentive model.

Section II provides a brief description regulation service that can be provided by EVs. Dispatch algorithm for EVs for switching signal reduction is presented in Section III. Simulation result and discussion is presented in section IV. Section V presents the conclusion of this work. References are included at the end of this paper.

II. Regulation Service

Energy and ancillary services from an electric vehicle (EV) to the grid is an important service to control the frequency of the system. With variation of load in the system frequency goes up and down continuously. This frequency can be controlled by controlling generation. Another mean of controlling frequency is demand response. Load aggregator can combine the capacity of many EVs to provide regulation service of to the system. Numerous studies have revealed that frequency regulation is the utmost valued facility that can be provided by an EV.

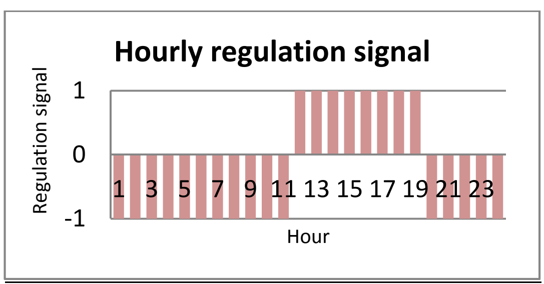

Fig. 1 Typical hourly regulation signal for 24 hours

Fig. 1 shows a typical regulation signal form the system operator. To follow this regulation signal, load aggregator need to turn on and turn off the electric vehicle. When regulation up signal is passed from the system operator, some EVs are turned off by the system operator to provide regulation service. On the other hand, when regulation signal is negative, load aggregator turns on more EVs in addition to the existing EVs to provide frequency regulation to the system.

III. Optimal Dispatch Algorithm

Load aggregator combines the preferred operating point (POP) of all EVs and then provides regulation service to the system by growing and decaying their charging around POP [16]. One major problem with such dispatch algorithm is that dispatch signal need to be directed to the all EVs to follow regulation signal and eventually it increases the number of signal. The number of signal can be reduced by turning on and off EVs in a binary fashion. This can be achieved by discrete dispatch algorithm as described in the following steps.

Step1: Calculation of POP and expected energy

Step2: Computation of percentage dispatch and percentage error of each dispatch.

Step3: Priority based "turn on" list and "turn off" list preparation to meet aggregated POP

Step4: Finding number of EVs (NEV) to track regulation signal

Step5: Calculation of difference of EV (DEV) between "turn on" list and NEV

Step6: If DEV is positive, transfer DEV from the lowermost of 'turn off' to the lowermost of 'turn on' list. If DEV is negative, move DEV from the upper of 'turn on' list to the upper of 'turn off' list.

Step7: Stop, if scheduling period is over. Otherwise, go to step4.

To test the above algorithm load data has been collected from ISO New England market. The algorithm starts with the calculation of POP of all EVs. POP can be calculated based on load, price, and maximum regulation participation. In this work, load based POP calculation has been used which is given as follows.

$$POP_i(t)=\frac{Mx_L-P(t)}{Mx_L-Mn_L}MP_i$$

Where, P(t) is the load at time t.

MxL is the maximum load over the given period.

MnL is the minimum load over the given period.

MP_i is the maximum power drawn by an EV when it is turn on.

Expected energy at period t is calculated using following equation.

$$ExE_i = POP_i(t) - RegUP_i(t) * Ex_U + RegDOWN_i(t) * Ex_D$$

Where, $RegUP_i(t)$ is the regulation up capability of i^{th} EV at at period t.

$RegDOWN_i(t)$ is the regulation down capability of i[th] EV at period t.

Ex_U is the anticipated up dispatch

Ex_D is the anticipated down dispatch

From the expected energy, percentage dispatch of each EV is calculated from the following equation.

$$DispatPer_i = \frac{Expected\ Energy\ of\ ith\ EV\ at\ period\ t}{Total\ Energy\ of\ all\ EVs\ for\ the\ whole\ period}$$

Then percentage error for each EV is calculated and based on error, urgency based turn on as well as turn off list is prepared so as to decrease the fast changing of the EVs while they are connected for charging.

Then, the regulation signal provided by the system operator is added to POP to get energy which is shown in the following equation.

$$Ener_R(t) = POP(t) + RS(t)$$

Finally, the number of electric vehicles (EVs) to track the regulation signal is calculated from the following equation.

$$Num_{EV} = Ener_R(t)/MP$$

After calculating the number of necessary EVs, it is subtracted from the number of turn off list. If the result is negative number (-N), then N number of EVs from the upper of turn on list is relocated to the upper of turn off list. On the other hand, if result in positive number (N), then N number of EVs from the end of turn off list is moved to end of turn on list.

IV. Result and Discussion

The algorithm has been coded in MATLAB. To test the algorithm following regulation signal has been considered over a 24 hour period.

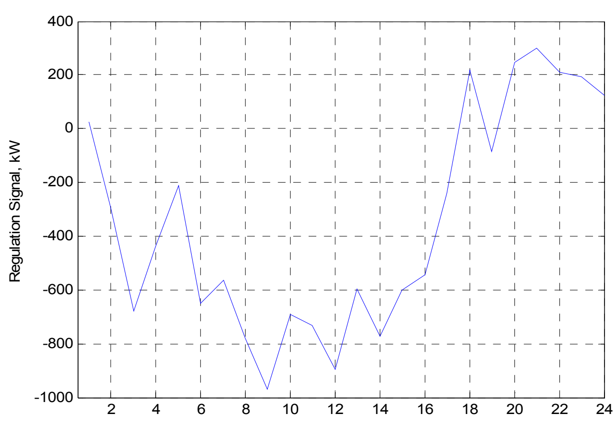

Fig. 2 Regulation signal for 24 hour period

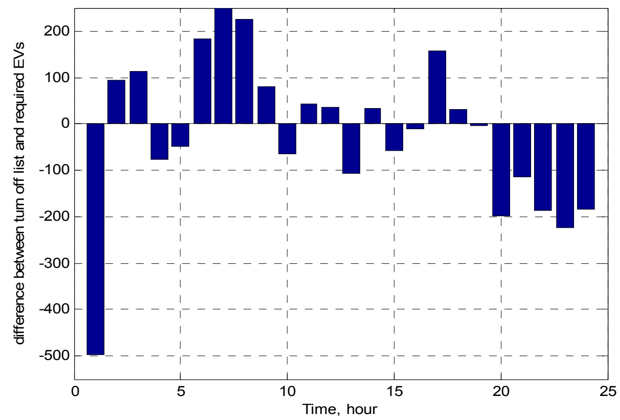

Fig. 3 Hourly difference between turn off list and required EVs.

Based on the difference between turn off list and the number of required EVs to track regulation signal, EVs are turned on or turned off as shown in Fig. 3.

Turn on and off states of EV1 and EV2 are shown in Fig. 4 and 5 respectively. In Fig. 4, we see that only 10 switching signals are required over a 24 hour period for EV1. On the other hand, incremental dispatch algorithm requires 24 signals. Thus, discrete dispatch algorithm reduces the number of switching signal for each new regulation signal.

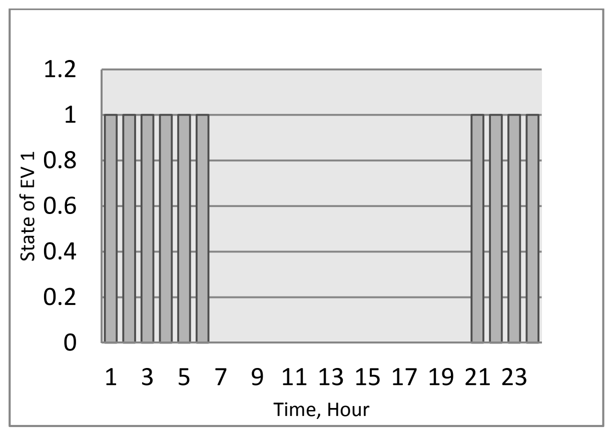

Fig. 4 Turn on and turn off states of EV 1 for 24 Hours

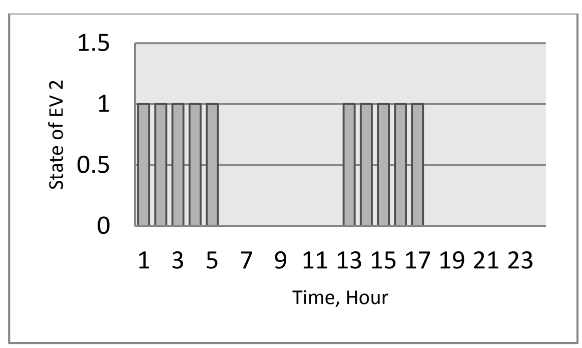

Fig. 5 Turn on and turn off states of EV 2 for 24 Hours

From table I, total number of switching signal required for discrete dispatch algorithm is 3066; this number increases to 24000 for incremental dispatch algorithm.

TABLE I: SUMMARY OF OFF AND ON LIST OVER 24 HOUR PERIOD

Difference between turn off list and required EVs	Number of EVs in turn off list	Number of EVs in turn on list
-498	998	2
95	903	97
112	791	209
-77	868	132
-49	917	83
183	734	266
297	437	563
226	211	789
81	130	870
-64	194	806
42	152	848
37	115	885
-107	222	778
33	189	811
-58	247	753
-10	257	743
158	99	901
32	67	933
-3	70	930
-197	267	733
-114	381	619
-186	567	433
-224	791	209
-183	974	26

V. CONCLUSION

In this work, discrete dispatch algorithm for EVs has been tested. Algorithm has been coded in MATLAB. EVs are turned on and turned off in binary fashion for each new regulation signal to provide regulation service to the electric grid. Simulation has been performed for 24 hours for a system consisting 1000 EVs. It has been shown that this algorithm reduces the number of switching signal compared to incremental dispatch algorithm. In discrete algorithm, switching signal is sent to those EVs which are going to change state; whereas in incremental dispatch all EVs require switching signal to increase or decrease their charging or discharging around POPs.

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