*International Journal of Engineering & Technology*, 7 (4.10) (2018) 182-189

International Journal of Engineering & Technology

*Website: www.sciencepubco.com/index.php/IJET*

***Research paper***

# Development of a Self-Coordinated Algorithm for Demand Side Management in the Case of Aggregated Electric Vehicle in a Grid Integrated System

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**Abstract**

Electric Vehicles (EV) are now a days proposed to serve the electric power grid bi-directionally by means of consuming energy from grid and also by injecting back the captive energy within the EV battery upon grid requirements. Thus EV and its known variants like Battery Electric Vehicles (BEV) and Plug-in Hybrid-Electric Vehicle (PHEV) possess unique rewards compared to the conventional fossil fueled vehicle. The increasing number of EVs integration with electricity network could have a significant knock on the performance and planning of a power system especially in the demand side management. The recent studies made by the National laboratory of U S Department of Energy clearly mentions the risks involved in EV integration in terms of its peak demand profile and spinning reserve profile. The work in this paper investigates the behavior of different types of EVs & its impact on the load profile in a grid connected system in terms of EV capacity, EV charging levels and EV penetration time. The charging profile thus obtained for the above different cases clearly conveys very significant and relevant information regarding its influence on the peak time demand. The peak time period is extended to late hours respective of the different charging conditions which has a definite impact of DSM. Also, an intelligent algorithm is developed to take care of the Demand Side Management (DSM) issues. For the same, the algorithm inputs the grid as well as the vehicle parameters. The uniqueness of the proposed algorithm is in its ability to avoid the communication complexities with the Independent System Operator (ISO) & aggregator. The work is done after studying relevant market models of EVs having different similar or different characteristics.

***Keywords***: *Electric Vehicle, Demand Side Management, Independent System Operator, Aggregator, Self Co-ordinated Algorithm*

## 1. Introduction

Electric Vehicles like BEVs and PHEVs are found to be more efficient in the scenario of road transportation. Technically, though they could be a burden over the existing grid system, their fitness into today's socio economic problems lift them up into the title of 'future transportation. (Kempton & Tomic 2005, P Pavani & B Bak-Jenson 2017). In the middle of scarcity of fossil fuels and increasing environmental pollution, the question pointing towards the category of people using the vehicle is out of scope. Within a span of a few years, the automobile industry will make a favourable shift towards the usage of EVs. Acceptable conversion efficiency of EV (about 80-90%), better mileage and low running cost per kilometre has a definite perspective impact among the people. In the above sense, two major versions of EVs such as BEVs & PHEVs will portray a crucial role in the scenario (G Boulanger 2011, Corvallis 2014, George Fernandez 2018).

The increasing Electric Vehicles (EV) population and its grid integration at electricity distribution network could have a significantly affect its operation in a greater extend in terms of power quality, and grid management (Chin Ho Tie 2014, M. Van Hoffen 2016). The increasing market penetration of EV has become a hovering attentiveness towards reliability. The recent studies on the worst-case service configuration of EVs shows that, an unplanned allocation of EVs in the existing grid system will question the reliability of the grid and sometimes may lead to grid failure. The present scenario of the power grid installed at all places is least concern about the penetration of EVs and therefore this will be definitely an unexpected challenge for the existing systems in the coming years. The recent studies made by the National laboratory of U S Department of Energy clearly mentions the risks involved in the life of utility in terms of its peak demand profile and spinning reserve profile. And the reports say that, in spite of its large advantages towards consumer side, more EV integrations will seriously create severe grid issues (Tony Markel 2015, Frank Labert 2002, Hyung Bin & Stephen Youngium 2018).

The different charging levels at which EVs are charging and also the incentives which the utility offers will have a definite impact on the load profile especially in the peak load time. Several other initiatives like charging schedule considering advanced forecasting of market price may also control the EV penetration during restricted hours (Lopes, Soares 2009, Z. Liu & Q. Wu 2016). EV integration is becoming uncontrollable these days with availability of wide range of vehicles as well as developmental welcome facil-

**Table 1:** Range of Evs available in market

| PHEV DATA | | | BEV DATA | | |
|---|---|---|---|---|---|
| **Vehicle Name** | **Rating (kW)** | **Battery size (kWh)** | **Vehicle Name** | **Rating (kW)** | **Battery size (kWh)** |
| Audi A3 E-Tron | 3.3 | 8.8 | BMW ActiveE | 7 | 32 |
| Audi Q7 E-Tron | 7.2 | 17.3 | BMW i3 2014-2016 | 7.4 | 23 |
| BMW 330e | 3.6 | 7.6 | BMW i3 2017 | 7.4 | 23 |
| BMW 530e | 3.6 | 9.2 | BMW i3 2017 | 7.4 | 32 |
| BMW 740e | 3.6 | 9.2 | Chevy Bolt | 7.2 | 60 |
| BMW i8 | 3.6 | 7.1 | Chevy Spark | 3.3 | 23 |
| BMW X5 xDrive-40e | 3.6 | 9 | Coda | 6.6 | 31 |
| Cadillac CT6 | 3.6 | 18.4 | Fiat 500E | 6.6 | 24 |
| Cadillac ELR | 3.3 | 16.5 | Ford Focus EV | 6.6 | 23 |
| 2016/2017 Chevy Volt | 3.6 | 18.4 | 2017 Ford Focus EV | 6.6 | 33.5 |
| Chevy Volt | 3.3 | 16.5 | Hyundai Ioniq | 6.6 | 28 |
| Chrysler Pacifica | 6.6 | 16 | Kia Soul | 6.6 | 27 |
| Fisker Karma | 3.3 | 16 | Mercedes B Class B250e | 9.6 | 28 |
| Ford C Max Energi | 3.3 | 7.6 | Mitsubishi i-MiEV | 3.3 | 16 |
| Ford Fusion Energi | 3.3 | 7.6 | Nissan Leaf(3.3kW) | 3.3 | 24 |
| Honda Accord | 6.6 | 6.7 | Nissan Leaf(6.6kW) | 6.6 | 24 |
| Hyundai Sonata | 3.3 | 9.8 | 2016-2017 Nissan Leaf | 6.6 | 30 |
| Karma Revero | 6.6 | 21.4 | 2017 Nissan Leaf S | 3.3 | 30 |
| Kia Optima | 3.3 | 9.8 | 2017 Nissan Leaf S | 6.6 | 30 |
| Mercedes C350 Hybrid | 3.3 | 6.2 | Smart Car | 3.3 | 17.6 |
| Mercedes GLE 550e | 3.3 | 8.8 | Smart Fortwo ED | 7 | 17.6 |
| Mercedes S550 Hybrid | 3.3 | 8.7 | Tesla Model S 60 Single | 9.6 | 60 |
| Mitsubishi Outlander | 3.3 | 12 | Tesla Model S 70 Single | 9.6 | 70 |
| Porsche Cayenne S E-Hybrid | 3.6 | 10.8 | Tesla Model S 85 Single | 9.6 | 85 |
| Porsche Cayenne S E-Hybrid upgrade | 7.2 | 10.8 | Tesla Model S 90 Single | 9.6 | 90 |
| Porsche Panamera S E-Hybrid | 3.6 | 9.4 | Tesla Model S 100 Single | 9.6 | 100 |
| Porsche Panamera S E-Hybrid upgrade | 7.2 | 9.4 | Tesla Model S 60 Dual | 19.2 | 60 |
| Porsche Panamera 4 E-Hybrid | 3.6 | 14.1 | Tesla Model S 70 Dual | 19.2 | 70 |
| Porsche Panamera 4 E-Hybrid upgrade | 7.2 | 14.1 | Tesla Model S 85 Dual | 19.2 | 85 |
| Porsche 918 Spyder | 3.6 | 6.8 | Tesla Model S 90 Dual | 19.2 | 90 |
| Toyota Prius EV | 3.3 | 4.4 | Tesla Model S 100 Dual | 19.2 | 100 |
| Toyota Prius Prime EV | 3.3 | 8.8 | Tesla Model X 60 Standard | 11.5 | 60 |
| Volvo V60 | 3.3 | 11.2 | Tesla Model X 75 Standard | 11.5 | 75 |
| Volvo XC90 T8 | 3.3 | 9.2 | Tesla Model X 90 Standard | 11.5 | 90 |

Ities like smart charging station and government incentives. The author in the paper (Foley, Tyther 2013, J. Mendoza & B. R. Cerda 2015) has showed the delayed charging time of EVs which is picturized as a merit by filling the valley profile during the night time. An actual modelling considering the real transportation data is required for analyzing the charging profiles of EVs in a aggregated system. A similar study was made in (NTHS survey 2017) which were conducted by National Household Travel Survey (NHTS) and the extracted load profiles must be undergone thorough study in order to assess the situations. A scrutiny of available variables like the charging time, charging level, running mileage, road pattern, battery capacity, state of charge (SOC) and type of vehicle is mostly required for evaluating the characteristic behavior of EVs.

The inference from the Grid to Vehicle (G2V) mode of operation is a little confusion in term of its slow charging rate and shifting daily hours. Though the terms slow charging rate/power is less demanded, we must satisfy with this while considering its uniqueness in extending the peak to late hours. From the results explained in (Trapti jain, Prateek Jain 2016, Hemkumar Reddy 2018), it is very clear that, for G2V operation, with higher power levels, the EV charging will have adverse effect on the hourly demand characteristics. Thus a low charging power along with a constant time approach is necessarily a smart strategy. With respect to the rating and type of charging, the EV will have definite adverse effect on the grid profile which makes the scheduling problem a complex one for the energy market controlling entities like Independent System Operator (ISO) and Power Exchange (PX) which in turn affect the Market Clearing Price (MCP) and Location Marginal Price (LMP). SAEJ1772 (Kalhammer, Kamath 2009) standards and NEC (Duvall 2011) standards are considered as reference marks for the proceeding works in which the addition of EV charging curves into the present system will question the scheduling of generators as well as the market prices. The reference transportation data is taken for various research reports and vehicle manufacturers (RWTH Achen 2010, Pasaoglu 2012, M r Sarker 2018).

The rest of the paper is arranged as follows. Part II will discuss about the different ranges of EVs currently available in the market and their common behavioral characteristics with respect to the vehicle type & charging level. In Part III, we will see the mathematical relationship of the EV charging & depending variables which have to be considered as strong constraints while analyzing the charging profile. In part IV, load profiles of selected EVs were analyzed with respect to the type of EV & the level of charging and analytical study is made on impact on any common load profile. Part V which details about a specially designed control algorithm as a solution methodology for intelligent grid integration. The considerations, objectives, simulation results are also discussed in that part of paper. At the end, conclusions are made in Part VI..

## 2. Market Evs and their Behavioral Parameters

An In this work, data of two categories of EVs viz, BEVs and PHEVs are collected and works are done for these identified categories only. The EVs now a day are available in different ratings and capacities. Particularly, there are several categories of EVs designed according to the costumer interest. Short-distance EVs and Long distance EVs are such a kind of those. The mileage group of EVs, battery capacity and the time taking for full charging are the basic three parameters which the customer would like to look into. Of which the customer could choose one which fits into their daily transportation requirement. In developing/ under developed countries, mostly, in the beginning stage of EV penetration into the markets, the city people will be more interested because of their daily short distance travel and considering the wastage of fuel in the traffic jams. Also, some government authorities might have brought strict regulations in using the conventional fuelled vehicles in a view of decreasing the pollution. In a view of the above plus bringing into the concept of Green Transportation, the EVs future is endless. This draw the attention of automobile manufacturers to step into the world of EV. Table 1 shows different types of EVS available now a day in the market, BEVs & PHEVs are the most common ones.

**Table 2:** BEV data evaluated for charging profile analysis

| **Vehicle** | **EV Rating (kW)** | **Battery Capacity (kWh)** | **Time to complete 100 % of SOC (hours)** | | **Estimated Miles Range Per Hour of Charge** | | **Time for 100% SOC (hours)** | | **Time for 1% SOC (hours)** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **L 2** | **L 1** | **L 2** | **L 1** | **L 2** | **L 1** | **L 2** | **L 1** |
| BMW ActiveE | 7 | 32 | 4.5 | 23 | 23 | 4 | 4.5 | 23 | 0.045 | 0.23 |
| BMW i3 2017 | 7.4 | 23 | 3 | 16.5 | 24.5 | 4 | 3 | 16.5 | 0.03 | 0.165 |
| Hyundai Ioniq | 6.6 | 28 | 4 | 20 | 22 | 4 | 4 | 20 | 0.04 | 0.2 |
| Smart Car | 3.3 | 17.6 | 5.5 | 12.5 | 11 | 4 | 5.5 | 12.5 | 0.055 | 0.125 |
| Tesla Model S 90 Single | 9.6 | 90 | 11.5 | 64.5 | 25 | 4 | 11.5 | 64.5 | 0.115 | 0.645 |
| Tesla Model S 85 Dual | 19.2 | 85 | 11 | 60.5 | 25 | 4 | 11 | 60.5 | 0.11 | 0.605 |
| Tesla Model X 100 Standard | 11.5 | 100 | 13 | 71.5 | 25 | 4 | 13 | 71.5 | 0.13 | 0.715 |
| Tesla Model X 75 Upgrade | 17.2 | 75 | 9.5 | 53.5 | 25 | 4 | 9.5 | 53.5 | 0.095 | 0.535 |

**Table 2:** BEV data evaluated for charging profile analysis

| **Vehicle** | **EV Rating (kW)** | **Battery Capacity (kWh)** | **Time to complete 100 % of SOC (hours)** | | **Estimated Miles Range Per Hour of Charge** | | **Time for 100% SOC (hours)** | | **Time for 1% SOC (hours)** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | **L 2** | **L 1** | **L 2** | **L 1** | **L 2** | **L 1** | **L 2** | **L 1** |
| Cadillac CT6 | 3.6 | 18.4 | 4.5 | 13 | 12 | 4 | 4.5 | 13 | 0.045 | 0.13 |
| Cadillac ELR | 3.3 | 16.5 | 4 | 12 | 11 | 4 | 4 | 12 | 0.04 | 0.12 |
| Chrysler Pacifica | 6.6 | 16 | 2.5 | 11.5 | 21 | 4 | 2.5 | 11.5 | 0.025 | 0.115 |
| Porsche Cayenne S E-Hybrid | 3.6 | 10.8 | 3 | 7.5 | 12 | 4 | 3 | 7.5 | 0.03 | 0.075 |
| Porsche Panamera S E-Hybrid upgrade | 7.2 | 9.4 | 1.25 | 6.5 | 24 | 4 | 1.25 | 6.5 | 0.0125 | 0.065 |
| Volvo XC90 T8 | 3.3 | 9.2 | 3 | 7 | 11 | 4 | 3 | 7 | 0.03 | 0.07 |

For further proceeding into the analysis, selected EVs from the above table were chosen and the study results are presented for those only. The study considers the available State of Charge (SOC) within it at the charging time, the choice of type of charging levels and the type of EV (BEV or PHEV). These parameters will be considered while bringing the mathematical modelling of the EV. And we are considering the situation that, most of the EVs are coming back to home around evening tome (between 4.00 pm & 7.00 pm) (Trapti Jain 2016). Since the peak demand is maximum in the evening, results are analysed for the evening peak periods.

## 3. Characteristics Mathematical Modelling

Considering the availability of different range of EVs in the market, a sensible mathematical model which brings all the EVs under one umbrella is discussed below. The hourly demands of EVs of different mileage groups are tabulated over a period of 24 hours to get the daily demand. But, in this scenario, since we are looking into only the evening peak period, the hourly demand equation will serve the purpose. Clearly, the demand of a vehicle coming for charging will depend on its SOC, mileage range, number of vehicles coming for charging (Jain 2016).

$$E^t = n^t_m (d^t_m . E_{avg}) \text{ if } d^t_m \leq AER_{avg} \quad (1)$$

$$E^t = n^t_m (AER_{avg} . E_{avg}) \text{ if } d^t_m > AER_{avg} \quad (2)$$

Where, $E^t$ is the charging energy required during the $t^{th}$ hour, $d^t_m$ defines the mileage of vehicle in terms of kilometer, $AER_{avg}$ is the Available Electric Range term of the vehicle which replaces the SOC, $E_{avg}$ is the energy consumed while charging for travelling d distance. Additionally, two more parameters such as the type of EV and the level of EV charging are also considered while forming the complete model of the EV.

Time for 1 % of SOC=Time for 100 % ÷ total charging time for full charge (3)

It is assumed that, as soon as the EVs reach home, it will be plugged into the station for charging. The remaining SOC will be different for all the vehicles. And it is the customer choice whether to plug into a Level 1 or Level 2 charging station. Also, the ISO might don't know the whether it is a BEV or PHEV integrating with the grid. The knowledge of the same is essentially required because I we look into the power levels of both category vehicles, unpredictable difference is there. However, in the session V these two controversial situations are discussed in detail and the results were analyzed. The results explained below are with reference to any typical daily load profile which we could find in common.

## 4. Primary Results and Discussions

The non-linear nature of Li-ion batteries commonly used in present EVs plays a remarkable role in scheduling the type of charging. Normally, there are two types of charging strategy namely Constant Current (CC) and Constant Voltage (CV); of which the smart charging stations will adopt itself towards the selection of charging modes. Usually up to 70 -75% of SOC, we go for CC mode and beyond that, the recommended mode is CV (Z. Darabi & M. Ferdowsi 2011). Here we have considered flat CC charging mode for all the EVs at any SOCs where the power handled will be varying for different EVs depending on their available reserve capacity. To an extent, CC mode is preferred in a view that it will support the peak demand profile when compared with the other mode which is a function of time. The below results is under the assumption that the EVs are plugged in immediately after arriving and they undergo full charging in CC mode.

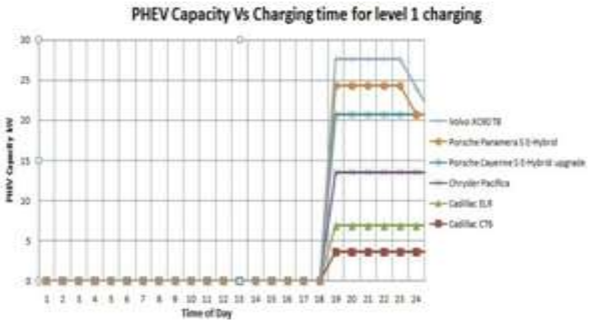



**Fig. 1:** PHEV Level 1 Charging hours

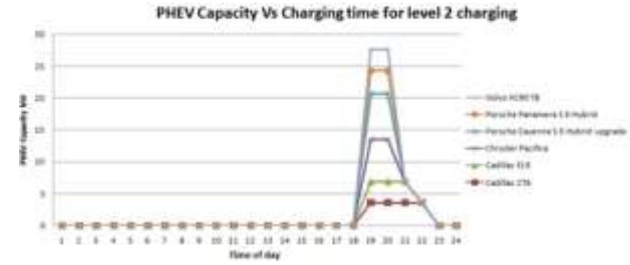



**Fig. 1:** PHEV Level 2 Charging hours

The Fig 1 and 2 shows the charging periods for different PHEVs under Level 1 and Level 2 charging strategies. It is done under the assumption that, majority of EVs is coming back in the evening time between 5.00 pm & 8.00 pm. The mathematical analysis was done to obtain the total time of charging for different EVs. We can see that, since the charging power levels are very low in the case of Level 1 , the EVs are taking more time when compared to the Level 2 charging. The same can be compared with the results shown in Fig 2. Though the PHEV rating are much low when compared to the BEVs, their impact on any load profile seems considerably commendable when we compare these two different levels of charging. If we compare the lowest rated EVs, say Volvo XC90 TS, the time of full charging at a particular SOC in L1 is nearly 6 hours whereas in the case of L2, it is only 2 hours. The L1 charging is actually shifting the load profile beyond the actual schedule. The same analysis is done for BEV category.

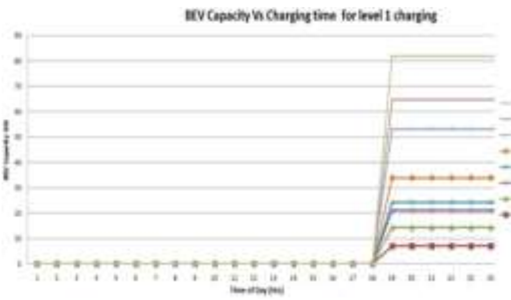



**Fig. 3:** BEV Level 1 estimated charging hour

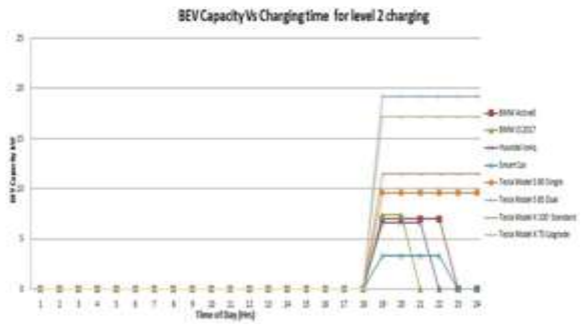



**Fig. 3:** BEV Level 1 estimated charging hour

The work scenario is exactly same as that discussed above. Here we have the results of BEVs. Consider the BMW ActiveE model. The L1 charging period is very lengthy when compared with the L2 charging period and likely for all the cases, it is the same result that we have obtained. If we look closely into the results, we can see that the charging period is shifting towards the right side of the load profile. So concluding with the above two analyses, we can confirm that, the Level of charging have a definite impact on the charging profile of an EV. And directly it will have an influence on any demand profile curve of a grid connected system considering the present and future scenario of increasing penetration of EV into the grid. Also, a question of scheduling as well as unit commitment could be thrown out at this point like the information regarding the levels of EVs charging must be well known to the ISO as well as the operators in the DSM.

The most common and globally accepted categories of EV are BEVs and PHEVs. Both have its own advantages and disadvantages which makes themselves unique among the customers. The parametric difference between these two categories is their difference in power levels. Normally the BEVs have more power rating when compared to PHEVs which uses & additional ICE engine along with. The Table 1 describes the above in a glance. This difference in power levels should be foreseen in the EV charging profile in order to have a hassle free schedule of market power among the utilities. The results below discuss the performance of BEVs and PHEVs together in a competitive market. The extracts from the above will convey the real picture.

The above figures deliver the analytical result of BEVs and PHEVs in another different perspective. The study was also made to analyze the influence of type of EV (BEV & PHEV) on the load profile. The power rating difference between these two categories has an impact on the demand profile. Clearly, we can see that, the BEVs which have a low power rating will finish the charging earlier than the PHEVs. Though there is significant influence from the levels of charging, we can conclude from the result that the PHEVs will shift the charging period beyond the peak period when compared with the BEV with respect to the particular level of charging.

## 5. Development of Control Algorithm

No The above discussed results clearly indicates the effects of the increased EV integration into the grid. Evidently it is very clear that the EV integrations in large number during the peak hours will extend the peak hours beyond its normal hours and thereby the grid utilities may experience severe congestion and management issues further for a long period. The solution for all the above is to operate the EV under a control algorithm which independently decides the charging status of the connected EV with respect to the grid parameters without an aggregator and Independent System Operator (ISO) thus making the EV integration self-adaptive and intelligent.

In many power systems, Electric Vehicles (EVs) are used as distributed energy resources for peak load management, Load Frequency Control (LFC) and voltage control. But it requires an Independent Source Operator (ISO), Aggregator and communication network to control EVs as distributed generating sources in a coordinated manner. So this Algorithm tries to eliminate the need of ISO, Aggregator and other communication devices and to make the EV controller self operated and intelligent. It decides and controls the operation of EV after sensing the system frequency, voltage, battery State of Charge (SOC) and time. It determines and governs the rate at which charging and discharging takes place as per the grid needs. The proposed system avoids peak time charging of EVs and facilitates DSM, LFC and voltage control. Algorithm makes EV self-sufficient and intelligent to decide itself its mode of operation in a grid friendly manner. Also, the algorithm is modelled in a way to adapt itself conditionally well in the case of G2V (charging) as well as V2G (dis-charging) operations. And therefore the station must be equipped with bi-directional converters and intelligent metering system. Standardization of requirements and infrastructure requirements, charging/discharging schedule, battery technology, vehicle aggregation & deployment, voltage – frequency levels are essentially required for successful deployment of G2V & V2G systems. Conventionally, the aggregator collects the EV information and communicates with the Independent System Operator (ISO), and ISO decides the mode of operation of the EV either to charge or discharge.

The algorithm is proposed with the objectives of demand supply balance, reactive power support, demand side management, life improvement of battery, independent control & co-ordination of EVs. Also there is a provision for emergency charging in order to take care of emergency situations rather than waiting in que despite of the integration time (peak/off-peak). The control algorithm introduced take cares of the following input parameters:

Utility Connection: Before the converter operates, it should be noted that whether the converter is connected to the utility or not. If it is not connected, the algorithm will wait till a secure connection is established.

Battery SOC: Algorithm needs the SOC of the EV battery which is coming for charging/discharging in order to select the mode of operation in which the converter should be operated.

Time of operation: To avoid the charging during the peak hours and also to ensure the charging during the off-peak hours, the knowledge of the time of integration is required.

Utility Voltage & Frequency: To determine the rate of power transfer and to provide synchronized operation and protection.

IEEE-1547 standards defines various features and factors to be considered for proper grid integration of EVs. EV station must be operated in proper synchronization with utility. Phase locked loop is used in our system to accomplish this task along with tracking the variations in the grid. In case if any abnormal voltage is detected at any stage of operation, the algorithm is designed so that the station will terminates the live connection from the EV irrespective of the mode of operation. Here we are considering a station with capacity of 2.8kWh. It is under the assumptions that there will be multiple charging stations which is run by the same algorithm. So, irrespective of the type of EV, the charging/discharging will be carried out according to the sensed parameters. Thus making the EV & station a self-coordinated and self-adaptive.

The scheduling/charging algorithm generally works and decision is made before they come to the station. Here also, the station possesses the grid/utility parameters and these parameters along with the EV parameters are assessed together and a wise decision is made by this algorithm. The algorithm focuses on the situations, only when the vehicle is connected to grid. In this stage, the converter can be used for charging and discharging or can be inoperative (no charging or discharging - idle). So, the possible modes of operation can be defined as follows:

1. Charging mode: In this mode, active power is absorbed from the grid. Power from utility is used to charge the battery. Charging in this mode is done in such a way that, it does not disturb the grid voltage and frequency by imposing heavy load on the grid. Rate of charging is determined by considering the voltage and frequency at which the utility operates. Also the time of operation and SOC must be considered before selecting this mode of operation. Controller algorithm selects this mode only during the off peak time as charging of the EV should not disturb the grid. Operation in this mode is preferred during the off peak time, when the generation is higher and the load demand is low. Hence the excess generation in the grid can be easily absorbed by the EV to fill the valley in the demand curve and thereby facilitating the load leveling.

2. Discharging mode: Power stored in the EV battery is injected back to the grid, as the grid can utilize this power. The quantity of active and reactive power injected to the grid depends on many factors. Discharging mode is selected only when the EV is plugged to the utility during the peak time. Algorithm does not support the off peak discharge. Operation in this mode is preferred during the peak time, when the generation is lower and the load demand is high. Hence the excess load in the grid can be easily met by the power injected by EVs to level the peak in the demand curve and thereby facilitating the load leveling.

3. Emergency charging mode: Other than injecting power to the grid, the primary objective of using an EV is for travelling. For this purpose, EV battery should be charged before the journey. But if the time before journey is peak time, the algorithm do not supports peak time charging. To solve this problem, the EV owner can manually select the Emergency charging mode in which the EV battery is charged irrespective of the time of operation.

4. Idle mode: In this mode, the EV may be plugged to utility but, the converter neither operates as a charger nor discharger. No operation is performed.

The proposed algorithm aims at operating EV as a load or as an energy resource, when require ie: selecting the right mode of operation suiting to situation and conditions. This should be done in a grid friendly manner. To accomplish this, the controller must know and measure several parameters and variables. Since the aim is to aid the grid during the peak time and to take power during off peak, controller has to identify whether the time is peak or not. Then to fix rate of charging and discharging, frequency and utility voltage should be measured and to select the mode of operation controller must sense SOC and time of operation. So monitoring of all these parameters are important in the control algorithm. Importance of sensing parameters can be explained as follows:

Frequency can be used as a key to identify the balance between the demand and supply. Decrease in frequency indicates the deficiency to meet the demand. ie., generation and load mismatch. Grid cannot withstand such an unbalanced situation. Hence it is evident that, frequency will be low during the peak demand time. So the dip in frequency can be measured to identify the time of high demand.

In India, peak load is observed usually during 6pm to 10pm. Also in some parts of the distribution systems, morning peaks are also observed during 5am to 8am. So usage of a timer can help the algorithm to select the correct mode of operation. Time can directly give the details of peak and off peak operation of grid. Normally irrespective of the peak or off peak time, as the load increases, the reactive power requirement in the grid also increases. The deficiency of the reactive power is reflected as voltage dip. This voltage variation can be sensed to identify the reactive power requirement of the grid. It is essential for the calculation of the reactive power to be injected. Sufficient SOC of battery is required before injection of power to grid is performed. Also the rate of charging and discharging needs the knowledge of battery SOC. So, SOC is also an important variable that decides the mode of operation of the converter. So the variables used in this algorithm can be summarized as follows: Time ‘t’, State of Charge of the EV battery ‘SOC’, Utility voltage ‘$V_g$,’ Frequency ‘f’, VA rating of the converter ‘S’. The SOC & time considerations are,

- Discharging to grid is allowed only if the SOC is greater than 75%.
- As apart of load levelling, charging is allowed only during off- peak time.
- Discharging time is from 6pm to 10pm, when the peak load is observed.
- Emergency charging till SOC becomes 75% is allowed even during peak time if an emergency ride is required.
- Peak time and SOC limits can be modified if required according to the grid behavior.

When the EV is plugged in, the control algorithm first checks whether emergency charging is required or not, which can be manually selected by the EV owner. If emergency mode is selected, the algorithm calculates the active and reactive power values as per the equations. But it operates in the emergency mode only if the voltage is greater than 180V and frequency greater than 48.5Hz. This charging continues till the battery SOC becomes 75%. Further charging is not permitted

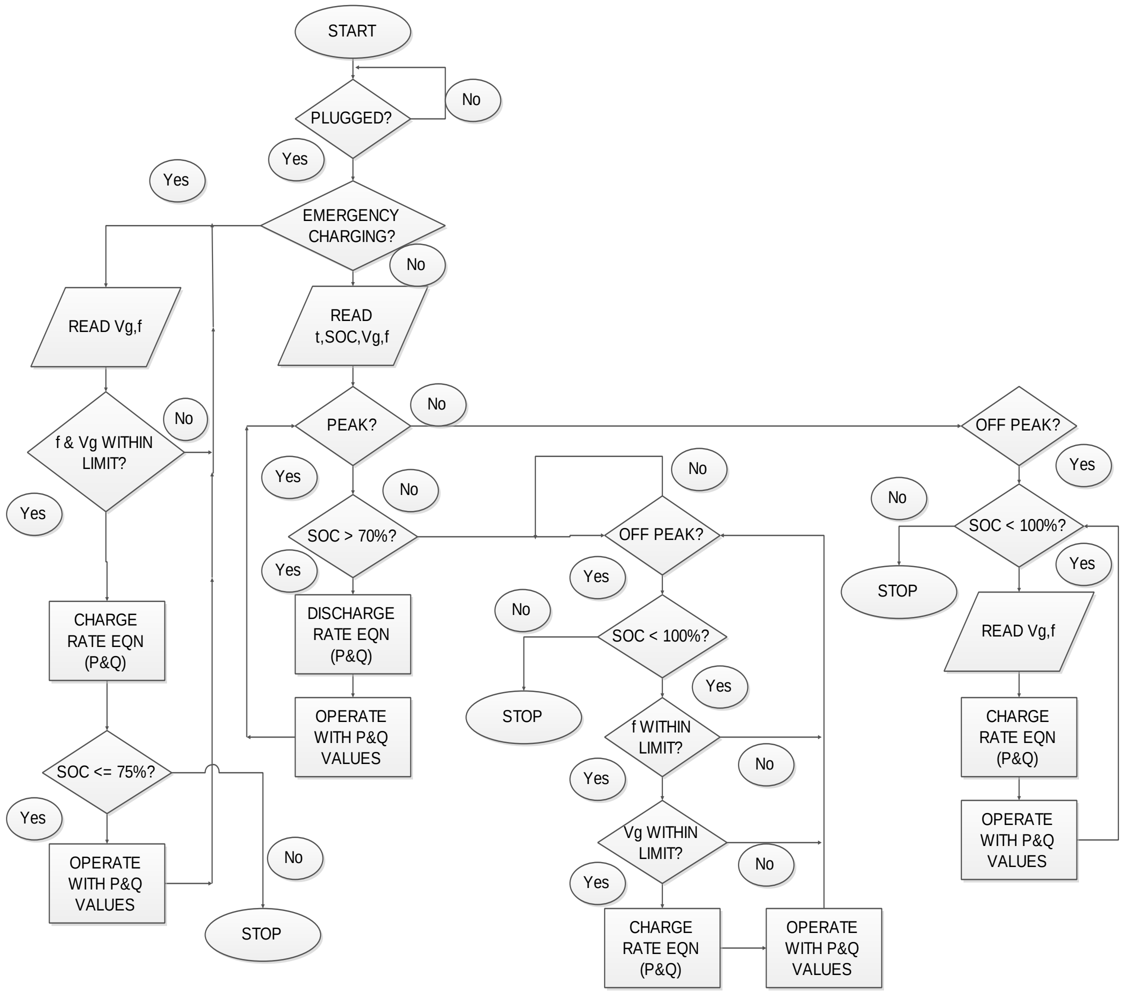



**Fig. 5:** Flow chart of proposed algorithm

Since the EV owner may be selecting the emergency mode during the peak time, which is disturbing the grid.

For charging mode also similar operation occurs. But charging continues till SOC becomes 100% and it takes place only during the off peak time. The algorithm allows the station to discharge only if the frequency lies between 48.5 and 50 Hz. Voltage range required for discharging is from180 to 260volts and the SOC should be greater than 70%.

A Simulink model for the proposed charging station incorporating the designed algorithm was developed in MATLAB. The Simulink analysis is done for a single EV station. The same will be taking place for the other EV stations also. The case is examined for individual EV which is coming for integrating (either to charge or discharge) with the grid. Below show the results extracted by running the model. The results demonstrate the charging and discharging mode of operation at different situations. It is evidently very clear from the results that the converter station behaves intelligently with respect to the system parameters. Clearly if you have a look into the initial SOC of the plots, the action undertaken could be justifies based on the earlier algorithm considerations. The system parameters are as below

**Table 4:** System parameters

| System Parameters | Rating/Capacity |
|---|---|
| Charging Station | 2.88kW |
| EV Battery Capacity | 9.6 kWh |
| Permissible Frequency Range (50 Hz as standard) | 3% |
| Time | 0 – 24 hour |
| Internal resistance of Battery | .24 Ω |
| Specific Heat of Battery | 600 – 1000 J/Kg |
| Permissible Voltage range (230V as standard) | 6% |

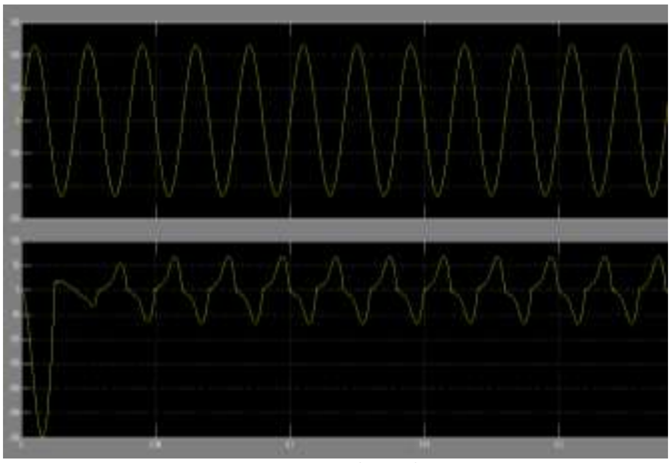


**Fig6:** Voltage and current waveforms for charging mode

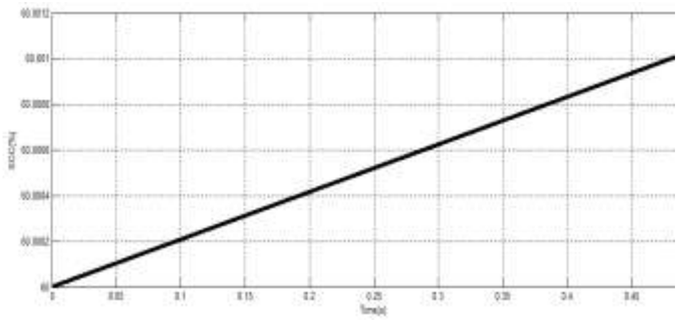
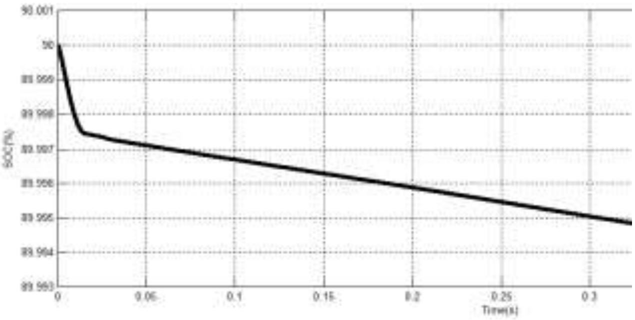


**Fig7:** SOC for charging mode




**Fi.g9:** SOC for discharging mode

Table below summarizes the results under various operations. ‘I’ represents idle mode, ‘D’ represents discharging mode, ‘E’ represents emergency mode and ‘C’ represents charging mode. Algorithm was programmed using Matlab editor and it was executed for finding the right mode of operation, active power and reactive power values for different time, frequency, SOC and voltage. From the results, we can infer that the algorithm made the EV self-sufficient in the mode selection and operation and there by facilitated Demand Side Management (DSM), peak shaving and valley filling. The proposed algorithm eliminates the communication systems, ISO, aggregator etc. required for coordinated V2G and G2V applications which in turn helps to bring out economic system operations without much complexity

**Table 5:** Algorithm simulation results

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Time (0-24 Hrs) (input)** | | 23 | 15 | 10 | 1 | 20 | 21 | 20 | 20 | 21 |
| **Utility Voltage (V) (input)** | | 175 | 200 | 200 | 230 | 210 | 190 | 200 | 200 | 200 |
| **Frequency (f) (input)** | | 49 | 49.5 | 47.5 | 50 | 48.5 | 49 | 48.5 | 49 | 50 |
| **SOC (%) (input)** | | 70 | 60 | 65 | 60 | 90 | 95 | 65 | 65 | 60 |
| **Charging Case** | Active Power (W) | 0 | 1755.6 | 0 | 2880 | 0 | 0 | 0 | 1275.6 | 2880 |
| | Reactive Power (Var) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Time (hrs) for 100% SOC | - | 2.2 | - | 1.4 | - | - | - | - | - |
| **Discharging Case** | Active Power (W) | 0 | 0 | 0 | 0 | 2000 | 1333.3 | 0 | 0 | 0 |
| | Reactive Power (Var) | 0 | 0 | 0 | 0 | 2072 | 2552.7 | 0 | 0 | 0 |
| **Mode of operation** | | **I** | **C** | **I** | **C** | **D** | **D** | **I** | **E** | **E** |

## 6. Conclusion

The work presented here looks into two important aspects of EV. i) the impact of BEV & PHEV on typical demand profile ii) Developing a coordinated self-sufficient algorithm for eliminating the DSM issues to an extent. The study was conducted only for a small group of vehicles which are currently available in the market. It is observed that, the with respect to the rating of EVs as well as the type of EV, the charging time varies drastically with commendable characteristics. The major parameters which governs the EV integrations are, SOC of EV, time of Integration and the Level of charging. The phenomenon of shifting the charging period beyond the peak hours is indeed a very good thing in power system point of view in utilizing the off-peak time power. But the scenario will get worse when bulk EVs get integrated into the system. In future, the penetration number will go beyond billions range for a particular country. So what happens then is that, the Off-peak generation won’t be able to meet these entire EVs. Thus creating a new problem of extending the peak period further to some late hours. And for this, sometimes, the operator must have knowledge of the type of EVs which are integrating and the level of charging which they are proposed to charge. This will become complex in a scenario where infinite number of EVs are integrating irrespective of time. The second phase of work explained in this paper looks into the aforesaid. An effective communication with the ISO & aggregator is not possible many times and will not be efficient too. In this scenario a model algorithm was developed which looks after the coordinated actions of EV with grid in which the communication between the ISO and the aggregator is not necessarily required. With the knowledge of the EV parameter, time of integration & Grid parameters the algorithm independently switches its mode of operation respective of the grid conditions. The proposed algorithm has visibly alleviated the problem of massive EV integration during peak hours and shifting the peak hours beyond. Thus aiding a better control in regards with the DSM. Also, the obtained results underline a coordinated & self-adaptive operation of EV stations with respect to the grid conditions.

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