Automatic shedding of non prioritized loads for reduced energy consumption in smart grid system using solar photovoltaic and electric vehicles

R Revathi¹, N Senthilnathan², V Kumar Chinnaiyan³ and J Sevugan Rajesh⁴

¹⁻³ KPR Institute of Engineering and Technology, Coimbatore, Tamil Nadu, India
² Kongu Engineering College, Erode, Tamil Nadu, India
⁴ Amrita College of Engineering & Technology, Nagercoil, Tamil Nadu, India

Abstract. The integration of solar Photovoltaic (PV) and Electric Vehicle (EV) in the grid connected system reduces the overall energy consumption in residential application. The Energy Storage Systems (ESS) is incorporated into the system for better reliability of the grid connected system. Demand Side Management (DSM) is proposed to balance the mismatch between load demand and generation level. The controller switches the loads as and when required, according to the generation of PV power for optimizing the stability of the power system. EV acts as load, whenever the charge of the vehicle is low, as source, when the vehicle is fully charged. A case study of household application is simulated using MATLAB Simulink and the model is analyzed by continuously changing the grid and PV panel parameters.

1. Introduction
Nowadays, fossil fuels are being depleted due to the continuous power production by the thermal power plants. Also the number of vehicle users is increasing day by day, so carbon emissions from the transportation of vehicles results in health and environmental issues. In order to protect the natural resources and to reduce the amount of greenhouse gas emission, the use of Renewable Energy Sources (RES) and Electric Vehicles (EVs) are introduced and integrated into the grid system [1]. Due to the intermittent nature of the solar energy and sudden variations in the power production, the Energy Storage Systems (ESS) and Demand Side Management (DSM) of the domestic loads are well suited for the system.

Due to increased population and technological growth in industries, the power demand is rapidly exceeding the power generation level. In order to optimize the life span of a grid connected power system and to meet out the power supply demand, there is a need to switch off the excess loads, when demand exceeds the threshold level. The proposed system categorizes the loads into prioritized and non prioritized loads. Both the current transducer (CT) and voltage transducer (PT) senses the current and voltage at regular intervals of time, so that energy consumed is determined corresponding to the load consumption.
Also solar PV is installed and PV voltage is integrated into the grid. The controller is used either to connect or disconnect the non prioritized loads (excess loads) from the grid whenever the demand goes beyond the generation level. So in the distribution system, the power is generated using solar PV and it is efficiently utilized using DSM and Vehicle to Grid (V2G) technology. If PV panel fails to support the grid, then the bidirectional flow of EV battery voltage helps in powering the load demand and support the grid connected system [2]. So the proposed system finds a better solution for the challenging load demand and helps in reducing the annual energy consumption.

The section 2 of the paper elucidates the energy storage systems, demand side management is discussed in section 3, and section 4 provides the case study of the proposed model. Subsequently, the simulation results and conclusion are given in section 5 and 6.

2. Energy Storage Systems

Electric power is generated, transmitted and it is distributed by substation transformers in conventional grid. In addition, there is no option for storing electric energy during off-peak hours and reducing electricity bills by the consumers. But this is eliminated through the proposed strategy that ESS will store the generated power and it is used for feeding the extra loads during peak hours, if necessary [3]. Also DSM is integrated in the system, to maintain the balance between load demand and PV power production.

The produced electric energy is converted into chemical energy and it is stored in the battery, which in turn, further the chemical energy from the battery is converted into electric energy, while it is given to the load demand of the grid. When the State of Charge (SoC) of the EV is not upto the threshold level, the stored energy in the battery charges the vehicle [4]. If it is fully charged, then the energy from the vehicle will be utilized depending on the demand of the grid system. Therefore the generated solar power, load demand and the battery storage is monitored periodically for the efficient use of ESSs.

Moreover, in Battery Energy Storage Systems (BESSs), the large number of charge and discharge cycles has a significant impact on the life time characteristics of the battery system [5]. In order to protect the battery from over charging or over discharging, the SoC limits are chosen in such a way that it should not reduce the operational life time of the battery. The block diagram of the proposed scheme is shown in figure 1 below.

![Figure 1. Block diagram of the proposed system](image-url)
3. Demand Side Management

Power demand is increasing day by day, due to the increased energy consumption by the residential, industrial and commercial purposes. It finds difficult to keep the power demand within the expected level, instead, there exist a solution in switching off the non prioritized loads (excess loads) for shorter interval of time during peak hours. The electronic management or the power conditioning unit is the heart of the system. It supplies the right voltage and current to all the appliances.

Here the loads are divided into priority loads and non prioritized loads. Utmost importance is given to priority loads such as lighting loads, circulating air loads, refrigerator loads, desktop computers and electric vehicles. The non prioritized loads include motor based loads such as washing machine, water heater and induction stove. The purpose of the controller is to check the availability of solar PV power and storage capacity, and accordingly, it switches the loads. If the PV power generated is higher than the load demand, then the controller connects all the loads of the grid connected system [6]. The storage capacity of the battery is monitored periodically, ensuring the ESSs to protect the battery from large number of charge and discharge cycles. If the storage capacity is higher than the generated power, then the power flows from Vehicle to Grid (V2G). Using DSM, the power is distributed among the loads, based on their needs, thereby avoiding the excess usage of energy from grid [7]. The flow diagram of the electronic management is shown in the figure 2 below.

![Flow diagram of the proposed algorithm](image)

**Figure 2.** Flow diagram of the proposed algorithm

The concept of EV technology mitigates the fuel consumption and greenhouse gas emission to a greater extent. The EV has the capability to deliver power to the utility and load, when the solar PV fails to generate power [8]. Even if the fully charged vehicle is in idle state, it can be utilized for energy storage and the power is retrieved for later purpose. The battery parameters like State of Charge (SoC), Depth of Discharge (DoD) and losses are uploaded in the electronic management and controlling system, so as to prevent the battery from over charging and over discharging [9].
The EV helps in feeding the loads during peak demand and the reactive power of the system is compensated in charging the vehicle. The controlling unit manages the bidirectional power flow either from Vehicle to Grid (V2G) or Grid to Vehicle (G2V), and it is well communicated to the distribution networks, thus avoiding the wrong switching in the direction of power flows [10].

4. Case Study
Solar based PV system is designed for residential applications. Power generation level and load demand are compared at every intervals of time, the solar PV feeds the loads if the generation is higher, the EV feeds the loads if the storage capacity of the battery is higher, EV gets charged if the SoC of the battery is low. Likewise, the electronic management and controller of the system balances the mismatch between the load demand and the capacity of power generation, by switching off the excess non prioritized loads for shorter duration to reduce the peak demand consumption, thus to minimize the electricity bills to certain extent [11]. Moreover, whenever the load capacity reaches the set or threshold value, then automatically the system controller will turn off the excess non prioritized loads for better optimization of the grid connected system [12]. The following table 1 lists the technical specification of the proposed system.

| Category           | Appliances   | Watts (W) | Quantity | Total Wattage (W) |
|--------------------|--------------|-----------|----------|-------------------|
| **Priority loads** | Lamps        | 22        | 6        | 132               |
|                    | Refrigerator | 400       | 1        | 400               |
|                    | Fan          | 60        | 4        | 240               |
|                    | PC           | 300       | 1        | 300               |
| **Total**          |              |           |          | **1072**          |
| **Non Priority loads** | Washing Machine | 500      | 1        | 500               |
|                     | Pump         | 375       | 1        | 375               |
|                     | Water Heater | 1200      | 2        | 2400              |
|                     | Split AC     | 2000      | 1        | 2000              |
|                     | TV           | 80        | 1        | 80                |
|                     | Induction stove | 1200     | 1        | 1200              |
|                     | Iron box     | 1000      | 1        | 1000              |
| **Total**           |              |           |          | **7555**          |
| **Total load**      |              |           |          | **8627**          |

The solar PV 50kW, Inverter 15kVA and battery capacity of 20kWh is designed for the residential load demand of 9kW. This system depicts the bidirectional power flow between the grid and vehicle. The DSM manages the right direction of power flow either from Grid to Vehicle (G2V) or Vehicle to Grid (V2G) according to the load demand [13]. The main benefits of the proposed system include vehicle and grid
interactions, power flow management, reactive power compensation, improved system stability, clean energy usage, reduced carbon emissions, reduced energy consumption and minimized electricity bills.

5. Simulation Results
This work combines the feature of EV charging provisions and residential load demand. The converter here, acts as a dual converter which converts dc to ac (inversion mode) as well as ac to dc (rectification mode), according to the need of the grid demand. According to the load demand and capacity of battery storage, the EV chargers draw or inject power from or to the grid. It is simulated using MATLAB Simulink and the parameters that assumed are 15% battery loss, 60% SoC, 25% loss in solar panel and 5% controller loss. With this design, the grid voltage of 300V and grid current of 45A is obtained from solar PV with the irradiation of 850W/m². In this result, EV charging time is controlled with the help of DSM and optimized to control the fluctuations in the power grid. The waveforms of grid voltage and grid current are shown in the figure 3 and 4 respectively.

During V2G interactions, the following waveforms of SoC, battery current and battery voltage are observed in the figure 5, 6 and 7 respectively as shown below.

![Figure 3. Grid Voltage Waveform](image3.jpg)
![Figure 4. Grid Current Waveform](image4.jpg)

![Figure 5. SoC of the battery](image5.jpg)
6. Conclusion

The battery storage technology with renewable energy resources will play an important role in the stability and economic operation of Smart Grids. The implementation of V2G prototype with DSM together, improves the utilization of green energy and hence saving the daily energy consumption of the residential system. The optimal power flow is provided by turning off the excess loads during peak time, voltage and reactive power control. The system operates with the effective utilization of the EVs battery, thereby reducing the overall cost of the system. This proposed strategy works well for the better optimization, reliability and stable operation of the grid connected system. This system reduces the overall energy consumption and electricity bills of the residence. Also, the proposed system will be more economic and complex when it is applied to the charging infrastructure of larger number of EVs.

References

[1] Studli S, Crisostomi E, Middleton R and Shorten R, International Journal of Control, vol. 87, no.6, pp. 1153–1162, 2014.
[2] Bonaiuto V and Sargeni F, Proc. IEEE 3rd Int. Conf. on Research and Technologies for Society and Industry, 2017.
[3] Damiano A, Musio C, Sanna C and Gowronska M, Proc. 4th Int. Conf. on Renewable Energy Research and Applications (Palermo) 22-25 November (Italy: IEEE), 2015.
[4] Kempton W and Tomi J, Journal of Power Sources, vol. 144, pp. 268–279, 2005.
[5] Divya K.C and Ostergaard J, Electric Power Systems Research, vol. 79, pp. 511–520, 2009.
[6] Saez-de-ibarra A, Martinez-Laserna E, Koch-Ciobotaru C, Rodriguez P, Stroe D.I and Swierczynski M, Proc. Int. Conf. on Industrial Technology (IEEE), pp. 2941–2948, 2015.
[7] Torres-Sanz V, Sanguesa J.A, Martinez F.J, Garrido P and Marquez-Barja J.M, IEEE Acesss, vol. 2, pp. 1–13, 2018.
[8] Neaimeh M, Wardle R, Jenkins A.M, Yi J, Hill G, Lyons P.F, Hubner Y, Blythe P.T and Taylor P.C, Applied Energy, vol. 157, pp. 688–698, 2015.
[9] Rasheed M.B, Awais M, Alquthami and Irfan Khan, IEEE Access, vol. 8, pp. 40298–40312, 2020.
[10] Knezovic K, Marinelli M, Codani P and Perez Y, 50th International Universities Power Engineering Conference, 2015.
[11] Yang H, Zhang J, Qiu J, Zhang S, Lai M and Dong J.Y, IEEE Transactions on Smart Grid, pp. 1–11, 2016.
[12] Ali S.M, Ullah Z, Mokryani G, Bilal Khan, Iqrar Hussain, Mehmood C.A, Umar Farid and Jawad M, IET Energy System Integration, vol. 2, no.1, pp. 1–8, 2020.
[13] Jialiang Yi, Investigation of energy storage system and demand side response for distribution networks, A thesis presented for the degree of philosophy, Chapter 2, pp 11-20, 2016.