International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-8 Issue-4, April 2019

An Operational Strategy for an Energy Storage System in a Renewable Supported PHEV Charging Station

B. Nagarjuna Reddy, A. Chandra Sekhar Reddy, G. Swapna

Abstract*: In this busy world charging stations are necessary at various places for effective use of Electric Vehicles (EVs). Energy storage systems (ESSs) are crucial at charging stations to make the stations more reliable, efficient and economical. The ESSs is a solution to reduce negative impacts of the station on the grid and to decrease the energy costs of the station. In this paper an approach is presented to find out the minimum required size of the ESS for a fast charging station. Firstly, by considering PHEVs demand in a station and electricity price of the grid the size of the Storage system required in the station is determined. This storage system is charged during off peak hours and discharged during the peak hours. To charge the ESSs apart from the grid integration of PV plant at the charging station is discussed. As an alternative when ESS energy is not enough during peak hours, vehicles charging is prioritized based on their state of charge (SOC), arrival and departure times.

***Index Terms*: Plug in Hybrid Electric vehicles (PHEVs), Electric Vehicles (EVs), Energy Storage System (ESS), V2G, PV plant.**

Nomenclature:

ESS	Energy storage system
L	Levelized cost of storage.
Acc	Annual capital cost.
Amc	Annual Maintenance cost.
Arc	Annual replacement cost.
Aep	Annual energy production.
Y	Life time of energy storage.
Eff	Efficiency of storage system.
Upc	Unit cost of power conversion system.
Usc	Unit cost of storage unit.
$Ubop$	Unit cost of Balance of plant.
A	Annual replacement cost.
Sp	Solar plant capacity.
h	No of solar hours in a day.
$SEss$	Size of storage system.
Np	No of solar panels.
Csp	Cost of solar plant.
SPp	Power of each solar panel.
$SPcost$	Cost each solar panel.
Y	Years of savings.
N	Solar plant replacement period.
Ypb	Years of payback.
bc	Cost of Storage system.
S	Savings per year.
$Ecij$	Energy consumed at ith hour by jth vehicle
Tcj	Time taken by jth vehicle to charge.
Pc	power of charging socket.
Ti	Time at ith hour.
Taj	Arrival time of ith vehicle.
$CBij$	Battery Capacity of jth vehicle at ith hour.
$CBaj$	Battery Capacity of jth vehicle at arrival.
$SOCij$	SOC of jth vehicle at ith hour.
$SOCaj$	SOC of jth vehicle at arrival.
$Cbevj$	Battery capacity of jth vehicle.

Manuscript published on 30 April 2019.
* Correspondence Author (s)
B. Nagarjuna Reddy, Department of EEE, Koneru Lakshmaiah Education Foundation, Vaddeswaram, A.P, India.
A. Chandra Sekhar Reddy, Department of EEE, Koneru Lakshmaiah Education Foundation, Vaddeswaram, A.P, India.
G. Swapna, Department of EEE, Koneru Lakshmaiah Education Foundation, Vaddeswaram, A.P, India

I. INTRODUCTION

To attain pollution free environment, world is focusing towards clean energy resources as well free energy resources. Transportation is important in our daily life, either to travel or transfer goods from one place to another place. Vehicles are very important means of transportation, so even they cause lot of atmospheric pollution they are still in use. The shortage of fossil fuels and increase in global warming are the main motives to use EVs. For the sake of transportation, the EVs are developing as a green solution for pollution. The cost required to run these EVs are also low compared to other fuel cars. Due to limited energy storage in EVs hybrid vehicles are growing research in the electric vehicles area. As PHEV's are used as both electrical and gasoline modes its growth is high and is very much necessary. These PHEV's are charged by connecting them in charging stations or in homes. Several charging methods are discussed in [1]. The level 1 charging uses 120V AC, 15 A or 25A charging supply, which provides a maximum power of 1.44 kW for a period of 4–8 h, it is the least and common supply level found in both residential and commercial buildings of United States. The Level 2 method uses a 230 to 240-V AC, single-phase, 40A to 80A. it can charge a 20kWh vehicle in 2-3 hours, which is primary and preferred method used in PHEV charging stations. The level 3 charging, also known as quick charging, provides 380–480 V DC connection, an EV with 150 kW battery capacity can be charged in 10–25 min. Fast charging stations gave more attention due to its time saving. As these vehicles need to be recharged, lot of energy must be required.

Though, PHEVs are good solution they create more problems on electric grid as they behave as load on distribution system. Frequently charging these PHEVs from grid causes power quality issues and power system unstable. It also creates unbalance between supply side and demand side. The impacts of these PHEVs on grid are illustrated and certain strategies are discussed to lessen power losses of power system in following [2-5]. In [2], a coordinated charging method is suggested to reduce the power losses in grid and to increase the grid load factor to provide an optimum charge profile for PHEVs. Reference [3] studies the impacts of different charging strategies on the reliability of network and provides a techno-economical approach that assess possible solution based on price performance ratio. [4] proposes the use of a large-scale distribution network planning model, which is used to examine the impacts of different levels of PHEV penetration on real distribution networks investment and energy losses. [5] states that uncontrolled charging of PHEVs from the grid will reduce the efficiency of grid and discusses on improving the power quality of grid by utilizing smart meters to provide coordinated charging for PHEVs. In addition, [6] to obtain optimal operation and management of microgrids a new framework is proposed by considering the charging demand of PHEVs on both public charging stations and residential. Some papers consistently propose strategies to control the charging demand on the station or house hold. For instance, [7] developed a detailed home energy management system to determine the optimal day-ahead appliance scheduling under hourly pricing and strategies on peak power limiting.

On the other hand, integrating renewable energy sources to smart grid is now growing research work too. Solar is one of the fastest growing renewable sources over a decade. Standalone solar plants are used in many industries as a backup power unit. As it is flexible with EV charging loads, PV plant for charging stations can greatly benefit the station owners. A study to assess the impacts of EVs and large-scale PV investment on economic future electricity generation portfolio is given in [8]. Managed and unmanaged charging of EVs on station with respect to the PV generation are the methods proposed in that paper. The energy storage system plays an essential part of the system due to the unpredictable nature of renewable energy sources, either it is microgrid or smart grid. Not only does the ESS deals with the unpredictable RES, it also helps to reduce the grid burden during peak load demand which was discussed in [9] and two different methods are proposed and compared of which Dynamic Threshold method gives more benefits in peak shaving the load. Thus, ESS is very much controlling the power flow in grid. This also increases the system reliability as far as power supply is concerned.

In this paper, an attempt was made by the authors to determine the size of the ESS suitable for a PHEV charging station. The capacity of ESS mainly depends on PHEV charging stations load demand at the different times of the day. Thus, firstly a method is proposed to calculate the size of the ESS based on the PHEV charging demand on the station as well as the electricity price on the grid. Then scheduling the charging time of this ESS is proposed. In brief, the main work of this paper is as follows:

1) Proposed a method to determine the required ESS on the station and its time of charging and discharging.

2) Determined the benefits of using the PV plant to charge the ESS.

As solar energy is inconsistent an alternative method such as vehicle prioritizing is proposed based on the SOC of PHEVs coming to the station. Section II discusses the method used to calculate size of the ESS, the size and years of payback for PV plant, and the vehicle prioritizing. Results of the method used in this paper are presented in Section III. A detailed conclusion of this paper is presented in Section IV.

II. METHODOLOGY

The block diagram of the charging station is shown in the figure 1. ESS is considered as a solution to store electrical energy during off-peak hours and discharge the stored energy during peak hours to decrease the operating costs of the fast charging station and to reduce its impacts on the power grid at peak load hours. The electricity is fed from the electric grid and goes to the rectifier to supply dc voltage for the PHEV charging sockets. During low load hours the electricity from grid is stored in ESS and it is discharged during peak load hours. The Power conditioning system (PCS) has the duty to convert the grid ac voltage into dc voltage which is appropriate form for charging ESS and to convert ESS stored energy into suitable voltage for PHEV charging. Half of the peak load at charging station is considered as base load, when the demand exceeds the base load the energy storage is used to charge PHEVs. Some of the possible methods are discussed in this paper which will benefits both the charging station as well as PHEV owners, in turn reduces the burden on the grid.

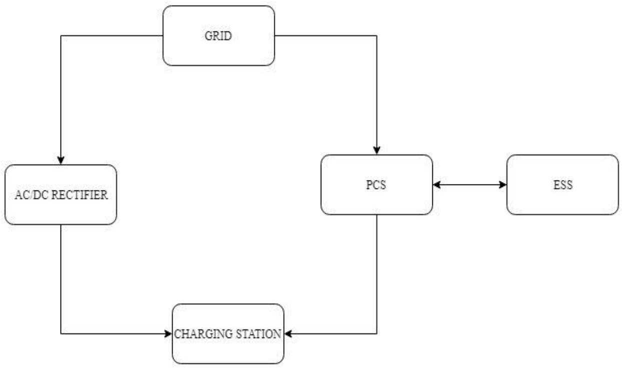

Fig. 1 Block diagram charging station model.

A. Energy storage system choosing and sizing

When a PHEV arrives the charging station, it is charged either from the grid or storage. Here in this paper, the energy storage is charged from the grid during off peak periods and by other means using renewables such as solar. To size the suitable energy storage system for a PHEVs charging station below mentioned things are taken into consideration.

1. The total load demand on the charging station.
2. The type of energy storage system.

To obtain the charging demand of a fast charging station authors in [10] considered the demand of each PHEV, its driving range and vehicle trip distribution to find the time at which the vehicle comes to charging station. Similar approach is followed in this paper to estimate the demand of charging station. As mentioned above half of the peak load in a day of the charging station as base load, the size of the ESS is calculated and a pseudocode is presented.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)

Figure. 2 represents the flow chart to peak shave i.e. to charge the ESS during low load hours and discharge during peak load hours.

Pseudocode:

```
Input: Load demand, Electricity price of grid, base load
Output: Size of ESS
for ii=1:24
   if(load(ii) is greater than base load)
      sum=sum+(load(ii)-baseload);
   end
end
```

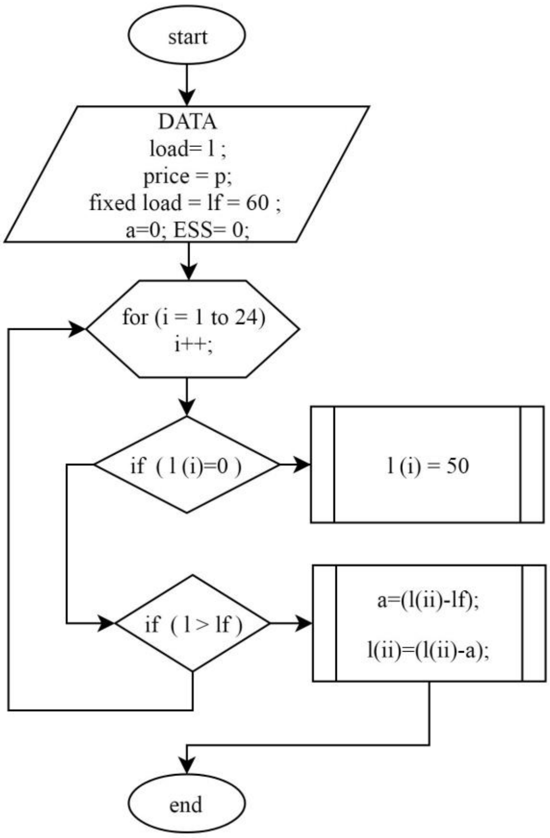

Fig. 2 Flow chart for peak shaving

The type of ESS selected will help the station economically. There are several kinds of ESS used for storing electrical energy. The best and suitable ESS are likely to be lithium ion and lead acid batteries. In this paper based on the expressions (1) given in [11], the levelized Annual cost of storage system is determined.

$$L = \frac{Acc + Amc + Arc}{Aep} \quad (1)$$

Equation (1) deals with the total energy discharged annually by an energy storage system which is denoted as annual energy production (Aep), The annual fixed operation and maintenance cost, the total cost for the power electronic, the total cost for storage units, and the total cost for the balance of plant [12-14]. The parameters of the lead acid battery and lithium ion battery are given in table 1.

Table:1 Storage system parameters [10].

	Leadacid battery	Lithium_ion battery
U_{pcs} $/kWh	175	175
U_{bop} $/kWh	50	0
U_{sc} $/kWh	200	500
U_{mc} $/yr	5	25
E_{ff}	0.56	0.72
N	3	3
D	365	365
I_r	0.009	0.009
Y	5	10
F	200	500

B. Renewable energy systems

Renewable energy sources are growing technologies where a lot of research is going to convert free and green energy to the electrical energy. Instead of charging ESS from the grid, solar plant is adopted to charge this ESS. The block diagram of station model with solar plant is shown in the figure 3. Mathematical formulations to determine the size of solar plant that suits the selected ESS are given by equation (2-6).

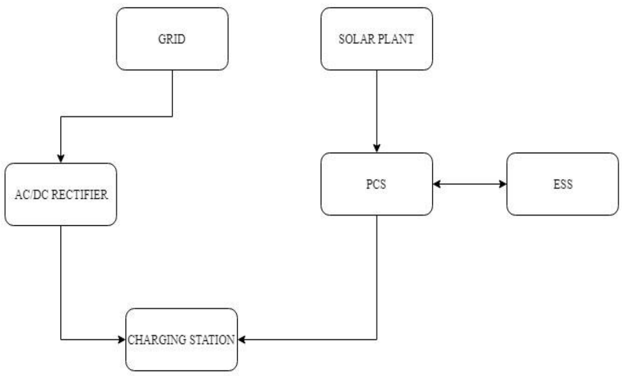

Fig. 3 Block diagram of charging station with solar plant.

The solar plant capacity can be determined by the ESS capacity to the number solar hours in a day.

$$SP = \frac{Sess}{h} \quad (2)$$

The number of panels required by plant is capacity of plant to the selected panel capacity.

$$Np = \frac{SP * 1000}{SPp} \quad (3)$$

The total cost of the plant is determined by (4) considering cost of each panel.

$$Csp = Np * SPcost \quad (4)$$

The required number of years to payback the investment on solar plant is given in (5) so that remaining life time of the plant can economically benefit the charging station.

$$Ypb = \frac{Csp + bc}{s} \quad (5)$$

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)

The total years of saving after installing the solar plant is determined by (6)

$$Y = N - Ypb \quad (6)$$

The above-mentioned formulations are executed in MATLAB environment. Though solar energy is free and green it is not predictable, due to seasonal variations as well as atmospheric effects. Therefore, the energy generated from solar may not meet the expected demand some time. So, as an alternative charging the PHEVs can be prioritized based on their battery SOC, arrival times and departure times.

C. Vehicle prioritizing

When ESS's energy is insufficient to meet the demand on the charging station during peak periods which is above the base load a strategy is proposed to schedule the vehicles based on their SOC at arrival and departure times. Vehicle prioritizing is considered as one of the methods which handles the tough situations. In this paper, based on the vehicles SOC rate priority of charging is determined. The vehicles having SOC greater than 70% are likely to be stopped charging and remining are vehicles are charged. This will reduce some burden on grid. Some expressions are given below to determine SOC ranges of each vehicle. The SOC of each vehicle is calculated for every i_{th} hour where the load is more than the base load. The amount of energy consumed by each vehicle is given by expression (7). The power delivered by each socket and time taken by vehicle to charge up to i_{th} hour are considered in this expression.

$$Ecij = Tc * Pc \quad (7)$$

Expression (8) tells us about the how much time the vehicle is charged i.e. difference between i_{th} hour and arrival time of vehicle.

$$Tcj = Ti - Taj \quad (8)$$

The amount of energy present in EV at i_{th} hour is summation of energy in EV at arrival and amount of energy the EV charged from station which is given in (9).

$$CBij = CBaj + Ecij \quad (9)$$

The amount of energy left in EV before coming to the station is calculated based on the SOC of EV at arrival and the maximum capacity of EV battery.

$$CBaj = SOCai * \frac{CbEVj}{100} \quad (10)$$

Finding the amount of energy present in the EV battery at i_{th} hour and Maximum capacity of EV battery will help in finding the SOC of EV at i_{th} hour which is given in (11).

$$SOCij = \frac{CBij * 100}{CbEVj} \quad (11)$$

By assuming vehicle data arrived at the station with some SOC range the above expression are formulated in MATLAB programming.

III. RESULTS AND DISCUSSION

After formulating the above expression in the MATLAB results are obtained. The load demand of the charging station taken from [10] is shown in figure 4. The electricity price on the grid for a day is shown in figure 5. Based on the pseudocode mentioned in section 2 the size of the ESS is calculated. The total load on the station is 1020kW. The total electricity price on the grid is 32.18$/day. In this paper as the peak load is 120kW, half of the peak load i.e. 60kW is considered as base load. The excess load i.e. loads above 60kW (base load) is considered as the size of ESS. Hence the size of the ESS obtained is 200kW. The energy storage system is charged during the low electricity price hours that is during morning 1 am to 4 am and discharged during the high peak hours as shown in figure 6. The Comparison of load demands before and after using ESS can be seen in figure 7. The electricity price after scheduling the ESS is 27.8$/day which is less than the case when ESS is not used. Hence using ESS is economically beneficial. Total electricity price for year is 11746.06 $/year. Electricity price with ESS scheduling for year is 10150.285 $/year. Thus, a charging station owner can save 1595.78 $/year.

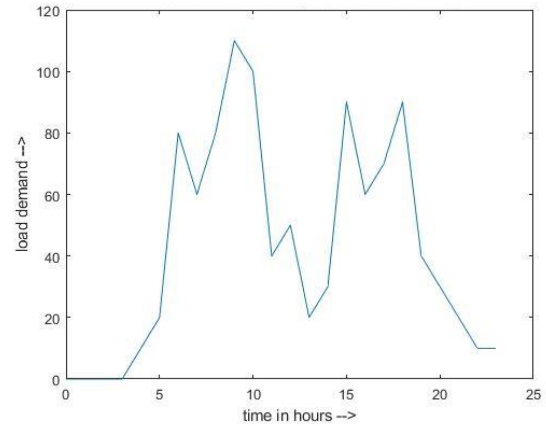

Fig. 4 Load demand on the charging station.

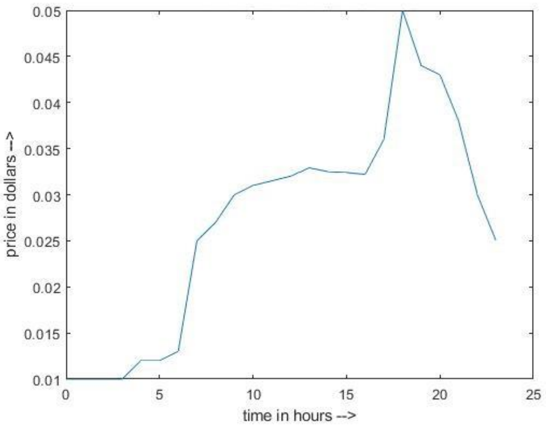

Fig. 5 Electricity price on the grid.

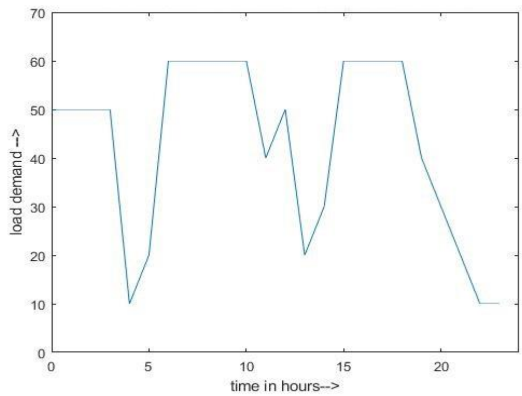

Fig. 6 Load demand of station after ESS scheduling

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)

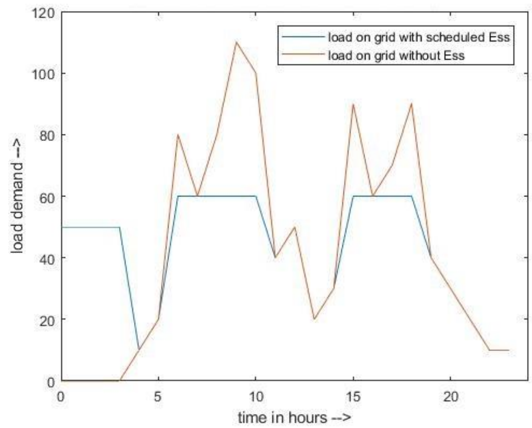

Fig. 7 Comparison of load demands before and after using ESS.

Choosing the data of storage systems from table 1, levelized cost of lithium ion and lead acid battery are found to be 0.176 and 0.137. Lithium ion is more efficient than lead acid battery though its levelized cost is higher. So, in this paper lithium ion is selected as a type of energy storage system. Assuming that a day consists of at least 5 peak solar hours, it is estimated that solar plant capacity for charging this 200kW ESS is 40kW. Number of panels required are 160 if each panel contributes a power of 250W. The total cost of solar plant and ESS is obtained as 32035 $ for 25 years. Charging the ESS using solar plant gives savings from which is 2325.7 $/year as electricity price on grid is 25 $/day. Since replacement period of the solar plant is 25 years, the years of payback is 13 years and the plant owner can save 10 years of savings considering 2 years savings as maintenance cost of solar plant. This result states that using solar plant to charge this energy storage is much better compared to charging it from grid. As solar energy is unpredictable, an example for vehicle prioritization is mentioned in this paper. Table 2 shows the vehicle parameters present at station in the morning. At 6 am in the morning the load is said to be 80kw from the figure 4. To reduce the load to 60kW (base load) vehicles with SOC greater than 70% is stopped charging. From the formulas mentioned in section 2, 6 am is considered as i_{th} hour.

Table 2 shows the EV parameters

	EV1	EV2	EV3	EV4
ARRIVAL TIME (AM)	5:00 am	5:20 am	5:40 am	6:00 am
SOC ARRIVAL (%)	30	35	30	35
BATTERY CAPACITY (KWH)	40	45	50	40
DEPARTURE TIME (AM)	6:30	6:50	7:40	8:00

From the table 2, at 6 am the SOC ranges of each vehicle is EV1-76%, EV2-65%, EV3-45%, EV4-35%. Thus, the SOC of EV1 is greater than 70% it is requested to stop charging and allowed to recharge when there is less load.

IV. CONCLUSION

In this paper, an approach is introduced to determine the size of the ESS for PHEVs charging station which decreases the energy cost and reduces the negative impacts of charging station on the grid. The method used in this paper is very simple and can be applied to any charging station if the load profile of the charging station and electricity price of grid are known. At first the size of the ESS required by station is calculated. ESS is charged from the grid during low price hours which benefits the station economically. Using renewables such as solar is another method proposed to charge the ESS apart from grid. The required size of the solar plant to charge the ESS, investment cost of this solar plant, and payback period of this investment are calculated. Though solar plant supports the station economically, climatic changes may affect its performance sometimes. Therefore, a strategy to schedule the vehicles based on their SOC is done which reduces burden on the charging station during peak periods. However, driving patterns of PHEV owners plays an important role. Thus, proper sizing of energy storage system and its management can acquire greater performance to charging stations and grid.

REFERENCES

1. I. Damnjanovic, S. Kim, M. Kezunovic, P. Dutta, and C. Pang “PHEVs as Dynamically Configurable Dispersed Energy Storage for V2B Uses in the Smart Grid”
2. E. Haesen, J. Driesen, and K. Clement, “Coordinated charging of multiple PHEVs in residential distribution grids,” in Proc. IEEE PES Power Syste., Confere., and Exposition. (PSCE), Mar. 2009, pp. 1–7.
3. M. Pantoš and D. Božic, “Impact of electric-drive vehicles on power system reliability,” Energy, vol. 83, pp. 511–520, Apr. 2015.
4. P. Frías, R. Cossent, C. M. Domingo, T. G. S. Román, and L. P. Fernández, “Assessment of the impact of plug-in electric vehicles on distribution networks,” IEEE Transaction on Power Syst, vol. 26, no. 1, pp. 206–213, Feb. 2011.
5. E. Haesen, J. Driesen, and K. Clement-Nyns, “The impact of charging plug-in hybrid electric vehicles on a residential distribution grid,” IEEE Tran. Power System., vol. 25, no. 1, pp. 371–380, Feb. 2010.
6. A. Zare, R. Hoseinzadeh, A. Abunasri, and A. Kavousi-Fard, “Impact of plug-in hybrid electric vehicles charging demand on the optimal energy management of renewable micro-grids,” Energy, vol. 78, pp. 904–915, Dec. 2014.
7. J. P. S. Catalão, A. G. Bakirtzis, O. Erdinç, and N. G. Paterakis, “Optimal household appliances scheduling under day-ahead pricing and load-shaping demand response strategies,” IEEE Transac. Ind. Information, vol. 11, no. 6, pp. 1509–1519, Dec. 2015.
8. Graham Mills, Member, IEEE, Iain F. MacGill, Member, IEEE, and Peerapat Vithayasrichareon, Member, IEEE “Impact of Electric Vehicles and Solar PV on Future Generation Portfolio Investment” IEEE Transactions on Sustainable Energy 2015.
9. Chunlai li, Chen, Donfang Wang, Gouzeng Yan, Bohan Liu, Ke Jia “ENERGY MANAGEMENT METHOD IN IES” Yiru Preprints of the 5th international conference on Electric Utility Deregulation and Restructuring and Power Technologies November 26-29, 2015. Changsha, China
10. Mahmud Fotuhi-Firuzabad, Mohammad Rastegar and Soodeh Negarestani, and Abbas Rajabi-Ghahnavieh “Optimal Sizing of Storage System in a Fast Charging Station for Plug-in Hybrid Electric Vehicles”.
11. W. T. Jewell and P. Poonpun, “Analysis of the cost per kilowatt hour to store electricity,” IEEE Transac. On Energy Conversi., vol. 23, no. 2, pp. 529–534, Jun. 2008.
12. T. Vijay Muni, D. Priyanka, S V N L Lalitha, “Fast Acting MPPT Algorithm for Soft Switching Interleaved Boost Converter for Solar Photovoltaic System”, Journal of Advanced Research in Dynamical & Control Systems, Vol. 10, 09-Special Issue, 2018

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication (BEIESP)

13. T Vijay Muni, SVNL Lalitha, B Krishna Suma, B Venkateswaramma, "A new approach to achieve a fast acting MPPT technique for solar photovoltaic system under fast varying solar radiation", International Journal of Engineering & Technology, Volume7, Issue 2.20, pp-131-135.
14. VM Jyothi, TV Muni, SVNL Lalitha, "An optimal energy management system for pv/battery standalone system," *International journal of Electrical and Computer Engineering*, 2016.

AUTHORS PROFILE

B. NAGARJUNA REDDY, UG student, Electrical and Electronics Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram-522502, AP, India. His Research interests includes Power Systems and Energy Systems. Mail: nagarjunabhimireddy@gmail.com

A. CHANDRA SEKHAR REDDY, UG student, Electrical and Electronics Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram-522502, AP, India. His Research interests includes Power Systems and Energy Systems.
Mail: sekharreddy119@gmail.com

G. SWAPNA, Assistant Professor, Electrical and Electronics Engineering, Koneru Lakshmaiah Education Foundation, Vaddeswaram-522502, AP, India. Her Research interests includes Power Systems and Electric vehicles. Mail: swapna@kluniversity.in

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication (BEIESP)