ANALYSIS OF ENERGY MANAGEMENT IN GRID CONNECTED RESIDENTIAL PV SYSTEM

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Abstract- Gird connected Photovoltaic systems are becoming popular among the public. This paper suggests an efficient energy management for the grid connected PV system. The loads are classified as critical and non-critical load. Based on consumption days are classified as high and low energy consumption days. The analysis is made on the terms of energy export to the gird and import form the grid. The results inferred that proper energy management system is needed to export more energy from the grid connected PV system.

Keywords- Grid Connected PV system, dispatch ratio, ToD Tariff, critical and non-critical loads.

1. INTRODUCTION

Global energy consumption has increased significantly in the last two decades due to living standards, technological development and population growth. Our world uses twenty-five times as much energy as it did 25 years ago. This has led to increased consumption of fossil fuels, leading to global climate change and environmental challenges. The transition from conventional power generation to clean power generation and hence reducing greenhouse gas emissions is a long-term solution to achieving sustainable development. The 2015 Paris Agreement aims to significantly reduce greenhouse gas emissions by 2050. The share of renewable energy sources, including hydropower, has increased from 1.1 percent of the world's total energy generation to 27 percent since 2000. Growth is mainly the addition of wind and solar energy. Skills. This contribution is due to the low cost of solar and wind power generation adopted by the European Union, US, China, India, Japan and Australia and the adoption of new climate policies.

Energy consumption per capita has increased exponentially due to increased energy consumption per capita. Fossil fuels play a key role in the power of all these sectors. Approximately 62.8% of electricity production in India is dependent on fossil fuels. Pollution and greenhouse gas emissions pose a major threat to earth, its climatic variations and its flora and fauna. Each individual's responsibility is to combat threats that harm the environment and maintain good health, clean air, clean water, a nutritious food supply and a safe haven. The importance of generating clean and renewable energy production is relevant here.

Solar PV generation is getting momentum due to the decreasing cost of generation and technological advancement in manufacturing efficient and cheap solar panels. Domestic solar energy generation is done presently utilised as a standalone power with storage element to supply during non-solar hours or as grid tied system where the total energy generated by solar panels is transferred to the grid. Both these systems have advantages and limitations. The presence of storage element enhances the cost of generation in case of a standalone system, whereas the customer will be in dark in case of power failure in the case of a grid tied system in spite of investing huge amount and supporting the efforts to obtain to uphold the merits of sustainability.

Researchers have worked a lot in this area to explore the possibility of developing and effective solar power generation suitable for domestic application. An optimized energy management strategy for a grid-connected microgrid system for domestic application constituting of renewable energy generation is proposed by Segarra-Tamarit et al., [1]. The energy cost is minimised with real time pricing by solving the energy management problem by the use of stochastic optimisation approach [2]. A home energy management system is developed for residential application by scheduling the residential loads [3]. An intelligent residential management system is proposed for smart buildings for reduction of energy bill through proper scheduling of loads [4]. An effective home energy management for residential solar PV system s with battery energy storage is proposed with the pricing of electricity under time of use [5]. The Energy Management System (EMS) with different combinations of generating systems including renewable energy system working under different strategies and control to meet the continuous demand of load is reviewed [6]. A real time energy management system for a residential system with ac/dc grid and renewable energy sources through proper scheduling and optimisation is proposed and seen to decrease the operational costs [7]. An online energy management of grid connected renewable energy sources along with storage element, diesel generators working on an effective load management system is proposed. An optimisation problem thus developed to minimise the considering operating costs and pollution [8]. A grid tied renewable energy system for charging electric vehicles (EV) reducing the energy drawn from grid is developed [9]. An energy management system to reduced the peak demand in a grid connected solar PV system for charging electric vehicles is simulated and experimented [10]. The energy management algorithm for a hybrid PV system with battery and fuel cell is done keeping the grid power drawn to a minimum is developed in Lab VIEW [11]. The operational cost of a microgrid with energy storage system for a residential load is studied an optimisation model to minimise the operational cost is developed for summer [12]. A control system is to operate in dual mode for a residential grid tied solar PV system is developed [13]. A grid connec6ed PV is system is performance evaluated [14]. The energy production of a roof top solar PV system is taken as a case study and its production is estimated [15].

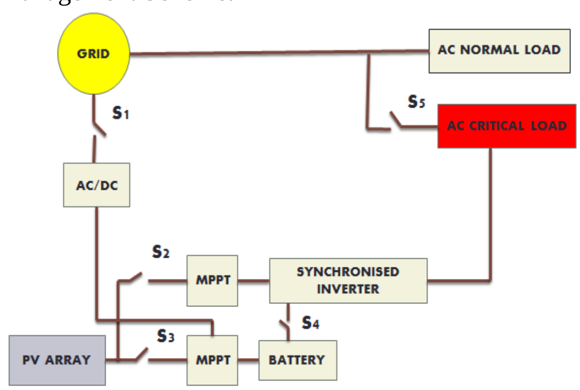
PSO is used for optimising the a microgrid system in real time [16]. For a residential PV tied to the grid genetic algorithm is used for optimising [17]. Various optimisation techniques are compared for a microgrid system [18]. Backup storage in an SPV system is optimised under economic considerations in a grid tied PV system . The effect of different storage devices are compared in a grid connected PV system. The battery life is compared for a solar home system.

The literature survey carried out by researchers concluded that the properly managed and scheduled Residential solar photovoltaic (RSPV) systems, can result in obtaining cost advantage to the customers. This paper deals with an Energy management of grid connected The literature survey carried out by researchers concluded that the properly managed and scheduled Residential solar photovoltaic (RSPV) systems, can result in obtaining cost advantage to the customers.

This paper deals with an Energy management of grid connected residential PV system working under Time of day tariff (ToD) . The aim is to maximise the energy exported to the grid and minimise the usage of energy during high ToD period thus maximising the customer benefit .

2 SYSTEM MODELLING

Effective utilisation of renewable energy generated is possible through proper energy management. The proposed system has a combination of stand alone system and a grid tied system. Here a part of the energy requirement during high ToD times is met by the storage device through proper scheduling. The export to the grid is kept constant so that battery is charged during solar hours directly from grid and is discharged to the load during grid failure and peak hours of the day. Thus, both comfort as well as economic benefit can be enjoyed by the customer. The load that can be fed by the storage device is termed as the critical load (CL) and the other loads are termed as normal loads (NL). Figure 1 shows Proposed Energy Management Scheme.



The proposed energy management system (EMS) also reduces the underutilisation of solar energy which can be seen in the conventional standalone solar PV systems. Normal loads are loads where the power requirement is high. The other load is the critical load which are to be energised always, either from the grid or storage device. Through proper source switching scheduling is possible. Controllers are integrated with the system for selection of source. By scheduling the source, the critical loads are energised either from storage device or from the grid.

The flow of power to the different branches are controlled by the controllers which determines the source and mode selection. The operation modes are achieved by switching the switches through. Here & are the mode selection switches and are used to select the sources which powers the load at a given time.Switch is used to control the power fed from the PV system to grid. The synchronizing inverter converts the DC supply from the PV or battery into AC which is synchronized with grid.

The system is supposed to operate on time of the day (ToD) tariff set by the utility company. The critical loads will be energised by the battery during peak hours, i.e., when the ToD tariff is high. Thus, the power drawn during peak hours is less, as critical loads are powered by storage devices. The inherent disadvantage of a standalone system which underutilizes of solar energy and the disadvantage of customer suffering when grid fails in a grid tied system is resolved in this proposed system.

3 SCHEDULING POWER

The operating modes and selection of sources are detailed in Table 1and switching sequence in Table 2.

Table.1 Operating conditions of EMS

Grid	PV	Battery	Function
0	0	0	No power
0	0	1	Critical load will be met by the battery
0	1	0	Battery charging from PV array
0	1	1	Battery charging + critical load
1	0	0	All loads met by grid + Battery charging
1	0	1	Normal loads met by Grid + Critical loads met by either battery or grid depending on SoC of battery
1	1	0	Grid tied system + Battery charging from PV array or grid depending on the mode
1	1	1	Grid tied system + Critical loads met by either battery or grid depending on SoC of battery

Table.2 Switching sequence

Grid	PV	Battery	s_1	s_2	s_3	s_4	s_5
0	0	0	-	-	-	-	-
0	0	1	0	0	0	1	0
0	1	0	0	0	1	0	0
0	1	1	0	0	1	1	0
1	0	0	1	0	0	0	1
1	0	1	0	0	0	0	1
1	1	0	1	1	1	0	1
1	1	1	0	1	0	0	1

4 OPTIMAL SCHEDULING PROCESS

The power management algorithm is arrived to reduce the energy bill and maximise the usage of solar energy generated. Figure 2 shows the power management algorithm, in which critical load is always energized.

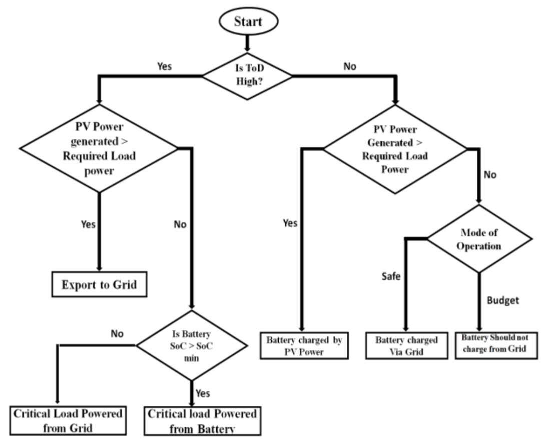


Figure .2 Power Management Algorithm

The flow of algorithm depends on the ToD and state of charge of battery. During peak hours, when the PV power delivered by the panels is larger than the load, the excess power is sent to the utility grid. Also, during peak hours, when the PV power delivered by the panels is less than the load, the battery supplies critical loads. During off-peak hours, when PV power delivered by the panels is larger than the load, the net PV power after covering the load will be used to charge the battery. During off-peak hours, when PV power is not sufficient to supply the loads, utility grid supplies power to the loads.

5 CONSTITUTION OF ENERGY MANAGEMENT PROBLEM

To overcome the deficiencies of a standalone system and a grid tied system energy export during the solar hours is maximised and the energy import during peak hours of the day is minimised. The battery is directly charged from PV. The power generated by PV is exported to the grid. The net energy drawn from the grid is indicated in the net-meter. Moreover, when power of the grid becomes costly or when there is a power outage, battery supplies power to the critical loads. The scheduling is based on the present policy of Indian government on grid tied PV systems. The time of day (ToD) prices are used by utility companies for arriving the energy cost for customers whose monthly consumption exceeds 500kWh. It can be seen from the Table 1 that the scheduling is dependent on the availability of the source and cost of utility power.

As per the Indian policies, scheduling power is done based on the following assumptions.

PV is connected to the grid. PV power generated ≥ Load power

PV power is directly used for battery charging

PV power after meeting the load and charging battery is fed to the grid.

When PV generation is less, then battery supplies critical load and balance load is supplied by the grid. The amount of energy exported to the grid can be defined in terms of dispatch factor. The dispatch factor can be defined by the equation [22]

$$\varpi = \frac{PV\ \ Energy\ \ \exp orted\ \ to\ \ grid}{PV\ \ energy\ \ generated}$$

Where ω is the optimization variable.

Based on the scheduling rules optimization problem is being formulated for the Energy Management of the system working with ToD (EMTOD). The cost advantage in electricity bill for a grid tied RPV is the objective function. The tariff of electricity influences the economics of the power system. The increasing demand and additions of solar power to the grid has made the utility companies in India to go in for ToD tariff-based billing for customers. By implementing smart meters for generating energy bills, the stepped tariff will be replaced with ToD tariff. Hence energy management is done for the system working on ToD tariff.

Based on the aforementioned terms, the objective function is to maximise the customer benefit by maximising the energy sold to the grid. Battery health is taken care by properly charging the battery and discharging during peak hours of the day.

6 CASE STUDY

A typical residential load in India is taken for the case study. The study is based on the present government policies for generating and supplying renewable energy to the grid.

6.1 Configuration Selected for the Case Study

A 3kW grid tied system working on a residence is taken for the case study. A battery backup of 150Ah takes care of the critical loads. The life of the system is estimated for 25 years. The connected load on the residential building is 4.8kW out of which 1.2 kW is the critical loads which has a backup. The backup battery supplies power to the load when PV power and utility power is not available and during peak load hours. The weekly load profile depicted in Figure 3 is obtained from the residence taken up for the study. The charging and discharging of battery will be different for different days in a week. The weekly load cycle is seen to be repeated. The weekly load profile is used for forecasting the load for the system.

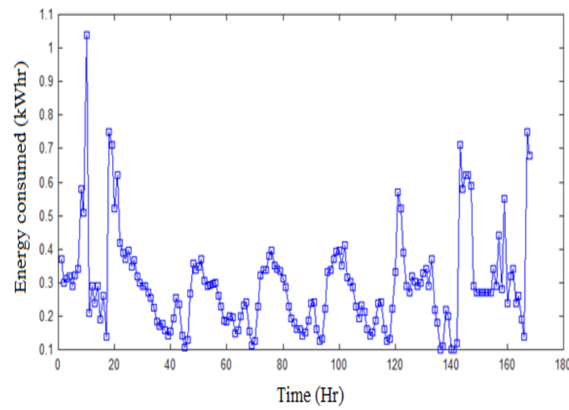


Figure 3. Weekly Residential load profile

The output from the solar panels depends on the light intensity and its location. The location of this case study is Palakkad in Kerala state of India. Solar data is obtained from National Renewable Energy Laboratory (NREL) which is compared with the observed data. This database is used for forecasting the daily solar output. Figure 4 depicts the plot of the solar data for a day.

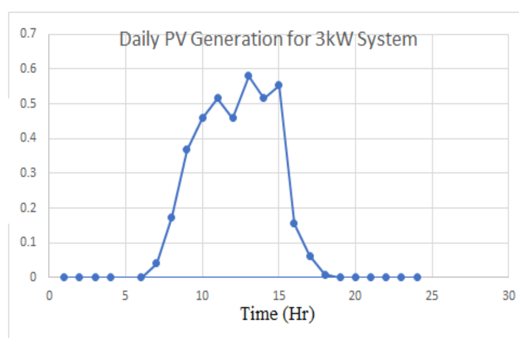


Figure 4. Daily PV Generation

The increasing contribution of solar power to the grid supports the consumer for the day time energy requirement. However, during night when PV power is not generated and the demand increases, the consumer have to purchase power during the peak hours of the day. This makes the consumer to adopt ToD tariff. The tariff selected in this case study is the prevailing ToD tariff fixed for domestic consumers whose monthly consumption is above 500 kWh by Kerala State Electricity Board (KSEB) the utility company in Kerala. The rates of the tariff are divided for three different timings of the day based on the demand pattern. Different rates fixed for the three timings namely peak, normal and off peak are given in Table.3.

Table .3 ToD tariff rates

Time	Tariff
6am to 6pm	Rs.7.90
6pm to 10pm	Rs.9.48
10pm to 6am	Rs.7.11

6.2 Analysis of Case Study

The residential system taken up for study has been simulated with MATLAB R2018a. The cost of energy export and import has been calculated based on the dispatch ratio ɷ, which is the ratio of power export to the power generated. The dispatch ratio ɷ is maintained as 0.3.During night time, in the absence of PV power, the battery supplies the load and energy is imported form the grid when ToD tariff is low. Also, in the absence of PV power, critical loads are powered by the storage device. When ToD is high and battery SOC is low, batteries are charged only by the PV system. All these constraints are simulated and the cost of energy sold i.e., energy export and cost of energy purchased i.e., energy import are calculated. The load profiles have been monitored for a period of three months and are categorized into two means, as high and low consumption days. In the regular working days, the members of the family in the residence taken up for study moved to their working premises. This reduces the load demand in the house. These days are considered as low consumption days. On the other hand, during weekends or festive timings when the family members are available at home, the load demand increases. Hence, these days are considered as high consumption days.

7. RESULTS AND DISCUSSIONS

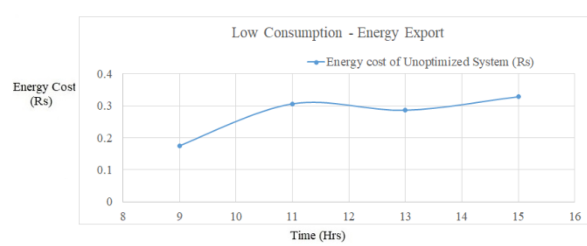
The energy demand and cost of energy during low and high consumption days were obtained. The analysis reveals that during low consumption days the energy export to the grid is higher than that during high consumption days. Also the energy imports during high consumption days is seen to be higher than during low consumption days Figure 5 shows the energy export and import during low and high consumption days. Figure 6 shows the comparative analysis of energy import and export during high and low consumption days.

Table.4. Benefits during low consumption period

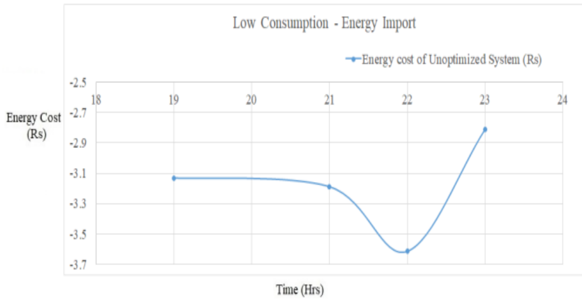
Time (Hrs)	Load Power (kW)	Energy cost of Unoptimized System (Rs)	Mode of operation
9	0.1962	0.1753836	Power Export to grid
11	0.1567	0.3064656	
13	0.1987	0.2863056	
15	0.2314	0.328608	
19	0.3211	-3.130296	Power Import from grid
21	0.3487	-3.188124	
22	0.3701	-3.613776	
23	0.3068	-2.810583	

Table .5. Benefits during high consumption period

Time (Hrs)	Load Power (kW)	Energy cost of Unoptimized System (Rs)	Mode of operation
9	0.28	-0.1187	Power Export to grid
11	0.24	0.257998	
13	0.34	0.256138	
15	0.26	0.305424	
19	0.75	-6.7308	Power Import from grid
21	0.71	-4.728	
22	0.62	-4.788	
23	0.42	-3.9816	

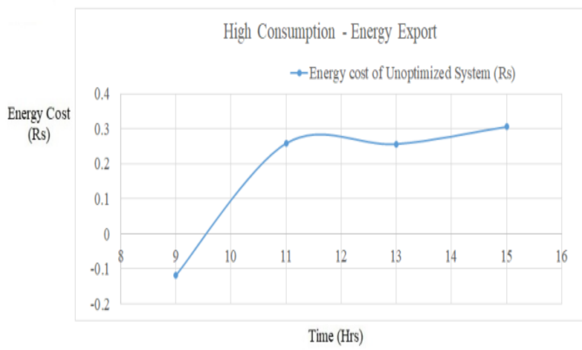


(i) Energy Export

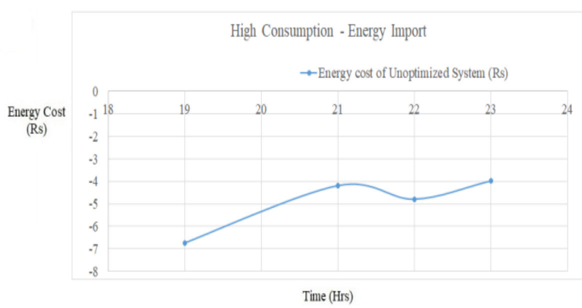


ii) Energy Import

(a) Low Consumption Days



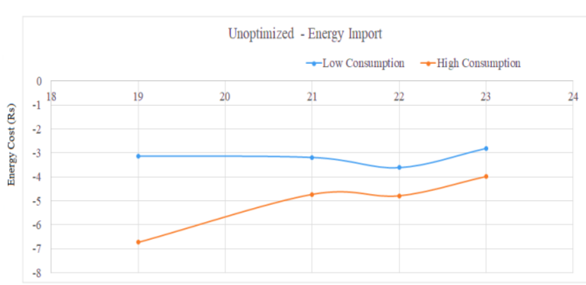
(i) Energy Export



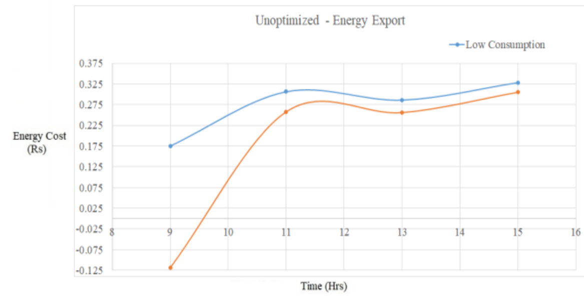
(ii) Energy Import

(b) High Consumption Days

Figure 5. Simulation Results



(a) Energy Import



(b)Energy import

Figure 6. Comparative Analysis

Table 4 and 5 provide detail of benefits during low consumption period and high consumption period

8 INFERENCES

The tabulated results and the corresponding analysis depicted in Figure 5 and 6 indicates that during day hours, when the solar insolation increases, the cost of energy export increases. On a low consumption day the load demand at 9Hrs was found to be 0.1962 kW. This is met by the solar energy generated and the balance of solar energy generated is exported to the grid fetching a revenue of Rs. 0.1754. during the high consumption day the load requirement incresed to 0.28 kW, however the PV power is insufficient and hence power is imported from the grid costing the customer Rs. 0.1187. More energy is seen to be exported to the grid during day time and when the load requirements decreased. During evening that at 22 Hrs on the low consumption days, the power demand was 0.3701 kW, and that during the high consumption day it was 0.62 kW. At these times, the storage device supported the load requirements. Thus the battery gets drained and has to be charged if SoCof battery goes below threshold level. Even it is seen that the battery is charged through the grid, as solar power is unvailable. This causes the energy import to increase.This is evidenced from the figure 5 and 6. During high consumption day, the cost of energy import from the grid was Rs. -4.788, whereas on the low consumption day it was Rs. -3.613 (-ve sign imported energy cost). The average energy cost of export during low consumtpion days was Rs. 0.274 and high consumption days was Rs. 0.183. Similarly, the import of power was Rs. -3.42 and Rs. -4.3 per day on the low and high consumption days respectively. The annual net cost of energy was found to be Rs. -1295 (Rupees One Thousand Two Hundred and Ninety Five only), contributing an average monthly payment of Rs. 108 (Rupees One Hundred and Eight Only). The result inferred that by using this energy management the annual energy bill to the customer reduced to Rs. 1295/-. Dispatch ratio is the factor that determines the amount of energy exported to the grid after meeting the load demands and battery charging power needs. In this system, the percentage of PV power exported is fixed. In this energy management system, the amount of energy exported does not vary based on the battery conditions. When the SoC of battery is 100%, the allocation of PV power to the battery is wasted and makes the generated solar energy underutilized. With higher fixed value of dispatch ratio, the battery takes longer duration for charging and hence affects the life of the battery. Varying the dispatch ratio increase or decrease of energy export is possible .This is depicted in figure 7.

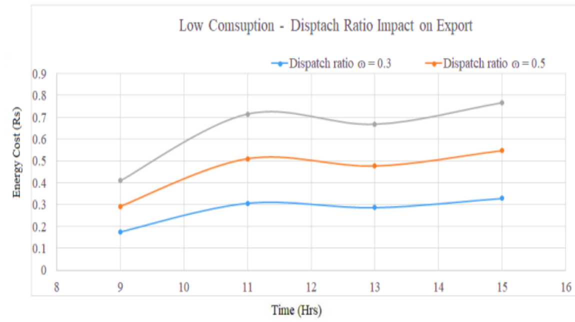
Table 6. Impact of dispatch ratio – Low Consumption Period

Low Consumption Period				
Time (Hrs)	Load Power (kW)	Dispatch ratio ω = 0.3	Dispatch ratio ω = 0.5	Dispatch ratio ω = 0.7
9	0.1962	0.1753836	0.2923	0.4092
11	0.1567	0.3064656	0.5107	0.7150
13	0.1987	0.2863056	0.4771	0.6680
15	0.2314	0.328608	0.5476	0.7667

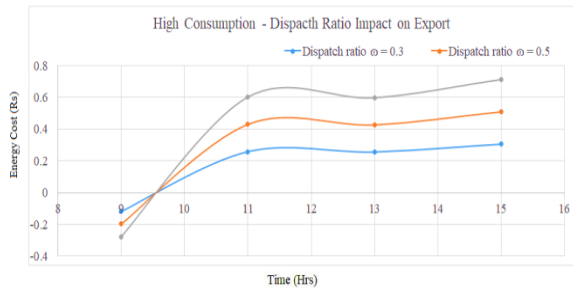
Table 7. Impact of dispatch ratio – High Consumption Period

High Consumption Period				
Time (Hrs)	Load Power (kW)	Dispatch ratio ω = 0.3	Dispatch ratio ω = 0.5	Dispatch ratio ω = 0.7
9	0.28	-0.1187	-0.1978	-0.2769
11	0.24	0.257998	0.4299	0.6019
13	0.34	0.256138	0.4268	0.5976
15	0.26	0.305424	0.5090	0.7126

Table 6 provide detail about impact of dispatch ratio – Low Consumption Period and High Consumption Period.



(a) Low Consumption



(b) High Consumption

Figure 7. Impact of Dispatch Ratio on Energy Export

9 CONCLUSION

Optimal scheduling of the sources is attempted in this paper, based on the load demand and ToD tariff. A case study with respect to Kerala State Electricity Board, utility company has been presented. The simulation results of the case study and its corresponding analysis exposed that the load demand varies based on the normal days and weekends or holidays. Accordingly, the days are categorized as low and high consumption days. During these days, when PV power is available, load demand is met by PV source. The excess energy is transferred to the grid, based on the dispatch ratio. When PV power is unavailable, power is imported form the grid based on ToD. If ToD is high and PV power is unavailable, battery supports the load. This caused the battery to be discharged. When battery SoC reduced below the permissible limit, battery is charged with PV source. If the battery drains, in the evening hours, it is charged by drawing power from the grid. Consequently, the imported and exported energy costs are calculated and the annual consumption is arrived as Rs. - 1296.00 (Rupees One Thousand Two Hundred and Ninety Six only). The analysis of impact of dispatch ratio makes it clear that it has to be varied based on the battery charging conditions.

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