A Dissertation Report On

Incremental Conductance MPPT Technique And Energy Management Based On The PV-HPCS With An Energy Storage Device

Submitted in partial fulfillment of the requirements for the degree

BACHELOR OF ENGINEERING

By

ALAM AFZAL

DILSHAD AHMED

ANSARI NOOR MOHAMMED

ANSARI MOHAMMED SHARIQ

Under the guidance of

MS. GULREZ BODHLE

Anjuman-I-Islam's

Kalsekar Technical Campus

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NEW PANVEL

Submitted to :

MS. GULREZ BODHLE

Submitted by :

NAME	ROLL.N0.
ALAM AFZAL	13EE35
DILSHAD AHMED	13EE14
ANSARI NOOR MOHAMMED	13EE11
ANSARI MOHAMMED SHARIQ	13EE09

MS.G. BODHLE	Prof. S.KALEEM	Dr. A.R.HONNUTAGI
(GUIDE)	(H.O.D)	(DIRECTOR)

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CERTIFICATE

This is to certify that the report entitled "Incremental Conductance MPPT Technique And Energy Management Based On The PV-HPCS With An Energy Storage Device" submitted by ALAM AFZAL, DILSHAD AHMED,ANSARI NOOR MOHAMMED, ANSARI MOHAMMED SHARIQ in partial fulfillment of the requirement for the award of Bachelor of engineering in "ELECTRICAL ENGINEERING"is an authentic work carried under my supervision and guidance.

Date:

Examiner ____________________

Ms.GulrezBodhle ____________________
(Guide)

Prof. S. Kaleem ____________________
(HOD)

Dr. Abdul RazzakHonnutagi ____________________
(Director)

DECLARATION

I declare that this written submission represents my ideas in my own words and where others ideas or words have been included,I have adequately cited and referenced the original sources. I also declare that I have adhered to all principle so academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

DATE ……………………….

PLACE……………………….

(NAME OF THE STUDENT)

ALAM AFZAL	…..…………………
DILSHAD AHMED	…………………..
ANSARI NOOR MOHAMMED	…………………..
ANSARI MOHAMMED SHARIQ	…………………..

ABSTRACT

Nowadays solar energy has great importance. Because it is easily available resource for energy generation. But the only problem is efficiency of solar system. And to increase its efficiency many MPPT techniques are used. Large number of papers were published on Maximum Power Point techniques (MPPT). And therefore many techniques are available for use. These techniques differs in many aspects. Incremental conductance is one of the important technique in this system and because of its higher steady-state accuracy and environmental adaptability it is widely implemented tracked control strategy. This paper presents details of Incremental Conductance algorithm with simulation results obtained using MATLAB and SIMULINK.

This system proposes the new energy management method based on the photovoltaic (PV) hybrid power conditioning system of 4 kW with an energy storage device (ESD). The use of the ESD such as a lithium-ion battery improves the energy efficiency of the overall system depending on time and weather conditions. In addition, the proposed system provides the new function for energy management in real time without weather forecasting while it considers the power generations from the PV system, residential load variations, and electricity price. In other words, the proposed energy management system (EMS) can reduce the electricity price by charging the energy of nighttime electric power. In addition, it can suppress the grid voltage variations caused by the large amount of PV generations during daytime with respect to relatively less load demand. The performances of the proposed EMS system based on the 4-kW PV HPCS with a lithium-ion battery are evaluated by time-domain simulation.

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CHAPTER 1

1.1 INTRODUCTION

Photovoltaic (PV) systems have been used for many decades. Today, with the focus on greener sources of power, PV has become an important source of power for a wide range of applications. Improvements in converting light energy into electrical energy as well as the cost reductions have helped create this growth. Even with higher efficiency and lower cost, the goal remains to maximize the power from the PV system under various lighting conditions. Unfortunately, PV generation systems have two major problems: the conversion efficiency of electric power generation is very low (9÷17%), especially under low irradiation conditions, and the amount of electric power generated by solar arrays changes continuously with weather conditions.

Moreover, the solar cell V-I characteristic is nonlinear and varies with irradiation and temperature. In general, there is a unique point on the V-I or V-P curve, called the Maximum Power Point (MPP), at which the entire PV system (array, converter, etc…) operates with maximum efficiency and produces its maximum output power. The location of the MPP is not known, but can be located, either through calculation models or by search algorithms. Therefore Maximum Power Point Tracking (MPPT) techniques are needed to maintain the PV array‟s operating point at its MPP.

Integration of large amounts of photovoltaic (PV) into the electricity grid poses technical challenges due to the variable power production. Solar distributed generation (DG) is often behind the meter and consequently invisible to grid operators. The ability to understand actual variability of solar DG power production will allow grid operators to better accommodate the variable electricity generation for resource adequacy considerations, such as scheduling and dispatching of power. From a system operator standpoint, it is desirable to understand when aggregate power output is subject to large ramp rates. If in a future with high PV penetration all PV power systems were to strongly increase or decrease power production simultaneously, it may lead to additional cost or even instability on the grid if the remaining generation cannot match the ramp rates and/or reserves may be exhausted. The ability to forecast such ramps can mitigate some of the economic and reliability issues.

Recently, the renewable-energy-based distributed generations (DGs) are being considered worldwide as an alternative solution to deal with the new constraints placed by economic, political, and environmental issues faced in the modern power system. In addition, their grid connections are attracting much concern. However, when they are taking the large portion of the overall power generation, the irregular and stochastic output variations caused by the characteristics of renewable energies can bring uncertainties in power system planning and operation. The energy storage device (ESD) such as a battery and an ultracapacitor is able to solve the above problem caused by the use of renewable energies and various technical issues according to load conditions. Moreover, it provides the additional benefits for utilities, independent power producers, and electricity consumers under the deregulation of electricity market by increasing the system efficiency and creating new business.

Among typical renewable energies, the photovoltaic (PV) generations are kept increasing worldwide. For example, the government of South Korea plans to expand the proportion of renewable energies into 12.5% of overall power generation until 2022. In particular, the PV generation is supposed to take 81% of renewable-energy-based power generations. In this case, the hybrid power generation technology, which consists of the PV system and the ESD, is required to guarantee controllability, stability, and reliability of the overall system.

On the other hand, the energy management system (EMS) is also necessary so that the consumers can achieve high energy efficiency with the use of the hybrid power generationsystem. It enables them to manage the energy effectively and sustainably according to certain procedures for achieving the goal. In this paper, the EMS implemented in the PV hybrid power conditioning system (HPCS) with the ESD can give the following benefits. First, the economic profit can be obtained by the transaction of electric powers on a real-time pricing (RTP) market [4]–[9]. Second, the EMS provides the efficient use of electric power with the consideration of predicted PV power output and load variations [9]–[12]. In other words, it can reduce the peak load by discharging energy from the ESD when the load demand is, for example, intensively increased during specific hours in the evening. Next, the EMS can mitigate the output power fluctuations from the PV system effectively by the charging and discharging operations of the ESD when insolation and/or temperature is changed [13]–[16]. In particular, when it exceeds the amount of load demand during daytime, the extra power output will flow to the grid without the ESD. Then, the grid voltage becomes higher than its rated value. In this case, the EMS compensates for the variations of grid voltage caused by PV generation.

In general, the real-time implementation of the EMS requires the reliable communication between the PV system and the grid, as well as the information of PV generation, load variations, electricity price, etc. Predicting the amount of power from the PV system and the load demand might be also required. In addition, a cheap digital signal processor (DSP) is necessary to process the data at the residential system. Nevertheless, the overall cost will be increased by the necessity of a supervisor controller, additional sensors to measure insolation and/or temperature to forecast the exact amount of power from t he PV system and load variation, and extra equipment to communicate the change of load demand and the real-time electricity price, etc. Moreover, the conventional EMSs such as the stepwise and linear reference methods have been applied to mitigate the output power fluctuations from the PV system. However, the rapid (nonsmooth) changes of output power, which have the negative effect on power quality, network reliability, and ESD, were still remaining.

In this system the new contribution is done by implementing the EMS in real time based on the 4 kW residential PV HPCS with the lithium-ion battery. The proposed EMS avoids the use of additional sensors for weather forecasting and additional controllers to communicate load variations, which are required in the other conventional EMSs. Moreover, it provides the new ESD control method to mitigate the output power fluctuations with the smooth behaviors. Then, it is verified that the customers can get the economic benefit by taking the advantage of nighttime electric power with the relatively low electricity price. In addition, the utility can mitigate the variations of grid voltage by charging the energy from the PV system in daytime while responding to the peak load.

CHAPTER 2

2.1 LITERATURE REVIEW

The rapid trend of industrialization of nation and increased interest in environmental issues recently led us to explore the use of renewable forms such as solar energy. Photovoltaic (PV) generation is gaining increased importance as a renewable source due to its advantages like absence of fuel cost, little maintenance, and no noise and wear due to the absence of moving parts, etc. In particular, energy conversion from solar cell arrays (SCAs) received considerable attention in the last two decades. There are different techniques for MPPT such as Perturb and Observe (hill climbing method), Incremental conductance, Fractional Short Circuit Current, Fractional Open Circuit Voltage, Fuzzy Control, Neural Network Control etc. Among all the methods Perturb and observe (P&O) and Incremental conductance are most commonly used because of their simple implementation, lesser time to track the MPP and several other economic reasons.

Under abruptly changing weather conditions (irradiance level) as MPP changes continuously, P&O takes it as a change in MPP due to perturbation rather than that of irradiance and sometimes ends up in calculating wrong MPP. However this problem gets avoided in Incremental Conductance method as the algorithm takes two samples of voltage and current to calculate MPP. However, instead of higher efficiency the complexity of the algorithm is very high compared to the previous one and hence the cost of implementation increases. So we have to mitigate with a tradeoff between complexity and efficiency. It is seen that the efficiency of the system also depends upon the converter. Typically it is maximum for a buck topology, then for buck-boost topology and minimum for a boost topology. Maximum power point trackers (MPPTs) play an important role in photovoltaic (PV) power systems because they maximize the power output from a PV system for a given set of conditions, and therefore maximize the array efficiency.

The topic of solar energy utilization has been looked upon by many researchers all around the globe. It has been known that solar cell operates at very low efficiency and thus a better control mechanism is required to increase the efficiency of the solar cell. In this field researchers have developed what are now called the Maximum Power Point Tracking (MPPT) algorithms. Mummadi Veerachary has given a detailed report on the use of a SEPIC converter in the field of photovoltaic power control. In his report he utilized a two-input converter for accomplishing the maximum power extraction from the solar cell. M. G. Villalva in his both reports has presented a comprehensive method to model a solar cell using Simulink or by writing a code. His results are quite similar to the nature of the solar cell output plots.

P. S. Revankar has even included the variation of sun's inclination to track down the maximum possible power from the incoming solar radiations. The control mechanism alters the position of the panel such that the incoming solar radiations are always perpendicular to the panels. M.Berrera has compared seven different algorithms for maximum power point tracking using two different solar irradiation functions to depict the variation of the output power in both cases using the MPPT algorithms and optimized MPPT algorithms. Ramos Hernanz has successfully depicted the modeling of a solar cell and the variation of the current-voltage curve and the power-voltage curve due the solar irradiation changes and the change in ambient temperature.

CHAPTER 3

3.1 PHOTOVOLTAIC TECHNOLOGY

3.1.1 INTRODUCTION TO PHOTOVOLTAIC TECHNOLOGY

Photovoltaic (PV) systems have been used for many decades. Today, with the focus on greener sources of power, PV has become an important source of power for a wide range of applications. Improvements in converting light energy into electrical energy as well as the cost reductions have helped create this growth. Even with higher efficiency and lower cost, the goal remains to maximize the power from the PV system under various lighting conditions.

Unfortunately, PV generation systems have two major problems: the conversion efficiency of electric power generation is very low (9÷17%), especially under low irradiation conditions, and the amount of electric power generated by solar arrays changes continuously with weather conditions.

Moreover, the solar cell V-I characteristic is nonlinear and varies with irradiation and temperature. In general, there is a unique point on the V-I or V-P curve, called the Maximum Power Point (MPP), at which the entire PV system (array, converter, etc…) operates with maximum efficiency and produces its maximum output power. The location of the MPP is not known, but can be located, either through calculation models or by search algorithms. Therefore Maximum Power Point Tracking (MPPT) techniques are needed to maintain the PV arrays operating point at its MPP.

3.2 BASIC BLOCK DIAGRAM

The basic block diagram is as shown in figure 3.1.It consists of Solar panel, DC-DC power converter, MPPT controller, Load. Initially voltage and current from the solar panel is sensed by using voltage and current sensor.

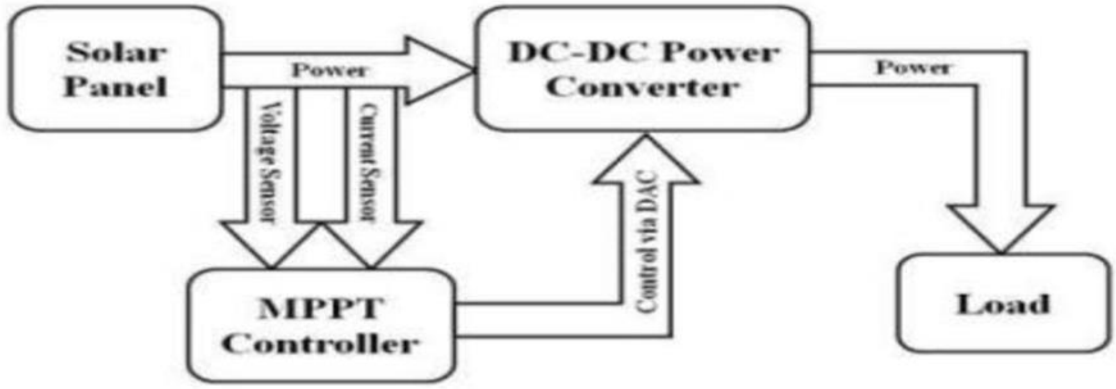


Figure 3.1 Basic block diagram

These voltage and current values can be input to the MPPT controller. Later these values can be proceeded according into the MPPT algorithm used to track the maximum power point of solar panel. The output of MPPT block is used as input to DC-DC converter which may be voltage parameter or duty cycle. DC-DC converter helps in maintaining the operating voltage at the maximum power point. By varying the duty cycle of DC-DC converter.

Usually Buck, Boost, Buck- Boost configuration is used according to requirement. In this system Boost converter is used to step up the operating voltage at the maximum power point. DC-DC power converter is connected between the solar panel and load. The heart of the model is the MPPT block which helps in finding the maximum operating point of solar panel. This can be done by using MPPT algorithms. Which in turn gives gating signal to Boost converter which maintains the operating voltage at the maximum operating point irrespective of solar irradiance and temperature.

3.3 MAXIMUM POWER POINT TRACKING (MPPT)

Maximum Power Point Tracking, frequently referred to as MPPT, is an electronic system that operates the Photovoltaic (PV) modules in a manner that allows the modules to produce all the power they are capable of. MPPT is not a mechanical tracking system that “physically moves” the modules to make them point more directly at the sun.

MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power. Additional power harvested from the modules is then made available as increased battery charge current. MPPT can be used in conjunction with a mechanical tracking system, but the two systems are completely different. The P&O and IC techniques are the most widely used.

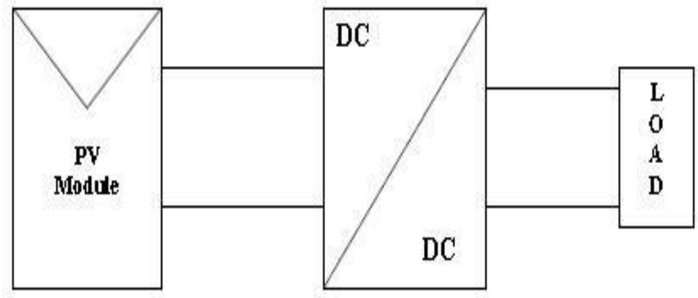


Fig. 3.2. Block diagram of Typical MPPT system

3.3.1 SYSTEM CONFIGURATION

Solar cell convert sunlight directly to dc power. Photovoltaic cell generates electricity from the sun. PV panel works under the phenomenon of photoelectric effect. When solar cell are exposed to sunlight , it converts solar energy into electrical energy.

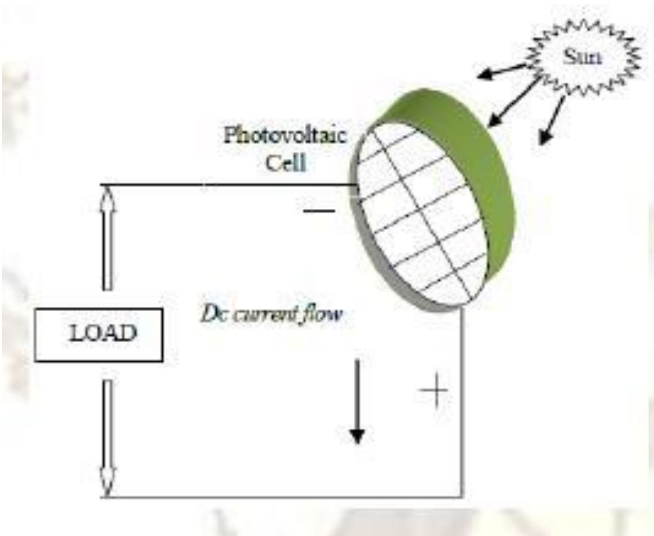


Fig 3.3. Photovoltaic cell

The system configuration for the topic is as shown figure 2. Here the PV array is a combination of series and parallel solar cells. This array develops the power from the solar energy directly and it will be changes by depending up on the temperature and solar irradiances.

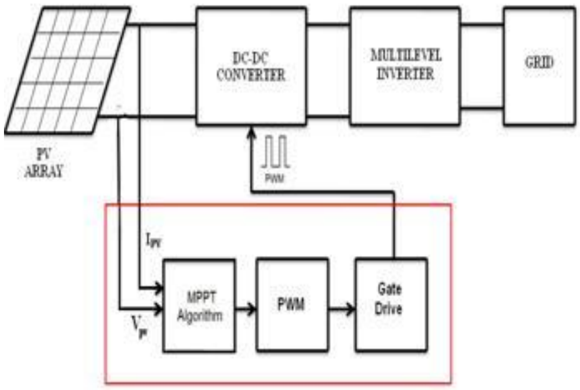


Fig. 3.4. System Configuration of PV System

So we are controlling this to maintain maximum power at output side we are boosting the voltage by controlling the current of array with the use of PI controller. By depending upon the boost converter output voltage this AC voltage may be changes and finally it connects to the utility grid that is nothing but of a load for various applications. Here we are using Five-level H-Bridge Cascade multilevel inverter to obtain AC output voltage from the DC boost output voltage.

3.3.2 ROLE OF MPPT IN PV SYSTEM

Photovoltaic systems normally use a maximum power point tracking (MPPT) technique to continuously deliver the highest possible power to the load when variations in the isolation and temperature occur, Photovoltaic (PV) generation is becoming increasingly important as a renewable source since it offers many advantages such as incurring no fuel costs, not being polluting, requiring little maintenance, and emitting no noise, among others. PV modules still have relatively low conversion efficiency; therefore, controlling maximum power point tracking (MPPT) for the solar array is essential in a PV system. The Maximum Power Point Tracking (MPPT) is a technique used in power electronic circuits to extract maximum energy from the Photovoltaic (PV) Systems. In the recent days, PV power generation has gained more importance due its numerous advantages such as fuel free, requires very little maintenance and environmental benefits. To improve the energy efficiency, it is important to operate PV system always at its maximum power point. Many maximum power point Tracking (MPPT) techniques are available and proposed various methods for obtaining maximum power point. But, among the available techniques sufficient comparative study particularly with variable environmental conditions is not done. This paper is an attempt to study and evaluate s60e main types of MPPT techniques namely, Open-circuit voltage and Short-circuit current, P&O, IC etc.

A solar cell basically is a p-n semiconductor junction. When exposed to light, a dc current is generated. The generated current varies linearly with the solar irradiance. The standard equivalent circuit of the PV cell is shown in Fig.1.

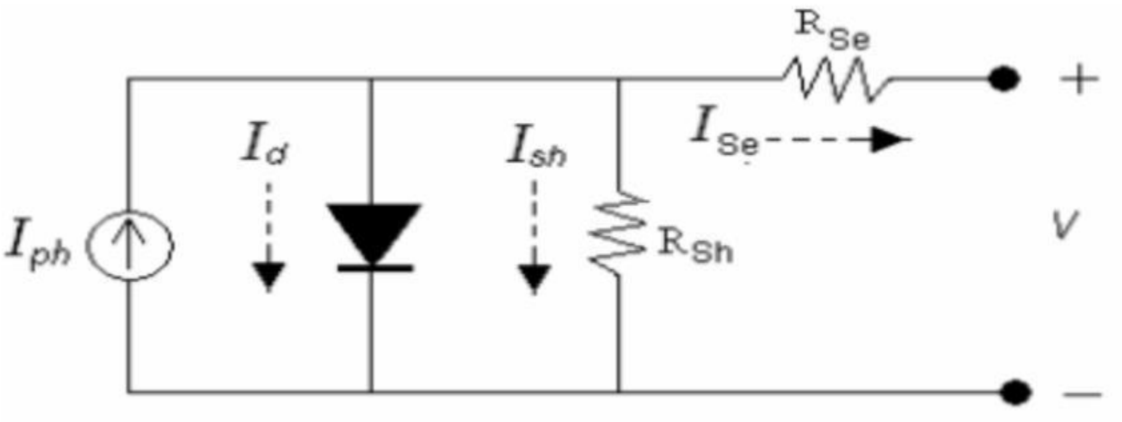


Figure 3.5. Equivalent circuit of PV cell

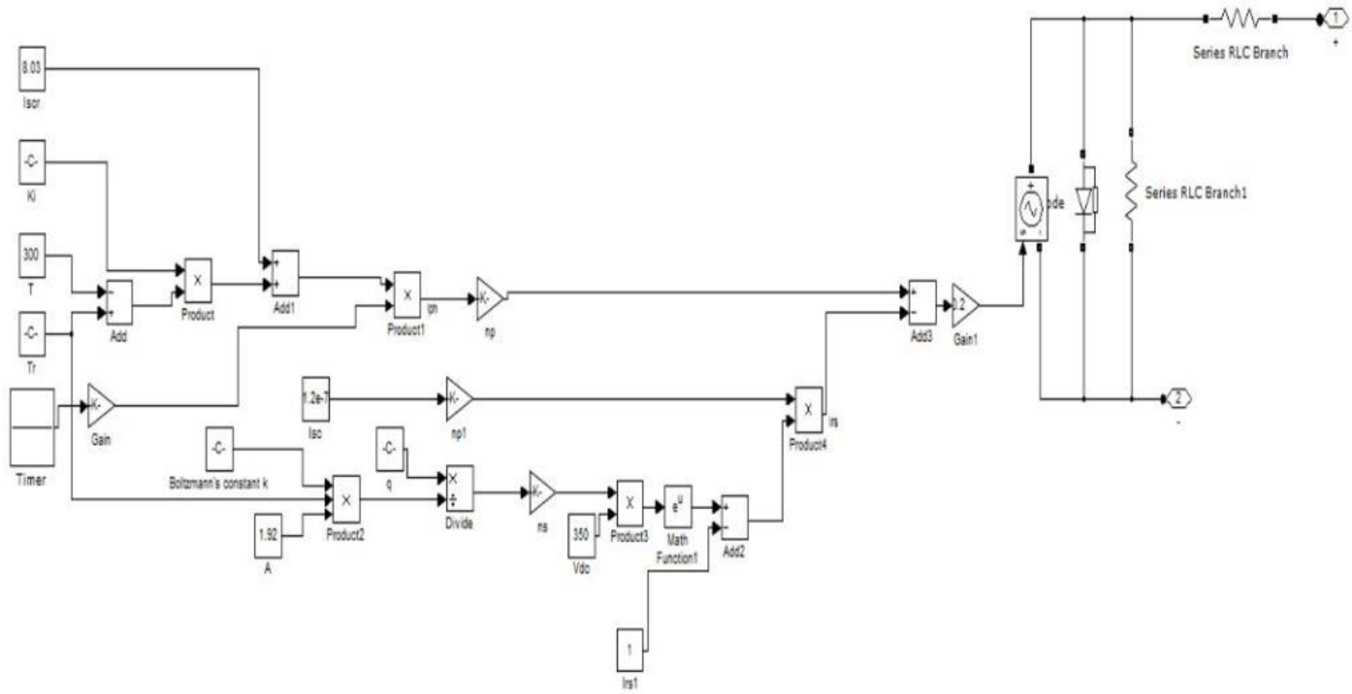
The basic equation that describes the I-V Characteristics of the PV model is given by the following equation:

$$I = I_L - I_o\left(e^{\frac{q(V+IR_s)}{kT}} - 1\right) - \frac{V + IR_s}{R_{sh}}$$

Where:

I	Cell Current (A).
I_L	Light Generated Current (A).
I_o	Diode Saturation Current.
Q	Charge of Electron = 1.6x10-19 (Coul).
K	Boltzmann Constant (J/K)
V	Cell Output Voltage (V)
R_s , R_{sh}	Cell Series and Shunt Resistance (Ohms).

This equation shows the dependence of PV current on temperature and hence the dependence of power drawn from the PV array.



3.6. Simulation block

In this system we take Iscr,Kv(Ki),Vr(T),V(Tr) as inputs

Where,

Iscr = short circuit current

Kv (Ki) = short circuit current of cell at 25°C & 1000 W/m2

Vr (T) = Operating temperature (k)

V (Tr) = Reference temperature

1. Standard Equation for Iph

$$I_{ph} = [I_{sc} + K_i(T - 298)] \times Ir/1000$$

Eq no3.3

Where,

Iph = Photo current

Hence for this equation

We take Iscr, Ki and difference between operating temperature & reference temperature

So we get

Iph = Isc + Ki (T-298) * Ir/1000 eq no 3.4

2. Standard equation for Irs

$$I_{rs} = I_{sc}/[\exp(qV_{OC}/N_S knT) - 1]$$

eq no 3.5

Where,

Irs = reverse saturation current

q=electron charge =1.60*10-19

Voc= open circuit voltage (v)

Ns= no. of cells connected in series

n=the ideality factor of the diode

k=Boltzmann’s constant=1.3805*10-23

so we add both currents Iph & Irs & gives to the our source.

3.3.3 BOOST CONVERTER

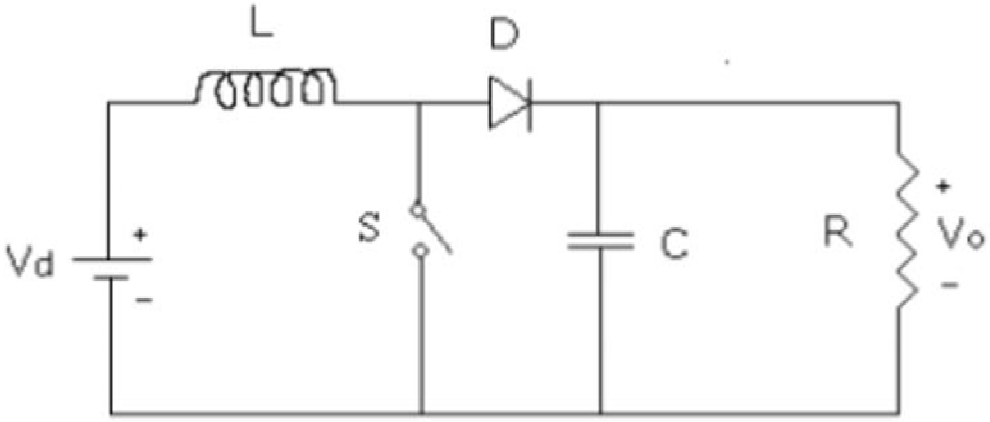


Figure 3.7. Schematic diagram of Boost converter

Boost converter is also called as the step up converter as output of Boost converter is always greater than that of the input. Figure 3.5 shows the schematic diagram of Boost converter.

3.4 INCRIMENTAL CONDUCTANCE MPPT TECHNIQUE

The disadvantage of the perturb and observe method to track the peak power under fast varying atmospheric condition is overcome by IC method . The IC can determine that the MPPT has reached the MPP and stop perturbing the operating point. If this condition is not met, the direction in which the MPPT operating point must be perturbed can be calculated using the relationship between dl/dV and –I/V This relationship is derived from the fact that dP/dV is negative when the MPPT is to the right of the MPP and positive when it is to the left of the MPP. This algorithm has advantages over P&O in that it can determine when the MPPT has reached the MPP, where P&O oscillates around the MPP. Also, incremental conductance can track rapidly increasing and decreasing irradiance conditions with higher accuracy than P and O.

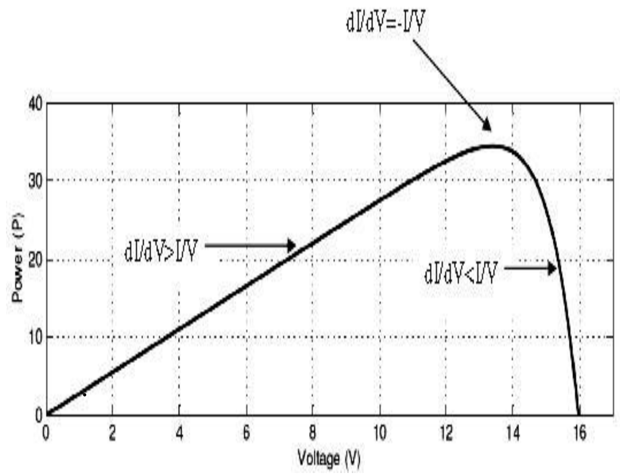


Fig. 3.8. Graph Power versus Voltage for IC Algorithm

Fig-4 shows that the slope of the P-V array power curve is zero at The MPP, increasing on the left of the MPP and decreasing on the Right hand side of the MPP. The basic equations of this method are as follows.

$$\frac{dI}{dv} = -\frac{I}{V} \quad \text{At MPP} \quad (1)$$

$$\frac{Di}{dv} > -\frac{I}{V} \quad \text{Left of MPP} \quad (2)$$

$$\frac{dI}{Dv} < -\frac{I}{V} \quad \text{Right of MPP} \quad (3)$$

3.4.1 INCRIMENTAL CONDUCTANCE MPPT ALGORITHM

This method exploits the assumption of the ratio of change in output conductance is equal to the negative output Conductance Instantaneous conductance. We have,

$$P = V\,I$$

Applying the chain rule for the derivative of products yields to

$$\partial P/\partial V = [\partial(VI)]/\,\partial V$$

At MPP, as $\partial P/\partial V=0$

The above equation could be written in terms of array voltage V and array current I as

$$\partial I/\partial V = - I/V$$

The MPPT regulates the PWM control signal of the dc – to – dc boost converter until the condition: $(\partial I/\partial V) + (I/V) = 0$ is satisfied. In this method the peak power of the module lies at above 98% of its incremental conductance. The Flow chart of incremental conductance MPPT is shown below.

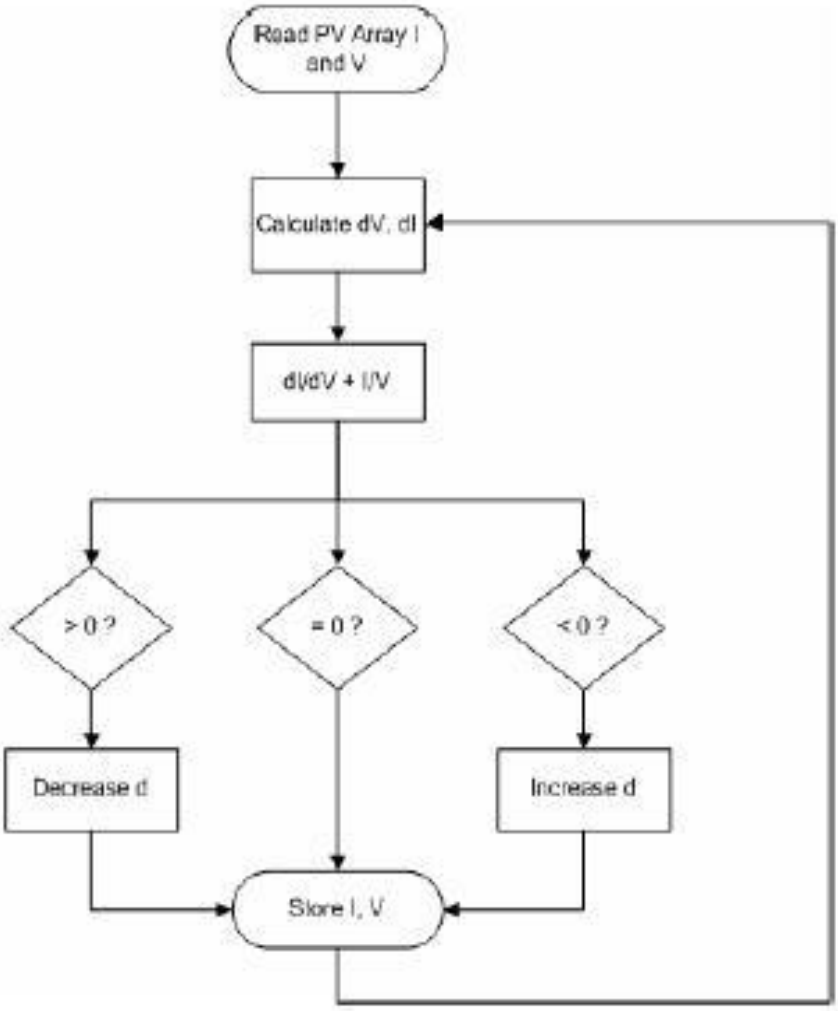


Fig.3.9. Algorithm

3.4.2 SIMULATION CIRCUIT

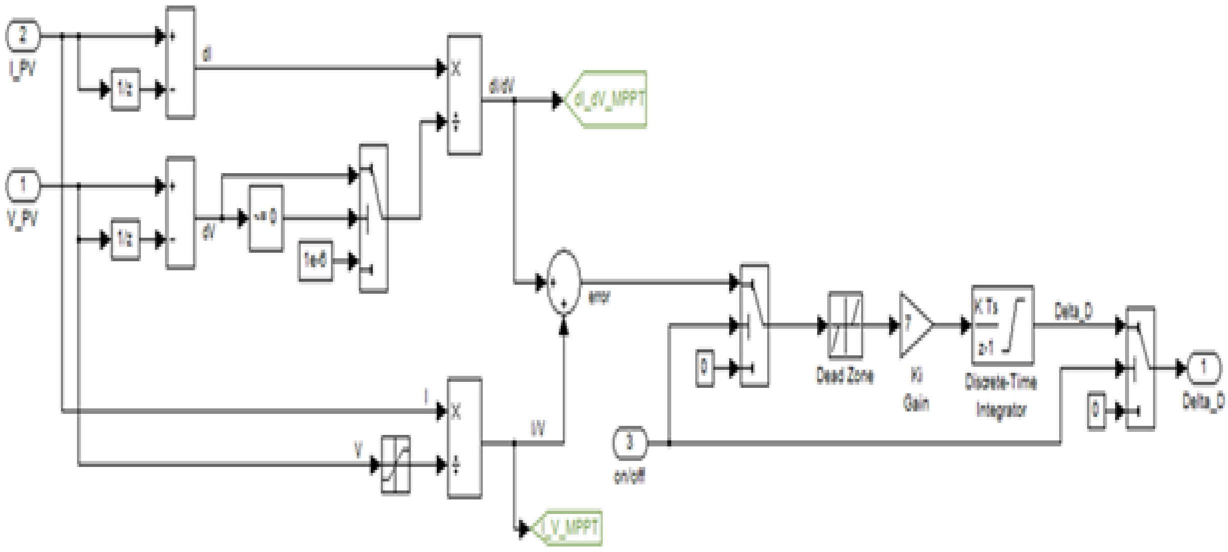


Fig.3.10. Simulation Circuit

CHAPTER 4

4.1 FACTORS REQUIRED TO IMPLEMENT THE EMS

The characteristics of various factors such as the PV system, residential loads, and nighttime electricity price, which are required to implement the EMS by the 4-kW residential PV HPCS, are examined in this section. Note that it is difficult to predict the exact amount of power generated from the PV system according to the variations of insolation and temperature, although they are measured in real time by sensors, so is the forecasting of accurate load demand during 24 h. Therefore, the proposed EMS is implemented based on inevitable assumptions and restrictions, which are described in the following.

4.1.1 CHARACTERISTIC OF THE PV SYSTEM

The time reference for EMS operation is established based on the amount of PV power, which also varies according to time periods. In addition, its operation is determined by comparing the current power generated from the PV system depending on weather conditions with its monthly average value. Based on the practical measurements during june 2011, the data in figure 4.1 give the percentages of daily output powers from the PV system and its average value with respect to its rated power. It is not surprising that the daily output powers on sunny days are higher than the average power at daytime, and the opposite applies to cloudy days. In summary, instead of predicting the exact amount of power from the PV system, the EMS operation can be performed by comparing the instantaneously measured power outputs from the PV system with their average value.

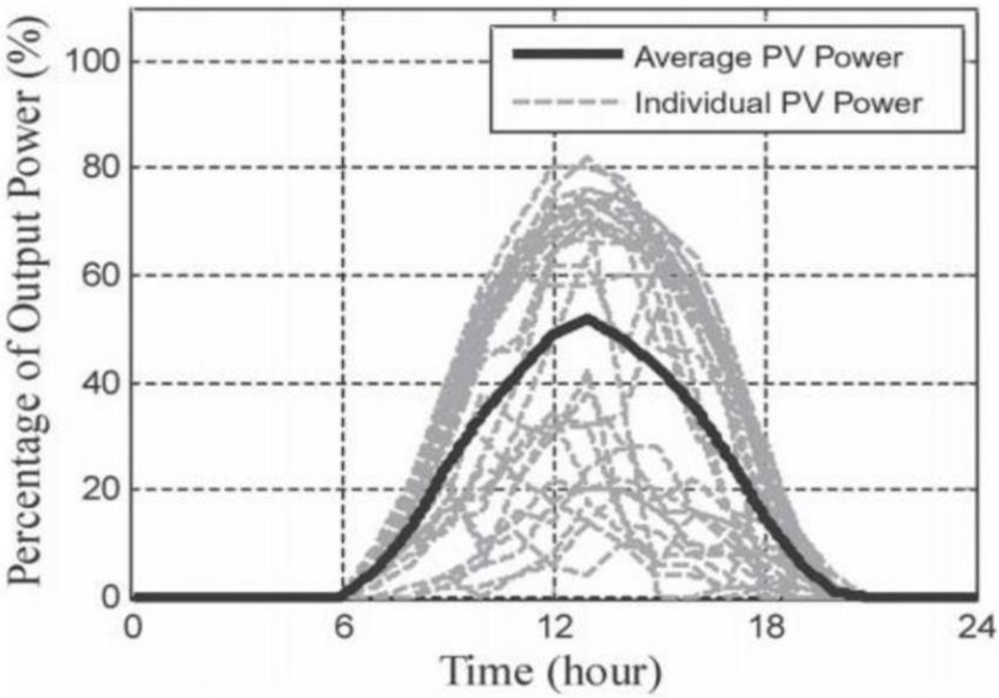


Figure 4.1: Percentages of daily output powers from the PV system and their average value with respect to its rated power during June 2011.

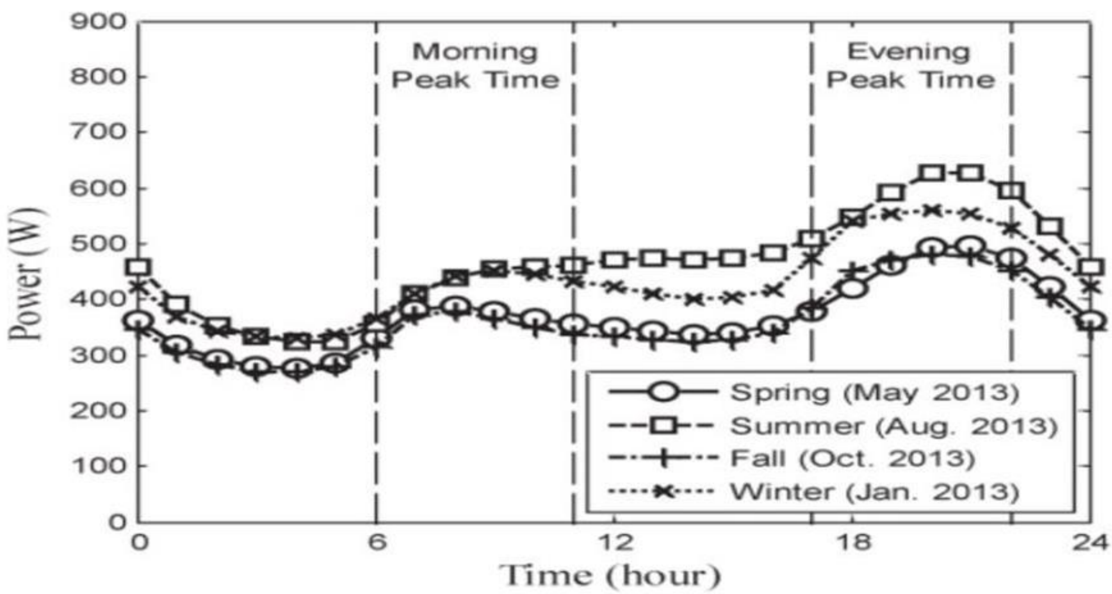


Figure 4.2: Average seasonal residential load variations in South Korea.

4.1 2 CHARACTERISTIC OF RESIDENTIAL LOADS

In general, the charging and discharging operations of the ESD in an EMS system might be adjusted according to the load variations, which are characterized by the amount of power consumed in household. However, as previously mentioned, the accurate forecasting of instantaneous load demands is not possible. Therefore, in this study, the load variation is referred by the analysis on statistics of residential electric power consumptions, which are obtained from the survey carried out in 2013. The average seasonal residential load variations in South Korea are shown in figure 4.2 The data have been obtained during one year from January 2013 to December 2013. Differently from the expectation that the national peak load might occur at around 14:00 in daytime, the peak load of residential houses for all seasons occurs at around 21:00 in nighttime. In particular, it is inferred that TV and air conditioners are mainly used at evening in summer.

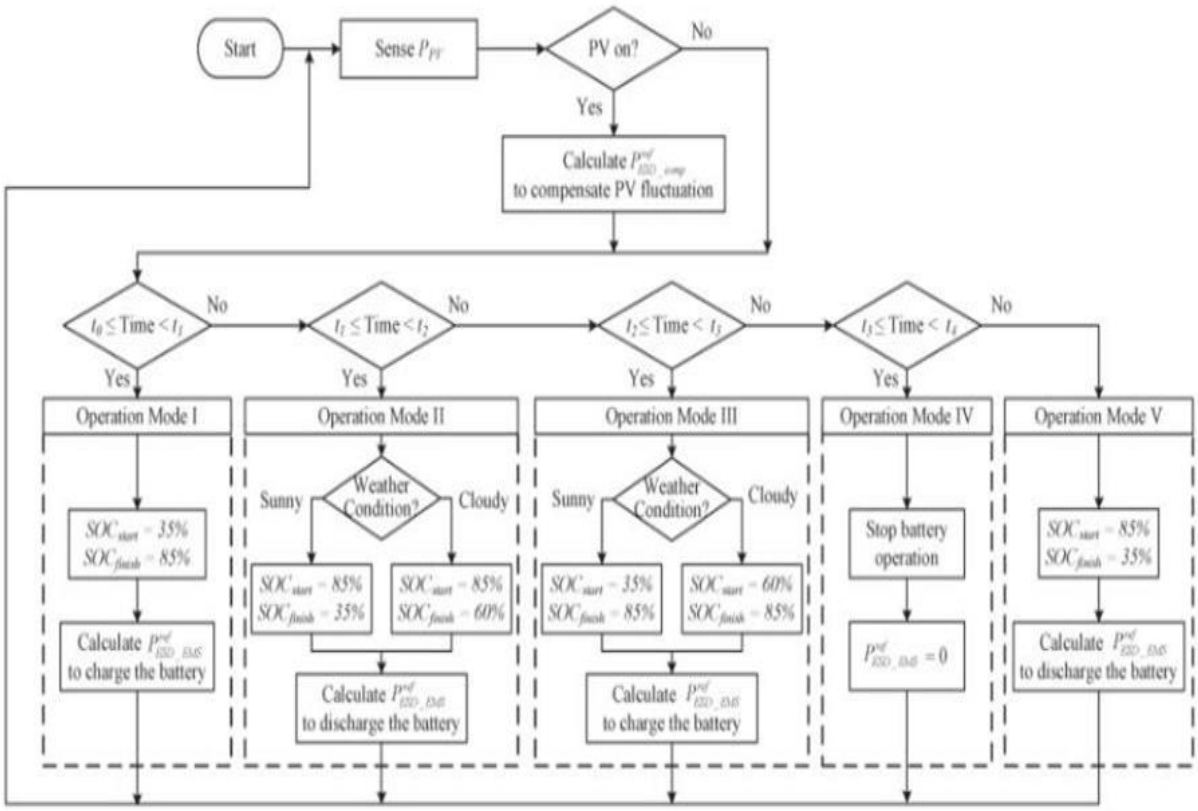


Figure 4.3: Proposed EMS algorithm.

As a result, to apply the proposed 4-kW residential HPCS, the lithium-ion battery used as the ESD must supply real power at the peak load by discharging its energy at night. In contrast, it must charge the energy from the PV system in daytime to prevent the large amount of power from flowing to the grid in the relatively light load condition. Therefore, this can also result in suppressing the rise of grid voltage. Note that the lithium-ion battery has a low self-discharge rate of 1%–5%, a high energy density of 100–200 wh/kg, and a long lifetime of 500–10 000 cycles. Moreover, its cost keeps decreasing to $200 U.S. dollars per kilowatt hour by 2020.

4.1.3 NIGHTTIME ELECTRICITY PRICE

The proposed EMS can also give the economic benefits to customers by managing the nighttime electricity with the relatively low price. In other words, the load demand is low in the time period from 24:00 at night to 08:00 in the morning of the next day, as shown in figure 4.2. Note that the residential electricity price of South Korea applies the progressive tax rate, and the RTP is not currently used. Nevertheless, it is expected that the RTP system will be applied in the near future. In this case, the proposed EMS can provide the economic benefits to customers by reducing the electricity price of about 40%–45% with the low electricity price at nighttime.

4.2 PROPOSED EMS ALGORITHM

The proposed EMS algorithm is shown in figure 4.3. First, it measures the output power of the PV system PPV and calculates the reference power of the ESD PESD ref _comp required to compensate for the fluctuations of PPV. Then, it sets the reference times (t0, t1, t2, t3, and t4) to perform their suitable functions in the corresponding five operation modes. Each reference time might be slightly changed depending on the average power from the PV system in every month and season. Then, the proposed EMS determines its operation modes described below, taking into account the change in state-of charge (SOC) of the ESD and the information of average seasonal peak day load variation.

4.2.1 OPERATION MODEI (T0-T1)

This operation mode is applied to the time period between t0 and t1, which are 01:00 and 06:00, respectively. The PV system stops generating the power, and the amount of load demand is relatively low. Therefore, the electricity price at this time is low, and the ESD is then charged with the energy from the grid by its SOC from 35% to 85%. Finally, the reference power used in the implementation of the EMS, i.e., PESDref _EMS, is calculated.

4.2.2 OPERATION MODE II (T1-T2)

In this operation mode, the time references t1 and t2 are 06:00 and 11:00, respectively. That is, the PV system starts generating the power from 06:00. However, the amount of its generated power is small. Therefore, the ESD is discharged in this operation mode to assist the mid load in the morning. The change in SOC depends on weather conditions, which are described in Section II-A. In the case of a cloudy day, it is changed from 85% to only 60%. This is because the bigger charging energy cannot be expected in the next operation mode when compared to that of a sunny day.

4.2.3 OPERATION MODE III (T2-T3)

In this operation mode from 11:00 (t2) to 16:00 (t3), the ESD is charged again with the real power supplied from the PV system. Therefore, this reduces the fluctuations of grid voltage, which might occur when all powers generated from the PV system flow to the grid. Moreover, the stored energy in the ESD will be used in the next operation mode V, which has the peak load in household. Likewise in the previous operation mode II, the change in SOC depends on weather conditions. In other words, it is changed from 60% to 85% and from 35% to 85% in cloudy and sunny days, respectively. Note that the upper (85%) and lower (35%) limits of SOC are used for the safe operation of the lithium-ion battery in real-time hardware implementation.

4.2.4 OPERATION MODE IV (T3 -T4)

From 16:00 (t3) to 18:00 (t4), the EMS stops the ESD's operation because it requires charging fully for the peak load in the next operation mode V. Therefore, the value of PESDref _EMS is zero.

4.2.5 OPERATION MODE V (T4-T5)

In this operation mode from 18:00 (t4) to 01:00 (t5, which is the same as t0) in the next day, the load consumption is kept increasing. The ESD starts discharging until its SOC reaches the lower limit of 35%, so that the EMS deals with the evening peak load in household. This relieves the power usage from the grid and therefore provides the economic benefits to the customers because the electricity price is relatively high. In addition, by consuming all energies during this time period, the ESD is ready to charge again in the next operation mode with the low cost at dawn.

4.3. POWER COMPENSATION AND CONTROL OF THE ESD

4.3.1. COMPENSATION OF OUTPUT POWER FLUCTUATIONS

Output power fluctuations result in frequency deviation and reduction in reliability of the microgrid when the large amount of power from the PV system is penetrated to the grid.

This problem becomes serious if many residential PV systems are operated at the same time. According to the grid-code standards, it is allowed to inject all their generated powers into the grid unless any regulations of the system are violated. Otherwise, the utility might request the system owner to smooth out the power fluctuations from the PV system or to restrict its generations to a certain limit. The use of the ESD gives the most effective and suitable solution to deal with this problem, although it requires scarifying the extra costs. The reference power compensated by the ESD, i.e., Pref ESD_comp, can be computed by filtering, as expressed in equation 4.1. Thus, the output power fluctuations, which exhibit dynamic behaviors over the cutoff frequency of high-pass filter, are reduced, i.e.,

$$P_{\mathrm{ESD\_comp}}^{\mathrm{ref}} = \frac{\tau s}{1+\tau s} P_{\mathrm{PV}} \quad \text{.........(4.1)}$$

where τ is the time constant related to cutoff frequency. In general, the power fluctuations within 600 s affect the variations of grid frequency. Then, the network operator can comfortably react in the time range over 600 s by adjusting powers from other sources. Therefore, the cutoff frequency is 0.0016 Hz, and the τ is set to be 100 s in this study.

4.3.2 ESD CONTROL IN THE EMS

When the ESD is used in the EMS, the sufficient flexibility and reserves should be available for its safe and reliable realtime operation [24]. For this purpose, the proper ramp rate is required to apply when it charges or discharges. For example, the stepwise (therefore nonsmooth) reference methods, which were used in conventional studies of the EMS, could have the negative effect on the ESD, particularly for the battery life. In other words, the gradual and smooth changes in charging and discharging operations are necessary. Therefore, the reference power of the ESD used in the EMS, i.e., PESDref _EMS, is formed with the second-order polynomial function as in equation 4.2 to apply the smooth changes in energy, i.e.,

$$P_{\mathrm{ESD\_EMS}}^{\mathrm{ref}}(t) = a(t-t_{\mathrm{start}})^2 + b(t-t_{\mathrm{start}}) + c \quad \text{........(4.2)}$$

where a, b, and c are coefficients. In addition, tstart is the time when each operation mode (described in Section III) starts. Then, the amount of reference energy EESDref _EMS, which are charged or discharged in the ESD, is calculated as

$$E^{\mathrm{ref}}_{\mathrm{ESD\_EMS}} = \int_{t_{\mathrm{start}}}^{t_{\mathrm{finish}}} P^{\mathrm{ref}}_{\mathrm{ESD\_EMS}}(t)dt$$
………(4.3)

where t_{finish} is the time when each operation mode is finished. It can be also computed with the changes in SOC of ESD as

$$E^{\mathrm{ref}}_{\mathrm{ESD\_EMS}} = \frac{\mathrm{SOC}_{\mathrm{start}} - \mathrm{SOC}_{\mathrm{finish}}}{100} \times \mathrm{Capacity}_{\mathrm{battery}}$$
……..(4.4)

where Capacity battery is the battery energy capacity in kWh. Finally, each coefficient is derived as

$$a = \frac{6E^{\mathrm{ref}}_{\mathrm{ESD\_EMS}}}{t^3_{\mathrm{period}}} - \frac{3P^{\mathrm{ref}}_{\mathrm{ESD\_EMS}}\left(t^{-}_{\mathrm{start}}\right)}{t^2_{\mathrm{period}}}$$
...…..(4.5)

$$b = -at_{\mathrm{period}} - \frac{P^{\mathrm{ref}}_{\mathrm{ESD\_EMS}}\left(t^{-}_{\mathrm{start}}\right)}{t_{\mathrm{period}}}$$
……..(4.6)

$$c = P^{\mathrm{measured}}_{\mathrm{ESD}}$$
……. (4.7)

where t period is the time duration between tstart and tfinish for each operation mode (i.e., $t_{period} = t_{finish} - t_{start}$). In addition, t−start indicates the last time step of the previous operation mode right before the present mode starts. PESDmeasured is the measured power output of the ESD. Note that tstart and tfinish can be changed to the proper times according to weather conditions. This enables generating the smooth reference signal required in the ESD regardless of the changes in operation mode and/or weather condition the responses of PESDref _EMS by the conventional and proposed control methods when the ESD discharges and hereafter charges the energy of 1 kWh during 3 h for each operation. It is observed that the stepwise nonsmooth behavior disappears by

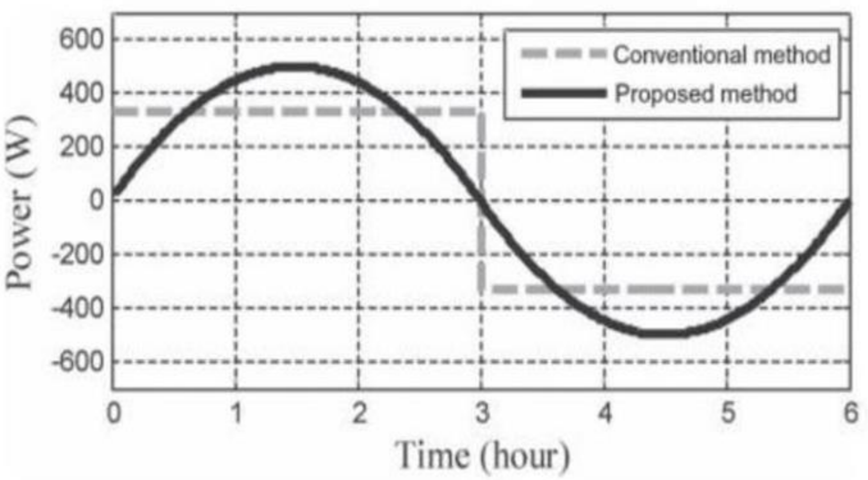


Figure 4.4: Reference powers of the ESD used in the EMS by the conventional and proposed control methods

the proposed method. This makes it possible to operate the EMS with the ESD more safely and reliably. Moreover, more energy can be effectively saved and used when the PV system generates its maximum power in daytime and the load reaches its peak point in the evening, respectively. Finally, the total reference power output from the ESD, i.e., Pref ESD, is obtained as equation 4.8 by considering the compensation of output fluctuations from the PV system and each operation mode in the EMS, i.e.,

$$P^{\mathrm{ref}}_{\mathrm{ESD}}(t) = P^{\mathrm{ref}}_{\mathrm{ESD\_comp}}(t) + P^{\mathrm{ref}}_{\mathrm{ESD\_EMS}}(t). \qquad \text{………(4.8)}$$

4.3.3 SIMULATION RESULTS

The performance of the EMS by the proposed residential PV HPCS is evaluated by the case study based on the simulation with MATLAB software. The HPCS with the rated power of 4 kW has the lithium-ion battery of 130 V–30 Ah. In addition, the actual PV generation PPV and load consumption PLoad are simulated with the measured data, the output power of the HPCS, i,e. Pinv,. The total of 48 h for simulation consists of the first sunny day and the second cloudy day, that the SOC of the battery is in the range from 35% to 85% for its safety. As described in the proposed EMS algorithm in figure 4.3 of, the battery charges before 06:00 in the morning. After that, it starts to discharge until 11:00. However, this amount of discharged energy depends on the weather condition if it is sunny or cloudy.

Then, it recharges until it has the SOC of about 85% from 11:00 to 16:00 during daytime. Thereafter, the battery discharges in the evening from 18:00 to 01:00 in the next day. As a result, the corresponding response of PESDref. It is observed that the ESD of the proposed system successfully controls to generate the smooth reference power, whereas the conventional stepwise EMS outputs the nonsmooth reference power. Finally, the output power of the HPCS Pout flowing to the grid. At 13:00, the maximum value of Pout is controlled not to exceed about 80% of maximum PV generation without the proposed EMS, so that the remaining generated power is supplied to the load and charged to the ESD. In addition, it is important to note that the conventional EMS by using the stepwise reference method causes the most serious abrupt change in Pout at 11:00 and the other sudden nonsmooth behaviors whenever the operation mode is changed at 01:00, 06:00, 16:00, 18:00, 25:00, 30:00, 35:00, 40:00, and 42:00.

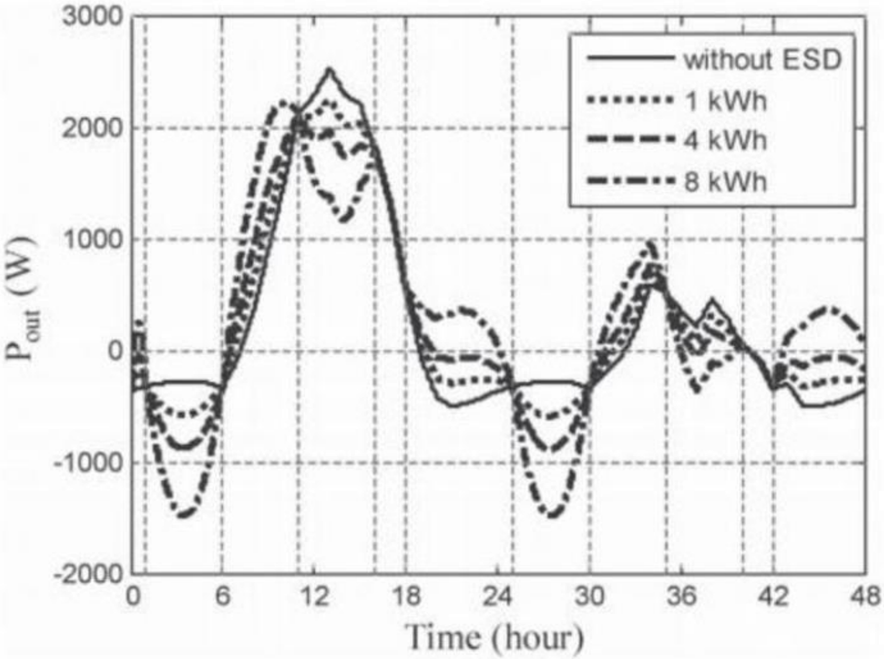


Figure 4.5: Responses of Pout corresponding to different sizes of the battery.

On the other hand, the responses of Pout corresponding to different sizes of the battery are compared. It is not surprising that the more power flows to the ESD in charging operation when its size increases. This might provide a chance to obtain more economic benefits to customers at dawn. In particular, this can reduce the grid voltage variations during daytime. For example, the peak value of Pout is reduced by 20% from 2.5 kW without the ESD to 2 kW with the battery of 4 kWh. It is clearly observed that more reduction can be achieved by the battery of 8 kWh. However, the bigger the battery, the larger the cost. Therefore, the battery of 4 kWh is suitably selected in this study.

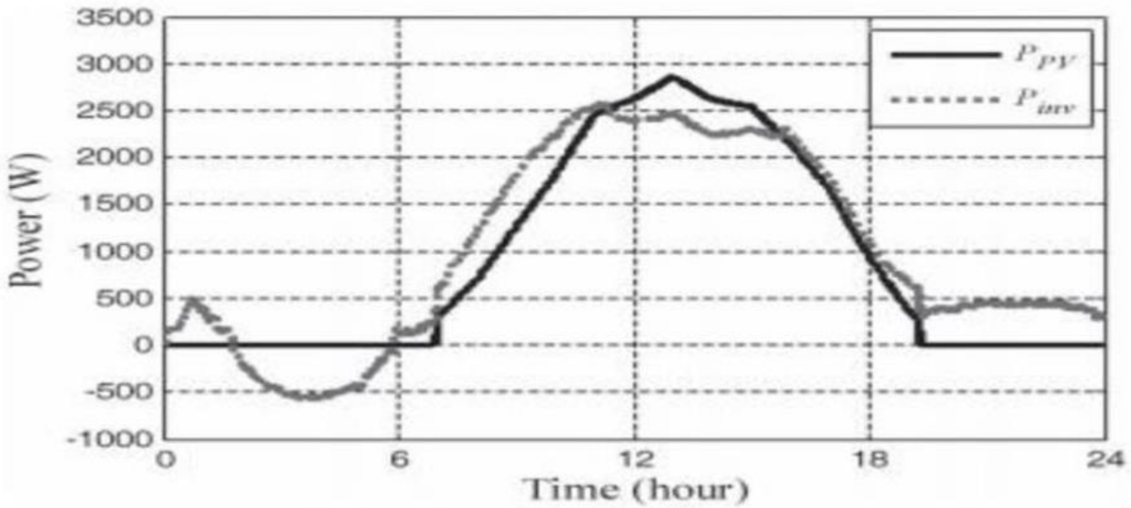


Figure 4.6: Responses of Ppv and Pinv on a sunny day

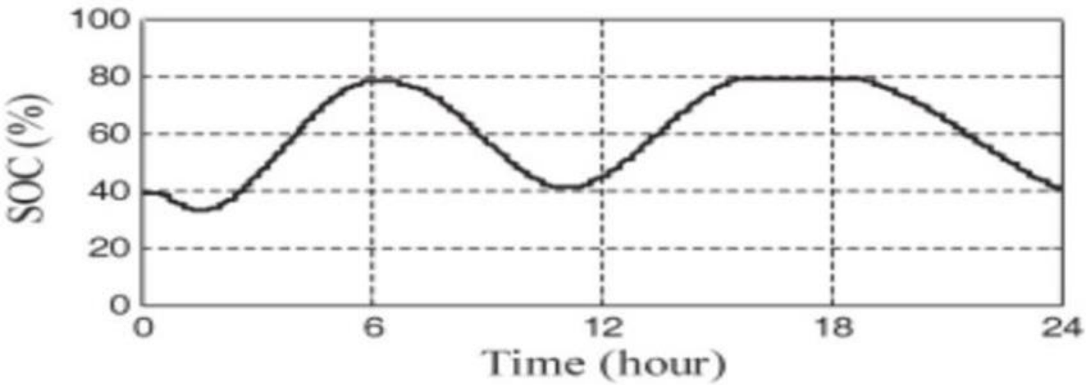


Figure 4.7: Variations of SOC on a sunny day

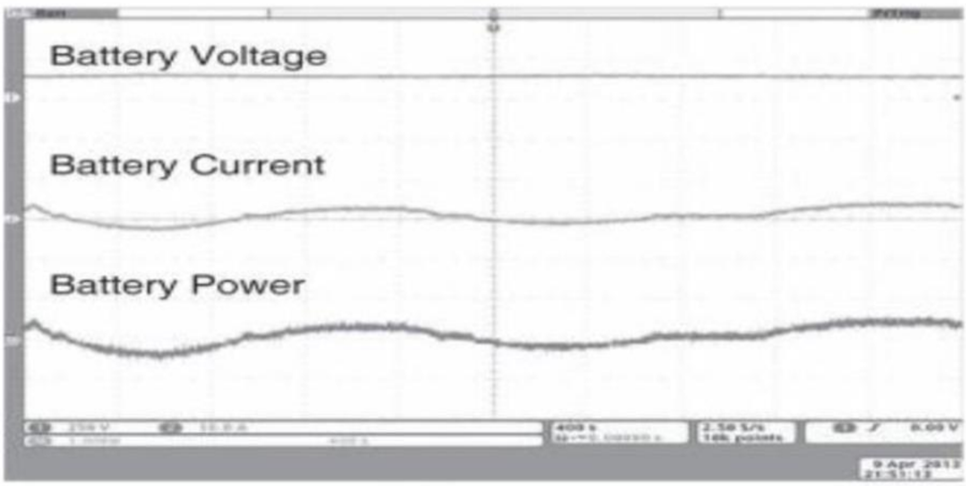


Figure 4.8: Responses of output voltage, output current, and output power of the battery on a cloudy day

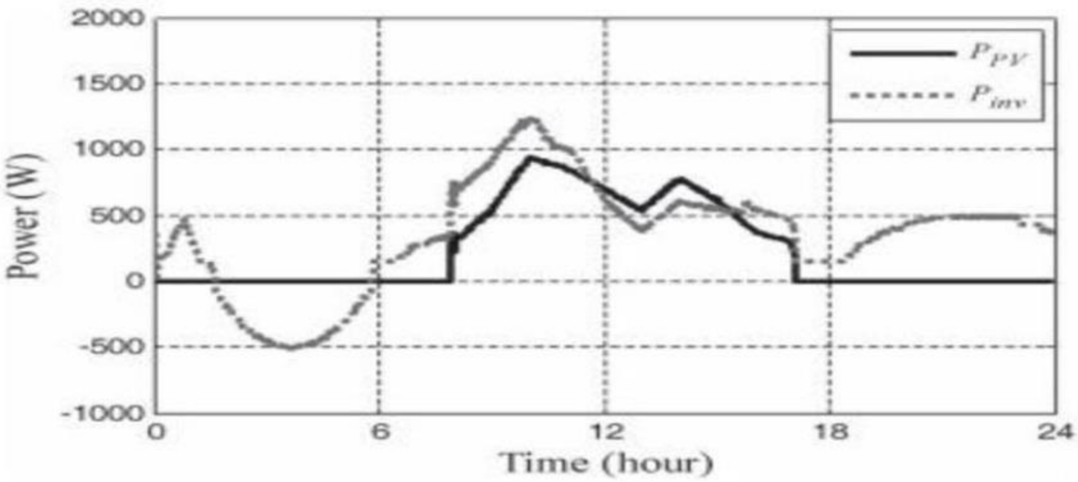


Figure 4.9: Responses of Ppv and Pinv on a cloudy day

The responses of output voltage, output current, and output power of the battery on a cloudy day. They all show similar characteristics. The responses of PPV and Pinv are and in Pinv has the peak value of 1.2 kW at around 10:00, which is larger than the value of PPV. This results from the discharging operation of the battery. However, the peak value of PPV at 14:00 is still higher than that of Pinv at 14:00. Similarly to the result of sunny day, Pinv is the same as the output power of the battery before 07:53 and after 17:06, when the PPV is suddenly changed. The corresponding SOC variations are shown in figure 4.10. It is observed that the amount of discharging energy between 06:00 and 11:00 is less than that in sunny day. Note that the experimental results for PPV, Pinv, and SOC are in close agreement with the simulation results.

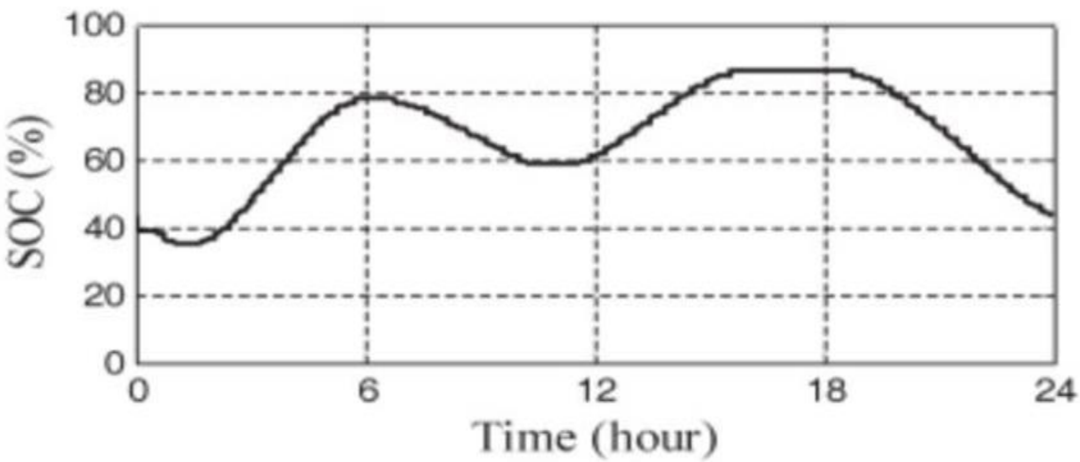


Figure 4.10: SOC

CHAPTER 5

5.1 SIMULATION BLOCK AND OUTPUT

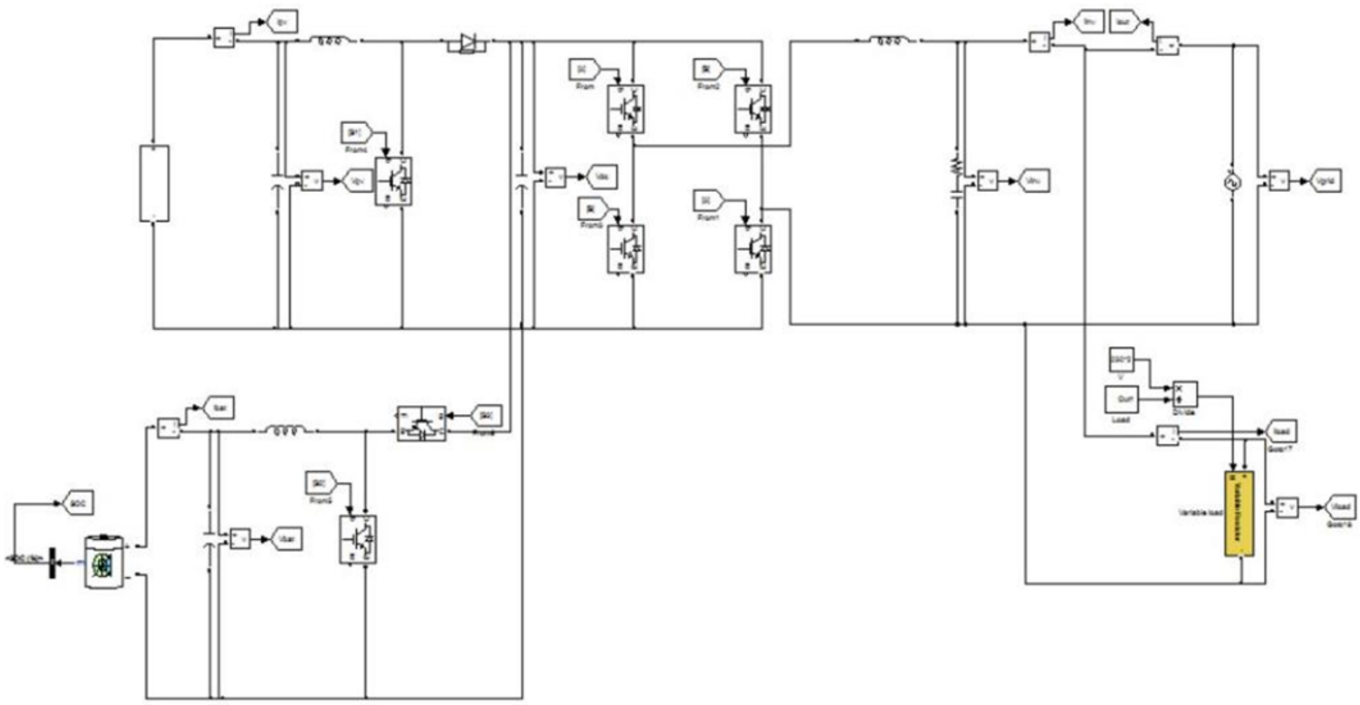


Figure 5.1 Simulation block

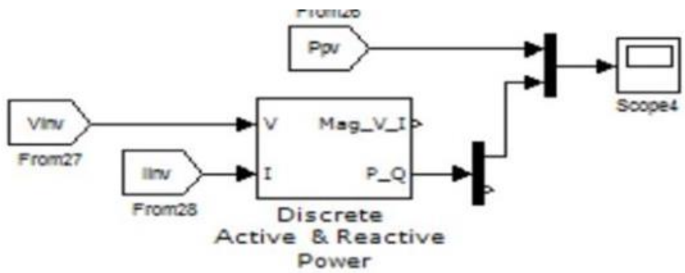


Figure 5.2 PrefESD and time output

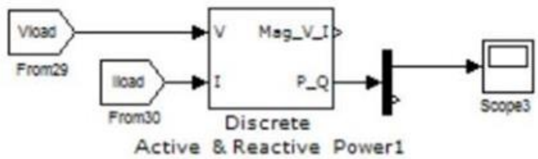


Figure 5.3 Output of SOC

Figure 5.4 SOC output

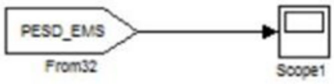


Figure 5.5 ESD output

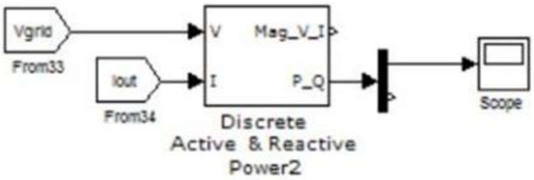


Figure 5.6 Grid power

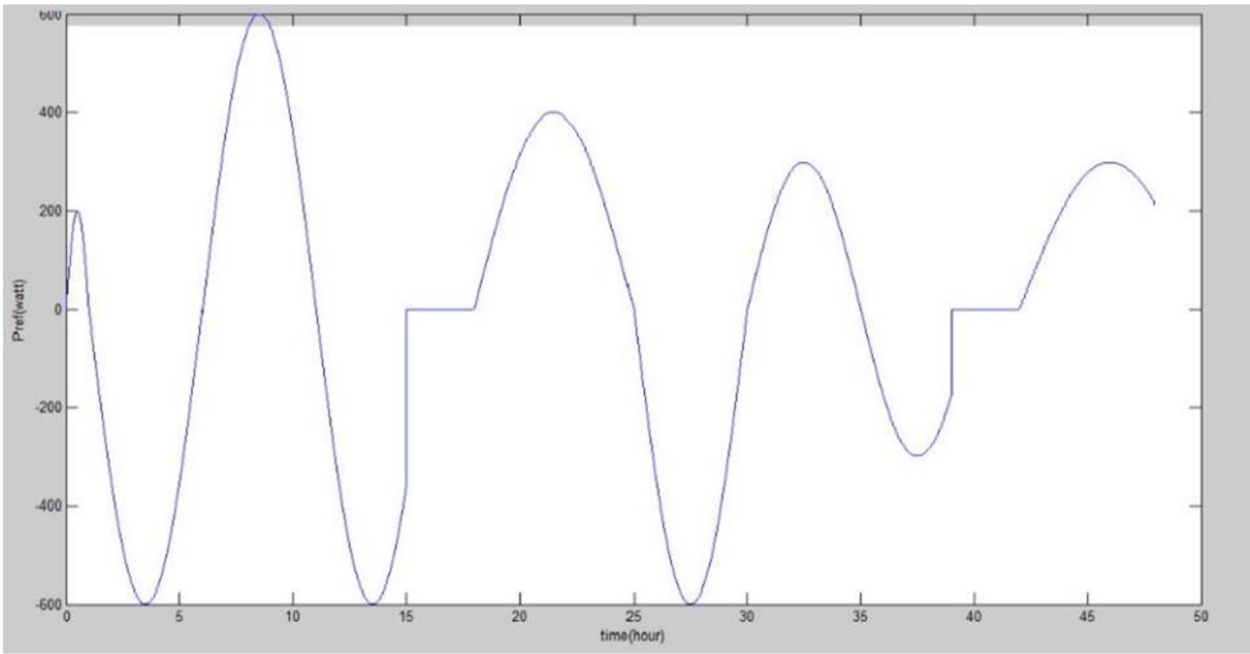


Figure 5.7 PrefESD and time stepwise method

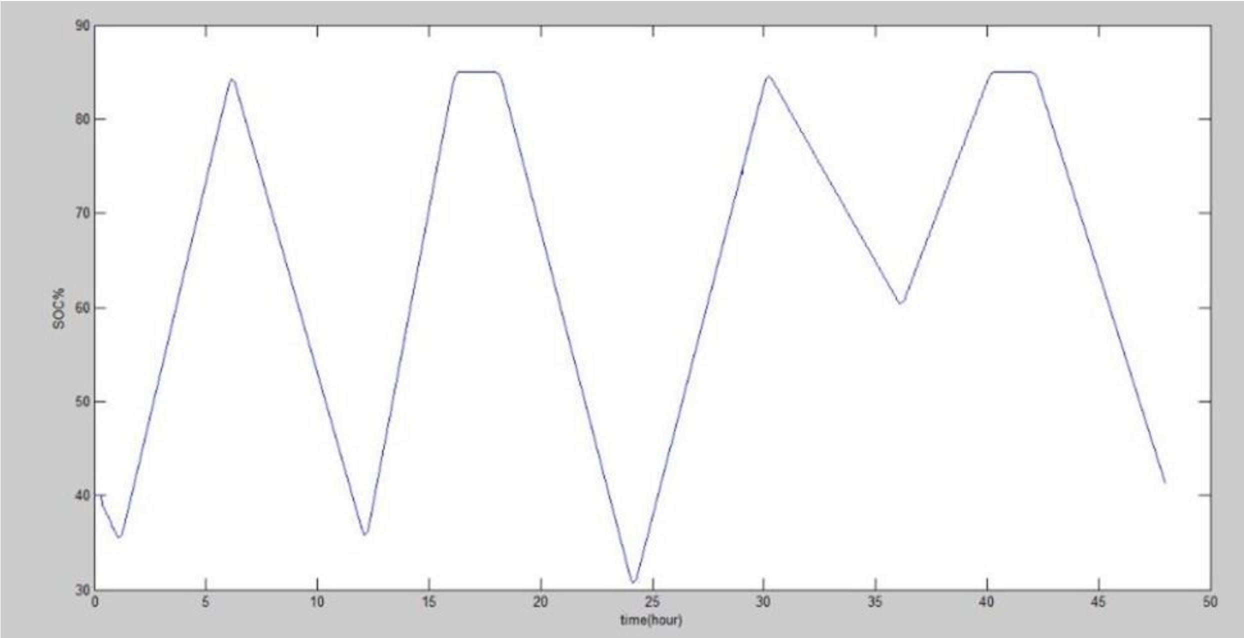


Figure 5.8 SOC and time stepwise method

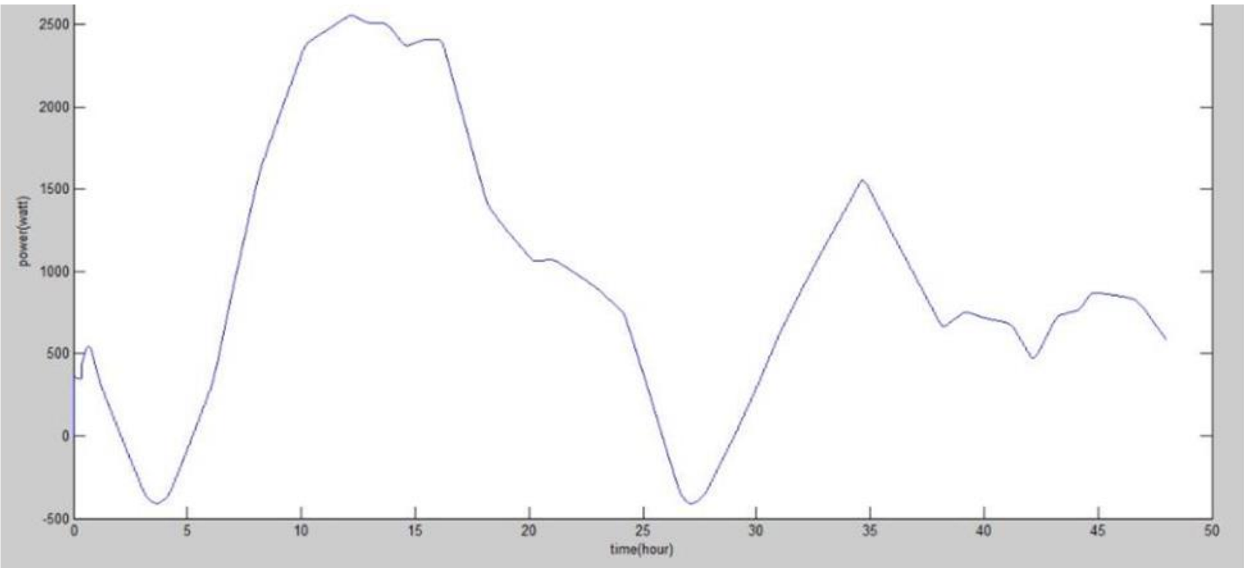


Figure 5.9 Pout and time power flowing to grid stepwise method

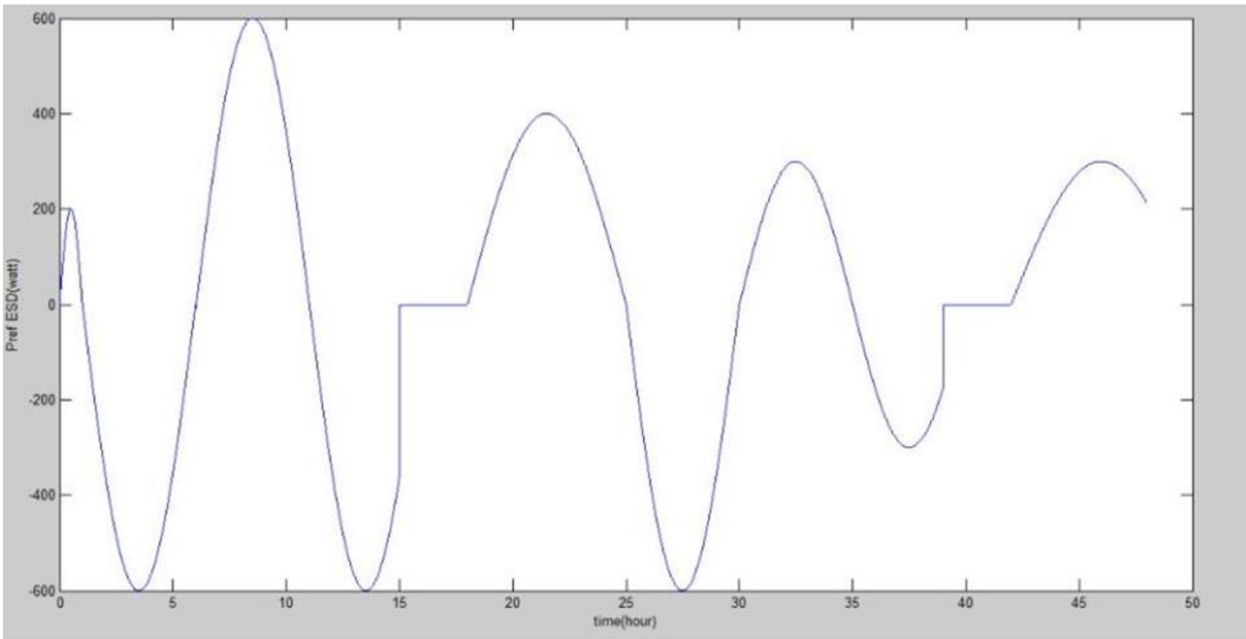


Figure 5.10 PrefESD and time proposed method

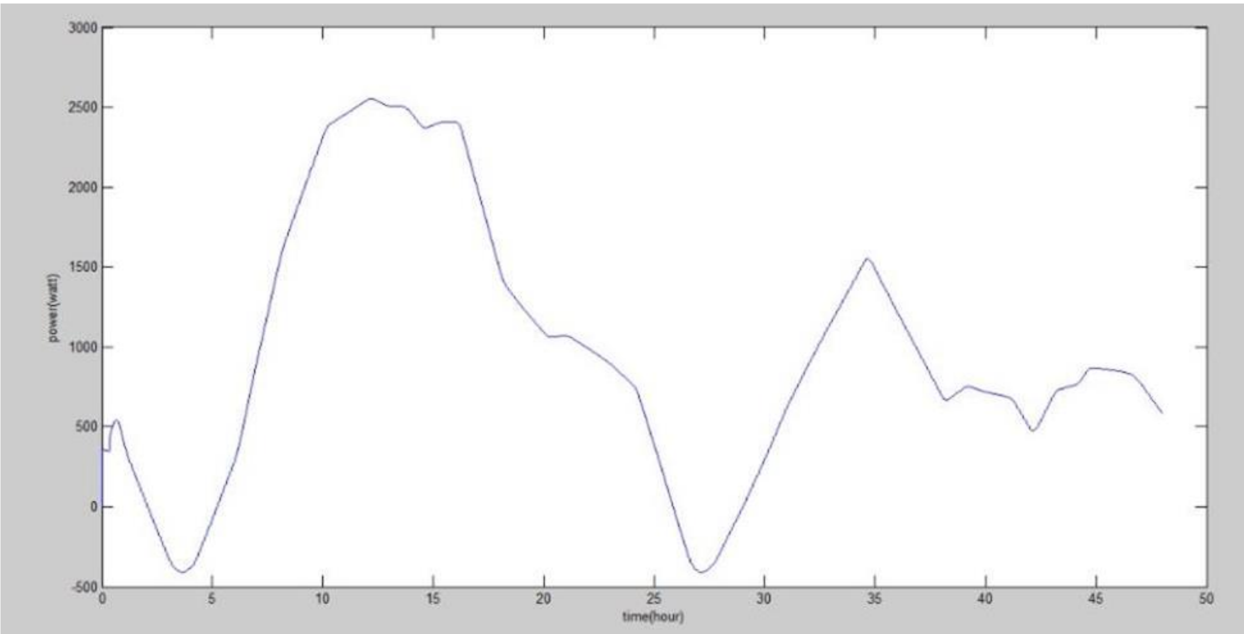


Figure 5.11 Pout and time power flowing to grid proposed method

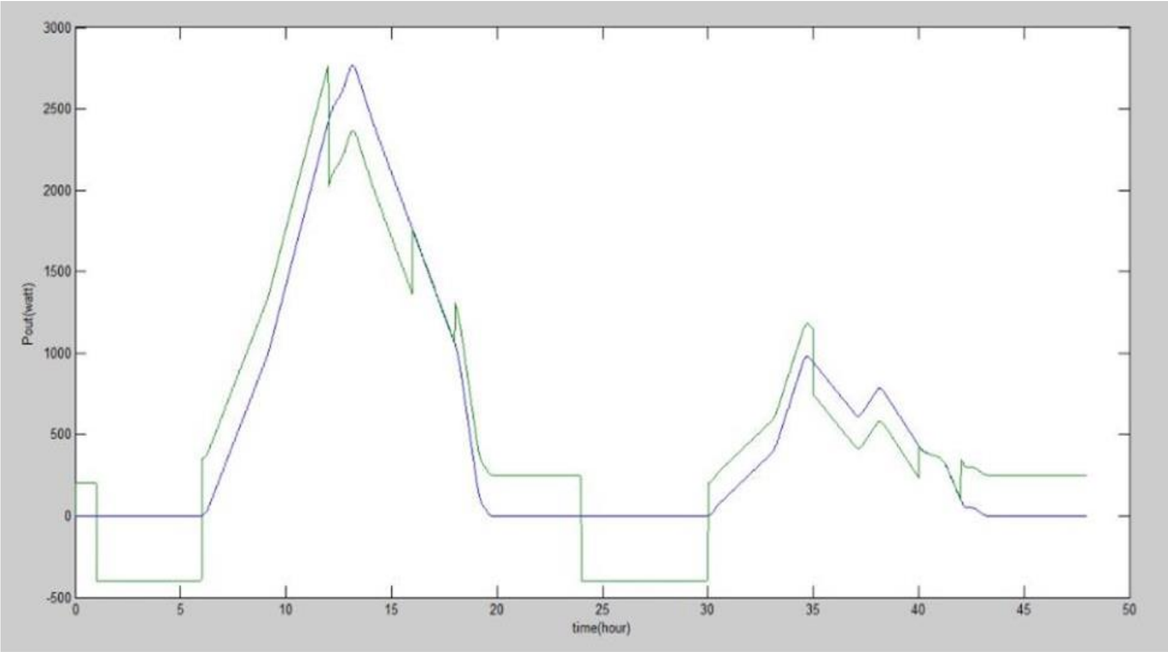


Figure 5.12 Pout and time power flowing to grid proposed method

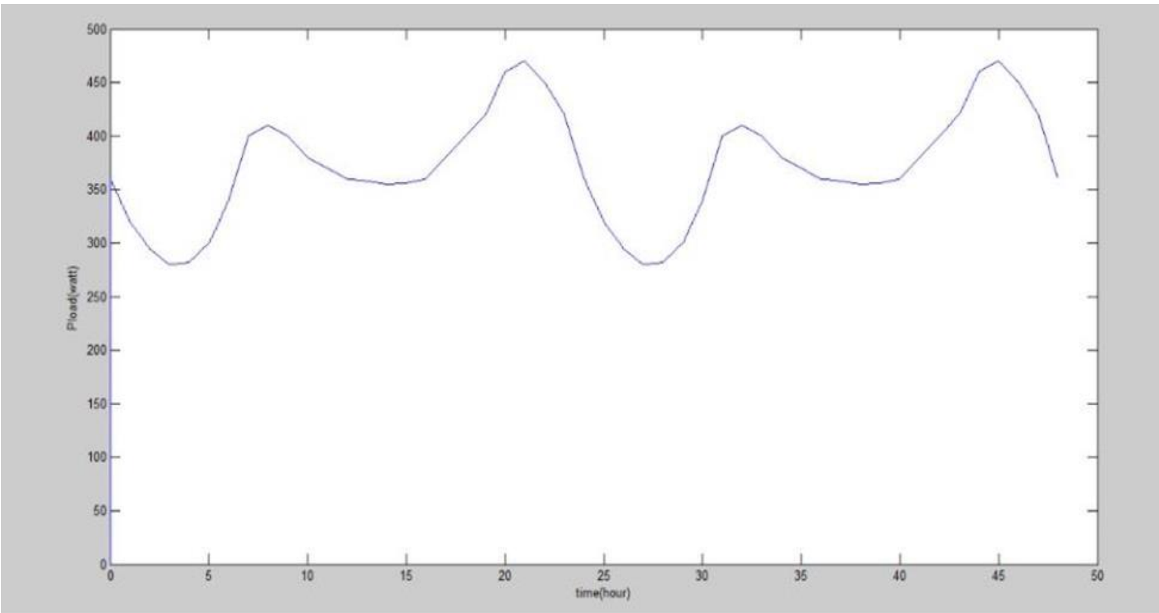


Figure 5.13 Pload and time curve

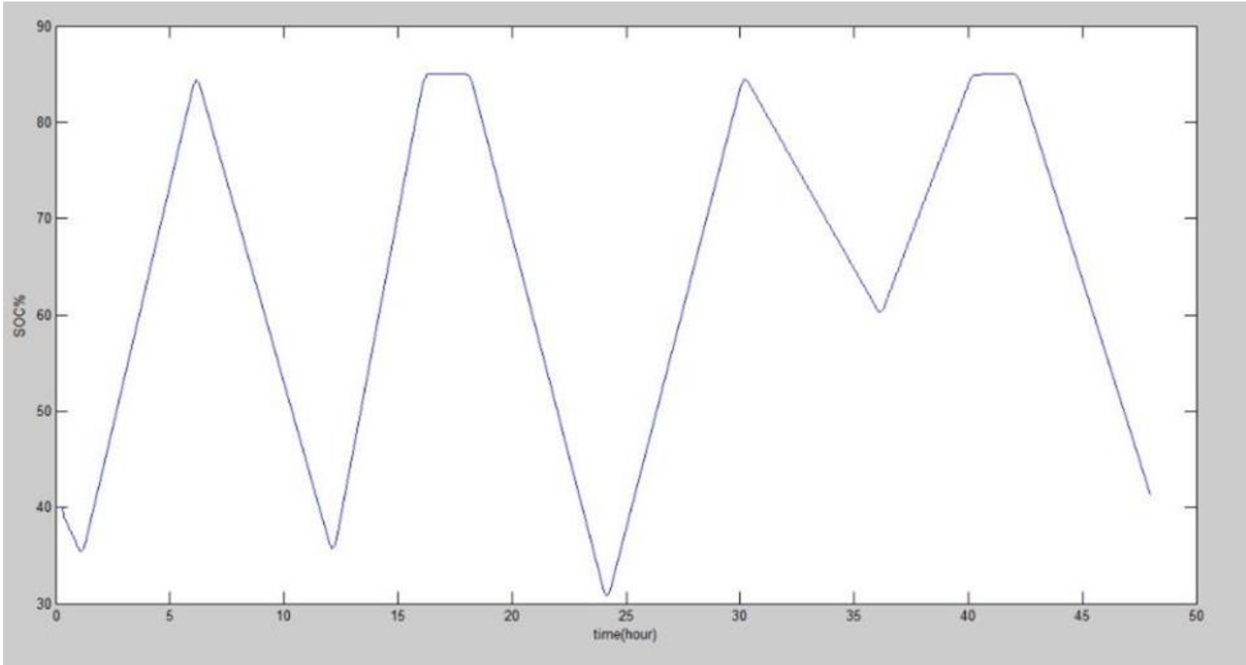


Figure 5.14 SOC and time proposed method

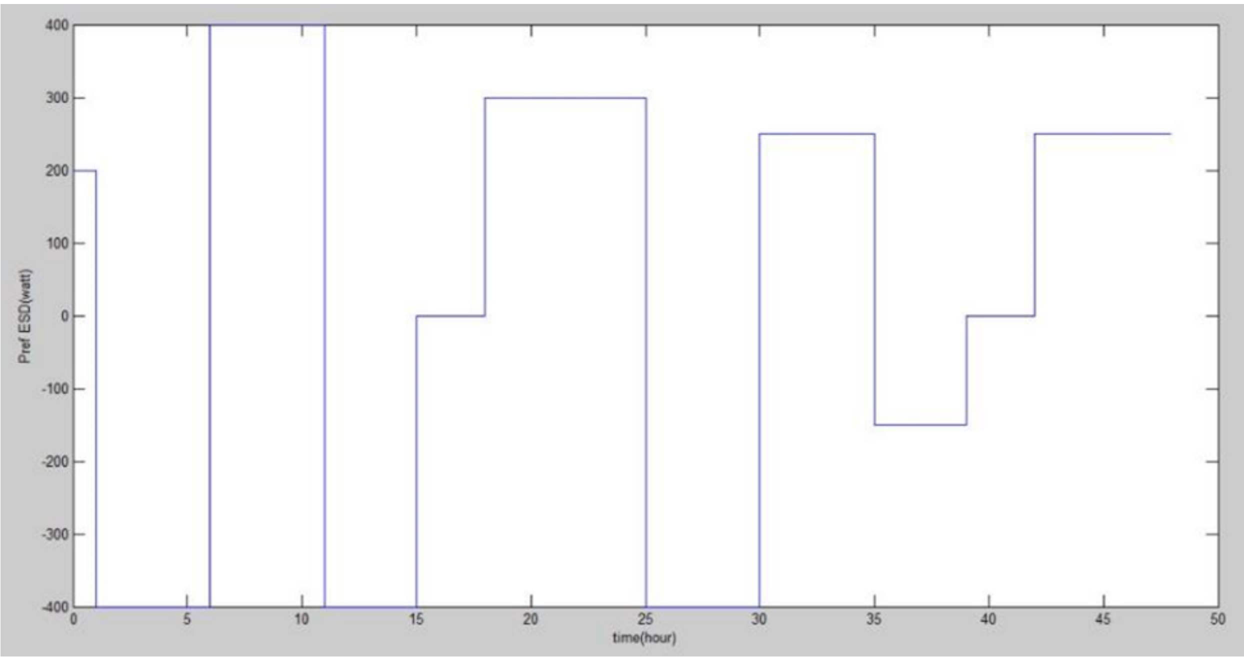


Figure 5.15 PrefESD and time proposed method

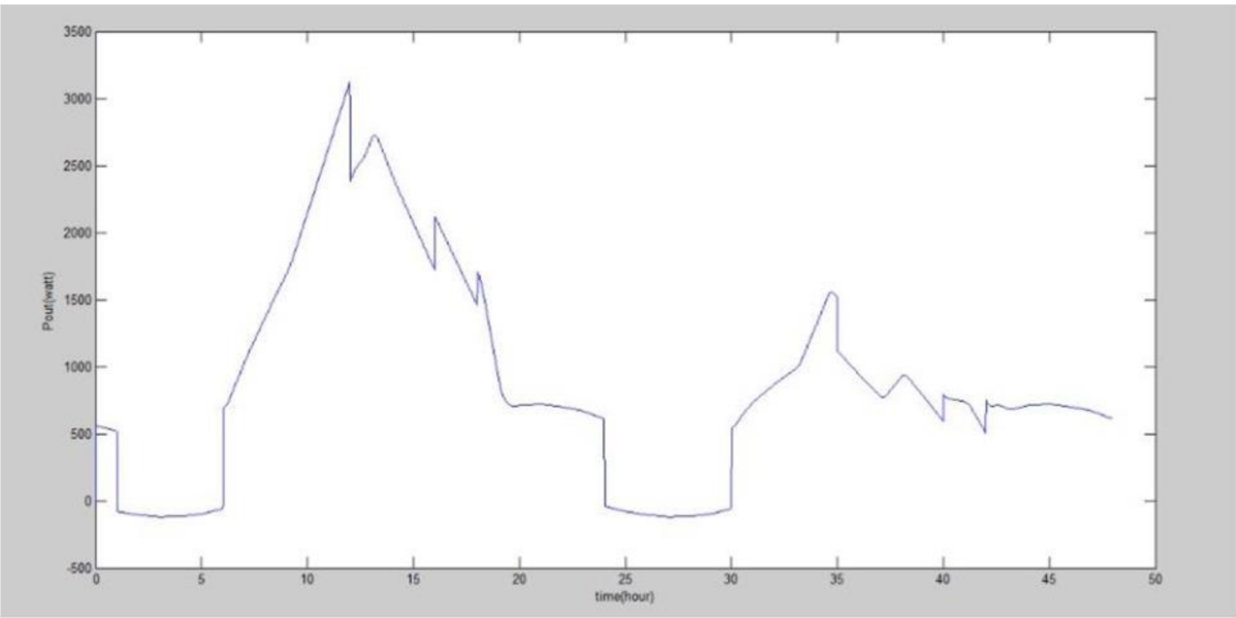


Figure 5.16 Pout and time

5.1.1 CONCLUSION

The project proposes a simple MPPT algorithm called Incremental conductance Method. This method computes the maximum power and controls directly the extracted power from the PV. The proposed method offers different advantages which are: good tracking efficiency, response is high and well control for the extracted power.

This system has proposed the new EMS based on the 4-kW residential PV HPCS with a lithium -ion battery. It could provide the chance to obtain the economic benefit to customers by taking the advantage of nighttime electric power with the relatively low electricity price. In addition thevariations of grid voltage could be mitigated by charging the energy from the PV system in daytime while responding to the peak load. Both simulation and experimental tests were carried out to verify the usefulness of the proposed system. In the future, it would be expected that the proposed EMS is preferably applied to a deregulated electricity market with the complete real-time pricing system.

5.1.2 FUTURE SCOPE

Improvement to this project can be made by tracking the maximum power point in changing environmental conditions. Environmental change can be change in solar irradiation or change inambient temperature or even both. This can be done by using hardware models to carry out MPPT instead of writing it code in Embedded MATLAB functions. In the hardware models the solar irradiation and the temperature can be available as variable inputs instead of constant values as done here.

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