Energy management and smart control of home appliances

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Abstract. In the twenty-first century, there is a drastic depletion of non-renewable resources and a steady rise in greenhouse gas emission which causes global warming. In this case, it is wise to increase the use of renewable energy instead of non-renewable ones which will reduce the consumption of AC power. Sustainable energy sources like solar and wind are also used to control AC or DC loads, yet the execution is unsteady because of the ecological issues. Hence, it is essential to have a system with various input power sources which could provide power during a power-cut, grid failure and peak demand. It ensures better to maximum energy utilization and also results in a low electricity bill. This paper analyses the battery energy management which is crucial in the lives of the residential consumers by forming a system which can be operated both in grid connected and battery fed modes. To perform switching, it is mandatory to monitor both the input power sources and the loads simultaneously. When the loads are light loads and the charge of the battery is sufficient to drive the load, the loads are driven through the DC source. When the loads are heavy loads or the charge of the battery is less, the consumer cannot rely upon the DC source for driving the load. So, AC source is used to drive the loads. Depending upon the type of load, battery status and grid availability automatic switching takes place between the AC and the DC source.

1. Introduction
Developing countries witness rapid urbanization and industrialization which is attracts the rural population to come to the cities mainly for education and employment. It results in the increase of energy demand. The conventional energies like oil, hydro-electricity, coal and nuclear energy are inadequate to meet the demands. Due to the increase in concern of creating an emission free environment, the mankind is forced to depend on recent technical revolution which could fulfil the current energy requirements. Renewable sources like solar is practically used in charging batteries for electric vehicles, energy supply in residential buildings, and satellite systems etc[1]. In India, photovoltaic solar energy resources prove to be one of the booming industries. The solar installed capacity in India has reached 29.55 GW as of 30 June 2019.

The term Energy Management means managing the utilization of energy which improves the efficiency of powering devices and the development of renewable energies. Energy management comprises of actions and methods which could help in the optimal consumption of energy. Energy management intense to analyse the ways and means by which energy could be conserved for future utilization. This technique can be used in factories, offices, sports centres, dwellings or any building which requires energy.

The electricity from the grid is restricted in the developed and under developed countries and therefore, there are minimum possibilities of providing power continuously for twenty hours. Since
there is an imbalance between the power obtained and the load requirement, frequent power cuts occur in these places. Industries are exempted from even a smaller power cut as it would lead to major economic. At this juncture, it should be observed that the industries are excluded from the power cuts. It is because a small power cut may lead to a major calamity and this would ultimately lead to the loss of economy. In such circumstances, the local consumers need to have a stable energy system which would save them suffering due to the frequent power cuts. This paper proposes to develop an automated energy management system which provides continuous power supply and effectively powers the load with the available source. This system is decided by various parameters like type of load, battery status and grid availability.

2. Literature Survey

2.1. Grid connected PV System with Battery based Energy Management technique

The output of PV system varies in wide range according to the nature of. This feature in PV system may not be feasible to all practical applications. Numerous methodologies have been developed in previous literatures to bring down the limitation of PV systems. Adding the battery based energy management technique to the grid connected PV system is one such a method by which could deliver stable output power though there are variations in the solar energy. This system comprises of PV panels, bi- directional DC-DC (BDC) converter, single phase inverter and loads. When there is an insufficiency in the solar energy during night times and cloudy climates, the stable power output can be accomplished by utilizing energy from batteries. In order to have a controlled charging and discharging of batteries, BDC converter is extensively used. The BDC acts in two different ways viz buck mode and boost mode. The former is used for charging and the latter for discharging [2].

Like the previous model, another system was developed entitled “Development of an Automated Multiple Power Sources Switching and Monitoring System”. This system is developed to scrutinize the on-state and to regulate the load in order to save the power. Solar power source was given topmost importance for better utilization of renewable energy. There is a need for an additional automated system which controls the switching between the power sources to have continuous power supply [3].

A Smart Home Energy Management System (SHEMS) was designed to utilize the renewable energy source like solar, wind along with the regular AC grid supply. This system uses a battery which is charged from the solar panels and monitors various parameters like availability of grid, Battery SoC, nature of the load. The loads are categorized as heavy, medium and light based on the amount of power consumed. The controller decides the choice of source to power the loads based on the above mentioned parameters. If the battery contains relatively sufficient amount of charge, the controller switches the load from the regular AC grid supply to the battery source. The presence of a battery level indicator in the Battery Measurement Unit (BMU) of the system senses the state of charge of the battery. Utilizing this system effectively reduces the consumption of power from the grid which results in low electricity bill [4].

2.2. State of Charge Estimation of a Battery

Battery Status can be determined by using the State of Charge which is a significant parameter of a Battery. The state of charge is nothing but the available capacity Q(t) divided by the stated capacity Q(n) ie maximum charge that a battery can contain. The stated capacity is generally determined by the manufacturing industries. The SOC can be defined as:

\[
\text{SoC}(t) = \frac{Q(t)}{Q(n)}
\]  

(1)

Though there are many strategies in the estimation of State of Charge, only four methods are frequently used which will be dealt in the following content.

Battery properties consisting of voltage and impedance is used in the SoC estimation through Direct measurement method. The discharging current characteristics are accounted in the calculation of state of charge in Book-keeping estimation method and SoC is estimated by assimilating the discharging current over time. The third method is Adaptive systems which helps the SoC to adapt itself to varied conditions of discharging characteristics. Hybrid method model was constructed by
taking into account the pros of all the above mentioned methods which could render an optimal performance in the estimation of SoC[5].

Of all the methods given in the previous paragraph, the most commonly used methods include direct methods such as Open circuit voltage method and Book keeping method such as Coulomb counting method [6].

2.3. Smart Control of Home Appliances

Unlike the conventional switches for the control of Home Appliances, an Android Application is developed for its smart control. When the smartphone has the access to Bluetooth, this android application has the ability to control any electrical appliance from a particular distance [7]. Bluetooth uses short-range wireless communication technology for combining two devices together. This leads to the discard of cables or wires which were used conventionally.

3. Methodology

This paper deals with the development of an automated energy management system which automatically powers up the load with available source. The following Figure 1 explains the working of the overall system with the help of a block diagram. The battery is assumed to be charged by the solar panel. The inverter unit converts the fixed DC voltage of the battery to fixed AC voltage. The voltage is stepped up by using a step up transformer to a voltage that is required to drive the housing loads. The domestic loads are either driven by the grid supply or the battery based upon the grid availability, load type (light or heavy load) and the battery status (charge of the battery). The gating pulses of the inverter unit is generated by the microcontroller which is the control unit in the block diagram. The control unit is also used to monitor the type of load and the battery status. Based on the monitored parameters the control unit decides whether to drive the loads through the battery or through the AC source (grid).

Figure 2 shows the working of the system as a flowchart. The ON/OFF state of the switch is continuously checked by the microcontroller. When the switch is ON the SoC of the battery is estimated. If the state of charge is between 70% and 100%, then both the loads are driven by the battery. When the state of charge is between 40% and 70%, one of the loads is driven by the battery and the other load is driven by the grid. When state of charge falls below 40%, then both the loads are driven by the grid and the battery is kept for charging. All of these operations are controlled by the signal that is generated from the microcontroller.
The inverter unit converts the 24V DC from the battery to 24V AC. The 24V AC is then stepped up to 230V with the current being stepped down from 20A to 2A. The housing loads are then driven by 230V AC. The inverter gating pulses are given by sine pulse width modulation technique. The inverter output voltage is maintained constant by varying the modulation index in the sine pulse width modulation (SPWM) approach. The following Figure 3 is the circuit diagram of the battery fed system.

**Figure 2.** Working of the overall system

**Figure 3.** Circuit diagram of the battery fed system
4. Hardware Implementation

To design an inverter, a house with common electrical appliances are modelled and the total wattage rating for the house is determined and it is approximately 10000 W. Out of all the loads that are available, the most essential loads are determined. The table 1 represents the most essential loads that are to be powered up by an inverter.

| Type of load | Number of appliances | Total wattage  |
|--------------|----------------------|----------------|
| Tube light   | 3                    | 3* 40 =120W    |
| Fan          | 3                    | 3 * 80 =240W   |
| CFL          | 2                    | 2* 15 =30W     |

TOTAL WATTAGE = 120+240+30 = 390W

Volt Ampere Rating of Inverter

\[
V * I * \cos \Theta = \text{Wattage Rating}
\]

Wattage rating = 390W

Voltage rating = 24 V

\[
\cos \Theta = 0.8
\]

\[
I = \frac{W}{(V * \cos \Theta)} = \frac{400}{(24 * 0.8)} = 20 \text{ A}
\]

VA rating of inverter = \[
\frac{\text{Wattage rating} \times \text{Inverter loss}}{\text{Power factor}} = \frac{400 \times 1.15}{0.8} = 575 \text{ VA}
\]

Therefore, VA rating of inverter = 600VA

Inverters are to be designed for the maximum peak load and for the typical continuous load. The reference signal for the SPWM inverter is a sinusoidal signal. The sinusoidal wave is matched with the triangular wave in order to generate the gating pulses for the switches. The sine wave is considered to be a reference wave while the triangular wave is considered to be a carrier wave. As the amplitude of sinusoidal wave varies, the pulse width also varies. Both the output waveform’s frequency and the reference signal frequency are the same. The Amplitude Modulation index (m_a) is used to control the RMS value of output sinusoidal wave. Modulation index can be calculated by dividing the magnitudes of modulating waveform (peak value) and carrier waveform. The magnitude of m_a lies within 0 and 1.

The output voltage of the inverter is maintained constant irrespective of the battery and the load status by varying the modulation index. The battery voltage at every instant is matched up with the reference voltage (24V) and the modulation index is varied accordingly so as to maintain a fixed output voltage of 24V. As the voltage decreases the modulation index increases and below 24V, modulation index is maintained at a constant value of one. Modulation index (m_a) is computed using the following relation.

\[
V_{out} = m_a \times V_{dc}
\]  

(2)

Where, \( V_{out} \) is the output ac voltage that is required to be maintained and \( V_{dc} \) is the input battery voltage which keeps reducing as the battery discharges.

The figure 4 exhibits the variation of modulation index with respect to the variation in battery voltage.
Coulomb Counting Method helps to determine the state of charge of the battery. SoC is obtained by performing the integration of the current that is going in and out of the battery over a time period. It is essential to have an initial SoC value of the battery and the SoC value changes according to the temperature, current, voltage level of the battery which is not considered in this method. The battery current and voltage is measured by current sensor ACS712 and Voltage sensor continuously. These sensors are interfaced with the Arduino and the state of charge is thus determined.

\[
Q_{\text{lost}}(t + \tau) = Q_{\text{lost}}(t) - \Delta Q
\]

\[
\Delta \text{SoC} (t + \tau) = \frac{Q_{\text{lost}}(t + \tau)}{Q_{\text{rated}}} \times 100\%
\]

\[
\text{SoC} (t + \tau) = \text{SoC} (t) + \Delta \text{SoC} (t + \tau)
\]

Where, \(Q(t)\) is the charge obtained in Open Circuit Voltage Method
\n\(\Delta Q\) is the charge obtained from time \(t\) to \(t + \tau\)
\n\(Q_{\text{rated}}\) is the capacity of the battery

The android app for ON/OFF control of home appliances is developed using MIT App Inventor 2 tool. The figure 5 represents the block diagram of Smart Control of Appliances. The system comprises of three main components: an Arduino, a Bluetooth module and a smartphone with the Android application which is developed to observe and control the home appliances. The Bluetooth module acts as a communication tool between the android phone and the microcontroller. Based on the commands received by the microcontroller, the signals to the relay drivers are generated which are connected to the load.

\[\text{Figure 4.} \ \text{Variation of modulation index w.r.t the variation in battery voltage.}\]

\[\text{Figure 5.} \ \text{Block Diagram of Smart Control of Appliances}\]
5. Results and Discussion

The battery fed system is simulated in MATLAB Simulink. The following figure 6 and figure 7 represents the Inverter Output Waveforms and Load Parameter Waveforms. A battery which is fully charged with 24 V that is connected to an inverter gives output voltage of 24V AC (RMS: 16.97V). The inverter output 24V AC is stepped up to 230V AC by a step up transformer. The output of the transformer is supplied to the loads and the loads are driven by 230V AC.

![Figure 6. Inverter Output Waveforms of the battery fed system](image)

![Figure 7. Load Parameter Waveforms of the battery fed system](image)

The overall system with two sources, both AC grid and Battery (DC) source is implemented in Hardware. The figure 8 represents the hardware setup of the system. Two 12V batteries are connected in series. The gating pulses of the SPWM inverter are generated by the Arduino and the inverter converts the 24V battery voltage to a 24V AC voltage. This 24V is stepped up by a step up transformer to 230V. Based on the SoC of the battery that is monitored by the Arduino, it generates the control signals that are given to the relay which does the switching between the two sources where the loads are connected to either DC or AC source.

![Figure 8. Hardware setup of the overall system](image)
The figure 9 is the frontend picture of the android application to control appliances. The button (Available_BT_Device) when pressed searches for the Bluetooth signal and it pairs up with the Bluetooth module. This application is created to ON/OFF two appliances L1 and L2.

![Android App control of appliances](image)

**Figure 9.** Android App control of appliances

6. Conclusion

The Energy Management system for the domestic appliances is simulated and implemented. The system consists of a battery, connected to an inverter which gives a steady output voltage of 24V that is fed to a step-up transformer where the AC voltage is stepped up to 230V and is fed to the loads. The gating pulses of inverter is given through SPWM technique. The inverter output voltage remains constant irrespective of the loads and the battery status. The charge estimation of the battery is also implemented in hardware setup. The switching between AC and DC sources to drive the domestic loads based on the state of charge of the battery is implemented and energy management system is achieved successfully. An Android Application is developed to control the ON/OFF operation of switches.

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