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Energy Saving by Direct Utilization of Solar Energy for Management and Control of Power Supply

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Abstract:

A supply from renewable energy source is need to be directly utilized for its maximum power extraction. A system of management and control of power supplies from renewable (solar) and conventional (mains) energy sources is proposed, where both supplies are managed in such a way that supply from solar is used to control the supply from mains in an inversely proportional manner so that resultant additive output from both sources should be remain balanced in order to draw maximum power from solar. A natural deviation in solar energy is utilized to alter the mains supply by using microcontroller based control unit and remaining supply after alteration is compensated again from solar energy. The resultant additive supply from both sources keeps the balanced physical output from electrical load. This supply management technique of controlling one supply using another is a way towards energy saving by direct utilization of solar energy.

Keywords **— Solar energy, microcontroller, energy management, renewable energy integration, relay coordination, optimal power flow.**

I. INTRODUCTION

Solar energy in electrical supply systems requires improvements in energy efficiency through its direct utilization by rectifying the portion of lost energy in intermediate processes of conversion and consumption. In this regard, a system is proposed which is a design and development of power supply management and control of energy from solar and mains. The supplies from both sources is automatically controlled with the help of microcontroller and its associated circuits in such a way that when supply from solar due to its irregular behavior is changed by either an increasing or decreasing manner, then mains supply is also forced to vary in inversely proportion of solar supply. Mains supply changed in this way according to solar supply finally changes the physical output of its electrical load. This creates the gap which is overcome with the help of solar supply by compensating the remaining physical output by its own separate electrical load. In this way, the overall physical output of the electrical system remains balanced. The system is a kind of supply side management where the supply from solar and mains are arranged in such a way that optimal power flow from both of the energy sources is achieved.

The requirement of proposed system comes to front because of the fact that solar energy has been a critical option for most of the areas due to its random behavior which is mainly due to atmospheric conditions such as solar radiation, temperature, dust accumulation and cloudiness. But, by using the proposed system, the random behavior of solar energy is harnessed effectively to control the conventional supply. In this system, the irregularity in solar supply is used as a control logic for the adjustment of mains supply. Another fact behind the need of this system is that solar supply is required where it can be directly fed to load for its maximum extraction of energy. The system provides this facility to electrical load by managing and controlling supply by the integration of renewable energy source with a conventional energy source.

In the context of India, it is an ideal place for electricity generation from solar energy [1]. The location of India between tropic of cancer and equator gives it an average annual temperature ranging from 25ºC to 27.5ºC which makes it solar

powered nation. Indian region collects more than 5000 trillion KWh solar energy every year which is far more than its total annual energy consumption [2]. The daily global radiation of India is 5 KWh/m2/day with the range of sunshine hours between 2300 and 3200 hours/year [3]. The so explained large amount of solar energy is required to be utilized for the generation of electricity which can be carried out with the help of solar panels [4]. The electricity from solar PV modules to electrical load can be supplied either directly or indirectly [5]. An indirect way uses charge controllers, batteries, inverters and converters which generates conversion losses [6,7]. Hence, a direct supply from solar panel without any intermediate converting components is required which gives rise to the design of proposed system. The system is developed with an objective to extract maximum solar energy by saving the conventional energy. The system will be helpful to meet the requirement of electricity supply and demand of nation, its energy security and for encouraging the use of renewable energy sources.

II. Design and Development of Hardware

The system of two electrical networks with a common control unit provides a new technique over conventional technique for electricity utilization from solar energy. A block diagram of this technique is shown in figure 1. One part of this system is solar circuit and another is mains circuit. Solar circuit comprises of solar panel, shunt resistor and LED lamp load connected to it whereas mains circuit consists of remaining part of the system.

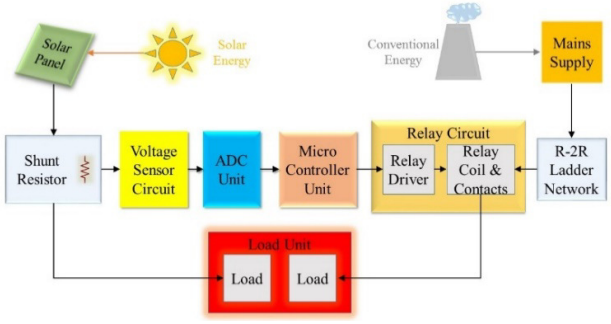

Figure 1. Block diagram of system.

The system receives solar energy from sun with the help of solar panel which generates electrical power. The complete solar power is then directly supplied to energy efficient LED lamp load through its limiting resistor. Limiting resistor prevents overcurrent for LED and its value is so chosen that maximum amount of current can be fed to LED. Limiting resistor is also used as a shunt resistor for voltage measurement. Voltage across shunt resistor is observed with the help of voltage sensor circuit which consists of operational amplifier based unit. The analog output corresponding to the fluctuating solar voltage of this unit is then applied to analog to digital converter (ADC) unit. The digital output is changed simultaneously at the conversion speed of ADC as the input voltage fluctuates. Digital output is then used to feed to microcontroller for data processing. Data received at the input of microcontroller is transferred at its output in the same form for fast data processing without extra execution time of program. Data generated by microcontroller is then sent to relay circuit where the relay driver complements the data received from microcontroller for maintaining the inverse relation of solar and mains current. The complemented data from relay driver is then sent to relay coil whose switching contacts are used by conventional circuit.

The hardware of system presented with the help of block diagram is developed which is shown in figure 2.

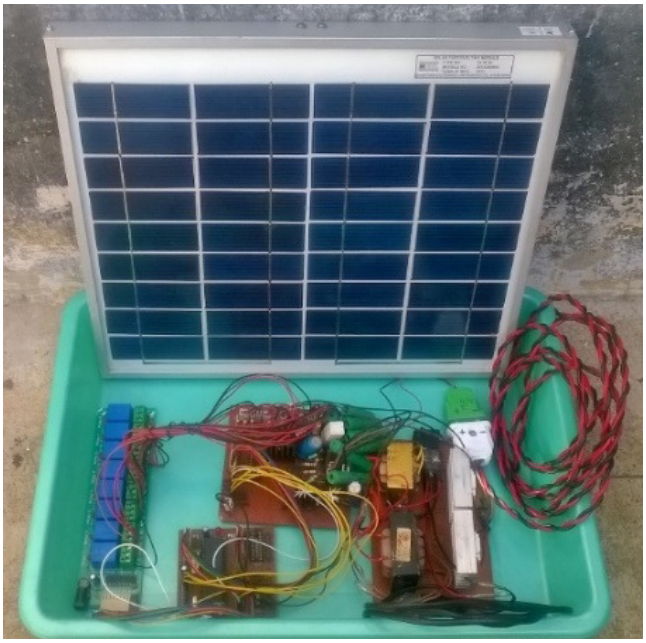

Figure 2. Hardware of system.

III. MATERIALS AND METHODS

Different parts of hardware can be explained in following paragraphs.

A. Solar panel

Solar photovoltaic panel is a renewable energy source in this system. It works on the basis of photovoltaic effect according to which it generates electricity when solar radiation in the form of light falls on it [8]. The solar panel generates electrical energy without going through thermal process as in case of conventional energy. Because of direct utilization of solar energy, no additional equipments for solar panel are required in this system to transform its energy into usable form or to store it for future use. Solar panels or dc generators without having any rotating parts as in case of conventional ac generators are maintenance free and don't emit greenhouse gases to environment [9].

The output power of solar panel mainly depends on ambient conditions which are input solar energy incident on its surface and temperature [10]. The output of different parameters [11]. These specifications are recorded under standard test conditions (STC) as follows:

Air mass (AM) =1.5

Solar irradiance intensity (I) = 1000 w/m2

Cell temperature (T) = 25℃

B. Shunt resistor

Shunt resistor is a component which has been used for voltage measurement of non-uniform solar supply in the system. Electrical energy extracted from solar energy by solar panel is fed to shunt resistor. Voltage across this resistor is proportional to the voltage of solar panel. Thus, the variation in solar energy again varies the output voltage across the resistor. This variation across shunt resistor is then utilized for the calculation in solar energy variation with the help of voltage sensor circuit.

The connection of shunt resistor (R2) with source and load is displayed in the developed hardware as shown in figure 3.

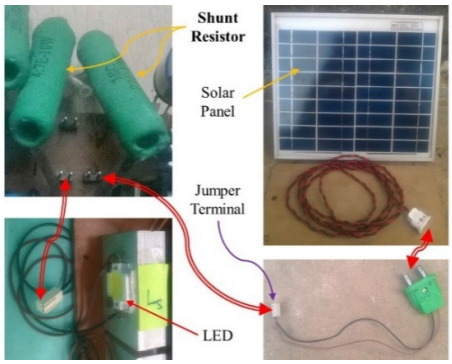

Figure 3. Hardware of shunt resistor with solar panel and LED load.

C. Voltage sensor circuit

Voltage sensor circuit measures any changes in the voltage across shunt resistor. Non uniform solar radiation changes the output voltage of solar panel which in turn changes the voltage of shunt resistor. This voltage is then measured with the help of difference amplifier of voltage sensor circuit. The voltage from solar panel at the input of amplifier is then amplified to appropriate level at its output and amplified output is further sent to ADC for digital processing.

The hardware of voltage sensor circuit is developed which is shown in figure 4.

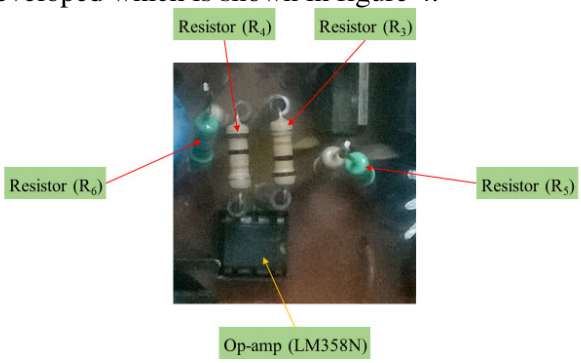

Figure 4. Hardware of voltage sensor circuit.

The operational amplifier assembled in IC LM358 has been configured as an inverting amplifier wherein negative feedback is used with the help of resistor R5 whereas R3 and R4 are input resistors. Some observations of the circuit are as follows –

Condition for difference amplifier.

$$\frac{R_5}{R_3} = \frac{R_6}{R_4}$$

D. ADC unit

The analog to digital converter (ADC) unit converts analog input data received from voltage sensor circuit to digital data for processing in microcontroller. Any voltage change at the input of ADC unit generates the digital data according to resolution of ADC.

The system uses parallel data based ADC0804 of CMOS family which has 8-bit resolution over any desired analog input voltage range. The ADC works on the principle of successive approximation logic according to which the output of 8-bit successive approximation resistor (SAR) is applied to an 8-bit D/A converter. The analog output of D/A converter is then compared by comparator with an analog input signal. The output of comparator is again applied to SAR in the form of serial data. The SAR then adjusts its digital output data until it is equivalent to analog input data [12].

A hardware of ADC is developed as shown in figure 5.

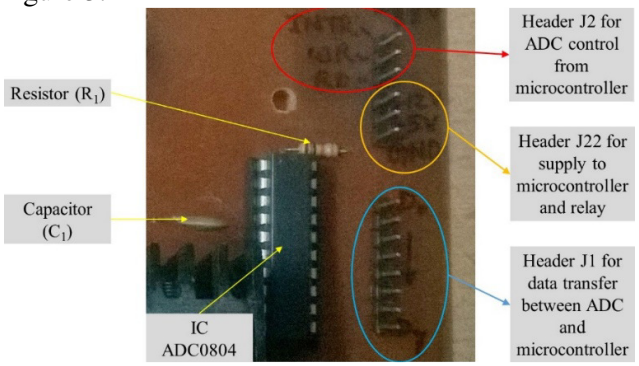

Figure 5. Hardware development of ADC unit.

E. Microcontroller unit

A control between solar and mains circuit is maintained by microcontroller unit. The unit decides which amount of current should by supplied to mains circuit for which value of current from solar circuit. A continuous instantaneous control of current between solar and mains circuit is the main function of microcontroller unit in the system. To perform this function accurately, an 8-bit microcontroller AT89S51 has been optimized for control purposes [13].

The program for microcontroller developed to control the system can be locked in three levels and can work under low power idle and power down modes. Dual data pointer and interrupt recovery from system program is also available in this microcontroller [14]. With watchdog timer, power off flag and fast programming time, the microcontroller AT89S51 provides a flexible and cost effective solution to the system.

The design of microcontroller circuit is developed on hardware platform which is shown in figure 6.

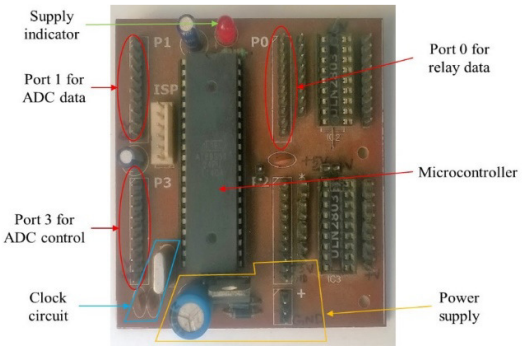

Figure 6. Microcontroller unit.

F. Relay circuit

The relay circuit is an intermediate path to current flow in R-2R ladder network of mains circuit. Relay coordination changes the current path in R-2R ladder network so that current flowing to LED lamp load should be inversely proportional to the current of solar circuit. The current flow is continued by relay contacts whereas these contacts are activated by its respective relay coils. Hence, apart from relay driver, the relay circuit has two parts as relay coil and its contacts. Both parts are electrically isolated but work together.

The 8-channel relay circuit consists of 8 different single pole double throw (SPDT) relays, a relay driver, common anode LED indicator for each relay and a power supply circuit to operate all these devices. Relays (RL1 to RL8) are solid state relays whose specifications are given in table IV [15].

Relays are driven by relay driver IC (U1) ULN2803 which has eight Darlington transistors with common emitters. Each Darlington with input resistance of 2.7KΩ provides a peak load current of 500mA with at least 50V output voltage in off state. These values are more than sufficient to drive a relay. Moreover, the input supply voltage can be up to maximum of 30V which is far enough for the supply of 12V given to this circuit. With power dissipation of 2.25W, relay driver has a continuous

base current of 25mA and has turn on/off delay time of 0.25µs [16].

A hardware shown in figure 7 has been developed for practical implementation of relay circuit.

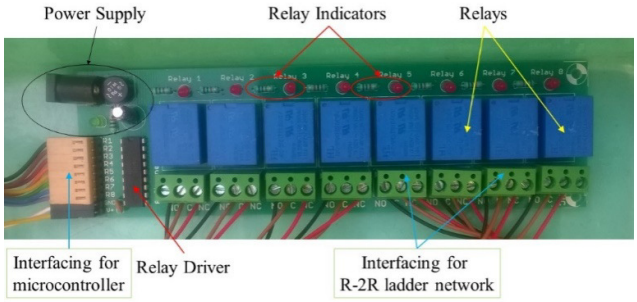

Figure 7. Hardware of relay circuit.

G. R-2R ladder network

The R-2R ladder Network is a distribution of resistors according to standard R-2R ladder form in mains circuit wherein the value of 'R' has been selected the same as that of shunt resistor in solar circuit. By choosing the same value for both 'R' and shunt resistor, same amount of current flowing in solar circuit can be controlled in mains circuit.

The R-2R ladder network is designed with two types of resistive branches as 'R' branch and '2R' branch. The 2R branches have been used for relay contacts for current controlling. By using the value of shunt resistor for resistor 'R', an 8-bit R-2R ladder network is formed by using relay contacts.

Now, a hardware has been developed for R-2R ladder network as shown in figure 8.

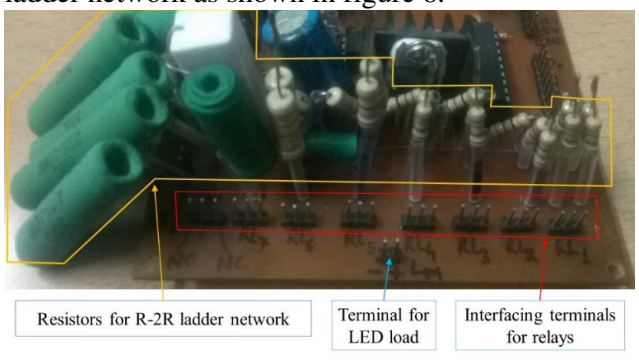

Figure 8. Hardware of R-2R ladder network.

H. Mains supply

Mains supply is a power supply required to operate mains circuit. This supply is from conventional energy source and provided to system during the unavailability of solar energy also, since the system has to be put under working condition all time. Three types of voltages (5V, 12V and 22.5V) are generated by mains supply. The ADC and microcontroller unit is supplied by 5V, op-amp is fed by 12V, whereas 22.5V is given to R-2R ladder network.

The supply arrangement is developed on the hardware platform as shown in figure 9.

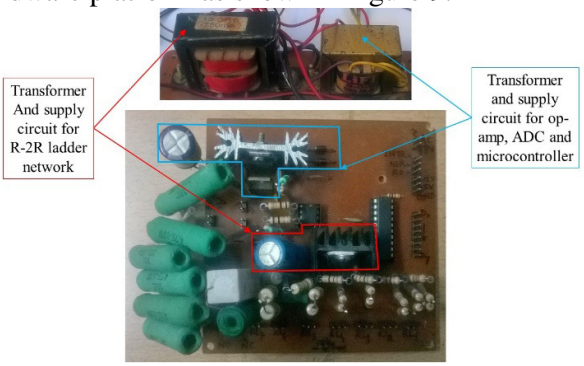

Figure 9. Hardware of load unit and mains supply transformers.

I. Load unit

Load unit is a lamp load which emits light continuously. It is a single unit of two LED lamps so that same amount of brightness can be generated when supplies to both LEDs are changed with respect to each other. Two LEDs of same power has been used in this unit in order to generate same amount of brightness at any instant.

The LED lamp load is chosen for its low power requirement and energy efficiency. It consists of 9 miniature chip LEDs arranged in 3 groups inside its body.

Besides the specifications of LED listed in table V, there are more factors for considering the LED as a lamp load. LEDs which work on the principle of electroluminescence consumes less energy as compared to conventional incandescent lamps. LEDs emit higher lumen per watt of output than incandescent lamps which makes it energy efficient. Also, the efficiency of LED lighting fixtures is not changed by shape and size as in case of fluorescent lamps.

Having smaller size, LEDs are physically robust and are mechanically resistant to strain and

vibrations. Moreover, LEDs have fewer environmental concerns related to their disposal. Moreover, LEDs have good protection against electrostatic discharge (ESD) and fall under the category of RoHS (Restriction of Hazardous Substances) [18].

IV. Development of Software Program

The software part of system has been developed for microcontroller and its peripherals. An assembly language is used to write a software program since it is fast and requires less memory space as compared to programs written in high level language. The program is assembled by using 'Keil µvision' software with 5.14.2.1 version. The program is burnt into microcontroller's internal flash memory by using 'Willar SP200S' programmer of version 2.20 beta. Different parts of software program has been discussed in the following sections.

V. Testing and Results

The developed hardware of system has been setup for testing according to figure 10.

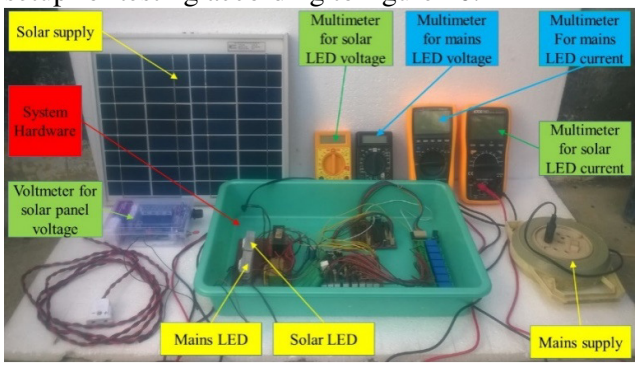

Figure 10. Setup for testing of developed hardware.

The setup has been tested at Indian location (latitude=23.21ºN, longitude=77.39ºE) of Bhopal (M.P.) on date 12/03/2017. The working condition of hardware during its testing has been shown by figure 11.

Figure 11. Hardware working under maximum solar supply.

According to figure 11, current due to mains supply is increased when current due to solar is decreased and vice versa. This performance of both supplies can be shown with the help of figure 14.

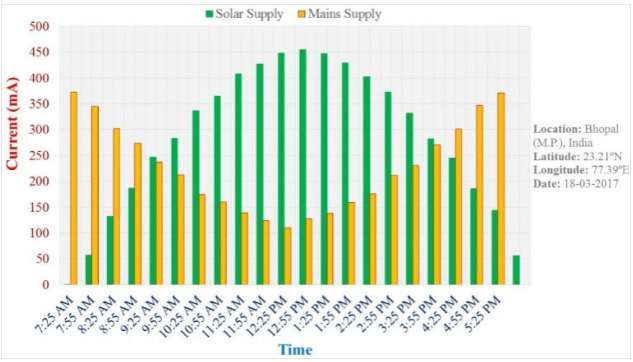

Figure 14. Current relation of solar and mains supply.

VI. Conclusion

A system of power supply management and control is designed and hardware is developed for this. The software written in assembly language for its fast processing time was successfully tested on this hardware and the values obtained were closely related to expected values.

The system is now able to directly utilize the solar energy. Direct utilization of solar energy in electrical supply systems prevents electrical as well as economical losses. Direct absorption of solar energy to load without any intermediate conversion is a way towards the lossless power supply.

In the control technique of developed system, a natural solar energy source is used as a comparator in order to control mains energy. This new control mechanism is useful for balancing the physical

output of the load running from solar and mains energy. Also, the energy efficient LED lamp loads of today's need have been used for each source.

Atmospheric conditions change the solar supply randomly and make it irregular source of supply but in this system, this irregular behavior of solar energy is successfully managed in controlling of power supplies. This type of control strategy will also be helpful in other solar energy related control operations. In rural and remote areas, this control strategy is very needful, because the hardware doesn't require any wireless connection, internet or even any human interference for controlling, but uses only solar energy source.

The technique presented in this work replaces the conventional control methods and suggests a new digital way of instant control of electrical energy of one source with respect to another source. This control technique is very much useful specially in rural and distant areas, where an automatic controlling without any human interruption is required.

A difference amplifier used in the system eliminates the need of extra voltage sensor device, since the amplifier works as both sensor and a conditioning unit for ADC.

The system is self-powered for its operation, since very less amount of power is required which can be fed with the help of solar energy. Also, the system can efficiently run dc loads which can be directly powered by solar energy however ac loads can also be operated with some extra hardware support.

The system will have its own power, control and lighting load when fixed at electric pole and it is one of the cost effective way to save electrical energy. In current energy scenario, the work like this system is very much useful to fill the gap between supply and demand of electrical energy by extracting maximum solar energy. In order to achieve energy security, the system is a new tool towards management and control of electrical energy and it is one of the way for the promotion of renewable energy source.

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