International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-12, October 2019

Maximizing Energy Saving by Solar Power based Optimal Supply Side Management

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Abstract**: *Energy saving can be maximized by rectifying the intermediate conversion processes involved during the utilization of solar energy. The system eliminates the transformation of electrical form of solar energy into another form by directly utilizing its electrical energy in the management and control of power supplies obtained from renewable (solar) and conventional (mains) energy sources. A current control scheme is presented in which current delivered by solar supply is used to control the current in mains supply in such a way that both currents are inversely proportional to each other. Any increment in solar current opposes mains current in the same proportion and vice versa. A balanced common physical output is resulted from the electrical load supplied by each source separately. A natural variation in solar radiation is utilized to fluctuate the solar current which is further used to change the mains current. Energy saving is maximized in this supply management by the optimal utilization of solar energy.***

Keywords* : *solar energy, microcontrollers, renewable energy sources, energy management, LED lamps.

I. INTRODUCTION

In solar energy based supply systems, energy losses are reported during energy transformation from one component to another. The energy drop by these components can be bypassed by direct utilization of solar energy. A system is designed and developed in which power supplies from solar and mains are used in such a way that current from solar supply is used to control the current from mains supply. A natural solar radiation helps to change the solar current which in turn change the mains current with the help of control unit interfaced by microcontroller. Any variation in mains current due to solar current changes the amount of current in its load. These changes then vary the physical output of electrical load. To balance the physical output, another electrical load connected with solar supply is used which compensates the remaining physical output developed by mains supply. The amount of current used for controlling by solar supply is obtained by the direct connection of solar supply to load.

Revised Manuscript Received on October 30, 2019.
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Only that amount of solar current is supplied which is not provided by the current of mains supply. In this way, current supplied by solar energy during its availability helps to maximize the energy saving.

Various energy management systems (EMS) have been come to front to fulfill the energy demand which integrates the renewable energy sources of varying nature [1-2]. Also, different techniques of demand side management (DSM) have also been implemented to meet the gap between demand and supply [3-4]. But, the energy shortages can be overcome at its supply level with an appropriate control. In this regard, a system is presented which controls the mains supply by using solar supply in such a way that maximum extraction of solar supply is resulted which then maximizes energy saving. The control strategy used in this supply side management (SSM) uses current parameter for controlling one supply with the help of other.

Another fact behind the use of this system is that solar radiation due to its random nature has always been creating problems to generate constant power supply by using solar panels [5-6]. The system utilizes this variable nature in current controlling of power supplies. Solar radiation changes the amount of current according to its variation. This variable solar current is then used to vary another mains current and both currents commonly generate a balanced physical output from the load connected with their supplies.

As very few works have been reported, where solar supply is used to control mains supply by its current parameter. Hence, a system of such kind can be one of the energy saving scheme in the energy management of power supplies. As a standalone system, the work can be a self-automated tool for solar energy based supply systems. In a scenario of continuous growing energy demand, reclining fossil fuels and increasing global warming, the system is one of the energy saving measure which utilizes solar energy and offers energy security to nation and promotes renewable energy sources.

II. TECHNICAL BACKGROUND

Solar energy in electrical systems is utilized with the help of charge controllers, inverters, converters and batteries. Involvement of these different electrical utilities yields conversion losses because most of the energy loss is due to the conversion loss within the components of these utilities. Energy is reduced with every process of conversion while transferring from one component to other [7]. The energy loss from renewable energy source (solar) to load during energy conversion is shown in Fig. 1.

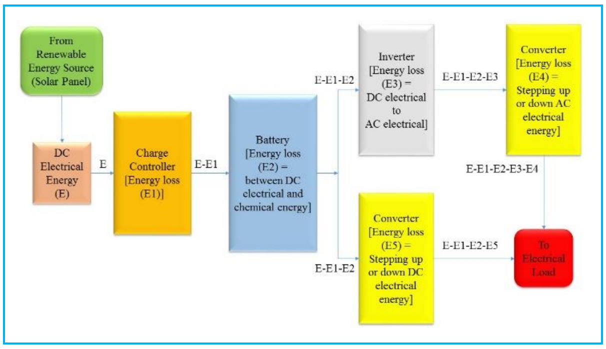

Fig. 1. Electrical losses from solar energy to load.

Solar energy is first converted into electrical energy in the form of dc supply with the help of solar PV panels. The electrical energy of dc supply is then stored in batteries in the form of chemical energy by using charge controllers. These controllers consumes electrical energy (E1) for its own operation. The energy transformation of electrical to chemical in batteries produces conversion loss (E2). Now, when sun radiation is not available on solar panels, the stored chemical energy again converted into electrical energy for the use of inverter and converter. This transformation of energy again affect the conversion loss (E2). Furthermore, the dc supply is stepped down or stepped up by using converter which consumes electricity and therefore, electrical loss (E5) again occurred. Moreover, the conversion loss (E3) is again produced when the dc supply is converted into ac supply by using inverter. The ac supply is then stepped up or down with the help of transformers and other associated circuits. This conversion again leads to energy loss (E4). In this way, to operate an electrical load from solar energy, there are consumption and conversion losses in the process of electrical supply from source to load. The proposed system rectifies these intermediate losses and offers a direct utilization of solar energy in electrical supply systems.

III. PROPOSED SYSTEM

The power supply management of system depends on irregular behavior of solar energy which is changed according to atmospheric conditions throughout the day. Solar energy in the form of non-uniform solar radiation changes the output voltage of solar panel. This fluctuating voltage is used to decide the current in the solar circuit with the help of series resistor. Current flowing in solar circuit is then used to decide the current in mains circuit by choosing an appropriate value of resistor in mains circuit. The value of mains resistor is selected with the help of relay based resistive ladder network which is activated by microcontroller. Total current of the system is always balanced while increasing or decreasing the mains current by using solar current. In this way, the current from solar is measured and the same amount of current is deducted from mains in order to keep the same total additive output of the system. A microcontroller and its supporting components are used for the implementation of this control logic. In this system, current parameter depended on solar voltage is used to maintain the balance in the output. Hence, it is also a voltage depended current controlled system. The control logic of this system manages both supplies to load in comparison to each other.

An arrangement of both power supplies in the proposed system is shown in Fig. 2.

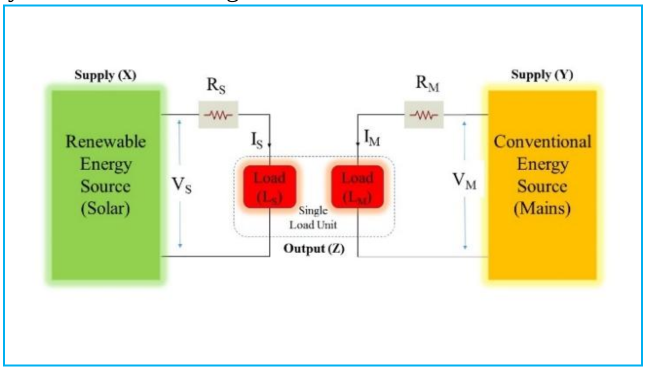

Fig. 2. Power supply management with load.

The system as shown in Fig. 2 is a combination of two separate electrical networks with a single load unit. Load unit consists of two separate equal powered electrical load in single casing, so that single physical output can be obtained. Both loads are supplied separately by two different sources of renewable and conventional energy. Supply (X) from solar energy having fluctuating voltage (VS) is applied to load (LS) through series resistor (RS). This action generates current (IS) in the solar circuit which is changed according to fluctuating voltage. The changes in solar current (IS) is used to change the mains current (IM) with the help of resistance (RM). The value of resistance (RM) is decided by resistive ladder network in which relays are used for the selection of appropriate resistor. These relays are energized by microcontroller. The value of resistance (RM) then affects the current (IM) generated by conventional supply (Y) having voltage (VM). When the current (IS) is decreased, the current (IM) is forced to increase in order to balance the output and vice versa. Thus, current (IM) flowing in conventional circuit is varied in inversely proportion to the current (IS) flowing in solar circuit so that total additive current (IT) of both circuits and total physical output (Z) of the system should be balanced. Therefore,

$$I_M \propto \frac{1}{I_S} \tag{1}$$

and $I_T = I_M + I_S$ (2)

In this way, solar supply is always present as a compensation to conventional supply during the availability of solar energy. In the system, relays are used as current controlling devices in the resistive ladder network. These relays are electrically separated from the current flowing circuit of mains and are activated by microcontroller. Hence, the control devices are not involved in intermediate consumption when both the energy sources are used for supply to load and therefore, the load consumes energy directly from both of the sources.

IV. MATERIALS AND METHODS

The proposed system has been developed on the basis of different hardware parts and various methods have been used to implement this. The different parts of the proposed system have been broadly mentioned in next coming sections.

International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-12, October 2019

A. Solar panel

The supply from solar panel is utilized for control purposes during the availability of solar energy. The 10WP panel having fill factor (FF) of 0.5857 and efficiency (η) of 9.382% can generate 16.4V voltage and 0.6A current at maximum power point, whereas Open Circuit Voltage (VOC) and Short Circuit Current (ISC) are 21V and 0.8A respectively [8].

The performance characteristics of solar panel for different values of voltage and current is shown in Fig. 3. This characteristic is drawn on the basis of datasheet based method where the values specified in panel datasheet is used. Different values in Fig. 3 are labelled according to panel specification.

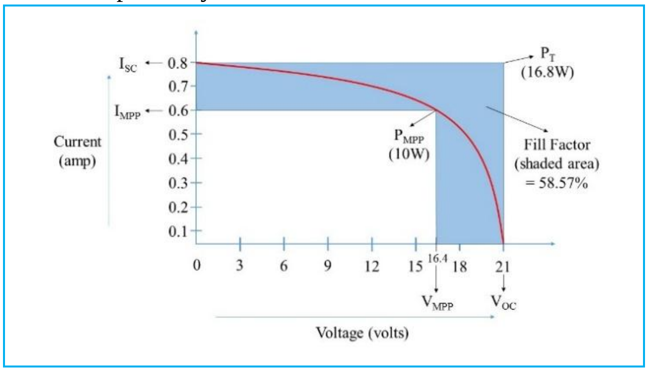

Fig. 3. V-I performance characteristics of 10W solar panel.

Solar supply hardly depends upon the radiation falling on the panel in the form of light [9-11]. Any change in radiation further changes the solar panel voltage.

B. Shunt resistor and Voltage sensor unit

Shunt resistor is the only component between the source and load for direct utilization of solar energy. Its presence is important without which the load can be over powered and can be damaged. It also works as a limiting resistor for LED.

In the circuit shown in Fig. 4, the solar supply voltage is applied to LED through shunt resistor. Jumper terminals are used for the connection of solar panel, LED and shunt resistor. LED has been used as a lamp load in this circuit.

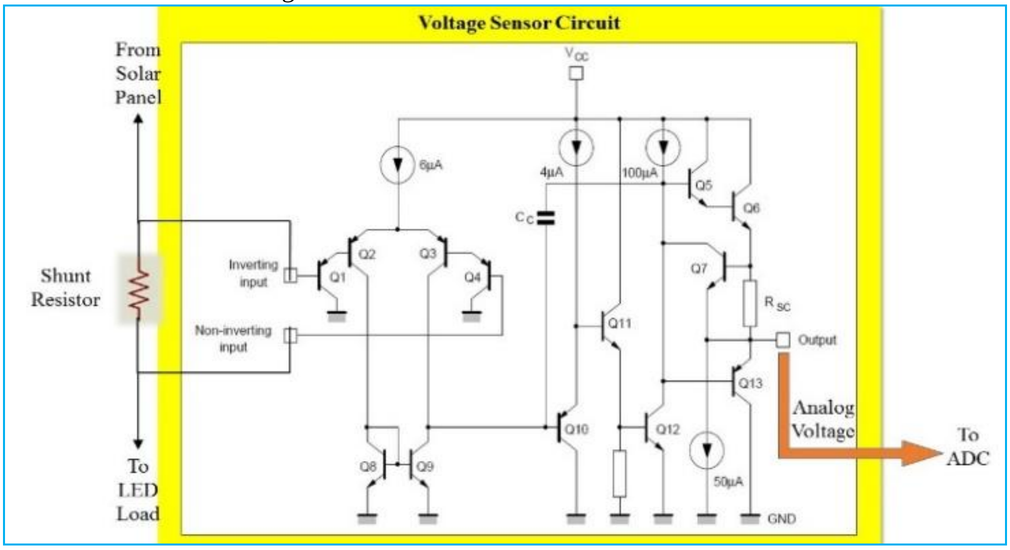

Fig. 4. Voltage sensor unit connected with shunt resistor.

The voltage of panel may exceeds the value of open circuit voltage, if solar radiation rises from 1000W/m^2. Therefore, for maintaining the voltage peaks and production tolerance, the value of shunt resistor is chosen slightly higher for the LED load, since open circuit voltage may also rise from 21V on other atmospheric conditions.

Now, by assuming maximum open circuit voltage (V_{OC}) at STC for supply voltage, the shunt resistance (R) can be calculated for LED forward voltage drop (V_F) and solar current (I_S) as follows,

$$R = \frac{V_{oc} - V_F}{I_S} \tag{3}$$

To maintain the production tolerance of solar panel and for safely handling the voltage peaks, the value of resistor should be more than its theoretical value. Another fact behind the value selection of resistor is that resistor value has been calculated according to open circuit voltage of solar panel at 1000 W/m^2 of standard test condition (STC), but solar radiation may rise more than 1000 W/m^2, therefore, the increased value of solar radiation further increases the open circuit voltage of solar panel.

If supply voltage rises only 2 volts from 21V to 23V, then the value of shunt resistor will also be increased. Thus, on the basis of availability of resistor to its nearest possible value, the value of shunt resistor is chosen slightly higher than its theoretical value. Now, the shunt resistor voltage (V_R) is utilized by voltage sensor circuit.

In the voltage sensor circuit, a classical four resistor difference amplifier is utilized because of its ability to reject signals that are common to both of its inputs. In case of solar panel voltage which continuously changes according to atmospheric conditions, it is desirable to obtain a difference voltage across shunt resistor connected with this solar panel in order to avoid interference. The circuit effectively ignores the inputs when they are same. The same voltage value at two inputs will result the interference or electrical noise but the difference amplifier rejects all such interference of common inputs and amplifies only the difference between two inputs. Also, the difference amplifier gives the protection against ground disturbances [12].

According to the op-amp configuration in the voltage sensor circuit, there is not a need of particularly very good CMRR of op-amp, since in case of input supply from solar panel, there are expectations of only very small common mode signals and hence the impact of CMRR is not very much [13].

The differential input voltage (V_{id}) is also the voltage across shunt resistor (V_R). Thus, maximum solar voltage (V_S) can be obtained as follows:

$$VS = VR + VF \tag{4}$$

The maximum voltage obtained from solar panel is measured properly by difference amplifier and fed to ADC in its range. Other values have been specified for difference amplifier in voltage sensor circuit, according to which input resistors are of 10KΩ and feedback resistors have the values of 4.3KΩ. All resistors can be tolerated to 2% of its value, which creates resistance imbalance factor of 0.08. With these resistors, differential input resistance of op-amp is 20KΩ, whereas common mode input resistance is 7.15KΩ. Having a differential gain of 0.4, common mode gain of 0.024 and CMRR of 24.436 dB, the difference amplifier generates output voltage according to the input voltage range of ADC unit. The values of different parameters are utilized to measure voltage across shunt resistor and corresponding output voltage of sensor circuit is then sent to ADC unit for digital data generation.

C. ADC Network

The ADC network accepts analog input data from voltage sensor circuit when it is powered up by mains supply voltage. Jumper terminals are used for interfacing with microcontroller and provides mains power supply path to microcontroller and relay. The data after processed in ADC by IC LM358 is then converted into digital form and fed to microcontroller for further processing. In the ADC circuit, internal clock generator is associated with resistor and capacitor since it also has self-clocking option. A suitable conversion time is set by selecting the proper value of these resistor and capacitor, since the speed at which analog input voltage is converted to digital output voltage, depends on the conversion time. The analog data converted in specified conversion time is then transformed to digital data according to the resolution or step size of ADC [14].

The specifications of ADC0804 used in the system is shown in Table I.

TABLE- I: Specifications of ADC0804

Parameters	Value
Supply voltage (V^+)	+5V
Supply voltage sensitivity	(V^+) ± 10%
Voltage at any input	V^+ + 0.3
Input resistant	1.3KΩ
Conversion time	110μs

On the basis of ADC specifications, a circuit shown in Fig. 5 then converts analog voltage to digital data for further processing in microcontroller unit.

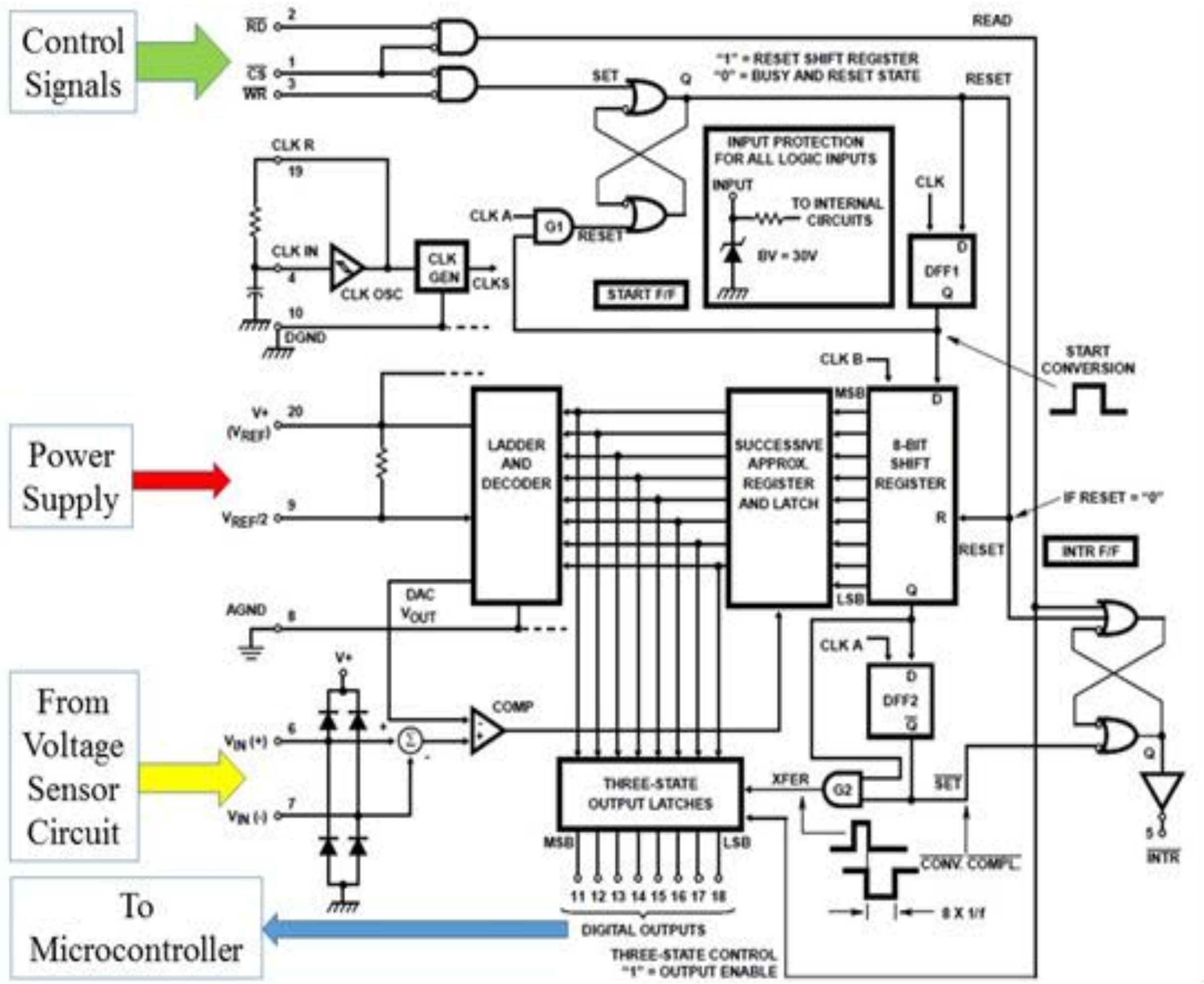

Fig. 5. Functional block diagram of ADC unit.

D. Microcontroller Unit

Microcontroller unit as shown in Fig. 7 receives the data from ADC at port 1 and provides the data to relay at port 0 according to the control parameter of program. Microcontroller uses port 3 pins to control ADC in order to get the data from it. Port 0 of microcontroller is open drain unlike other ports and hence, 10KΩ of resistors have been externally connected in order to use it like other ports [15]. Now, to run the microcontroller, an external clock is required which is setup by a clock circuit having capacitors and a quartz crystal oscillator. A supply of +5V required to operate the microcontroller is arranged by a circuit which consists of filter capacitors and a supply indicator with resistor and LED diode. This supply circuit works from AC supply which is provided from mains transformer by using Jumper terminal. This terminal is also used to provide ground connection for relay circuit.

The Microcontroller AT89S51 is a CMOS based 8-bit control unit. It has extensive Boolean processing with a single bit logic capability. It has vide memory space for RAM and in-system programmable (ISP) flash memory. Both of these memories are on-chip available in microcontroller [16]. It can process a variety of instruction sets. It provides the facilities of byte processing and numerical operations on small data structures. In order to access internal RAM at fast pace, it has fast addressing modes [17]. To process the data, a large number of instruction set is available in this microcontroller. Having aforesaid specifications and properties, a microcontroller circuit designed for the system is used for data transformation to relay network.

E. Relay and R-2R ladder Network

Relays are activated through its relay driver ULN2803 in a relay circuit which is shown in Fig. 6. The circuit is designed for interfacing with microcontroller and R-2R ladder network.

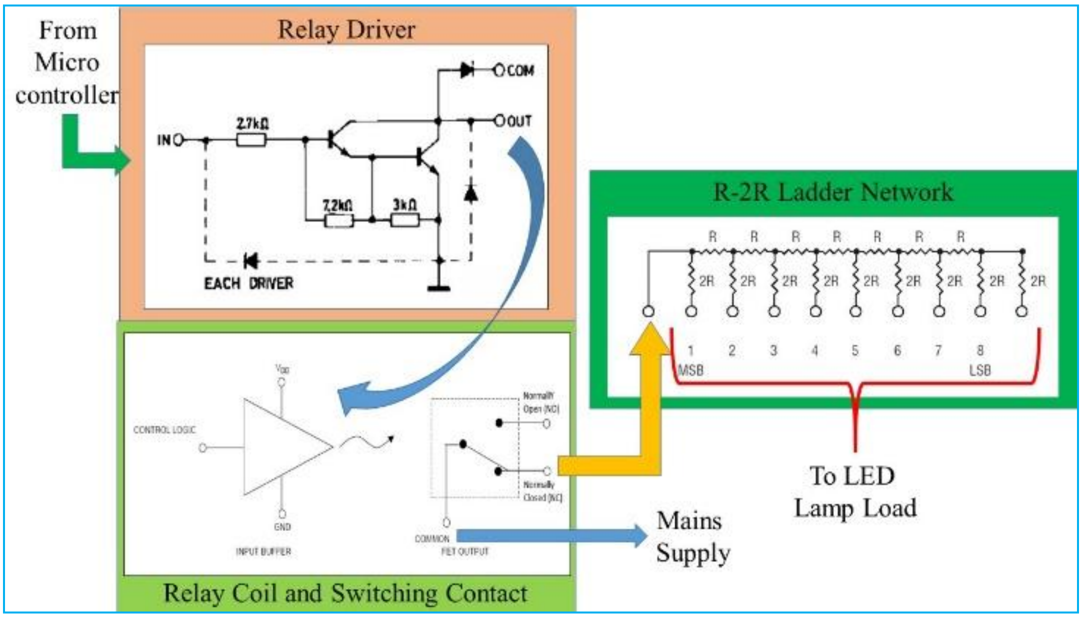

Fig. 6. Block diagram of relay unit connected with R-2R ladder network.

This driver with maximum input voltage of 30V can allow continuous base current of 25mA with turn on/off time of 0.25µs and power dissipation of 2.25W [18].

mpers have been inserted in such a way that their center terminal contact should be connected with resistor, NO contacts of all jumper terminals should be connected to LED and NC contacts of all jumper terminals should be connected to mains supply directly. LED lamp load fed by mains supply is connected to R-2R ladder network using jumper terminals.

The R-2R ladder network is supplied by mains voltage (V_M) whose value (22.5V) is selected according to maximum permissible current (463mA) to LED and maximum solar panel voltage. Power supplied to R-2R ladder network generates the current in each branch of ladder network. The additive current through relay contacts of all branches is then fed to LED lamp load.

F. Mains supply and LED lamp load

In order to provide supplies to different parts of mains circuit, a power supply circuit is designed. Supply for op-amp, ADC and microcontroller circuits is designed by using step down transformer (9V-0-9V) to step down AC voltage to 18V, bridge rectifier for AC to DC conversion and filter capacitors. Voltage regulator IC LM7812 is used for op-amp supply of 12V, whereas 5V supply for ADC is generated by voltage regulator IC LM7805. Jumper terminals are used for the connection of transformers which are out of the circuit board. Another supply circuit is designed for R-2R ladder network which consists of a bridge rectifier for AC to DC conversion, filter capacitors, voltage regulator IC LM7824 and a diode for further small voltage drop. Supply transformer (15V-0-15V) has been used for stepping down AC voltage to 30V.

The load for solar and mains supply consists of LED diode which are energy efficient and more better as compared to incandescent lamps and CFLs [19-23]. LEDs are connected with female jumper terminal. These terminals are connected to male jumper terminal mounted in circuit board. According to the internal arrangement inside the body of LED, there are

In an 8-bit R-2R resistor network, there are 'R' value resistors and '2R' value resistors. For each resistive branch having '2R' value, three terminals ju 9 miniature LEDs which are arranged in series-parallel combination. The combination has 3 parallel groups and each group consists of 3 LEDs arranged in series. Equations (5) and (6) are used for LED related calculations as follows:

$$\text{Current in each group} = \frac{\text{Power of each group}}{V_F} \quad (5)$$

$$\text{Maximum current in LED (IS)} = \frac{P_{LED}}{V_F} \quad (6)$$

Where, P_{LED} is the power of LED.

For the value of open circuit voltage of solar panel and value of shunt resistor, maximum value of current to LED is given as follows,

$$IS = \frac{V_{oc} - V_F}{R} \quad (7)$$

Now, on the basis of solar current in LED, the mains current is controlled to another LED by appropriate circuits.

V. RESULTS AND DISCUSSION

A programming based control unit which includes microcontroller works on the basis of program instructions. These instructions have been written in assembly language, since a fast processing time is required for instant switching in control operations. Software 'Keil µvision' of 5.14.2.1 version has been used to assemble the program, whereas the programmer 'Willar SP200S' has been used to burn the developed program into microcontroller's internal memory.

The assembly language program has been written on the basis of program logic and its algorithm which have been mentioned in following sections.

A logic behind writing of the program is that the amount of current is to be controlled in such a way solar current should be inversely proportional to the mains current, so that same amount of currents can be controlled.

To implement this operation, a logic has been developed according to which solar current is calculated for the measured value of solar panel voltage and shunt resistance. The solar current is then used to calculate the voltage across shunt resistor. The calculated resistor voltage at every instant is then conditioned with ADC unit with the help of voltage sensor circuit. The analog input voltage received at the input of ADC is then converted into digital data for microcontroller. The microcontroller processes this data and transfers this in the same form to relay driver. An active low output of relay driver complements the input data which is further transferred to different relays. Relays activate their respective switching contacts according to input data. The continuous instant switching then change the amount of mains current through R-2R ladder network. Hence, mains current is controlled in the same amount but in inversely proportional to solar current with the help of program logic. The implementation of program logic for the microcontroller has been carried out according to following algorithm:

1. Allow input data from ADC at port 1.
2. Allow output data for relay network from port 0.
3. Transfers control signals to ADC for data fetching from port 3.
4. Start sending control signals to ADC for its initialization.
5. Write read command for ADC and insert delay subroutine for waiting data.
6. Start communication from ADC to microcontroller.
7. Repeat the task for continuous data transformation.

For the testing of the system, a hardware is developed which is shown in Fig. 7.

Fig. 7. Hardware development of the system.

VI. CONCLUSION

A current control scheme was presented which maximized energy saving by the utilization of solar energy. An instantaneous variation in solar current due to continuously varying solar radiation was utilized to control the mains current. A system is able to control mains current by any possible value of solar current. A hardware for this scheme was developed for which a high speed assembly language program was executed on the microcontroller platform. Also, the stability of microcontroller was enough for sudden input and output reactions. The testing results were closely related to the expected values in local environmental conditions.

An architecture of hardware is able to use natural solar energy as a comparative parameter for controlling currents automatically during any climatic conditions. The control technique doesn't involve internet or wireless connectivity or even human intervention. Hence, it is one of the cost effective solution for rural and distant areas. As a standalone system, the work is one of the daylight option which uses solar energy for lighting energy efficient LEDs by minimizing mains supply while maximizing solar supply. The work is able to manage both AC and DC supplies and can also be extended for hybrid supply to integrate multiple renewable energy sources for maximum utilization of green energy.

Apart from using software based MPPT techniques or hardware based solar tracking devices, the proposed system is another way to obtain maximum power from solar energy. The system is a new technique over conventional techniques towards harnessing the solar energy for any atmospheric conditions.

A control technique developed for a current parameter provides a way to supply side management (SSM) which is useful for combining multiple supplies obtained from different energy sources. By utilizing atmospheric conditions for controlling current, the work is useful for maximizing energy saving, energy security and further promotion of renewable energy sources.

REFERENCES

1. H. E. Gelani, F. Dastgeer, "Efficiency Analyses of a DC Residential Power Distribution System for the Modern Home," Advances in Electrical and Computer Engineering, vol.15, no.1, pp.135-142, 2015, doi:10.4316/AECE.2015.01018
2. Marilyn A Brown, Benjamin K Sovacool, "Promoting a level playing field for energy options: electricity alternatives and the case of the Indian Point Energy Center," Energy Efficiency, vol.1, no.4, pp.35-48, 2008, doi:10.1007/s12053-007-9002-6
3. Wina Graus, Eliane Blomen, Ernst Worrell, "Global energy efficiency improvement in the long term: a demand- and supply-side perspective," Energy Efficiency, vol.4, no.3, pp.435-463, 2011, doi:10.1007/s12053-010-9097-z
4. C. Nemes, F. Munteanu, "Potential Solar Irradiance Assessment based on a Digital Elevation Model," Advances in Electrical and Computer Engineering, vol.11, no.4, pp.89-92, 2011, doi:10.4316/AECE.2011.04014
5. Richa Mahtta, P.K. Joshi, Alok Kumar Jindal, "Solar power potential mapping in India using remote sensing inputs and environmental parameters," Renewable Energy, vol.71, pp.255-262, 2014, doi:10.1016/j.renene.2014.05.037
6. K. Zaplatilek, J. Leuchter, "Behavioral Model of Photovoltaic Panel in Simulink," Advances in Electrical and Computer Engineering, vol.11, no.4, pp.83-88, 2011, doi:10.4316/AECE.2011.04013
7. Srinivasa Rao Potnuru, Dinesh Pattabiraman, Saravana Ilango Ganesan, Nagamani Chilakapati, "Positioning of PV panels for reduction in line losses and mismatch losses in PV array," Renewable Energy, vol.78, pp.264-275, 2015, doi:10.1016/j.renene.2014.12.055
8. REIL (2017), SPV Module, http://www.reiljp.com/pdf/SPV_MOD.pdf, Accessed 18 January 2017
9. K. Zaplatilek, J. Leuchter, "Implicit Approximation of Photovoltaic Panel Characteristics Using a Stochastic Approach," Advances in Electrical and Computer Engineering, vol.12, no.4, pp.53-56, 2012, doi:10.4316/AECE.2012.04008
10. H. Rajendran, R. Ramabadran, R. Sankararajan, "Design and Implementation of PV based Energy Harvester for WSN Node with MAIC algorithm," Advances in Electrical and Computer Engineering, vol.15, no.2, pp.109-116, 2015, doi:10.4316/AECE.2015.02014
11. S.S. Chandel, M. Nagaraju Naik, Vikrant Sharma, Rahul Chandel, "Degradation analysis of 28 year field exposed mono-c-Si photovoltaic modules of a direct coupled solar water pumping system in western Himalayan region of India," Renewable Energy, vol.78, pp.193-202, 2015, doi:10.1016/j.renene.2015.01.015

12. Shahram Minaei, Cem Goknar, Oguzhan Cicekoglu, “A new differential configuration suitable for realization of high CMRR, all-pass/notch filters,” Electrical Engineering, vol.88, no.4, pp.317-326, 2006, doi:10.1007/s00202-004-0284-9
13. Farzan Rezaei, Seyed Javad Azhari, “Rail-to-rail input/output operational transconductance amplifier (OTA) with high CMRR and PSRR,” Electrical Engineering, vol.94, no.3, pp.165-175, 2012, doi:10.1007/s00202-011-0229-z
14. Shreeniwas Daulatabad, Vaibhav Neema, Ambika Prasad Shah, Praveen Singh, “8-Bit 250-MS/s ADC Based on SAR Architecture with Novel Comparator at 70nm Technology Node,” Procedia Computer Science, vol.79, pp.589-596, 2016, doi:10.1016/j.procs.2016.03.074
15. Muhammad Ali Mazidi, Janice Gillispie Mazidi, Rolin D Mckinlay, “The 8051 microcontroller and embedded systems”, Pearson Education, 2nd edition, India, 2013.
16. Kenneth J. Ayala, “The 8051 Microcontroller”, Penram international publishing private limited, 2nd edition, India, 2005.
17. Ajay V. deshmukh, “Microcontrollers”, Tata mcgraw hill education private limited, 15th edition, India, 2010.
18. SGS Thompson (2017), Technical Document, http://www.st.com/content/ccc/resource/technical/document/datasheet/f3/6e/c8/64/4d/b3/4e/38/CD00001244.pdf/files/CD00001244.pdf/jcr:content/translations/en.CD00001244.pdf, Accessed 15 January 2017
19. Evan Mills, Arne Jacobson, “From carbon to light: a new framework for estimating greenhouse gas emissions reductions from replacing fuel-based lighting with LED systems,” Energy Efficiency, vol.4, no.4, pp.523-546, 2011, doi:10.1007/s12053-011-9121-y
20. Chin Kim Gan, Ahmad Farid Sapar, Yik Chee Mun, Kuan Eng Chong, “Techno-Economic Analysis of LED Lighting: A Case Study in UTeM's Faculty Building,” Procedia Engineering, vol.53, pp.208-216, 2013, doi:10.1016/j.proeng.2013.02.028
21. Bin-Juine Huang, Chun-Wei Chen, Po-Chien Hsu, Wei-Min Tseng, Min-Sheng Wu, “Direct battery-driven solar LED lighting using constant-power control,” Solar Energy, vol.86, no.11, pp.3250-3259, 2012, doi:10.1016/j.solener.2012.07.028
22. Kuldip Singh Sangwan, Vikrant Bhakar, Shilpa Naik, Sylvi Nazareth Andrat, “Life Cycle Assessment of Incandescent, Fluorescent, Compact Fluorescent and Light Emitting Diode Lamps in an Indian Scenario” Procedia CIRP, vol.15, pp.467-472, 2014, doi:10.1016/j.procir.2014.06.017
23. Andrea L Hicks, Thomas L Theis, “Residential energy-efficient lighting adoption survey,” Energy Efficiency, vol.7, no.2, pp.323-333, 2014, doi:10.1007/s12053-013-9226-6

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