Hardware Implementation of Automatic Power Source Controller Cum Power Optimizer

A. Kunaraj, J. Joy Mathavan, and K. G. D. R. Jayasekara

Abstract A device that can switch from one source of power to the other or add on two power sources based on the real-time energy requirement. Power can be generated by various sources. Solar, wind, diesel generator, and electric board main grid supply are the four sources of energy tested here. The number of sources can be more based on user requirements. If the demand exceeds the supply, the device is programmed through AT Mega 2560 microcontroller to add more than one power source to meet the excess demand. With the help of electrical parameters, the power optimizer automatically switches and controls the power source based on the power consumption. If the demand exceeds the total supply, the device is programmed to stop certain devices until the consumption becomes normal.

Keywords Power optimizer · Power source controller · Solar power · CEB grid

1 Introduction

In the developed world, people use innovative ideas to invent new electrical/electronic appliances to do work more efficiently and effectively. The demand for electricity keeps on increasing when everyone starts using electrical appliances. The objective of this research work is to propose an automatic power controller cum power optimizer to switch the power from one source to another or to add up more than one power source based on demand for power. A power generation system should be able to produce enough power using various sources. This device is designed to go for the energy produced by cheap and available sources first, and if the demand exceeds the supply, the device will switch to the next available power source. It can be

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used in situations where the electrical energy consumption is high and fluctuating in an unpredictable manner. Mainly, four power systems can be connected with this proposed device. The power optimizer can measure the power requirement of the consumer and take a suitable real-time decision automatically to process and switch to the next available power source. In most of countries, the energy produced by private companies or by individuals, if it is excess, can be supplied to the main grid line of government, based on the energy requirement. The sources of power generation may be costly or cheap depending on the availability of those sources. If a cheap and available energy resource are used to produce maximum power, a large amount of money could be saved. Solar and wind power are cheap renewable energy sources. In contrast, coal and diesel are non-renewable sources and they harm the environment as well.

Based on the power requirement of the industries and domestic users, there is no proper power optimizing devices for power management. People usually use the main grid line to their electrical energy requirements. When there is a power cut or low voltage supply, they use solar energy, if they have it. If there are only two power sources, it can be switched at least manually. But when the number of power sources increases, it is very difficult to manage the switching between power sources. This project considers a new device to control four power sources manually and automatically. The automatic mode operated based on the power requirement of the industries as well as domestic purposes. In case if the power consumption is high due to the heavy use of electrical appliances, it can be controlled using the wireless control method. The control method can either be switching to the next available power source or turning off certain devices for a limited period.

Solar energy, which is obtained from the sun, can be converted directly to solar energy using photovoltaic solar cells [1]. Ricardo Orduz et al. discussed the development of the PV cell and maximum power point tracking (MPPT) system. Generally, the solar panel combination has one MPPT; but in this work, each PV panel has an individual MPPT module and all the MPPT modules connected [2].

Wind energy is also a readily available and eco-friendly source of energy [3]. The usage of wind energy to produce electrical energy is first implemented in America in 1887 [4]. Various developments in the selection of composite materials for wind turbine blades are still in progress [5]. Sara Mac Alpine et al. discussed mitigating the losses related to non-uniform operating conditions in grid-tied photovoltaic arrays [6]. Elkamouny et al. mentioned in their research work about the recent developments in the technologies associated with capturing solar energy through solar cells [7]. Sanz et al. researched DC-DC converter PV system architecture and they have mentioned that almost all the mismatching losses between modules are eliminated in their outcome, and the energy output has increased [8]. Muthamizhan mentioned that coupled inductor and switched capacitor technologies were used to get high voltage gain when considering DC distribution system with solar power optimizer [9]. Salpe performed research in solar power optimizer to get maximum energy from a photovoltaic panel and send this energy to a DC microgrid. A coupled inductor and switched capacitor are used to increase the voltage gain [10]. Sivakumar explained about boost converter using SIC diodes for PV applications. The converter designed here has two switching cells to distribute the output current [11]. Haoxiang et al. focused on developing a multi-objective optimization algorithm (MO-OPA) for power management in the radio networks. This method helps to reduce power consumption by minimizing the delay in communication [12]. Smys developed ad hoc networks in various traffic conditions [13]. Most of the researches mainly focus either on one or two power sources. One among solar panels or wind or hybrid sources and the other one is the AC grid line. These researchers tried to mitigate the existing issues in the available two power source switching systems. In this current research work, the necessary power is supplied by a design of four power sources that can switch to manage the power requirement.

2 Methodology

The automatic power optimizer cum power source controller can be divided into two parts namely the master module and the slave module. All the slave modules can be controlled by the signals of the master module. The number of slave modules can be increased according to the user requirement. This research work aimed to switch four power sources based on the energy requirement. The master controller mainly focuses on increasing the use of renewable energy sources and if the demand exceeds only, it will switch to the other source. Solar energy is an environmentally comfortable, renewable, limitless [14], and cost-effective [15] source among all other alternative sources used here. Solar energy will become an economical source of energy in the coming years and developing good technology for solar cells, reduction of cost, and efficiency in an application [16, 17]. So, the use of solar power is prioritized here according to the control given to the master controller. Usually, if the solar power supply is not enough to operate appliances which need high power, like refrigerator, cooler or motor, those appliances should be turned off.

But in this device, the power derived from the next available source will be added up with the existing power source and the continuous working of those appliances is ensured. High power electrical equipment is controlled by a slave module which automatically switches off certain devices, in case, if the total power supplied by all the available power sources cannot meet the demand. The slave modules are connected with the master module by the radio signal. If the demand exceeds the supply, the slave module sends an RF signal to the master module, and the master module gives the command to switch up or shut down that particular device. Within 100 m^2, the master module and other slave modules can communicate with each other. The workflow diagram of the system is shown in Fig. 1, and the block diagram of the system is shown in Fig. 2.

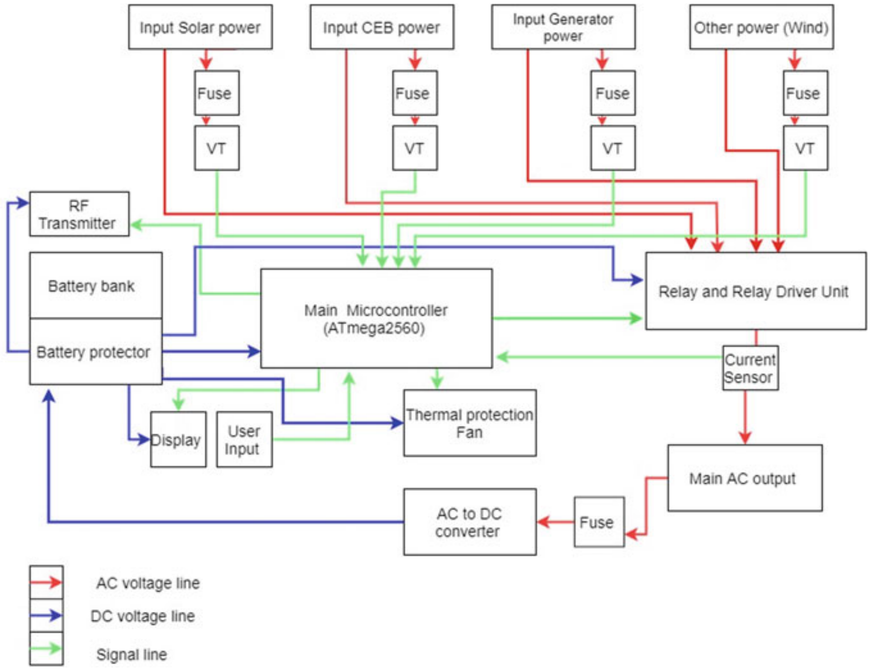


Fig. 1 Conceptual overall workflow diagram

2.1 AT Mega 2560 Microcontroller

AT Mega 2560 microcontroller is selected in this project since a large number of input and output are expected to be controlled by the microcontroller. AT Mega 2560 microcontroller is the big member of AT Mega series, and it has more number of I/O pins. The specifications of it is shown in Table 1. There are 16 analog pin in AT Mega 2560 microcontroller for analog processing, 54 pins for the general digital input–output processing, and 15 pins for the Pulse Width Modulation (PWM) processing.

In this research, work pins of all those categories are used to get inputs and give outputs. The keypad and wireless communication are connected as inputs such as the relay driver circuit, LED indicator, and LCD are connected as output in digital input–output pins. The current sensor is connected as input, and the VT transformer input is connected as output with Pulse Width Modulation (PWM) pin. Generator and solar data input are connected as the input to the system protection (Fan) are connected as output with analog pins.

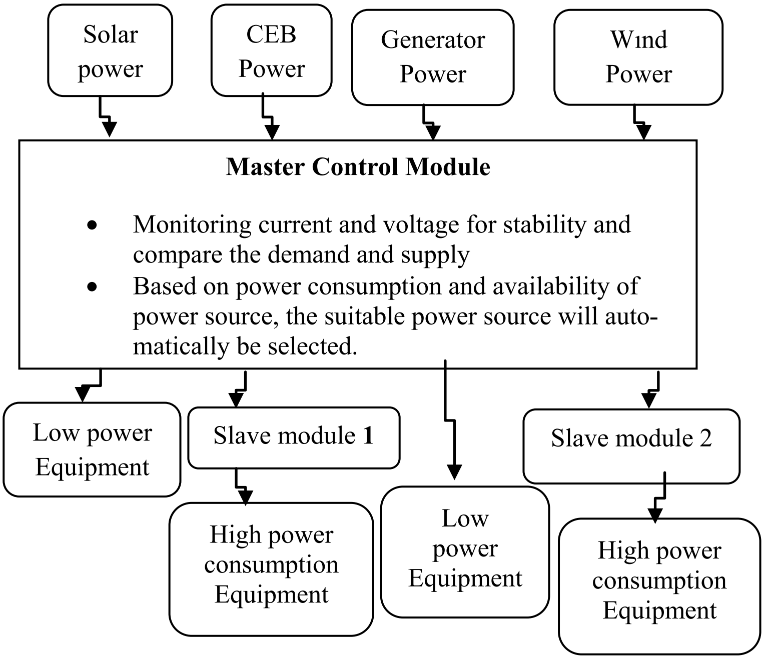


Fig. 2 Power optimizer full system block diagram

Table 1 Specifications of AT Mega 2560 microcontroller

Parameters	Range
Microcontroller	At mega 2560
Operating voltage	5 V
Digital I/O pins	54
Analog pins	16
PWM pins	15
Crystal oscillator	16 MHz
Current rating per I/O pin	20 mA

2.2 Relay Controller Module

The relay module is an important component in this equipment since all the processing is done on the AC power sources through the relay module. The relays are driven by relay driver circuit, and relay driver circuit is controlled by the main microcontroller (Fig. 3).

Based on the power requirement, the relay controller module switches from one source of power to the other or add up with the other and it is shown in Fig. 3. Four power sources namely solar, Ceylon electric board (CEB), generator, and wind are

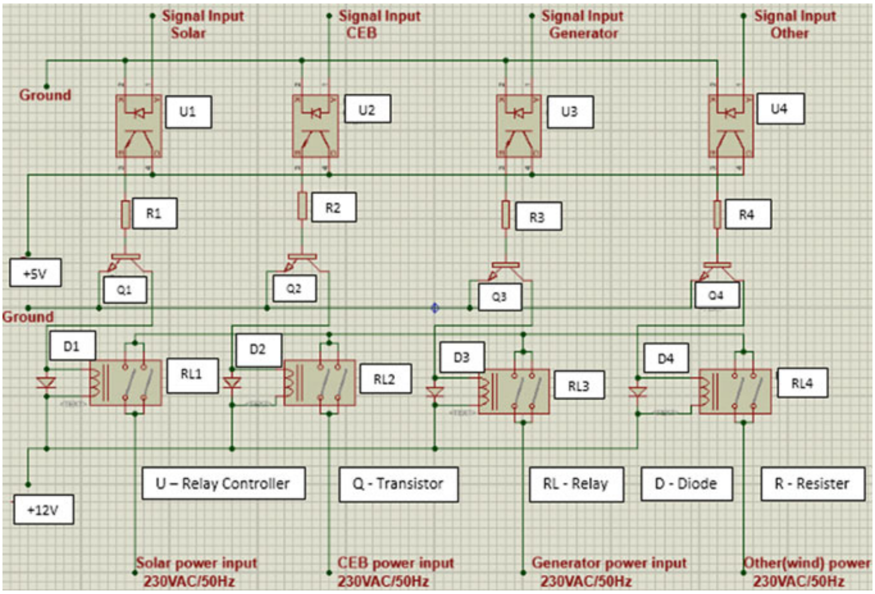


Fig. 3 Relay driver circuit diagram

occupied. The last source is mentioned as "other" in the diagram since any other source of power can be annexed with the existing design. Depend on the power demand, the microcontroller sends the signal to the relay circuit and energizes the relevant power source. When the relay is operated, back EMF would be generated and this signal affects the performance of the microcontroller since the relay is connected directly with the microcontroller. The rectifier diode is connected with the relay driver to send back EMF to the ground and prevent the intervention of back EMF in the performance of the microcontroller.

2.3 AC to DC Converter

Since all the processing inside the master controller module is occurring in DC voltage, the AC voltage needs to be converted to DC voltage by the AC to DC converter as shown in Fig. 4. Firstly, 230 VAC is reduced to 12 VAC, and after rectification and smoothening, 12 VDC output is obtained. 7805 IC is used to regulate the voltage from 12 to 5 VDC since 5 VDC is required to operate the microcontroller. One microfarad capacitor is used to get smoothened 5 VDC output.

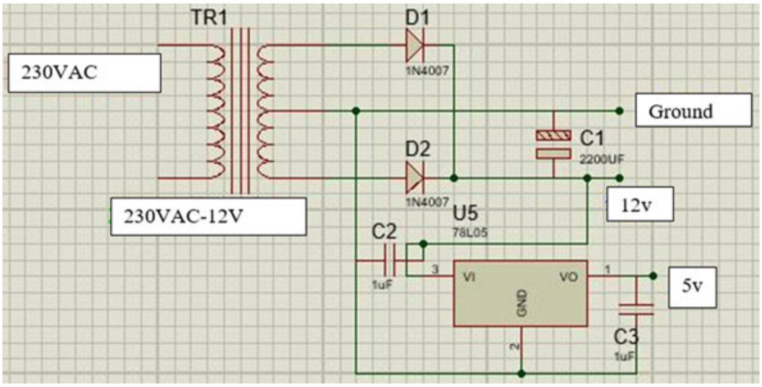


Fig. 4 Circuit diagram of AC to DC converter

2.4 Battery Bank

A battery bank is used as a reserve power source for the internal operation of the master controlling module. If the main power source failed to provide power to the device, the battery bank will provide it. If there is any interruption in the supply power to the master module, the whole system will be shutdown. Since the proper functioning of the device is needed always to switch the power, the battery bank is used as a backup and it is used to store the electricity to provide to the master controlling module. Three Lithium-ion batteries each of 3.7 V and 4000 mAh as shown in Fig. 5 are connected in series to give an approximate of 12 V output.

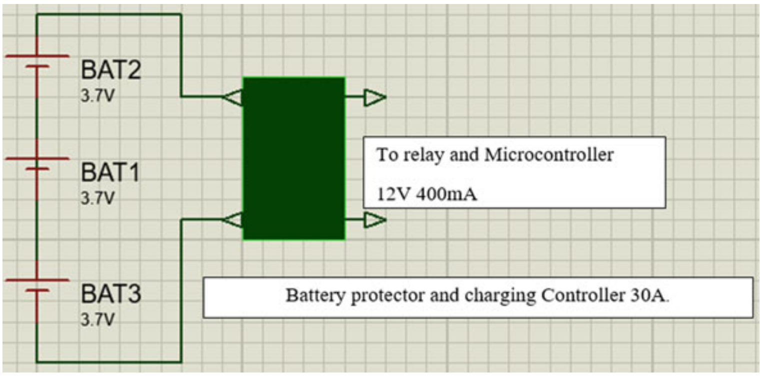


Fig. 5 Circuit diagram of battery bank

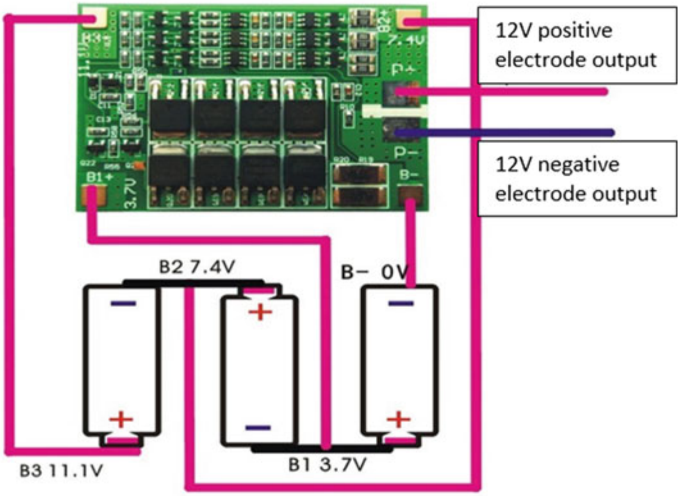


Fig. 6 Charging controller

2.5 Charging Controller and Battery Protector

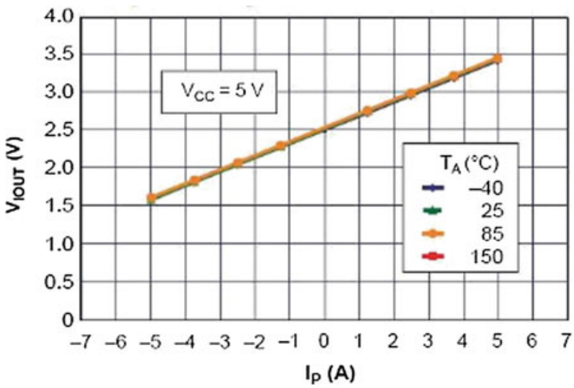
The charging controller is designed in a way as shown in Fig. 6. Usually, the batteries are charged in a way that all batteries are connected in series. In case if one battery is damaged, none of the other batteries would be charged. Therefore, to prevent such happening and to protect the battery and other equipment connected with the battery, the individual charging of each battery is designed. In this way, the battery is charged individually and the lifetime of the battery will also be high.

2.6 Current Sensor

The current sensor is used to detect the electric current in a circuit. This sensor generates a signal proportional to the current. The generated signal may be voltage or current or digital output. ASC712 IC is used as a current sensor.

It has 8 pins and the supply voltage to it is 5 V. One pinout is provided for the analog output. When current flow through the ASC712 IC, the IC output analog voltage change between 0 and 5 V. The variation is mentioned in Fig. 7.

Fig. 7 Variation of current with voltage supply



2.7 Display Module

The display module shown in Fig. 8 is used to display the data needed by the user. 128 * 64 display is used in this project, and it has 20 pins which are also suitable for displaying the graphics. There are many Arduino libraries that can support this display module.

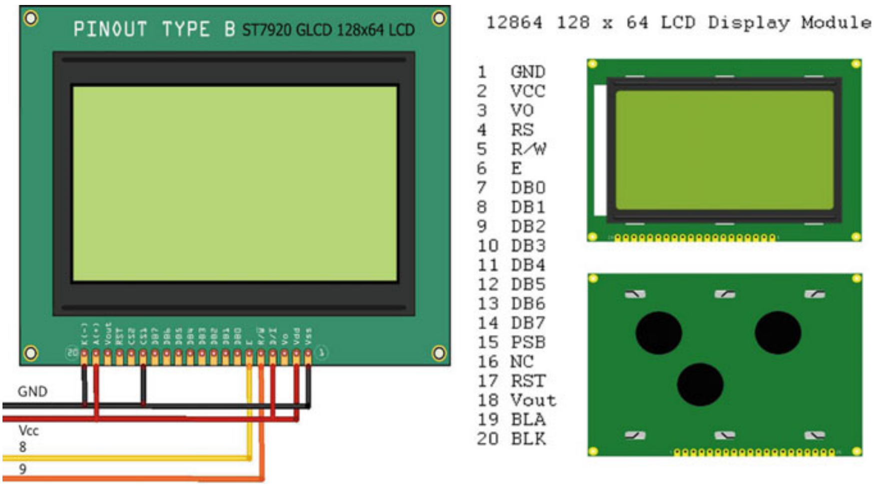


Fig. 8 Display module

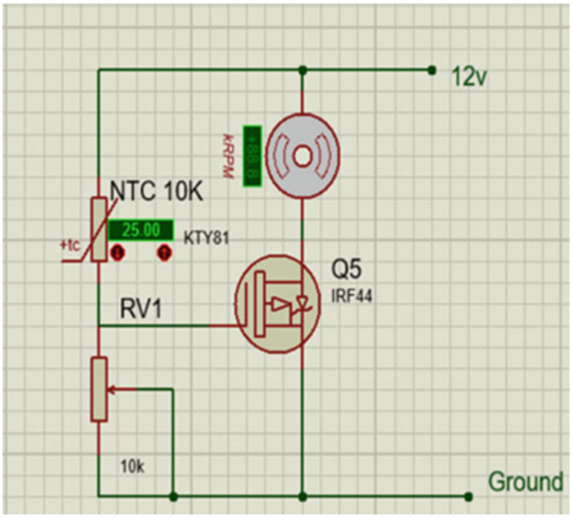


Fig. 9 Cooling system

2.8 *Thermal Protection to the System*

The master controlling module is a multi-processing unit and VT transformers are installed inside the module. Usually, transformers heat up while operating. In order to prevent the heating up of the transformers, normally an in-built cooling system would be provided in most of the transformers. But VT transformers usually does not have a cooling arrangement. Therefore, a separate cooling system is provided in this research work as shown in Fig. 9. The temperature should be maintained at the proper level by the automatic cooling fan for the efficient functioning of the transformer. When the temperature increases beyond a certain point, the driver circuit of the fan identifies it based on thermistor reading because the resistance of the thermistor changes with temperature. NTC thermistor is used in this project. If the temperature increases, the resistance across the terminals would be reduced. In this condition, IRF44 MOSFET would be biased and current flows through the source to drain. This will switch ON the fan and thereby cool the system. Once the temperature reduces below the prescribed value, the fan automatically switches off.

2.9 *Voltage Transformer*

The voltage transformer is used to measure the AC voltage. The 230 VAC is converted to 6 VAC, and it is rectified and smoothened by 10 microfarad capacitors to get the regulated voltage of 5.1 V and this is the input voltage signal to the microcontroller. The primary coil side of the transformer is connected with 800 mA fuse in series

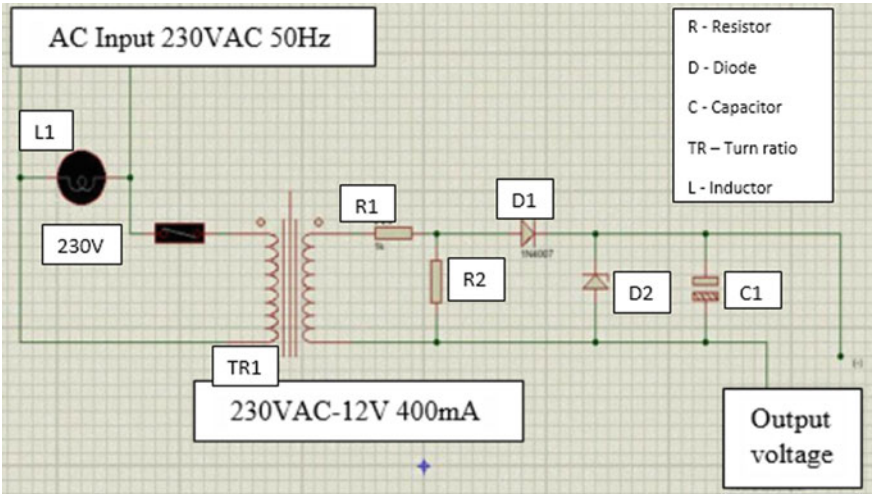


Fig. 10 Circuit diagram of voltage transformer

to protect the VT transformer from overvoltage. The circuit diagram of the VT transformer is shown in Fig. 10.

2.10 Data Access Port

When operating various energy sources, the master controlling module needs the amount of energy that can be supplied by each source. The data access ports are introduced to access the data of each power source. The solar power source produces solar radiation and heat. And, if it is an electricity generator calculate the amount of fuel left and if it is a wind power source determine the speed of wind, etc. Not only the basic data, but also the data like inverter mode and PV voltage for solar source, the pulse of starting motor and generator temperature for generator source, and all the data necessary for the user would be provided by data access port. These data are provided to the master module through a data access port. 5.1 V zener diode is used in this module to limit the input signal up to 5 V since the input data to solar and generator sources should be around 5 V since the operating voltage of the microcontroller is 5 V. If more than 5 V flows through the microcontroller, it will be damaged. The circuit diagram and schematic diagram of the data access port are shown in Figs. 11 and in 12, respectively.

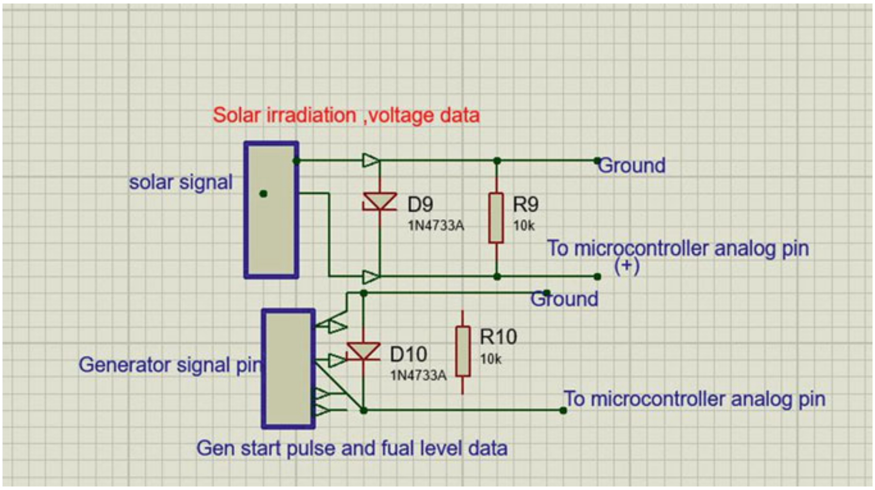


Fig. 11 Circuit diagram of data access port

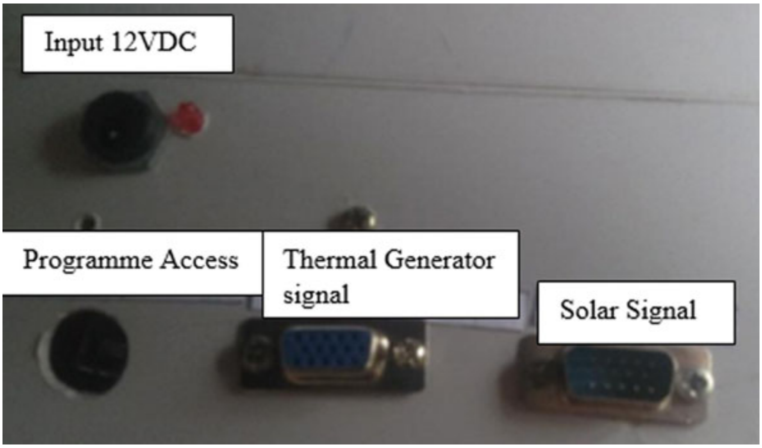


Fig. 12 Diagram of data access ports in the device

2.11 Fuse

Each circuit has a series of fuses connected with it to protect the circuit from the threat of overvoltage or short circuit as shown in Fig. 13. The damage occurs in the circuit of one source, damaging the other circuit is also prevented by the introduction of fuses. The fuses can easily be replaced since the fuse holders are mounted outside the module case. Connectors are used to connect each input and output wires, and it can easily be removed and safely be connected with the master module. Each connection have a separate terminal as shown in Fig. 14.

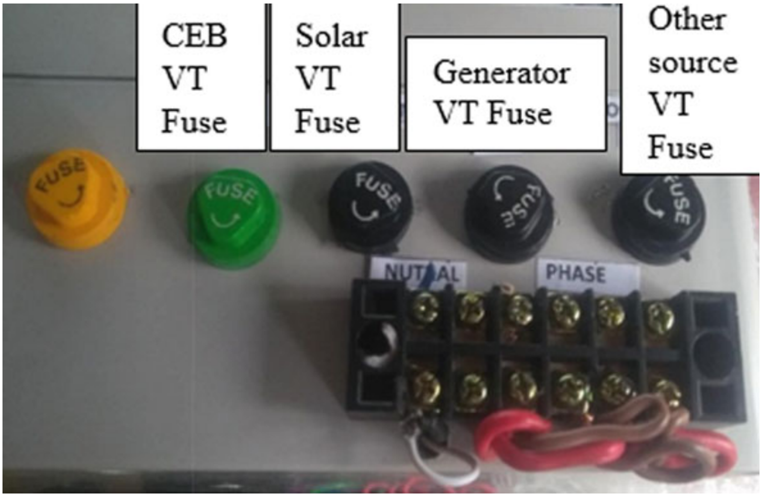


Fig. 13 Arrangement of fuses

Fig. 14 Diagram of connector terminal bar

2.12 Slave Module

The slave module could be located in different locations that are connected with the master module. Heavy equipment that consumes high power is connected with the main output AC line through a slave module as shown in Fig. 15. In case if the combined power supply by all four sources cannot meet the demand, the slave module needs to turn off some equipment connected through it with the main AC line. The power is supplied to the slave module as shown in Fig. 16.

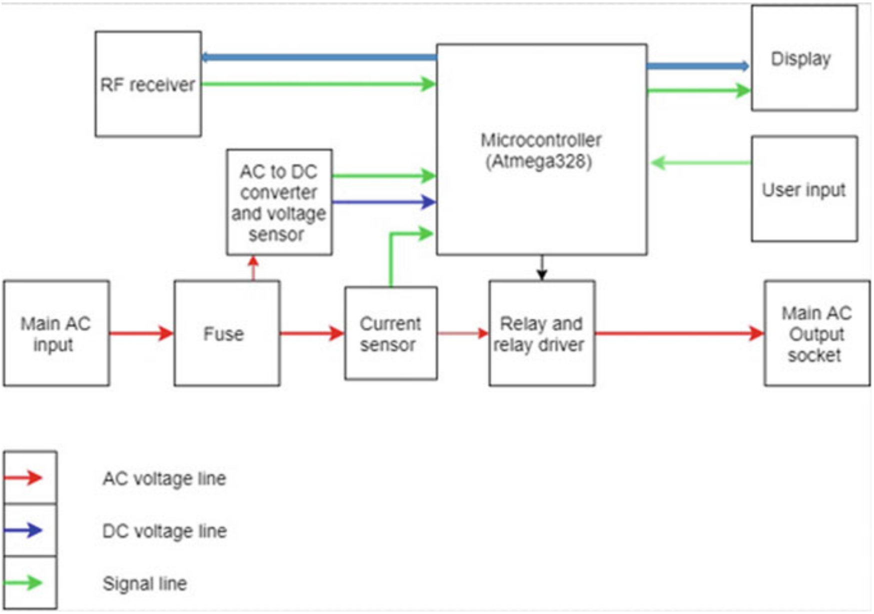


Fig. 15 Block diagram of slave module

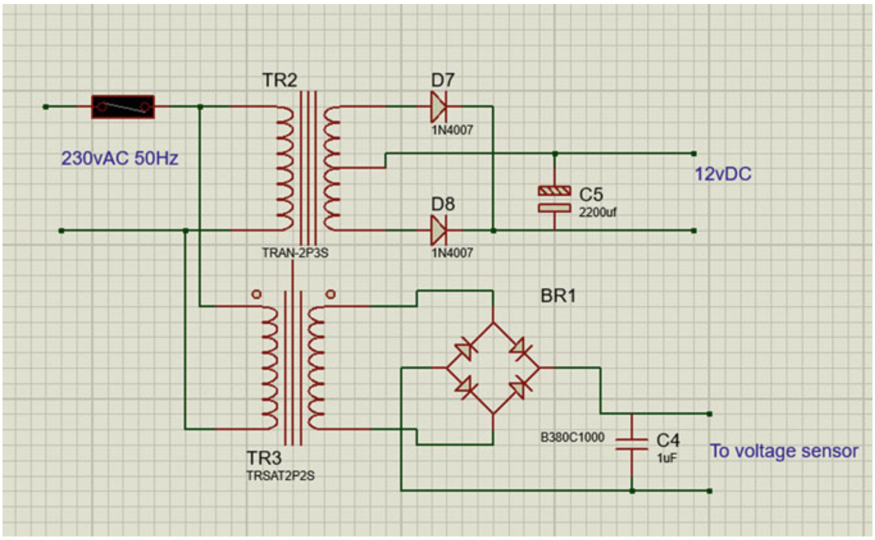


Fig. 16 Power supply for slave module

3 Results and Discussion

Wireless connection is established between the master controlling module and the slave module. A cheap and reliable method of wireless connection are a radio signal. 433 MHz transmission module is used since it can cover a large working area of 100 m and it is comparatively cheap. The transmitter module is in the master controlling module and the receiver module is in each slave module. When four power sources are connected with the master controller module, it checks the availability of the power sources, reads the voltages and currents of all power sources, and also reads the power consumption of the main AC output. The master controller module always tries to connect with the solar power sources at the first attempt.

At first, the master control module checks the availability of solar power. If solar power is available, the solar power source would be selected and connected with the main AC output. If the solar power source is not available, on the next turn, the master control module checks the availability of CEB power. If CEB power is available, the main AC output would be connected with the CEB power source. If the CEB power source is not available, the master controller module on its third run checks the generator fuel level. If the fuel level is sufficient, the master control module sends the signal to the generator to start. So, the generator would be started and generator power can be connected with the main AC output. During peak hours, the solar power is not sufficient most of the time. Therefore, the master controller module always checks the availability of CEB and generator.

In case if the combined supply of all four power sources together is not enough during peak hours of power consumption, the master controller module sends the signal to the slave module to cut-off the power from equipment like air conditioner which consumes high power. Equipment consume less power to keep on working while equipment consumes high power would be shut down until the balance between supply and demand arise. The basic idea of this device is to increase the usage of easily available renewable power sources instead of conventional government power supply. The prevention of environmental pollution and the economic growth of the country is also expected to be addressed through this research work. For example, coal and diesel power which are used in thermoelectric plants are polluting the environment and, it has the threat of extinguishing soon. In most of the countries, coal and petroleum products are imports. Renewable resources like solar, tidal, wind, and hydro energy are environment-friendly and readily available energy sources (Fig. 17).

4 Conclusion and Future Scope

There are two modules developed in this design, one is the master control module and the other one is the slave module. The master control module has control over the power sources and the parameters of all individual power sources. The slave module is used in a way that the heavy equipment which consumes high power is

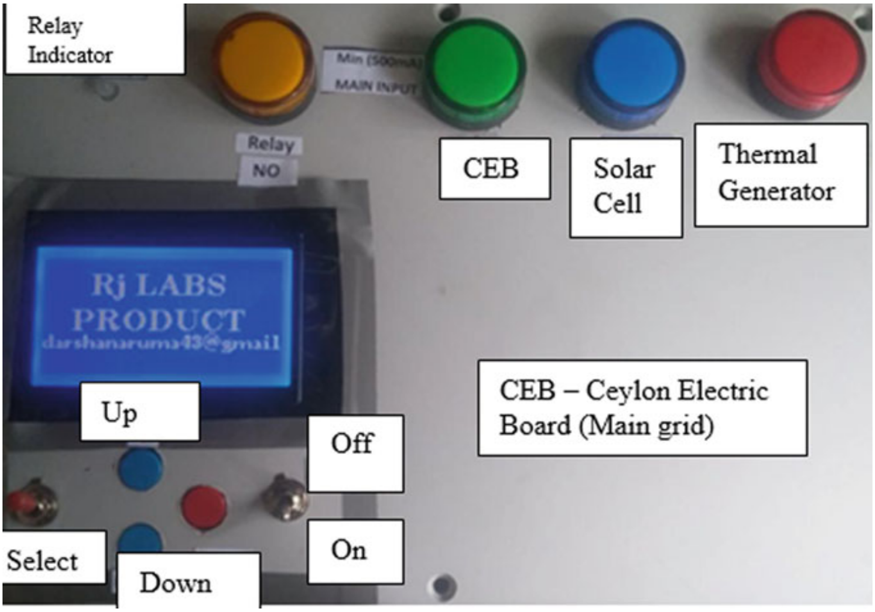


Fig. 17 Real-time working model of the proposed system

connected through the slave module with the main AC grid line. If power production from one source is not enough, the master module programmed to add up more than one power source to provide the necessary power. If the combined supply of all four power sources becomes lower than demand and the power supply from the source is detected by the master controlling module as low, it sends a signal to the salve module to switch off certain devices based on the output AC voltage. Similarly, if the master controlling module detects sufficient power from the sources, then it sends the signal to all the slave modules to switch ON the output AC supplies which are closed.

The working of the power optimizer cum automated power sources controller is based on the availability of the power sources and power demand on the main AC output. As a development of this controller, the addition of the power consumption for every month is expected to be calculated daily based on KW/h to find a graph of peak hours. If it is found, then the master controller can select the power sources according to this graph as a predetermined function. And also it would be very useful in the industrial point of view since the industries run cyclic workloads on their day-to-day functioning. If the heavy-duty hours of the industries are found accurately, this device can be programmed appropriately and maintenance of the device and the system will also be easy.

References

1. Shaikh MRS, Waghmare SB, Labade SS, Fuke PV, Tekale A (2017) A review paper on electricity generation from solar energy. Int J Res Appl Sci Eng Technol 5(IX):1884–1889
2. Orduz R, Solórzano J, Egido MÁ, Román E (2011) Analytical study and evaluation results of power optimizers for distributed power conditioning in photovoltaic arrays. Fundación Tecnalia Research and Innovation, Energy Unit, Edit. 700 Derio 48160, Spain
3. Suresh Babu K, Raju S, Srinivasa Reddy M, Nageswara Rao DN (1887) The material selection for typical wind turbine blades using MADM approach & analysis of blades. In: MCDM 2006, Chania, Greece, June 19–23
4. Kumar A, Dwivedi A, Paliwal V, Patil PP (2014) Free vibration analysis of Al 2024 wind turbine blade designed for Uttarakhand region based on FEA. Procedia Technol 14:336–347
5. Mathavan JJ, Patnaik A (2020) Development and characterization of polyamide fiber composite filled with fly ash for wind turbine blade. In: Emerging trends in mechanical engineering. Springer, Singapore, pp 131–139
6. MacAlpine SM, Erickson RW, Brandemuehl MJ (2013) Characterization of power optimizer potential to increase energy capture in photovoltaic systems operating under nonuniform conditions. IEEE Trans Power Electron 28(6):2936–2945. https://doi.org/10.1109/TPEL.2012.2226476
7. Elkamouny K, Lakssir B, Hamedoun M, Benyoussef A , Mahmoudi H (2017) Simulation, design and test of an efficient power optimizer using DC-DC interleaved isolated boost PV-micro inverter application. In: 2017 14th ınternational multi-conference on systems, signals & devices (SSD), Marrakech, pp 518–525. https://doi.org/10.1109/SSD.2017.8167019
8. Sanz A, Vidaurrazaga I, Pereda A, Alonso R, Román E, Martinez V (2011) Centralized vs distributed (power optimizer) PV system architecture field test results under mismatched operating conditions. In: 2011 37th IEEE photovoltaic specialists conference, Seattle, WA, pp 002435–002440. https://doi.org/10.1109/PVSC.2011.6186440
9. Muthamizhan T (2016) Performance analysis of solar power optimizer for DC distribution system. Int J Adv Res Electr Electron Instrum Eng 5(8):6708–6715
10. Salpe AD (2016) Design, analysis, of efficient solar power optımizer for DC mıcro grid system. Int J Adv Res Sci Eng 5(6):182–189
11. Sivakumar K (2014) Implementatıon of interleaved boost converter using SIC diodes in residential PV pre-regulator application. Int J Adv Eng Technol 6(6):2537–2547
12. Haoxiang W (2019) Multi-objective optimization algorithm for power management in cognitive radio networks. J Ubiquit Comput Commun Technol (UCCT) 1(02):97–109
13. Smys S, Josemin Bala G, Jennifer S (2010) Mobility management in wireless networks using power aware routing. In: 2010 International conference on intelligent and advanced systems, pp. 1–5. IEEE
14. Chu Y, MeisenP (2011) Review and comparison of different solar energy technologies. Report of Global Energy Network Institute (GENI), Diego
15. Choubey PC, Oudhia A, Dewangan R (2012) A Review: solar cell current scenario and future trends. Recent Res Sci Technol 4:99–101
16. Wall A (2014) Advantages and disadvantagesofsolarenergy. Process Industry Forum, 7 Aug 2013. Web, 2 Feb 2014
17. Bagher AM, Vahid MMA, Mohsen M (2015) Types of solar cells and application. Am J Opt Photon 3:94–113