http://doi.org/10.35784/iapgos.3755

received: 18.06.2023 | revised: 08.09.2023 | accepted: 27.09.2023 | available online: 30.09.2023

A NEW AUTOMATIC INTELLIGENCE-BASED SOLAR LOAD CONTROL SYSTEM

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Abstract. *In modern times, solar panels have become a common sight in many households as they provide electricity for various purposes. Typically, the solar panel's charges a battery, and any excess energy generated is usually wasted once the battery is fully charged. However, by utilizing this extra energy, heavy loads can be powered as well. This is where a solar power controller comes into play, which measures the parameters of the solar cell through multiple sensor and adjusts the load accordingly. When the power output of the PV cell is high, the load runs on solar power, and if the power is not sufficient, the load switches to the main supply. The load switches back to solar power when it becomes high again. Monitoring the solar cell parameters allows for real-time identification of the power produced by the solar panel.*

Keywords: load control system, solar PV

NOWY, AUTOMATYCZNY SYSTEM KONTROLI OBCIĄŻENIA SŁONECZNEGO OPARTY NA SZTUCZNEJ INTELIGENCJI

Streszczenie. *W dzisiejszych czasach panele słoneczne stały się powszechnym widokiem w wielu gospodarstwach domowych, ponieważ zapewniają energię elektryczną do różnych celów. Zazwyczaj panele słoneczne ładują akumulator, a nadmiar wytworzonej energii jest zwykle marnowany po pełnym naładowaniu akumulatora. Jednakże, wykorzystując tę dodatkową energię, można również zasilać duże obciążenia. W tym miejscu do gry wkracza kontroler energii słonecznej, który mierzy parametry ogniwa słonecznego za pomocą wielu czujników i odpowiednio dostosowuje obciążenie. Gdy moc wyjściowa ogniwa fotowoltaicznego jest wysoka, obciążenie jest zasilane energią słoneczną, a jeśli moc nie jest wystarczająca, obciążenie przełącza się na główne źródło zasilania. Obciążenie przełącza się z powrotem na zasilanie energią słoneczną, gdy jej moc ponownie staje się wysoka. Monitorowanie parametrów ogniwa fotowoltaicznego pozwala na identyfikację mocy wytwarzanej przez panel fotowoltaiczny w czasie rzeczywistym.*

Słowa kluczowe: system kontroli obciążenia, panel słoneczny

Introduction

Solar radiation is a readily available and clean source of energy. Being situated in tropical regions, India has a high availability of solar energy, which can be harnessed to meet a significant portion of household energy needs. As a result, the solar power market has emerged as one of the fastest-growing renewable energy markets globally. Solar panels are widely used for both industrial and household purposes, with power stations available to monitor the solar panel circuits and parameters. In households, it's essential to monitor solar panel parameters such as voltage, current, and power. Solar power is stored in batteries, and when the battery is fully charged and the energy production is high, shifting loads to solar power becomes necessary. However, this shifting process is currently manual and not particularly user-friendly.

1. Objectives

In order to effectively utilize solar energy by selecting loads to operate on solar power and to monitor solar panel parameters and power output, a system is required. The solar power controller is an essential component that enables the optimal use of solar energy by measuring the solar parameters in real-time. Based on the measured values, the system adjusts the loads and allows for seamless switching of loads between the solar inverter and main supply, ensuring efficient utilization of solar energy.

2. Proposed system design

The block diagram and circuit diagram of the solar power controller with an auto intelligence load control system are shown in figures 1 and 2 respectively.

When a solar panel is exposed to sunlight, it generates electricity. To measure the output voltage of the solar panel, a voltage divider circuit is connected across it, which reduces the voltage to a measurable range [2, 3, 6, 7, 8, 9, 14, 15]. The output voltage is then directed to pin A0 of the Arduino microcontroller. In addition, a current sensor is also incorporated into the circuit to sense the current produced by the solar panel. The current sensor output is connected to pin A3 of the Arduino [17]. To regulate the battery charging voltage and avoid voltage fluctuations, a buck converter is used as a charge controller in the circuit [1, 5, 10, 11, 16].

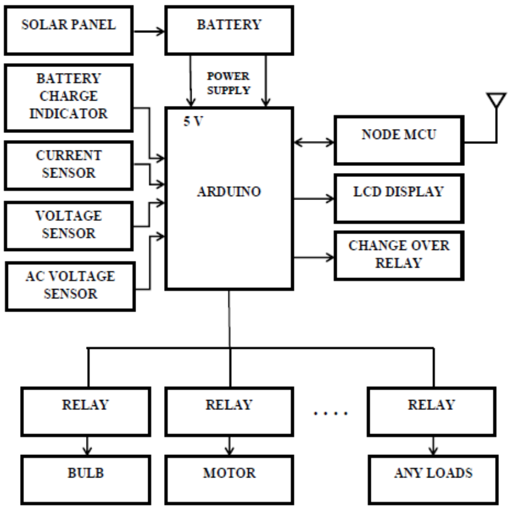


Fig. 1. Block diagram of Solar power controller

In order to monitor the battery level of the solar panel system, a voltage divider circuit is connected across the battery, and the output is displayed on an LCD screen [4, 12, 13, 18]. The voltage divider output is then directed to pin A1 of the Arduino. To measure the KSEB (Kerala State Electricity Board) current, a small step-down transformer is used, which converts 230 V to 9 V, and its output is connected to pin 2 of the Arduino. A voltage regulator reduces the 9 V to 5 V. If KSEB power is available, pin 2 of the Arduino becomes high, and low otherwise. The relay circuit is connected to pin 3 of the Arduino. When the solar panel output is high, the relay circuit closes, and the common pin switches from normally closed to normally open, connecting KSEB power to the normally closed pin and solar power to the normally open pin. An alarm is connected to pin A2 of the Arduino. An LCD converter is used to connect the LCD screen to the Arduino, with pins A4 and A5 of the Arduino connected to the SDA and SCL pins of the LCD converter. The LCD displays the panel voltage, panel current, battery voltage, and source of supply. Four loads are connected to pins 10, 11, 12, and 13 of the Arduino. Two light loads are connected to pins 10 and 11, and two heavy loads are connected to pins 12 and 13. A NodeMCU module is connected to pins 0 and 1 of the Arduino, which enables communication with the user.

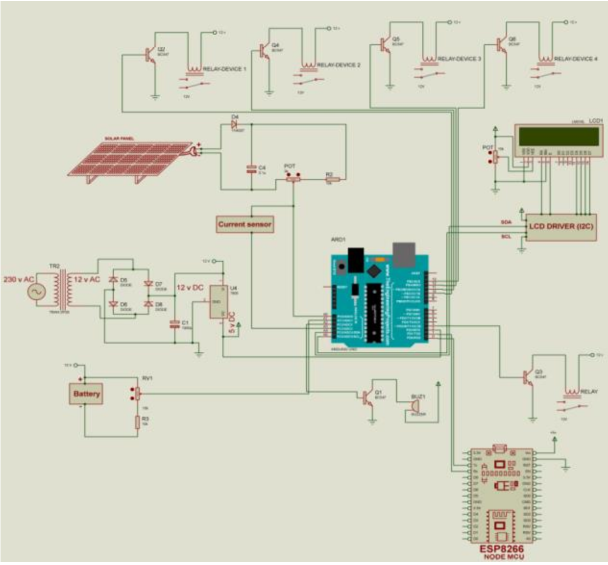


Fig. 2. Circuit diagram of Solar power controller

2.1. Experimental analysis

The system uses a current sensor called the ACS712 to sense current, and if the output voltage of the solar panel exceeds 12 V, the system shifts the supply from the KSEB to the battery. This is done by triggering a transistor, which energizes the changeover relay and switches the load connection from the AC mains to the battery. During this shift, light loads like fans and lights can continue to operate using solar power without interruption, while heavy loads like washing machines and induction cookers can be manually switched on as needed.

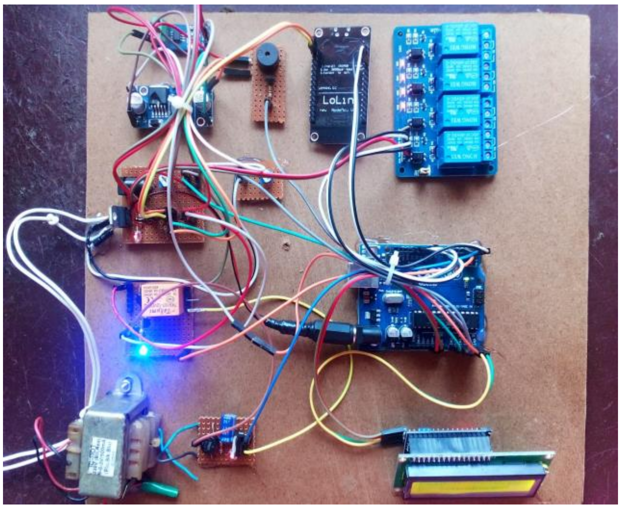


Fig. 3. Hardware implementation

2.2. Result analysis

2.2.1. Battery charging estimation

We have taken a 10 W solar panel and 12 V, 7 A battery.
So current produced,

$$I = P/V$$

$$I = 10/12 = 0.833 \text{ A}$$

So charging time,

$$T = 7/0.833 = 8.5 \text{ hours}$$

2.2.2. Working Conditions

There are three conditions are considered.

- Condition 1 – Solar panel output power is higher than 12 V.
- Condition 2 – Solar panel output power is less than 12 V.
- Condition 3 – Solar power and KSEB are not available.

Condition 1: When solar panel output becomes higher than 12 V then the system will shift from KSEB to solar power and displayed values in LCD are shown in figure 4(a). Here panel voltage is 19 V and panel current is 0.53 A. The Source of supply is displayed as solar.

Condition 2: When solar panel voltage becomes less than 12 V then the system switched to KSEB or main supply and the displayed value in LCD is shown in figure 4(b). Here the source of supply is displayed as KSEB.

Condition 3: If solar power and KSEB are not available, then the system will be shut down and the status displayed in LCD is shown in figure 4(c). Here the source of supply is displayed as no power.

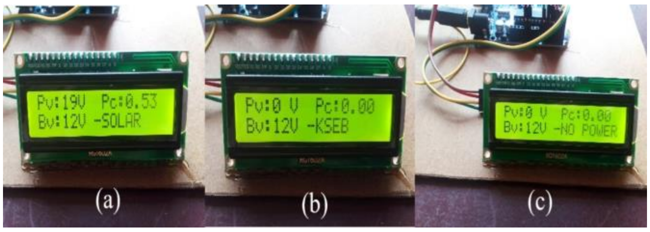


Fig. 4. Displayed values in: (a) condition 1, (b) condition 2, (c) condition 3

Measured parameters can be checked on a webpage. It shows solar panel voltage, solar panel current, and battery voltage. The webpage contains device status, and it is possible to on/off devices through it.

3. Design and implementation

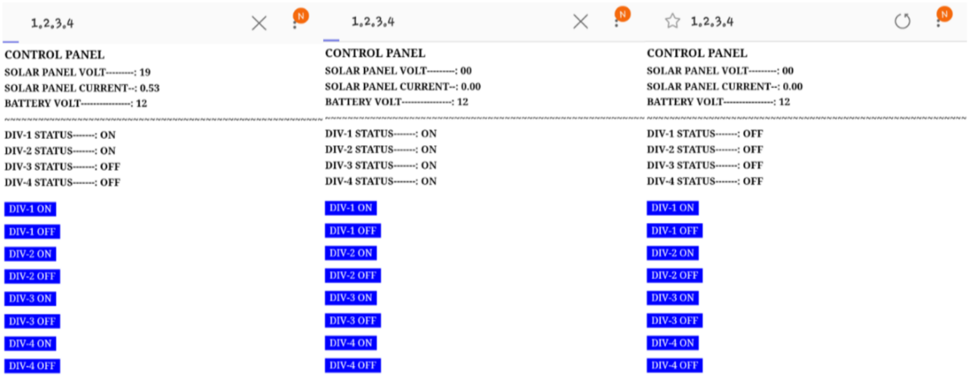
The process of system sizing involves determining the minimum sizes of PV panels, inverters, batteries, and charge controllers necessary to meet the required electrical energy demand based on the specific solar conditions at the site. This process ensures a balance between the system's output and solar input, while also accounting for any losses within the system. The design process encompasses the following steps:

1. Identify the watt-hour/day load that needs to be served.
2. Determine the average monthly solar energy available.
3. Calculate the solar panel size required to meet the load during the least favorable month.
4. Determine the appropriate size and type of battery to ensure reliable power supply.
5. Select the suitable type of charge controller.
6. Determine the capacity of the inverter needed for the system.

To perform system sizing accurately, the following information is crucial:

- The solar energy available in kWh/m2/day at the site during the month with the lowest solar energy.
- The average daily energy requirement in watt-hours (Wh) for operating the desired appliances, as well as any specific power needs that exceed the average.
- The losses that occur within the PV system, which diminish the energy available to the user.

System sizing involves determining the minimum sizes of PV panels, inverters, batteries, and charge controllers necessary to deliver the required electrical energy under the specific solar conditions at the site. It aims to achieve a balance between the system's output and solar input while taking into account losses within the system.



a) b) c)

Fig. 5. Webpage for: (a) condition 1, (b) condition 2, (c) condition 3

The design process for system sizing consists of the following steps:

1. Identify the load to be served, measured in watt-hours per day.
2. Determine the average solar energy available, considering a month-by-month basis.
3. Calculate the required size of the solar panel to meet the load demand during the worst month conditions.
4. Determine the appropriate size and type of battery necessary to ensure the desired power reliability.
5. Select the suitable type of charge controller for the system.
6. Determine the capacity of the inverter required to meet the power needs.

In order to do the system sizing, we need to know the following in formations:

- The solar energy available in kWh/m^2/day at the site for the lowest solar energy month of the year.
- The average Wh/day required by the user to operate the desired appliances and any special need for power that go much beyond the average.

The losses that occur in the PV system that reduces the energy available to the user.

3.1. Load estimation

The process of estimating the total watt-hours to be supplied involves the following steps:

1. Determine the power rating, measured in watts, for each appliance that will be used in the household.
2. Estimate the number of hours per day that each appliance is expected to be used.
3. Multiply the power rating of each appliance by the estimated hours of use to calculate the watt-hours per day for each individual appliance.
4. Calculate the total watt-hours per day by summing up the watt-hour values obtained for all appliances combined.

The different power ratings of household appliances in watts are listed in Table 1.

Table 1. Household appliances usage

Load	Watt(W)	Number of Load	Working Hours per Day
LED Bulbs	12	3	5
	9	5	5
CF Lamps	20	4	5
	15	3	5
	8	4	5
LED TV	45	1	4
Washing Machine	2150	1	1
Pump	500	1	½
Refrigerator	135	1	5
Mixer Grinder	600	1	1/6
Fan	40	10	4
Computer	90	1	1/3

Average watt-hours used by,
LED Bulbs = (9×5×5) + (12×3×5) = 225 + 180 = 405 Wh
CF Lamps = (20×4×5) + (15×3×5) + (8×4×5) = 400 + 225 + 160 = 785 Wh
LED TV = 45×1×4 = 180 Wh
Washing Machine = 2150×1×1 = 2150 Wh
Pump = 500×1×(1/2) = 250 Wh
Refrigerator = 135×1×5 = 675 Wh
Mixer Grinder = 600×1×(1/6) = 100 Wh
Fan = 40×10×4 = 1600 Wh
Computer = 90×1×(1/3) = 30 Wh
Total watt-hour required per day = 405 + 785 + 180 + 2150 + 250 + 1600 + 675 + 30 + 100 = 6175 Wh

3.1.1. Solar panels sizing

If the solar panel of 250W is chosen, with Open circuit voltage of 37.8 V, with physical dimensions of 250 watt panel and the dimension is 1650 mm×992 mm×40 mm.
Surface area of 250 W/ panel = 1.65 × 0.992 = 1.6368 m^2
Therefore, the roof area required for installing the solar PV system will be:
Roof area required = Number of panels × Surface area of one module = 10 × 1.6368 = 16.368 m^2

3.1.2. Battery sizing

The battery specification is 2500 cycles to 50% depth of discharge means that a solar system is discharged on an average to a depth of 50% per day then it could be expected to have a life of around 2500 days or 6.8 years.

The following assumptions are made for selecting the capacity of the battery bank:

1. Battery efficiency is assumed to be 85%
2. Depth of discharge is assumed to be 50%
3. Cloudy days assumed to be 2 (battery supports 2 days of energy requirements)
4. Battery voltage levels are chosen based on the wattage capacity of the plant

Battery sizing calculation:
Wh/day required by the load = 6175 W
Battery must supply = 6175 ÷ 0.85 = 7264.7 W ≈ 7265Wh/day (based on asssump-1)
Battery bank must supply = 7265 ÷ 0.5 = 14530 Wh (based on assump-2)
Battery bank must be sized = 14530 × 2 = 29060 Wh (based on assump-3)
With 48 V battery, Ah capacity = 29060 ÷ 48 = 605 Ah
Therefore, it is better to choose 16 Numbers of 200 Ah, 12 V batteries connected as 4 in series and 4 in parallel (4×200 = 800 Ah at 48 volts) and this will be able to supply the load for 2 day without 36 interruption.

3.1.3. Load shifting

Solar power can be utilized to power various household loads, but it is essential to install the appropriate panels and batteries based on the load requirements. In the earlier mentioned case, the total watt-hours required per day amounts to 6175 Wh. All loads can operate using the main supply, and when the shift is made from the main supply to solar power, the light loads can continue functioning seamlessly. The light loads include LEB bulbs, CF lamps, fans, LED TVs, refrigerators, and computers. On the other hand, other loads such as pumps, washing machines, and mixer grinders can be switched on directly or controlled through a webpage. Figure 6 illustrates the loads that can operate without any interruptions during the transition.

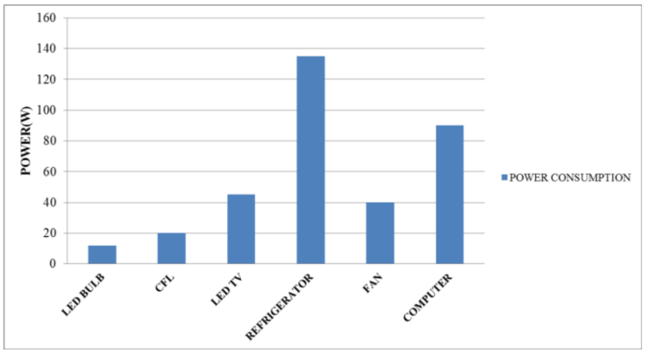


Fig. 6. Load operation with solar power

4. Conclusion

The typical means of measuring solar panel performance involve either costly and specialized systems utilized by the industry or specialized testing laboratories. These systems are both rare and expensive, and they require skilled personnel to maintain them. In contrast, the system developed for this project is designed for household use, providing a means to measure solar panel parameters and calculate solar power output in real-time. By using this system, it is possible to optimize the use of solar energy and reduce electricity costs. The IoT-based platform also enables communication with the user.

Conflict of interest

The authors have declared no conflict of interests.

Funding

This research work is not funded by any external agencies.

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