2 to N Smart Distribution Board for Low-Cost Solar System

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DOI: 10.29322/IJSRP.14.02.2024.p14635
https://dx.doi.org/10.29322/IJSRP.14.02.2024.p14635

Paper Received Date: 22nd January 2023
Paper Acceptance Date: 24th February 2024
Paper Publication Date: 29th February 2024

Abstract- A low-cost solar system consists of a limited power capability, making it a challenging research task to manage and distribute power from both the solar source and the main source. As a solution to this challenge, this research focuses on developing a smart power distribution board that provides two inputs: solar and main power sources, and multiple outputs. This embedded system is designed to efficiently utilize solar power to its maximum potential, enabling 2-to-n power distribution. This paper presents a low-cost, scalable solar power management system with 2 to N Smart Distribution Board which aims to address the economic barrier to the use of solar energy. The system is specifically designed for homes with high electricity bills. It effectively transfers solar power to low- power devices, guaranteeing energy savings and uninterrupted operation even in the event of a power loss. With the least amount of modification to the current electrical infrastructure, our approach optimizes energy consumption through intelligent switching and real-time monitoring. Preliminary experiments show a noteworthy decrease in grid energy usage, underscoring the system's potential to increase the accessibility of solar power for a larger population. System has been tested within a laboratory environment and successful results are achieved.

Index Terms- Solar Power Management, Sustainable Energy Solutions, Smart Distribution System, Renewable Energy Adoption, Low-Cost Solar Infrastructure

I. INTRODUCTION

The growing global demand for sustainable energy solutions has driven the widespread adoption of solar power systems. However, the intermittent nature of solar energy poses challenges in terms of managing and utilizing this renewable resource effectively. To address these challenges, the "2 to n Smart Distribution Box for Low

Cost Solar Power System" presents a cutting-edge concept that combines advanced switching mechanisms and intelligent control algorithms to regulate the flow of electric current between solar panels, the main grid, and various electrical equipment. By incorporating intelligent decision-making processes and real-time monitoring of available power sources, this system aims to optimize the distribution of energy and ensure uninterrupted power supply.

In today's world, the cost of electricity has become a major concern for people of all classes, ranging from the lower to the middle to the high class. The electricity bill is becoming increasingly expensive, causing a significant impact on people's lives. In Sri Lanka, for instance, the cost of electricity is determined by the units consumed per month, with different charges applicable for each range of units. For example, for 0-60 units, the energy charge for each unit is 7.85, and there is no fixed charge and , for 61-90 units, the energy charge for each unit is 10, and there is 90 fixed charge and for 91-120 units, the energy charge for each unit is 27.75, and there is 480 fixed charge and, for 121-180 units, the energy charge for each unit is 32, and there is 480 fixed charge and, for more than 180 units, the energy charge for each unit is 45 and fixed charge is 450. However, as the number of units consumed increases, the charges also increase, along with a fixed charge.

So as solution for the day to day increasing prices of current, we could end up with two solutions. One is we can reduce daily electricity usage by reducing the daily electric equipment that we needed and another one is that we can invent new alternative power solution. As we know that the first solution is not practical, we can take the solution as finding new power resource. Solar energy is the best power resource for now these days and it is renewable natural energy that we could use these days. But the problem is that when we are going to build form scratch to build solar power system for our homes it is very difficult because of equipment of solar system. So we have to spend minimum one million rupees to build solar system for our houses for daily usage but according to Sri Lanka economic crisis, people cannot afford that much of amount for solar system.

So as a solution we can make a solar power system that can reduce specific number of units from your monthly electric bill which can built below 100,000 rupees. So basically, we can reduce at least 30 units from the bill amount. When we are reducing 30 unites from the electric bill means we can save thousands or rupees every moth. So, this system can be made out with two batteries, inverters, and solar panels which are lower range. So as our main goal is to reduce the electric bill using the low-cost solar power system, we can use the solar power for the lower power required devices and rest of devices are switch into the main power channel. So, the main advantage from this system is that we can use the system in power cuts also. We can powerup low power required electric equipment like bulbs, TV, radios and specially fish tanks during the power outages also and day time. So as an example when we having fish tanks, we are usually spending 240W per day. If it is 10 days it would be 2400W which would be 2.4 units. So we have to spend around 7200W by the end of the month that would be 7.2 units. So by using this system we can reduce this amount around to 2 units by switching the power source to solar energy.

So as you have seen ,our research aims to address the financial barriers to solar power adoption. The high upfront costs of solar panels and the associated infrastructure have often been cited as a significant hurdle, particularly for average income households. Purchasing solar panels to power an entire house can be prohibitively expensive, making the transition to renewable energy less attainable for many people. To mitigate this challenge, we are developing a Smart Distribution Board that optimizes the use of solar power, even from a limited number of solar panels. By doing so, our system allows for the efficient distribution of solar energy across various household applications, thus maximizing the utility of each watt generated. This not only makes the most out of the solar energy available but also makes solar power adoption a more affordable and accessible option for the broader population.

And also, today exists solar systems are 2:1 systems. Which means two inputs which ae from solar channel and main grid channel and also one output. So, if we want to implement new solar system in our homes we have to change entire houses' wiring which would we bit complex procedure. But in here we are building 2:n system which is we can output several power channels for the system. So the most important this is the safety, in this system we are no directly contacting with the main current. Apart from that we are using wireless current sensor to measure the amount of current required.

In this paper we propose 2 to n distribution box which is capable to handle current load of the solar system and main power to make maximum usage of the solar power. The distribution box consist of number of smart MCBs capable to switch solar power or main power according to its current usage therefore this system can be easily use to build low power solar system without much changing on existing wiring of the main electricity supply.

The structure of the paper is systematically arranged to facilitate a coherent flow of information and discussion. Section 2 provides an overview of related works, wherein we explore and analyze existing research and methodologies pertinent to our study, establishing the context and identifying gaps in the existing body of knowledge. Section 3 elucidates the design methodology adopted in our research, presenting a detailed account of the theoretical framework, design principles, and conceptual strategies employed. The implementation details, including the practical aspects of translating our design into a functional system, are articulated in Section 4. Section 5 focuses on testing and evaluation, offering insight into the experimental setup, methodologies, and metrics used to assess the effectiveness and reliability of our implemented design. Section 6 draws conclusions from our research findings and also maps out potential avenues for future work, providing a perspective on possible extensions and improvements to our work. Finally, Section 7 enumerates the references, acknowledging the scholarly works and resources that have underpinned our research.

II. RELATED WORKS

Significant improvements in solar power systems have been made because of the need to create affordable and efficient energy alternatives. In order to democratize access to clean and sustainable energy across many socio-economic strata, the development of low-cost solar power systems has emerged as a key field of research and innovation. Researchers and practitioners have engaged in a variety of studies and implementations to lessen the cost burden of deploying solar technology in view of the rising environmental concerns and the worldwide push toward renewable energy adoption. The following section guides readers through an interconnected set of related works that includes analyses, models, and technological advancements that have helped pave the road for affordable solar energy alternatives. We traverse a wide range of approaches that all work to reduce prices and improve the accessibility and uptake of solar power systems, from technical developments and material science breakthroughs to legislative interventions and financial models.

One of the foundational aspects of this section is understanding the types of solar systems that are available in the market. We have created a table summarizing three primary types: Off-Grid, On-Grid, and Hybrid Solar Systems.

Type	Unites Generated (kW)	Cost(LKR)
Off Grid System	1-10	500,000 - 2,500,000
On Grid System	5-50	1,000,000 - 5,000,000
Hybrid System	3-20	750,000 - 3,000,000

Table 01: Cost range of different solar system types

Another crucial consideration is the amount of energy generated by these solar systems. We have created a table that starts from the most basic unit of 200W to give a clear idea of the investment required.

Units(kW)	Cost(LKR)
200W	50,000 - 100,000
500W	100,000 - 200,000
1kW	200,000 - 500,000

5kW	1,000,000 - 1,500,000
10kW	1,500,000 - 2,500,000

Table 02: Cost range to build solar systems that generate specified power units

The table shows that even a system as small as 200W could require an investment of 50,000 to 100,000 LKR.

A significant hurdle in the adoption of solar power systems is the need to restructure the existing wiring system of a house entirely. This adds both complexity and cost to the overall project. Our proposed Smart Distribution Board eliminates this challenge by providing a plug-and-play solution that seamlessly integrates with the existing electrical infrastructure. This simplifies the transition to solar energy and lowers the barrier to entry for many households., depending on various factors like installation costs, panel type, and local market conditions.

The widespread use of renewable energy calls for complex analyses that consider a variety of practical technical possibilities. When a reasonable battery cost is attained and an acceptable system is designed, battery assistance may help to produce hydrogen at a cheaper cost. The electrolyze, battery, and PV installation capacity are compared to decide whether the battery should be used. The cost-competitive generation of hydrogen in future energy markets is supported by the achievement of the future cost objectives in the respective technological roadmaps of photovoltaics (PV), electrolyzes, and batteries.[1] It has been shown that hybrid geothermal and solar energy systems (such as photovoltaic and concentrated solar power) are advantageous to both parties and a promising mix of renewable energy sources. Because the efficiency of power production from thermal energy is directly related to resource temperature, the geothermal business seeks for geothermal resources with high temperatures. Since many sites have both strong geothermal heat flow and surface sun radiation, it is conceivable to combine geothermal and solar energy globally. In terms of financial success and thermal efficiency, hybrid geothermal-solar power systems may outperform standalone geothermal or solar power systems. Despite the fact that hybrid solar-geothermal power plants offer a number of benefits, present research mostly focuses on conceptual and theoretical issues with few actual power producing field operations accomplished. The overall complexity and high initial cost of hybrid systems might be the primary causes.[2]

In order to meet our demands for green and renewable energy while also conserving the environment, solar energy offers a compelling answer. One of the most researched alternating copolymers for use in plastic solar cells is PCDTBT. Since spin coating is a precise and repeatable deposition approach, it is often employed to prepare the active layer of lab-scale polymer/PCBM BHJs. Low production rate, a tiny working area, and high production costs are the drawbacks, however, since a lot of material is wasted in the course of the operation.[3] A viable method for capturing this energy is solar energy. The exponential increase in global population and economic development is driving up energy consumption. While nanowires (NW) are much better at producing high-efficiency low-cost solar cells, it is challenging to balance the cost and efficiency of conventional thin-film solar cells. When compared to planar material of an equal volume, NWs significantly improve light absorption, enabling the use of relatively insignificant quantities of more costly materials to provide appropriate light absorption. Although there has been substantial development and a bright future, there are still certain obstacles to overcome before creating high-efficiency NW solar cells.[4] A microcontroller and a Lab view data collecting card make up the hybrid control system for power management. Most controllers have certain restrictions on power management, making it difficult to provide a workable solution for hybrid power plants. In order to offer a sustainable source of energy in a solar hydrogen hybrid power plant, a real- time control system with designed control and measurement cards are built.[5] While in autonomous systems the environmental advantage over diesel alternatives may be attained via direct optimization, in grid-linked systems emission is another variable that has to be controlled so that the use of renewable energy can be justified. Another factor that must be reduced so that using renewable energy may be justified. A controller is created that keeps track of how the autonomous/grid-linked systems are functioning. Such a controller establishes the energy accessible from each system component as well as the system's environmental credit. Then, information on costs, wasted and spilt energy, and battery losses is provided.[6] In the US, California has the most installed home solar capacity. Solar- powered houses are pricey. The price to install such a system may be $30,000. Numerous federal and state initiatives actively support this investment. There is limited direct evidence about the market capitalization impact, despite the residential solar house sector's continued growth. We discover that solar panels are capitalized at a premium of around 3% to 4% using both hedonics and a repeat sales index technique.[7]

The main obstacle preventing the widespread use of solar-powered water pumping systems, which improve energy and water efficiency in comparison to traditional irrigation techniques, is high capital costs. When sunshine is present, the solar panels' function is to charge the batteries throughout the day. The batteries then provide the pump with electricity, providing consistent voltage. In contrast to systems that only utilize solar energy while they are active, the system employed in this research uses solar energy whenever it is available during the day and stores it in batteries.[8] Wind turbines, hydroelectric generators, and solar photovoltaics are the main components of the clean energy portfolio that CSP technology shares. Each technology has unique benefits and may be more suitable to a particular environment or use case than another, such as the use of photovoltaics in arid, sunny regions or hydropower next to a naturally flowing body of water. An area with great cost-saving potential in CSP systems has previously been highlighted as the efficiency of the thermodynamic power block. However, the initial investment was quite expensive.[9]

The foundation of a completely renewable energy system in Europe will be a variety of renewable energy sources, with wind and solar power playing a major role. It takes a tremendous amount of storage and balance to handle these variations system. Different combinations of wind and solar power production have been shown to be ideal depending on the goals to reduce storage energy capacity, yearly balancing energy, or balancing power. The needed storage and balancing demands based on the hourly power imbalances turn out to be quite substantial in the lack of extra wind and solar power supply.[10] A power system's flexibility is its capacity to adapt to variations in power demand and generation. The complementary system, which is typically hydrothermal and must balance the fluctuations of variable generation, may experience a significant increase in the flexibility requirements because of the integration of significant amounts of variable renewable energy sources, particularly wind and solar. Future

European power system flexibility needs will be influenced by three key factors: the proportion of variable renewable energy sources, the composition of those sources, and the size of the balancing region. Operators of the power grid will need to adapt their infrastructure to the anticipated renewable installations. The system will benefit from incentives for highly flexible power plants, storage, and demand-side response.[11]

The Organic Rankine Cycles also use waste heat from the thermal engine's block cooling and exhaust gas cooling (ORC). Given the relatively limited power range of such a pilot plant, the integration of a thermal Diesel engine to the superposed Organic Rankine Cycles of the thermal solar plant has proven effective with respectable efficiency. A totally renewable alternative with power availability that is mostly independent from atmospheric conditions would be provided by replacing the fuel source with biodiesel, which still must be proven. However, it will be pricey and we need higher temperature turbines for this procedure.[12] Fuel sustainability for future energy needs is becoming a key worry due to the fuel prices' ongoing fluctuation. The use of renewable energy resources may make energy consumption clean and sustainable by reducing the environmental deterioration caused by harmful gas emissions during the energy production process. In comparison to traditional energy sources, solar power technologies have drawn a sizable number of clients and have established themselves as a sustainable energy source. The CSP plant generates more energy than a PV plant with the same nominal output power, indicating that the CSP plant has higher economic returns than a PV plant. A CSP plant, however, requires a far larger initial investment than a comparable PV unit. [13]

No more gas stops, transmission towers, or towers, The only sources of energy you'll need to survive are the sun and your house. By tackling the trinity of secure, carbon-neutral, and abundant low-cost energy, science and engineering pursues the aim of customized energy directly to the core of the energy dilemma. The growth of the nonlegacy world may take place inside an energy infrastructure that is of the future, not the past, if science and engineering can lower the cost of customized energy via discovery.[14] Due to its quantity, accessibility, and simplicity of obtaining electric power, wind and solar energy are becoming more and more popular as alternative energy sources. The hybrid system uses rechargeable batteries that are powered by solar energy or wind energy through solar cells and a maximum power point tracking (MPPT) module, respectively. As a result, the prototype was constructed using low-cost and readily available parts, such as the wind system alternator, which was derived from a ceiling fan motor and then modified inside. The procurement of the photocells may have been the system's most significant expense. Additionally, an MMPT module was added to the hybrid system to recharge the batteries for optimal power.[15]

Recently, research was funded by the World Bank to see whether solar thermal power facilities could match the cost of traditional power plants. Future costs may be similar to those of traditional fossil fuels. The adoption of parabolic trough technology would probably be considerably accelerated by the implementation of CO2 taxes.[16] Numerous collector methods, including the Fresnel linear collector, the parabolic trough, the solar dish, and the solar tower, have been used in concentrating solar power (CSP) systems. This method involves high collector temperatures and needs a few MWe of minimum power to be competitive. Remote off-grid locations of impoverished nations are highly suited for small-scale solar organic cycles. They are also more adaptable and permit the by-product of hot water production. It is also the fluid that requires the largest expander swept volumes, which raises the system's cost.[17] Solar modules on Grid-Tie Systems transform sunlight into pure DC voltage, which is then outputted from the solar module. The PLN power source is then connected to the inverter block, which converts the pure DC voltage into AC voltage so that it may provide or create electrical power. Sunlight is transformed into pure DC electricity and outputted by the solar module as part of the Off Grid-Tie System as DC power. Then a DC to DC regulation module, also known as a DC regulator, is used to regulate the pure DC voltage. The purpose of a DC regulator is to control how much DC is stored in a battery. In order to backup and store the charging current from the solar panels, batteries are required in the design of solar panels. Batteries come in a wide variety of kinds, including lead acid, lithium ion, nickel cadmium, and nickel metal hybrid. The off-grid system's functioning is impacted by the solar panel's huge capacity in terms of battery charging and inverter operation; the higher the home load, the shorter the battery life will be. Because of the inverter's very low input voltage for 12 volt DC loads while it is supplying loads with significant abrupt current spikes [18]

If the cost of cooking can be decreased via improved cooking efficiency, electric cooking may be a desirable option in grid-connected locations. The cost of the ingredients and the energy used in cooking are included in the cost of cooking. Integration of solar PV without an inverter with a cooking system in a grid-connected region to save costs and boost efficiency. They changed the voltage level and the kind of voltage supply (DC) using a control circuit to accomplish the decreased power consumption of the kitchen equipment and low-cost integration with solar PV. In recent years, the cost of solar PV modules has decreased to the point that, in most nations, solar power is now more affordable than grid electricity. Despite the added cost of the solar PV and other system components, cooking costs are around 32% cheaper than those of grid-based cooking while grid energy usage is also about 78% lower.[19] One of the essential elements for the growth of economies and raising of living standards in emerging nations is power. One of the essential elements for the growth of economies and raising of living standards in emerging nations is power. The PV was estimated to cost $0.36 per WP . Other expenses like installation have been estimated at $360, and $5 per year for operation and maintenance has been calculated using the average current market value. It is anticipated that batteries last for five years. One battery's expenditures for installation, replacement, operation, and maintenance are estimated at $180, $180, and $7 each year, respectively. The charge controller offers protection against excessive voltage, excessive current, short circuits, polarity inversion, and illumination. It controls the voltage and current that the solar panels output and that flow into the battery. Installation and replacement expenses for a 1-kw inverter are calculated at $310 and $310, respectively. An inverter is assumed to have a 15-year lifespan and a 90% efficiency. It is important to remember that users must refill every five years. due to the battery's short lifetime. Once 15 years have gone, the cost of the inverter and charge controller will increase, and at the end of the system's lifespan, the salvage value will either recover or the system will be totally replaced. [20]

Photovoltaic (PV) panels, inverters, and wiring systems make up the bulk of a Home SPP. Selecting components from the commercial market is the first stage. Next, build the ideal Home SPP setup based on the information already available. Finally, the residential electrical system that has been linked to the State Electricity Company is equipped with the design outcomes. Equipment for creating Home SPP that is purchased in the low-to-mid-level business market often has a lower efficiency than the statistics shown in the product's specification. As a result, it's important to choose

Home SPP components wisely from the retail market. The operational voltage of a mini-grid system with a PV energy source is increased. This gain in efficiency is applicable to solar cells constructed from materials of moderate to poor levels.[21] Installing off-grid solar photovoltaic (PV) systems in rural countries minimizes the country's need for load shedding by drastically reducing the electric load, mostly on the local utility grid. DC-DC converter and PWM solar charge controller with a common ground device. The fixed frequency current mode approach is used in the construction of the controller's two components. This is also a kind of power consumption, even if the electricity has only been utilized for around 30 seconds throughout the last 24 hours. The push switch circuit mechanism, which mostly comprises of an Op-amp and an NPN transistor, performs this function. Based on the frequency fold-back, the controller maintains very low stationary power consumption while operating with exceptional efficiency under light load situations. The controller can generate an excellent output for the intended design thanks to specific frequency, ramp correction, and flexible latch feedback. To maintain the VCC voltage of the controller at its threshold level when the no-load input power is zero, the low power consumption off-mode is turned on from across the self-supply circuit. A novel approach that directly addresses the issues with self-power consumption while lowering costs has been developed. It combines the push switch mechanism with a fixed frequency current control algorithm. [22] Lead acid and lithium-ion (Li-ion) batteries are mature solutions for batteries. Manufacturers claim that both systems can operate in temperatures as low as 0°C for charging and as low as -20°C for discharge/storage. Because of their historically cheaper initial investment costs, lead acid batteries presently dominate stationary systems. Systems based on PV show 31-42% lower costs of power production and higher resilience regarding cost sensitivity than a business as usual configuration with solely diesel generators. Compared to the BAU scenario, they reduce greenhouse gas emissions by 40% to 100%. Systems with hybrid energy storage and 100% RES cost 6-9% more than those with supplementary diesel backup. [23] Annually, 3,987.7 kWh of electricity is produced by solar panels, 924.9 kWh is used by grid power, and 3,226.4 kWh is sold. The power transmission losses are 263.1 kWh at the power conditioner and 121.8 kWh within each device. If there are no subsidies or political benefits to employing it, a DC power supply system is an expensive option under the existing circumstances. Due to R&D and energy conservation measures, the initial prices of DC power supply systems may be decreased while the easy payback time might be shortened. Even with the cost decrease taken into account, the basic payback time is more than 20 years when adding DC power to low voltage DC equipment and certain high voltage DC equipment.[24] The evaluation of meteorological conditions, analysis of electric load demand, hybrid system configurations, development of a hybrid system model, analysis using simulation and optimization, and operational analysis of the resulting system are the six fundamental steps in the design and planning of a hybrid system. The boost, floating, and trickle phases of battery charging are all clearly shown, and the test period runs from 9 am to 4 pm. The battery voltage climbed from 9.7 to 11.6 V between 10 and 11 am, signifying the floating stage. The trickle stage was place throughout the peak hours of 12 to 4 pm, gradually raising battery voltage to 11.8 V.[25]

Hybrid off-grid technologies have made power available to places that are remote or have no grid network connectivity. In rural areas without access to or remote from the grid network, hybrid renewable energy sources have come to be seen as a superior option to single energy sources. They presented Numerous cutting-edge optimization techniques were put into practice. In order to determine which scheduling method is ideal for obtaining least cost at high dependability, three distinct scheduling methodologies were originally developed. Second, in order to understand the outcomes of their techno-economic consequences, we analyzed two distinct PV modules made using each a different production technology. In order to determine which tracking system is suitable for the specified area, four different solar tracking technologies were taken into account. Last but not least, eight alternative situations were taken into account, each of which is a component of a PV module and a tracking system that must each be explored in accordance with the three scheduling methodologies. Due to the fact that practically all of the scheduling scenarios were able to handle the necessary load, the third scheduling strategy is thought to be the most trustworthy.[26]

Comparison of existing solar system and cost and features

Solar System Type	Cost(LKR)	Features
Grid-Tied Solar	400000	• Connects to the grid for surplus power. • Lower upfront cost. • Reduced electricity bills.
Off-Grid Solar	600000	• Independent power supply. • Battery storage for nighttime use. • Suitable for remote areas.
Hybrid Solar	550000	• Combines grid-tied and off-grid features • Backup power during grid outages • Maximizes self-consumption of solar energy
Solar Water Heater	150000	• Heats water for domestic use • Reduces water heating costs • Lower maintenance requirements
Concentrated Solar	900000	• High efficiency for electricity generation • Requires tracking systems for sun tracking • Suitable for large-scale power generation

Table 03: Comparison of existing solar systems with cost and features.

MCBs for current control

A Miniature Circuit Breaker (MCB) is a crucial electrical component designed to safeguard electrical circuits and equipment from overcurrent and short circuits. MCBs are compact and highly efficient devices that play a pivotal role in ensuring electrical safety within homes, commercial buildings, and industrial installations. There are several types of MCBs, each tailored to specific applications. The most common types include Type B, Type C, and Type D MCBs, which differ in their tripping characteristics. Type B MCBs are typically used for general household circuits, while Type C MCBs are suitable for circuits with moderate inrush currents, often found in commercial settings. Type D MCBs are employed in circuits with high inrush currents, such as those connected to large motors or industrial equipment.

MCBs are instrumental in controlling the distribution of current within an electrical system. They are installed at various points in an electrical circuit to interrupt the flow of current when it exceeds safe levels. In cases of overcurrent or short circuits, the MCB trips, effectively disconnecting the circuit and preventing damage to connected devices or fire hazards. This precise current control and protection mechanism offered by MCBs make them indispensable components in electrical distribution boards and switchgear, ensuring the reliability and safety of electrical systems in a wide range of applications.

In modern electrical systems, circuit breakers (MCBs) have become the preferred choice over traditional fuses due to several advantages. As the demand for electrical components in grids continues to grow, higher-rated MCBs are essential to handle increasing short circuits effectively. Unlike traditional fuses, MCBs can also offer protection against overheating caused by improperly secured conductors in their terminals. Furthermore, the transition to digital MCBs has significantly improved reaction times, enhancing overall safety and efficiency in electrical installations.[27] The MCB functions by quickly disconnecting electrical circuits during short circuits, and the old MCB, with specs of 220V, 50Hz, 20A, and 10kA short circuit current, needed replacement due to high contact resistance and inability to handle rated current. Nanoparticles in transformer oil enhanced the MCB's efficiency, reducing resistance from 65 mΩ to 7.5 mΩ and improving insulation resistance from 5.4 GΩ to 10.7 GΩ, approaching the performance of the new MCB with a 7 mΩ resistance and 11 GΩ insulation resistance.[28] Miniature circuit breakers are essential mechanical switching devices within distribution lines, offering reliability crucial for household and similar installations. To advance the study of their reliability, the development of a dedicated reliability testing device becomes imperative. Such a device would enable the implementation of rigorous reliability standards, ensuring the dependability of miniature circuit breakers in various applications.[29] Leakage current, overload, and short-circuit events can pose significant risks to both human safety and electrical appliances. Traditional RCBOs, which rely on thermal and magnetic mechanisms, exhibit specific time delays in responding to faulty currents. To address this concern and enhance circuit protection, the introduction of smart RCBOs with shorter reaction times becomes imperative. These advanced devices are poised to replace conventional RCBOs while maintaining similar essential features, ensuring faster and more effective responses to electrical faults, thereby improving overall safety.[30] The proposed smart distribution board for low- voltage residential and commercial systems introduces an innovative approach to electrical protection by incorporating a solid-state circuit breaker as the primary protection device. This advanced breaker utilizes a bi-directional SCR (Silicon Controlled Rectifier) switch, coupled with a cost-effective Arduino micro-controller for intelligent control, enabling rapid and precise interruption of extreme currents. This combination not only enhances the safety and reliability of the electrical system but also offers the flexibility to adapt to varying load conditions, ultimately paving the way for more efficient and responsive energy management solutions in both residential and commercial settings.[31]

The concept of "Intelligent Operation" for high voltage SF6 gas circuit breakers, which involves self-adaptive control of moving contacts based on real-time system conditions, aligns with the objectives of creating a smart distribution board for low-cost solar systems. Additionally, the use of synchronous phase control technology to synchronize switching moments and optimize arcing times is a relevant technique to ensure efficient and reliable operation.[32] The Smart ELCB represents a crucial safety enhancement for residential and industrial premises by combining traditional ELCB functions with advanced features enabled by the Internet of Things (IoT). It offers real-time monitoring of voltage, current, and power parameters through a web server, allowing users to remotely control and adjust the tripping current limits. Moreover, it highlights the use of the ESP8266 WiFi module for IoT communication, offering dynamic control and monitoring capabilities. [33] We can see that there are limitations of conventional miniature circuit breakers (MCBs) by proposing a Numerical Overcurrent Relay (NOCR) system. This NOCR utilizes microcontrollers and micro current transformers, making it compatible with smart grid technology and high-voltage systems, such as electric vehicles. Unlike fixed-amperage MCBs, the NOCR allows users to adjust the set current and sensitivity with ease, providing advanced protection against electrical hazards. Additionally, they highlight the cost- effectiveness of their system, which is significantly cheaper than commercial numerical overcurrent relays.[34] Some authors propose a novel approach for optimizing the rescheduling process in the context of a miniature circuit breaker (MCB) workshop. The traditional rescheduling methods discussed in the paper are shown to be time consuming and reactive, which can hinder manufacturing efficiency. To address this challenge, they introduce a digital twin-assisted preventive rescheduling strategy based on the order arrival hypothesis. This approach aims to obtain optimal reschedules before the actual order arrivals, significantly reducing reactive time and improving real-time manufacturing performance. We can also highlights the importance of digital twin technology in driving the preventive rescheduling process by leveraging real-time production data.[35] we can aim to overcome the limitations of traditional electromechanical circuit breakers by providing enhanced protection for residential and commercial areas. It utilizes advanced current measurement techniques, fault diagnosis systems, and Hall-effect transducers to detect and respond to short circuits and earth faults. The system ensures power supply continuity while improving safety. Additionally, it discusses the importance of such systems in preventing accidents and electric-related deaths, highlighting the need for advanced protection mechanisms in electrical distribution systems.[36] The critical issue of strong magnetic interference in intelligent miniature circuit breakers, which can lead to mis operation and refusal, posing a significant risk to electrical safety and power distribution systems. The paper introduces an innovative approach to optimize the design of these circuit breakers, focusing on the control system, DC motor, and switching power supply modules. It proposes a dual-mode detection system combining micro-switches and Hall-switches to enhance position detection accuracy, both in hardware and software. Additionally, the optimization of the DC motor and switching power supply materials and designs is discussed to improve their resistance to magnetic interference.[37] There are innovative solutions for high-speed AC circuit breakers and overcurrent relays (OCRs) in electrical power systems. With

a growing emphasis on smart grids and networked systems, faster protection mechanisms are essential for ensuring system stability during short-circuit incidents. The paper introduced prototypes capable of interrupting short-circuit currents within a single 60Hz cycle, greatly improving response times. Two high- speed circuit breaker mechanisms were proposed. The first utilized a hybrid approach combining a permanent magnet actuator (PMA) and a Thomson coil actuator, while the second leveraged a conventional spring mechanism with a quick-responding solenoid device.[38]
Two layer approach for disaggregating unknown PV generation and native demand from known hourly net demand data recorded by smart meters. The approach leverages spatial correlations of native demand and PV generation. The study is significant as it provides a practical solution for utilities to manage distribution systems optimally.[39] There are challenges and solutions for real-time monitoring and management of smart distribution grids. They focus on the use of shared cellular LTE networks to provide secure and reliable communication for smart grid ICT solutions. [40] And also there are a model to forecast household solar generation and electricity demand. The model uses a conditional generative adversarial network (CGAN) and serves as an input to chance-constrained optimal power flow for computing fair operating envelopes under uncertainty. This research is pertinent for understanding how to manage variable solar energy in smart distribution boards.[41] Some of them investigate power conservation and cost-saving problems in distribution systems. They propose a model predictive control (MPC)-based algorithm for optimal usage of future information prediction.[42]

III. DESIGN

In here, two power sources are being employed in this system. They are energy derived from the main grid and energy from solar panels.The current generated from solar panels is harnessed and managed through a series of components before reaching household equipment. The journey begins with the solar panels themselves, which absorb sunlight and convert it into direct current (DC) electricity. This DC current then flows to a charge controller, a crucial component that regulates and optimizes the charging process of batteries. Next in the circuit is the battery bank, where excess electricity generated by the solar panels is stored for later use. Batteries play a vital role in ensuring a steady power supply, especially during periods of low sunlight or at night when the solar panels cannot produce electricity. From the battery bank, the DC current continues its path to an inverter, a device responsible for converting DC electricity into alternating current (AC). Most household appliances and equipment run on AC power, so the inverter's role is essential in making solar-generated electricity compatible with the standard power requirements of the household. Finally, the AC current leaves the inverter and is directed to the household's electrical distribution system. From here, it branches out to power various devices and appliances, such as lights, electronics, heating, cooling systems, and more. In this way, the solar energy harnessed from the panels is put to practical use, reducing dependence on traditional electricity sources and contributing to a more sustainable and eco-friendly energy solution for the household.

Likewise, electrical current sourced from the main grid follows a pathway through various components before reaching household equipment. The journey starts at power supply towers, where alternating current (AC) is transmitted. From there, it flows through energy meters, allowing measurement of the electricity consumed by the household. Next, the current passes through the main switch called Miniature Circuit Breakers (MCBs), which provide overcurrent protection and help control the flow of electricity to different circuits within the house. Additionally, safety is ensured by Residual Current Devices (RCDs), which monitor for any leakage or fault currents that could pose hazards. Finally, the AC current arrives at household equipment, energizing appliances and devices like lights, electronics, heating, and cooling systems.

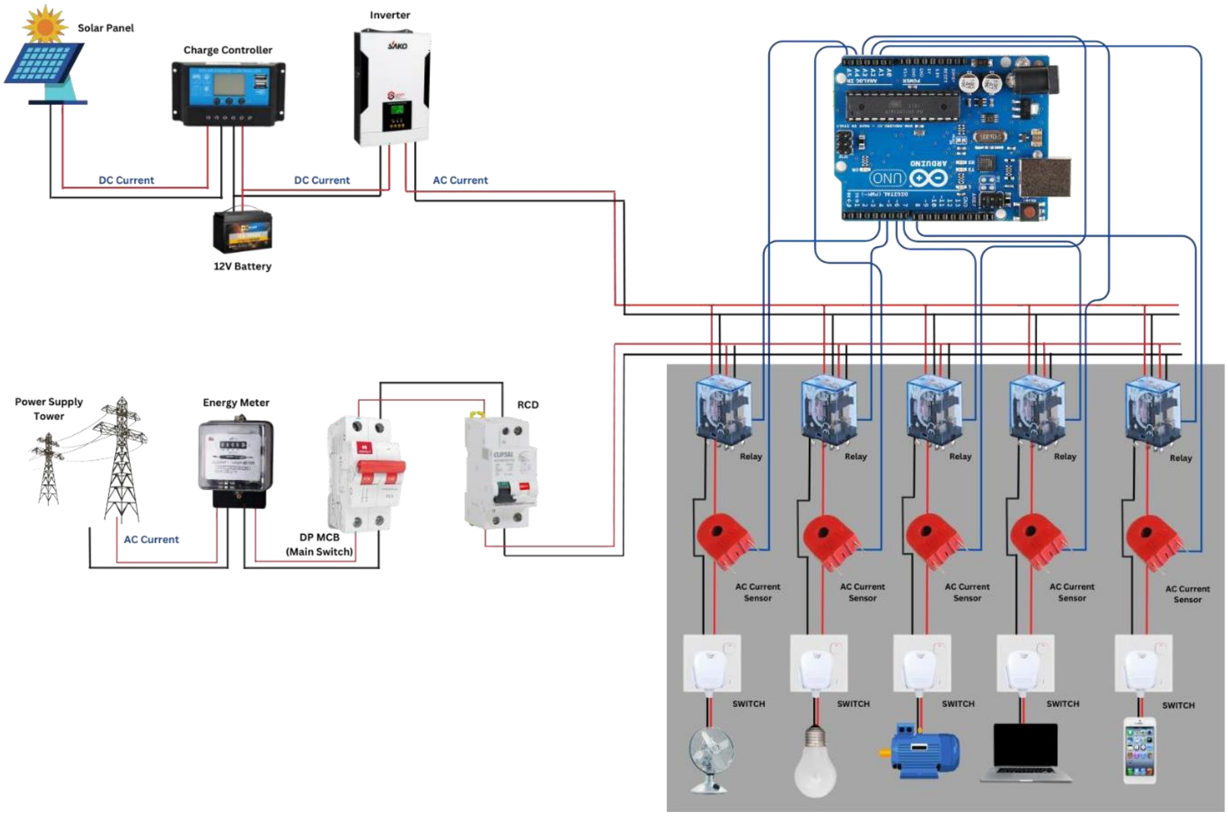


Figure 01: Design diagram of the system structure

So, by using above power sources, we are making hybrid power system that is to create an integrated and dynamic energy solution that harnesses the benefits of both solar panels and the main grid. By synergizing renewable solar energy with the conventional grid supply, this innovative approach seeks to achieve optimal energy utilization and address the pressing challenges of escalating energy costs and environmental impact. At the core of this system lies a sophisticated network of intelligent algorithms and advanced technology, meticulously designed to manage the power sources seamlessly. The system is capable of detecting and analyzing real-time data, including solar energy generation, energy consumption patterns, and grid demand. With this comprehensive understanding, it makes informed decisions on when to draw power from solar panels and when to rely on the grid supply. During periods of abundant sunlight, the system strategically prioritizes the use of solar energy, maximizing its utilization and reducing dependency on non- renewable resources. Conversely, in instances of low solar generation or heightened power demand, the system intuitively switches to the main grid, ensuring a consistent and reliable electricity supply to meet user requirements.

This intelligent power management not only empowers users to contribute significantly to a more sustainable and greener future but also offers tangible cost savings. By making the most of solar energy when available, users can potentially lower their electricity bills and reduce their environmental footprint. The hybrid system's adaptability and efficiency further enhance its appeal as an eco-friendly and economically viable energy solution. Moreover, this innovative energy approach holds promise for a diverse range of applications, from residential settings to commercial and industrial environments. As the world moves towards a more sustainable future, embracing such forward-thinking solutions becomes vital in combatting climate change and safeguarding the planet for future generations. So, this hybrid power system exemplifies the integration of cutting-edge technology and renewable energy sources to pave the way for a more sustainable and efficient energy landscape. By harnessing the potential of solar energy and intelligently managing the power supply, this system offers a transformative path towards greener energy practices and a brighter, eco-conscious future for all.

To seamlessly transition between solar power and the main grid, we employed a 12v AC relay with 8 pins. This relay serves as a crucial component in our system, allowing for efficient power switching. Additionally, to accurately calculate the current flowing through the wire that connects to the equipment, we integrated the AC Current Sensor. This specialized Sensor is adept at transforming AC signals of significant current into smaller amplitude signals, ensuring precise measurements and optimal power management. By utilizing these advanced components, our power system can intelligently and effectively balance the utilization of solar energy and grid supply, providing a seamless and sustainable energy solution. Upon the initial connection of household equipment such as fans and bulbs to the hybrid power system, a crucial process commences. The system intelligently calculates the current flowing through the live wire of each equipment, employing above mentioned specialized current sensors to obtain precise data. This information is then transmitted to the central control unit, which serves as the brain of the operation. Equipped with sophisticated algorithms, the control unit meticulously analyzes the data, considering various factors to determine the most suitable equipment to switch to solar power. The algorithms consider a range of parameters, including the available solar energy, the power requirements of each equipment, ensuring optimal power management. Once the analysis is complete, the control unit efficiently communicates with the relays responsible for power switching. These relays, acting as the bridge between the solar panels and the equipment, respond promptly to the control unit's instructions, flawlessly transitioning the selected equipment to solar power. By leveraging cutting-edge technology and intelligent decision-making processes, the hybrid power system optimizes the usage of solar energy and reduces reliance on the main grid, paving the way for a more sustainable and eco-conscious energy solution.

The foundation of our research lies in the development and implementation of an algorithm designed to intelligently allocate power supply sources between solar energy and the conventional grid (CEB). This algorithm serves as a pivotal decision-making mechanism, driven by real-time data collected from current sensors strategically placed within the electrical system. The overarching goal is to optimize the utilization of solar energy, harnessing its environmental and cost benefits, while seamlessly integrating it with the existing electrical grid. The process commences with the data collection phase, wherein current sensors capture and relay vital information about the electrical load. These sensors provide continuous and precise measurements of current flow through the system, offering invaluable insights into the real-time power demand. Crucially, the algorithm leverages the power of data sorting and analysis. The collected current readings are subjected to an ascending order arrangement, allowing us to identify the highest current-consuming devices or equipment within the system. This sorted data serves as the foundation for informed decision-making, providing a clear picture of which components draw the most power at any given moment. However, the true innovation of our algorithm lies in its capacity to dynamically distribute the current flow between the solar and grid sources. This distribution is guided by a predefined current limit, a threshold carefully determined to balance the load between the two power supply options effectively. When the algorithm detects that the current demand is below this predetermined limit, it orchestrates a seamless transition, directing the power supply source towards the solar energy system. This strategic allocation ensures that solar power is utilized to its maximum potential during periods of lower demand, thereby reducing dependency on the conventional grid and lowering electricity costs. In essence, the algorithm's decision to switch the power supply of specific equipment below the current limit is a testament to our commitment to sustainable and cost-effective energy solutions. By intelligently harnessing solar power during opportune moments, our research aims to not only reduce carbon footprints but also offer economic benefits to consumers.

This intricate interplay between data collection, sorting, and dynamic distribution represents the heart of our research endeavor. It epitomizes our dedication to creating a more efficient and sustainable electrical ecosystem, one where the power of solar energy seamlessly integrates with conventional grid sources, optimizing energy consumption for a brighter and greener future.

IV. IMPLEMENTATION AND TESTING

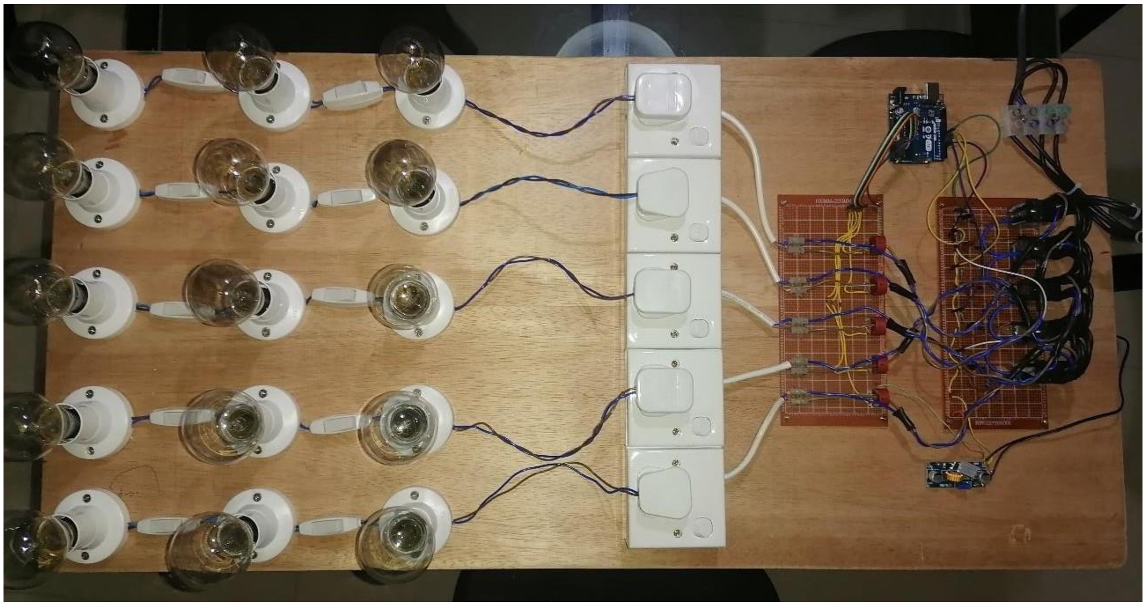


Figure 02: Implemented system of the distribution board

In the intricate architecture of our research system, a diverse assembly of hardware elements plays pivotal roles to materialize our vision of efficient and adaptable energy management. At its current stage, the prototype boasts five distinct electrical outputs. However, the system's underlying framework is inherently modular, enabling us to expand the number of outputs to cater to the multifaceted and unique energy needs of individual households.

One of the standout components in our design schema is the wireless current sensors. These aren't merely sensors; they act as vital conduits that furnish real-time electrical data. Ingeniously linked to lighting fixtures such as bulbs, these sensors are configured to function autonomously, outside the direct circuitry of the central system. Their role is to collate data on current usage and forward this information to a set of 12V AC relays. These relays bear the responsibility of dynamically toggling the source of electrical current, alternating between solar energy and the conventional grid supplied by the Ceylon Electricity Board (CEB).Beyond this, a strategically positioned buck converter amplifies the system's operational efficiency. Located on the left flank of the control unit, this technological marvel serves dual yet interrelated functions. It down-converts the standard 230V AC mainline current to a manageable 12V, thereby satisfying two critical operational needs. Firstly, it provides the requisite power to energize the wireless sensors, ensuring they remain in a state of constant readiness. Secondly, it supplies the necessary electrical control to the 12V AC relays, granting them the capability to seamlessly switch between different power sources.

Through this intricate arrangement, our system doesn't merely transition between power sources it does so while constantly analyzing real-time current demand. It's a symphony of coordinated hardware components, all orchestrated to optimize energy usage and ensure adaptability. In doing so, the system provides a robust and extensible platform designed not just to meet but to adapt to the evolving energy requirements of modern households.

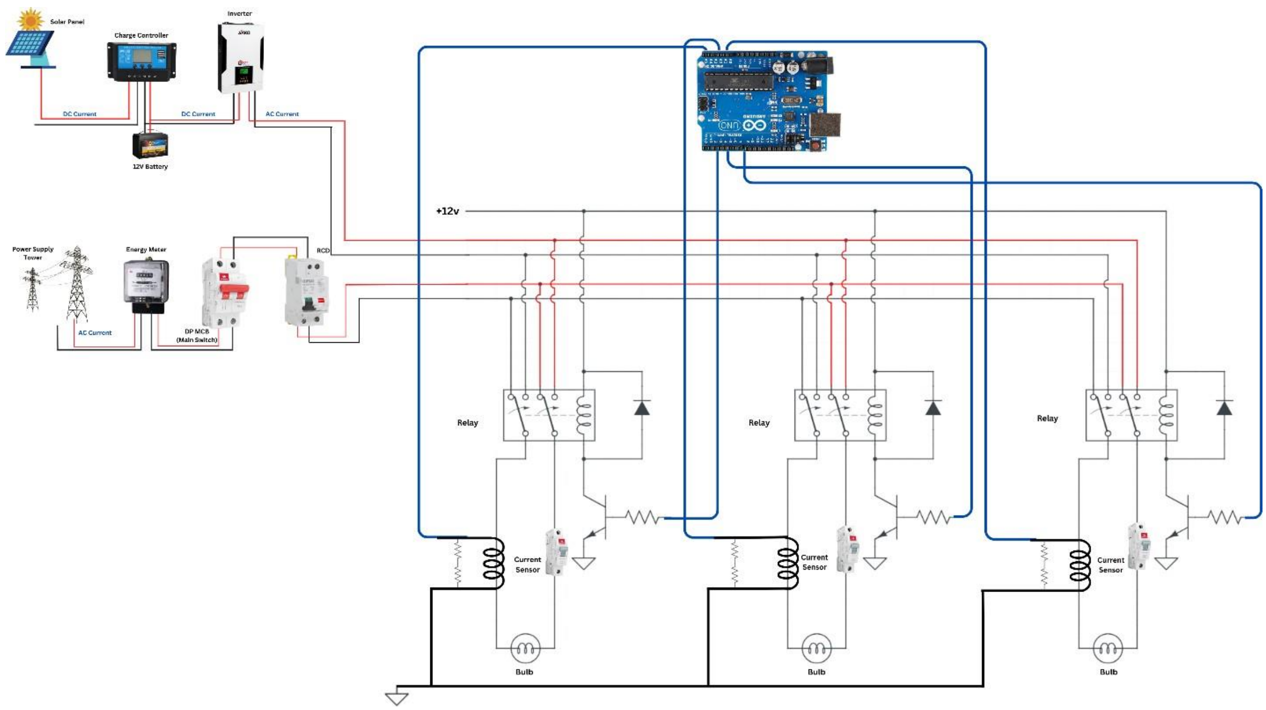


Figure 03: Circuit diagram of the distribution box

In the intricate schematic presented in Figure03, we observe a sophisticated interplay between relays and current sensors, forming the backbone of the power management system. As electricity from both solar panels and the CEB (Central Electricity Board) flows, its initial encounter is with an 8-pin relay, designed meticulously for optimal power routing. Of these pins, two distinct pairs are dedicated to solar and CEB lines respectively, representing the neutral and live conduits. Another pair drives the output, directing electricity to its eventual endpoints. The remaining two pins play a crucial role in the relay's modus operandi, a process governed by the ATmega328P microcontroller. This controller dispatches a signal that courses through a transistor, amplifying and channeling it towards the relay. To safeguard the transistor and adjacent circuitry from potential harm, a diode is strategically positioned parallel to the relay coil. Renowned as a "flyback diode", it acts as a protective sentinel against voltage spikes, especially when the relay coil is deactivated. As for the current sensors, they act as vigilant sentinels, capturing and translating real-time electric flow from both sources into analog data. This vital information enables informed decisions regarding power management and distribution, ensuring efficiency and continuity in the system.

When we write the code which is related to the management and distribution of electrical current, specifically between solar power and the CEB (Central Electricity Board) based on readings from current sensors. To start, the system receives data from the current sensors. This data provides insights into the electrical current flow through various pieces of equipment or circuits. Once this data is gathered, it's crucial to ensure that we operate within a predefined safe limit for current flow. To manage this, the initial step involves sorting the sensor data. The array SnArCp[] contains this sorted current data in ascending order. Sorting the data allows for efficient identification and selection of current values, especially when there's a need to operate below a certain limit. After sorting, the system identifies the highest current values that remain under the specified current limit. These values are then transferred to the solAr[] array. This array specifically includes the readings from the equipment that are safely below the current threshold. The purpose of this is to then manipulate the distribution of current, redirecting flow towards solar power for the equipment represented in the solAr[] array. It's worth noting that while SnArCp[] is the sorted version of the current array, SnAr[] remains the non-sorted or original version of it.

The distinction is important to ensure the accurate correlation of current values to the equipment or circuits they pertain to. In essence, this mechanism allows for optimized usage of solar power. By intelligently distributing current between solar power and the CEB based on real-time sensor data, the system ensures efficient and safe energy consumption. So lets see the components that we used above one by one.

Current Sensor

The AC Current Sensor is a non-contact device that safely transforms high AC currents into small amplitude signals. Using a magnetic field, it accurately measures current in live wires without direct connection, ensuring enhanced safety. Suitable for energy monitoring, smart homes, and industrial controls, it provides precise current data. Its durable design offers long-term reliability, aiding in optimizing energy usage and efficiency..

12V AC Relay

The 12V 8-pin relay seamlessly switches between solar and main grid power in our hybrid system. Compact and versatile, it ensures efficient power management with its 8 intelligently arranged pins. The relay uses advanced algorithms to optimize solar power utilization. A specific pair of pins controls the output power line for uninterrupted electricity. Its robust design ensures reliable performance in hybrid power systems.

ATmega328p Microcontroller (From Arduino UNO Board)

The ATmega328p Microcontroller is central to our hybrid power system, chosen for its performance, low power consumption, and features. It processes real-time data from current sensors to determine optimal power sources for household equipment. Using built-in features, it facilitates seamless switching between solar and grid power. The microcontroller also controls the 8-pin relay, optimizing power transitions. This ensures efficient energy use and promotes sustainable energy solutions.

ALGORITHM

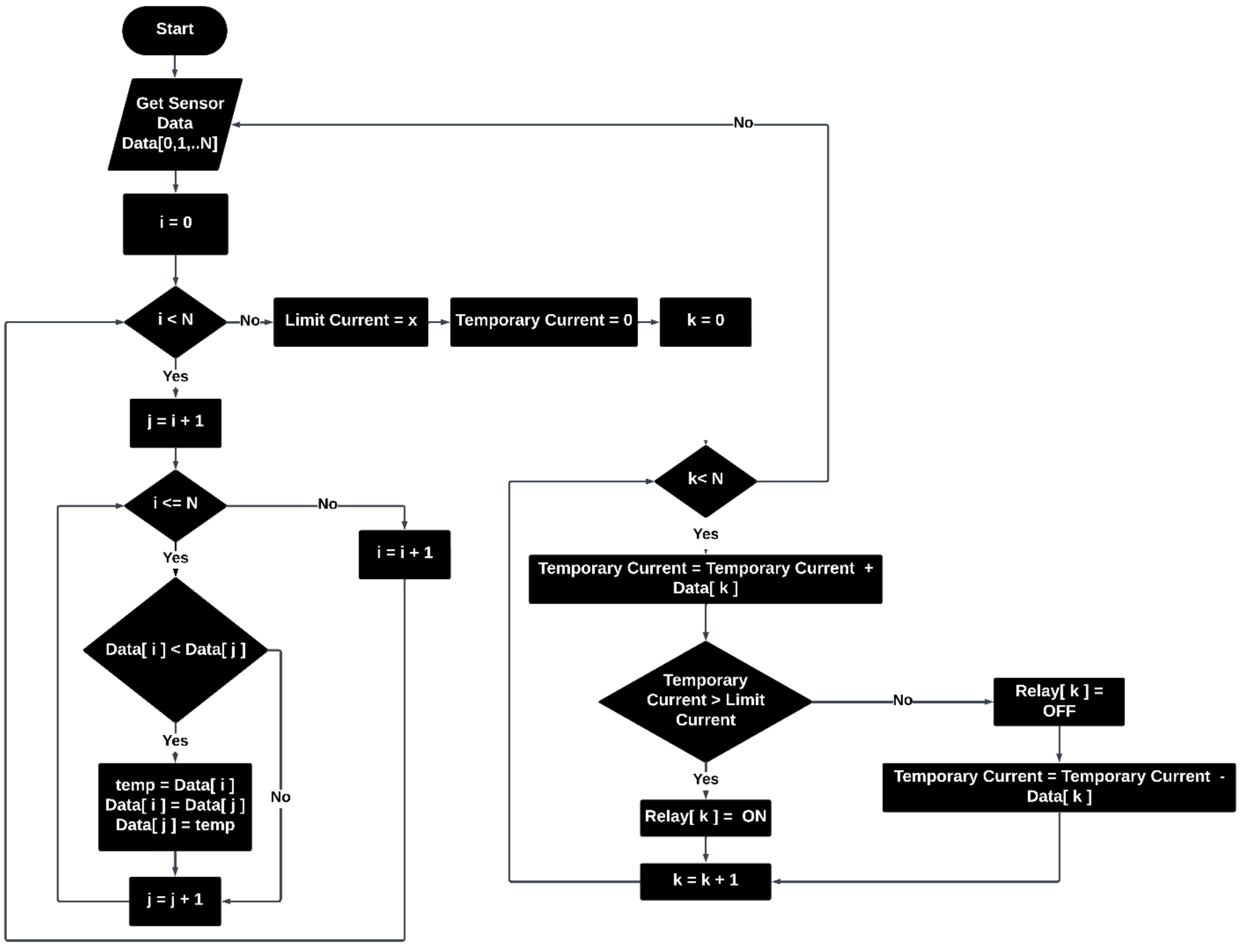


Figure 04: Working algorithm diagram

By utilizing the current sensor, it first obtains all the current required from the home appliances. Next, we arrange the equipment's most recent data in decreasing order. We then change the list items beneath the current limit, starting from the largest and going in descending order, into the solar line, using temporary data as the current limit. so that we can use the solar panels as efficient as possible.

In the quest to optimize the utilization of solar power within our innovative system, a meticulously orchestrated series of steps is followed to manage electrical current allocation. The system is equipped with wireless current sensors strategically connected to various electrical outputs, ranging from light bulbs to more power-intensive appliances. These sensors serve as vigilant data collectors, constantly monitoring the electrical current consumed by each device.

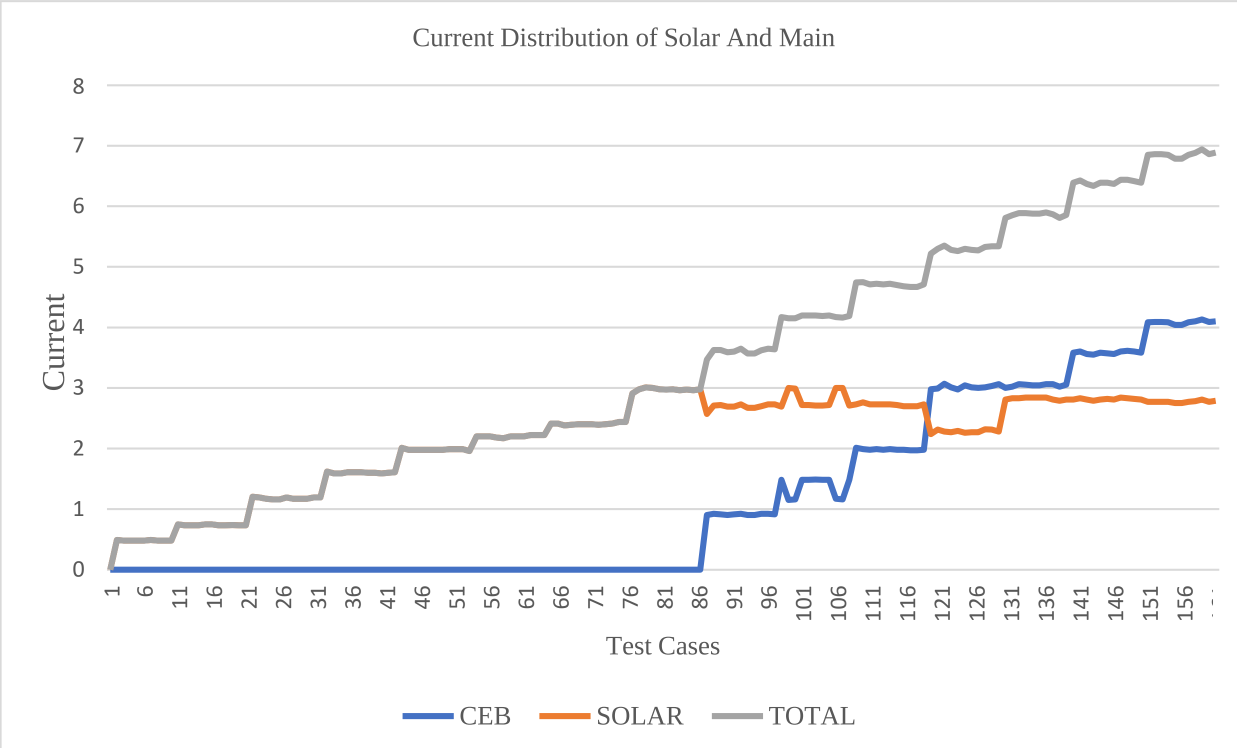
Once this data is gathered, it's methodically organized into an array. But not just any array this array is carefully sorted in ascending order to facilitate intelligent decision-making. At this juncture, we are interested in the higher-end of the current spectrum while still keeping an eye on a crucial number: 3A. This is the upper limit set for solar power output in our system, serving as a benchmark for the algorithm that follows.We initiate our algorithmic process by focusing on the highest current value in the sorted array. A pivotal check is performed to assess whether this highest value is below the 3A solar power limit. If it passes this initial litmus test, we move on to an additive process involving the next highest current values on the list. These are then summed with the highest current value, progressively building a composite total. With each addition, a rigorous verification is carried out to ascertain whether this newly calculated sum remains below the critical 3A threshold. This iterative procedure continues, each step serving as a filter that sifts through possible combinations of electrical devices. By so doing, the system identifies which sets of electrical appliances or devices can be most efficiently powered by the available solar energy, all the while ensuring the total current does not exceed the 3A limit. Through this sophisticated method, we achieve a dual objective: maximizing the use of solar energy and ensuring the most efficient allocation of electrical current. The system, therefore, doesn't just switch to solar power; it does so in the most effective manner possible, identifying the electrical equipment that can function under the set solar power limit. This results in an intricate but highly effective energy management system, fine-tuned to make the most out of every ampere generated by the solar power unit.

V. EXPERIMENTAL RESULTS

Outputs(A)										Power Distribution		Total(A)
1		2		3		4		5		Solar(A)	Main(A)	
0	Main	0	Main	0	Main	0	Main	0.49	solar	0.49	0	0.49
0	Main	0	Main	0	Main	0	Main	1.08	solar	1.08	0	1.08
0	Main	0	Main	0	Main	0	Main	1.63	solar	1.63	0	1.63
0	Main	0	Main	0	Main	0.46	solar	1.62	solar	2.08	0	2.08
0	Main	0	Main	0	Main	0.83	solar	1.63	solar	2.46	0	2.46
0	Main	0	Main	0	Main	1.43	Main	1.63	solar	1.63	1.43	3.06
0	Main	0	Main	0.47	solar	1.43	Main	1.64	solar	2.11	1.43	3.54
0	Main	0	Main	1.04	solar	1.42	Main	1.62	solar	2.66	1.42	4.08
0	Main	0	Main	1.26	solar	1.42	Main	1.63	solar	2.89	1.42	4.31
0	Main	0.46	Main	1.24	solar	1.4	Main	1.61	solar	2.85	1.86	4.71
0	Main	1.02	Main	1.24	Main	1.39	solar	1.6	solar	2.99	2.26	5.25
0	Main	1.24	Main	1.24	Main	1.39	solar	1.6	solar	2.99	2.48	5.47
0.45	Main	1.25	solar	1.25	Main	1.4	Main	1.6	solar	2.85	3.1	5.95
1.02	Main	1.25	Main	1.25	Main	1.4	solar	1.59	solar	2.99	3.52	6.51
1.57	Main	1.24	Main	1.24	Main	1.39	solar	1.59	solar	2.98	4.05	7.03

Table 04: Current load distribution for 5 outputs

The table and its accompanying graph provide a detailed look at how power from solar energy and the Ceylon Electricity Board (CEB) is allocated across five different electrical outputs based on varying levels of current demand. The system is set with a 3A current limit for solar power, which serves as a threshold for automatic switching between solar and mainline power sources. Initially, when the 5th output is loaded, the current is sourced entirely from the solar line, provided the total sum of current from all five outputs remains below the 3A threshold. As the current requirement increases, the system smartly allocates the power sources. When the current demand reaches 4.71A, for example, the system automatically assigns the 3rd and 5th lines to draw from the solar source. This is because the combined current requirement of these two lines is 2.85A, which falls below the 3A limit set for solar power. This dynamic allocation allows for the optimal use of available solar power while seamlessly switching to traditional grid power when necessary. Notably, this setup ensures that even the highest current-required lines can effectively function below the 3A limit, showcasing the system's efficiency in power distribution.



Graph 01: Current distribution between solar and ceb

As shown in Graph 01,we have taken 161 outputs from the system and graph out the "Graph 01" the In the graph, there is a clear trend that as the total current load continues to increase, the primary source of the electrical current shifts from solar to the Ceylon Electricity Board (CEB). Initially, the system effectively utilizes solar energy, especially when the current requirements are low. However, as the total current load escalates, the graph reveals that the majority of the electrical current starts to be sourced from CEB. This shift indicates that while solar energy is highly efficient for lower current demands, the system has been designed to rely more heavily on traditional grid power from CEB as those demands climb. This observation suggests that as consumption grows, the system dynamically prioritizes grid electricity to meet the higher current requirements. According to the analysis, we can conclude that for smaller current requirements, such as charging phones or watching TV, the system can efficiently source the current from the solar line.

VI. CONCLUSION AND FURTHER WORKS

In our research, we explored the intricate dynamics of power distribution between solar and CEB sources. Our objective was to create an efficient mechanism that not only seamlessly distributes power to various output equipment but also optimizes the utilization of solar energy. By harnessing the potential of algorithmic control, our system can adeptly switch current between devices, ensuring maximum solar energy usage. A significant aspect of our research's novelty lies in its scalability and ease of integration. As we venture into the future, our primary focus will be to evolve our system into a 'plug-and-play' model. This will eliminate the need to rewire entire household structures when integrating our distribution board. Such an advancement would significantly reduce installation complexities and costs. Moreover, the flexibility of our system will be further enhanced, allowing for the effortless addition of new systems. Simply put, if there's a need to integrate additional equipment, one would just have to connect the wires to the distribution board without extensive modifications. Our goal is to create a low-cost 2 to n distribution board, where the two inputs (solar and CEB) can cater to any number of output devices. By doing so, we aim to revolutionize the way power is distributed in households, making the process more efficient, flexible, and sustainable. This endeavor, we believe, will greatly contribute to the broader narrative of clean energy solutions and household energy management.

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