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# Optimum Integration of Solar Panel with Battery Energy Storage System for EV Application

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**ABSTRACT:** This project presents a low-cost prototype for monitoring online the maximum power produced by a domestic photovoltaic (PV) system using Internet of Things (IoT) technology. Using IoT technology, users can check in real time the change in power produced by their installation anywhere and anytime without additional effort or cost. The designed prototype is suitable for domestic PV applications, particularly at remote sites. It can also help users check online whether any abnormality has happened in their system based simply on the variation in the produced maximum power. The system performs well. Moreover, the prototype is easy to implement, low in cost, saves time, and minimizes human effort. All input data will be gathered and sent over Bluetooth using a working prototype built on an Arduino board. The mobile application is also used to let individual users monitor the system in real-time, alert users about electrical system issues, display their energy use in real time, and provide other essential alerts and warnings. This work proposes an internet of things (IoT) based architecture for HRES, consisting of a wind turbine, a photovoltaic system, a battery storage system, and a diesel generator. The proposed architecture is divided into four layers: namely power, data acquisition, communication network, and application layers. Due to various communication technologies and the missing of a standard communication model for HRES, this work, also, defines communication models for HRES based on the IEC 61850 standard. The monitoring parameters are classified into different categories, including electrical, status, and environmental information. The network modeling and simulation of a university campus is considered as a case study, and critical parameters, such as network topology, link capacity, and latency, are investigated and discussed.

**KEYWORDS:** smart distribution board; renewable energy; photovoltaics

## I. INTRODUCTION

Power generation from renewable sources has grown significantly in recent years due to increasing energy demand as well as the environmental and economic concerns with fossil fuels. Photovoltaic (PV) is one of the renewable energy sources with the greatest future projection as it possesses features such as simple installation, high reliability, low maintenance cost due to the absence of moving parts, and zero fuel cost [1,2]. Solar trackers are used to increase the energy output from solar panels and solar receivers and used to keep solar collectors/solar panels oriented directly towards the sun as it moves through the sky every day. Therefore, creating renewable energy-based smart home systems to monitor and control electrical energy has become critical and needed on a large scale [3]. The Internet of Things (IoT) is a system of related computing devices, digital and mechanical machines, objects, people with unique identifiers, and potential transfer of data over a network without human-to-human or human-to-computer interaction [4].

Circuit breakers, RCBOs (Residual Current Operated Circuit Breaker), and ELCBs (Electric Leakage Circuit Breaker) are some examples of safety devices that are housed inside the modern distribution board. It was needed to upgrade the distribution boards to be smarter in order to meet the ever-increasing demands of today's electricity grids, to make it easier to integrate distributed energy resources, solar PV panels, and electric vehicles into the grid, and to increase the system performance and reliability of low voltage distribution boards. Therefore, a user-friendly system for monitoring and warning energy consumption could help to some extent to prevent unnecessary energy consumption and

disagreements over electricity bills. Numerous incidents are happening as a result of the electrical system. As a result, it is crucial to focus on creating and developing a smart distribution board equipped with a variety of sensors and integrated with an application that could inform users about electrical system faults, provide information about their real-time energy consumption, provide necessary alerts and warnings, etc. [5]

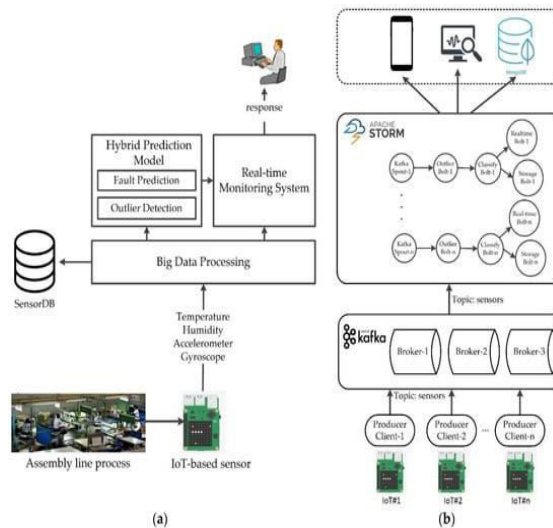


Fig: Analysis of IoT-Based Sensor

In [6], the process of tracking solar panels in three different areas with different amounts of dust was analyzed to present an IoT system based on detection, monitoring, and automatic cleaning system for the soiling of PV solar panels. In [7], a particle swarm optimization (PSO) augmented internet of things (IoT)-based maximum power point tracking (MPPT) algorithm for solar photovoltaic (PV) systems has been proposed. The IoT-based control system provides monitoring and compiling of PV reference voltage for the MPPT controller of the PV system. Further, the experimental results validate the improved performance of the proposed algorithm. In [8], one of the causes of reducing the efficiency of solar systems is the temperature increase in solar panels. To prevent this phenomenon, a cooling fan can be installed on the back side of the solar panel. The solar system efficiency also decreases due to weather conditions and unexpected situations. The IoT system was used to monitor the state of the solar system and control the cooling fan. The authors proposed to use the IoT system for monitoring and controlling fan-based cooling systems.

### Related Work

Renewable energy sources, such as photovoltaics and wind energy, are receiving significant attention to increase the penetration rate of renewable energy sources and reduce greenhouse gas emissions, due to their energy potential and the maturity of these technologies [12]. These sources are alternatives for conventional energy sources that supply power for self-consumers and remote communities. Different energy configurations could be configured to enable systems operation in both a grid-connected mode as well as a standalone mode. As renewable energy sources are intermittent in nature, it becomes challenging to integrate a significant number of renewable energy sources with the power grid. Communication infrastructure is the crucial element and the main building block for future smart grids, which enables the integration of DERs and bidirectional energy and information flow in the power distribution system. Figure 1 shows a schematic diagram for the grid integration of HRES. In this integration, HRES will provide many services for electric power utilities during peak demand by supporting different services such as demand response and demand-side management. The underlying communication network will play an essential role in enabling the integration of DERs with improved resilience, reliability, and efficiency.

The HRES is a cyber-physical system that can be divided into two layers: the power infrastructure and the communication infrastructure layers, as shown in Figure 1. The power infrastructure layer consists of different energy sources (e.g., wind turbines, photovoltaics, diesel generators, and batteries), transformers, feeders, converters, and electrical connections. The communication infrastructure layer supports the physical infrastructure by an underlying communication network, linking between sensors and actuators nodes. This enables the local control center to manage

the system operation. In this integration, ICTs play an essential role in allowing the transition from the conventional power grid to the future smart grid by supporting the integration of HRES.

Many researchers and studies have investigated hybrid renewable energy systems, and from different perspectives, such as energy management systems [13], demand response [14], economic cost [15], carbon dioxide emissions and environmental impact [16], optimizing source size [17,18], communication network [19,20], IoT-enabled smart grid [21,22,23], HRES optimization [24,25], modeling based on international standards [26,27,28,29], optimal location [30], and capacity planning [31]. The author in [13] provided an overview of energy management agent (EMA) framework architectures' ability to manage the energy generation/consumption of DERs/HRES in homes, buildings, and communities. The proposed framework consists of four layers: an infrastructure, a control, a service, and an application layers. The infrastructure layer covers different smart grid domains, including generation, transmission, distribution, and consumption. The control layer is realized through a supervisory control and data acquisition (SCADA) system, programmable logic control (PLC), substation control, and home/building automation system. The work highlighted the need for a standardized EMA data model and communication protocols.

The authors in [14] proposed a novel demand response strategy for sizing a HRES consisting of a wind energy system, a PV energy system, batteries, a diesel engine, and loads. The demand response strategy aimed to increase/reduce the tariffs, with respect to generation from renewable energy systems, for load requirements. The optimal size of each HRES component has been optimized using different techniques, including particle swarm optimization (PSO), social mimic optimization, and bat algorithm (BA). The real data for a load of a rural city in the North of Saudi Arabia has been considered for the design of HRES. Authors in [15] presented a feasibility study for using a hybrid renewable energy system for supplying a university building in Al Baha University, Saudi Arabia. The hybrid renewable energy system consisted of PV/WT/FC/BSS. The building's AC loads included an air conditioning system, laboratories, lighting, and other equipment.

## II. METHODS

### IoT-Based Architecture for Hybrid Renewable Energy System

In HRES, communication infrastructures are crucial elements that are responsible for data exchange among data resources (sensors and meters), controllers, and the control center. In order to support remote monitoring and control operation, the information flow from different entities defines the system architecture [19]. The IoT technology will provide great opportunities for sensing, communication, processing, and actuating to support various microgrid applications. First, measured data are acquired and transmitted to the local control center using a communication network. Then, decisions are made with this data, and control commands are sent through the communication network where the control commands are run using controllable devices. Two main types of communication schemes could be considered: centralized schemes and distributed schemes. In the centralized scheme, all data are transmitted to a central control center where data are processed and control commands are transmitted to controllable entities. In the distributed scheme, all data are received and processed using the local controller. In order to control the entire system, local control centers need to share information with each other through the communication network.

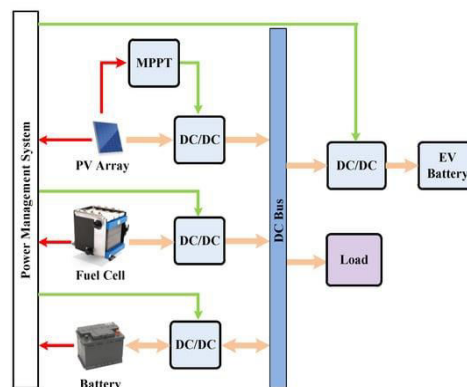


Fig 2: Work Flow

#### Power Layer

The power layer covers residential power generation and consumption. Examples of power consumption are residential homes/buildings that include different applications such as heating, ventilation, and air conditioning (HVAC), lighting, electric vehicles, and various appliances. Residential energy generation consists of various renewable energy sources, such as wind and solar power, conventional sources, such as diesel generators, and energy storage systems, such as batteries. Other elements that are part of the power layer are transformers, buses, and loads. Loads could be classified into three main types: residential, commercial, and industrial. In addition, various sensor nodes, measuring devices, and actuators are attached to the power system layer.

#### Data Acquisition Layer

The data acquisition layer includes different types of sensor nodes and measurement devices connected to different subsystems of HRES. Data collected utilizing various sensor nodes and measurement devices is transmitted to the application layer through the communication network layer. Based on the data from different energy sources such as wind energy, photovoltaic system, diesel generator, and battery storage, HRES can be operated in island mode or grid-connected mode.

#### Modeling of Hybrid Renewable Energy System

HRES are designed to generate electric power using different power generation sources, such as small-scale wind turbines, photovoltaic systems and/or other conventional sources, such as diesel generators. These systems can support power ranging from a single house/building to a large system such as a village or an island. Based on the connection with the main grid, the system can be classified as in standalone mode or grid-connected mode [24]. In the case of the standalone mode, HRES should be designed to meet the required power demand. There are different configurations for the hybrid renewable energy system such as AC, DC, and hybrid AC/DC, based on the voltage of the main bus linking all assets. In the AC configuration, all assets are connected to an AC bus directly or via converts, while all assets are connected to a DC bus for the DC configuration [25].

In this work, the main components of HRES are energy sources (PV systems, wind turbines, diesel generators, and electric grids), energy storage system, and load. The selection of HRES elements is based on the scenario of Saudi Arabia because the electricity generation costs for isolated areas, such as mountainous, villages, and desert areas are expensive and face many challenges, such as difficult access to remote sites and low population density. Therefore, hybrid renewable energy generation would benefit such remote areas and reduce dependence on fossil fuels. Different standards have been considered for the information model of the hybrid energy system, such as IEC 61400-25, IEC 61850, and IEC 61850-7-420 [26]. The information model uses the logical node concept to represent the information model for a real device that needs to be exchanged with other devices and/or systems. **Figure 3** shows the basic building blocks of the energy management system (EMS) for the hybrid energy system. It consists of two main parts: EMS sensing devices and EMS analytics.

### III. RESULT ANALYSIS

The required hardware consists of Arduino Mega2560. The Arduino Mega 2560 is a microcontroller board based on the ATmega2560. It has 54 digital input/output pins (of which 15 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller. Simply connect it to a computer with a USB cable or power it with an AC-to-DC adapter or battery to get started. The Mega 2560 board is compatible with most shields designed for the Uno and the former boards Duemilanove or Diecimila. The Mega 2560 is an update to the Arduino Mega, which it replaces. The other components are ACS712 AC/DC Current Sensor, voltage sensor, HC-05 Bluetooth module, relay module, some M-F/F-F jumper cables, load (LED), and fuse. The hardware module is connected to an Arduino Mega microcontroller. The microcontroller is responsible for all of the system's communication and control. In ACS712 AC/DC current sensor and voltage sensor, the system receives various data, including voltage (V), current (I), and power (P) [19]. The system receives the V, I, and P data from the measuring sensors. These data can be visualized through LCD display. The character LCD is ideal for displaying text and numbers, and special characters.

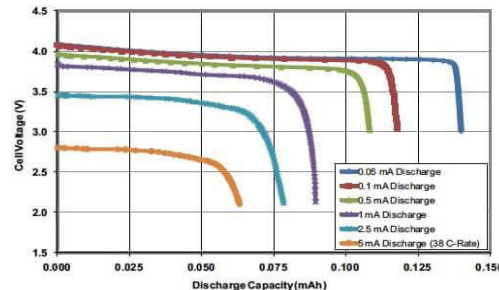


Fig 3: Result analysis Inter-Integrated Circuit

A standard LCD requires over ten connections, which can be a problem if Arduino does not have many GPIO pins available. Using an I2C (Inter-Integrated Circuit) interface, only two connections for an LCD character display are possible. The relay module has one, two, four, and eight channels. The relay module should be powered with 5 V, which is appropriate to use with an Arduino. There are other relay modules that are powered using 3.3 V, which is ideal for ESP32, ESP8266, and other microcontrollers. The calculated power is compared with a predefined value based on the rating of the monitored device. If the measured power exceeds the set limit, the associated relay is activated to disconnect this device. Otherwise, the normal operating condition is maintained. The Electrical load used in this prototype is a 12-volt LED strip, and we can use more than one electrical load up to four loads. The HC-05 Bluetooth module is employed to receive and transmit the data from the sensors to the mobile app that requires a fingerprint sign-in. In addition, the application is employed to monitor the usage wirelessly and remotely. The mobile app receives the sensor's data through an HC-05 Bluetooth module. The fuse is used to comply with the safety regulations of the buildings equipped with the system, A 2-A fuse is recommended and is used in the experimental setup.

#### IV. CONCLUSIONS

As today's houses are supplied with a variety of smart appliances, energy management of such devices has become critical. This project created an IoT-based smart household distribution board to monitor the functioning of various appliances. The proposed system consisted of two parts, the first part is considering a photovoltaic system with a tracking and cleaning system to guarantee the maximum power that can be delivered to a load that is connected through a smart distribution board. The second part is a smart distribution board, which is a significant improvement over traditional distribution boards in terms of security and safety. If there are any defects, such as short circuits, the user will be notified in real time via the app. This solution encourages users to use energy wisely by delivering real-time usage data, thereby improving their quality of life. Some of the ideas that can be added to the project in the future include implementing artificial intelligence for prediction and analysis, new features like online energy bill payment directly through our application, and online support feature and feedback system for our app to provide a better experience.

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