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# SMART SOLAR GRID WITH IOT BASED LOAD SHIFTING

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**Abstract**— The increasing demand for electrical energy and the integration of renewable energy sources have created the need for intelligent power management systems. This paper presents a Smart Solar Grid with IoT-Based Load Shifting system designed to optimize energy utilization, reduce peak load demand, and improve grid efficiency. The proposed system integrates solar photovoltaic (PV) generation with Internet of Things (IoT) technology to monitor real-time energy consumption and automatically shift non-critical loads during peak demand periods.

The system employs sensors, smart relays, and a microcontroller-based control unit connected through an IoT platform for continuous monitoring and control of voltage, current, power consumption, and battery status. Load shifting is achieved by prioritizing essential and non- essential appliances based on energy availability and grid conditions. During low solar generation or peak tariff hours, selected loads are shifted or scheduled to operate during off-peak periods, thereby minimizing energy wastage and reducing electricity costs.

The proposed model enhances energy reliability, supports renewable energy integration, and promotes efficient demand-side management. Experimental analysis demonstrates improved power utilization, reduced dependency on the conventional grid, and effective real- time monitoring through cloud-based communication. This system can be implemented in residential, commercial, and smart grid applications to achieve sustainable and energy-efficient power distribution.

**Keywords**— Smart Grid, Solar Energy, Internet of Things (IoT), Load Shifting, Energy Management, Renewable Energy, Demand- Side Management.

## Introduction

The increasing demand for electrical energy, rapid urbanization, and environmental concerns have accelerated the adoption of renewable energy sources in modern power systems. Among various renewable sources, solar energy has emerged as one of the most reliable and sustainable alternatives due to its abundant availability and eco-friendly nature. However, the intermittent nature of solar power generation creates challenges in maintaining grid stability, efficient power utilization, and continuous supply to consumers. To address these challenges, smart grid technology integrated with the Internet of Things (IoT) provides an effective solution for intelligent monitoring, automation, and energy management.

A Smart Solar Grid with IoT-Based Load Shifting system enables efficient utilization of solar energy by dynamically managing electrical loads according to power availability and demand conditions. IoT devices such as sensors, smart meters, and microcontrollers continuously monitor parameters including voltage, current, power consumption, and battery status. The collected real-time data is transmitted through wireless communication networks to a cloud platform or centralized control unit for analysis and decision-making. Based on the availability of solar energy and grid conditions, the system automatically shifts non-critical loads to off-peak periods or to renewable energy sources, thereby reducing peak demand and improving energy efficiency.

The proposed system aims to minimize dependency on conventional power sources, reduce electricity costs, and enhance reliability of the power distribution system. Load shifting also helps in balancing demand and supply, preventing overloading, and maximizing the usage of renewable energy resources. Furthermore, IoT integration enables remote monitoring, predictive maintenance, and user-friendly control through mobile or web applications.

This project contributes toward the development of sustainable and intelligent energy management systems aligned with modern smart city initiatives. The implementation of IoT-based load shifting in smart solar grids can significantly improve energy conservation, operational efficiency, and overall grid performance while supporting environmental sustainability and reduction of carbon emissions.

## I. SYSTEM AND METHODOLOGY:

### METHODOLOGY:

The proposed Smart Solar Grid with IoT-Based Load Shifting system is designed to optimize energy utilization by integrating solar power generation, real-time monitoring, and intelligent load management. The methodology is divided into four major phases as shown below.

**Phase 1: Solar Energy Generation and Data Acquisition**

In the first phase, solar photovoltaic (PV) panels generate electrical energy from sunlight. The generated DC power is regulated using a charge controller and stored in a battery system for continuous supply. Voltage and current sensors are interfaced with the microcontroller to measure real-time electrical parameters such as solar power generation, battery status, and load consumption.

An ESP8266/NodeMCU controller collects the sensor data and transmits it to the IoT cloud platform through Wi-Fi communication. This enables continuous monitoring of energy production and system performance.

**Phase 2: IoT-Based Monitoring and Communication**

In this phase, the acquired data is uploaded to an IoT platform such as Blynk, ThingSpeak, or Firebase for remote monitoring and analysis. The cloud platform displays parameters including voltage, current, power consumption, battery level, and load status in real time.

The IoT interface allows users and utility operators to monitor system behavior remotely using smartphones or computers. Alerts and notifications can also be generated during overload conditions or low battery situations.

**Phase 3: Intelligent Load Shifting Mechanism**

The third phase focuses on automatic load shifting based on solar power availability and demand conditions.

Loads are categorized into:

Priority Loads – essential appliances

Non-Priority Loads – controllable appliances

When solar generation is high, all loads operate normally using renewable energy. During peak demand or low solar generation, the controller automatically shifts or disconnects non-priority loads using relay modules to reduce stress on the grid and maintain uninterrupted power for critical loads.

The decision-making process is controlled using predefined threshold algorithms programmed in the microcontroller. **Phase 4: Smart Grid Integration and Performance Evaluation**

In the final phase, the smart solar system interacts with the utility grid to ensure reliable power distribution. The system continuously analyzes energy consumption patterns and evaluates performance parameters such as:

Energy savings
Load balancing efficiency Reduction in peak demand System reliability
Experimental results are monitored to verify the effectiveness of IoT-based load shifting in improving renewable energy utilization and minimizing power wastage.

**SYSTEM:**

The proposed Smart Solar Grid with IoT Based Load Shifting system operates through the integration of solar power is described below:

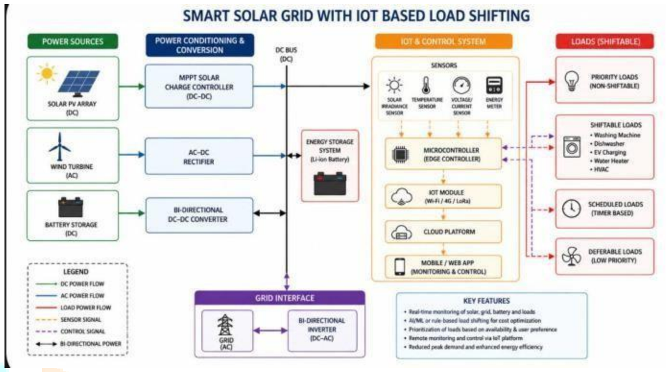


Fig:1 system block diagram of SOLAR AND WIND ENERGY SYSTEM

*A.* **System Overview**

*A.* **WORKING:**

The proposed hybrid renewable energy system for sustainable electric vehicle operation works through the integration of renewable energy generation, power conditioning, intelligent control, energy storage, and motor drive operation. The following describes the complete operational workflow of the system:

2.1 **Solar Energy Generation**

At system startup, the solar panel converts sunlight into DC electrical energy using photovoltaic (PV) cells. The generated power is supplied to the solar charge controller, which regulates the voltage and protects the battery from overcharging and deep discharge conditions. The regulated DC power is then supplied to the smart grid distribution system for powering connected loads and charging the battery.

2.2 **Battery Charging and Energy Storage**

The rechargeable battery stores excess solar energy generated during peak sunlight hours. The stored energy is utilized during nighttime or low solar generation conditions. The battery acts as a backup power source and ensures continuous power supply to critical loads during power fluctuations or grid failure conditions.

2.3 **Grid Power Integration**

When solar power generation becomes insufficient and battery voltage drops below the threshold level, the conventional AC grid supply acts as a secondary backup source. The AC supply is converted into regulated DC power using an AC-to-DC converter and supplied to the system. This hybrid operation ensures uninterrupted power availability for all connected loads.
generation, smart monitoring, intelligent load management, IoT

2.4 **Voltage, Current, and Load Monitoring**

communication, energy storage, and automated control techniques. The complete operational workflow of the system Voltage sensors and current sensors continuously monitor solar voltage, battery voltage, grid voltage, and load current in real time. The collected sensor data is transmitted to the Arduino Nano/ESP8266 controller for processing and analysis. These measurements help determine energy availability, power consumption, and load conditions.

### 2.5 IoT-Based Smart Monitoring

The ESP8266 Wi-Fi module provides IoT connectivity for the smart solar grid system. Real-time parameters such as voltage levels, battery status, power consumption, and load conditions are uploaded to a cloud platform or mobile application through the internet. Users can remotely monitor system performance and receive status updates from anywhere.

### 2.6 Intelligent Load Shifting Operation

The Arduino Nano acts as the central control unit of the system. Based on power availability and load demand, the controller automatically performs load shifting using relay switching circuits. During peak load conditions or low solar power availability, non-essential loads are temporarily disconnected or shifted to alternate power sources, while essential loads continue receiving uninterrupted supply. This intelligent load management improves energy efficiency and reduces unnecessary power consumption.

### 2.7 Relay Switching and Smart Control

The relay module automatically controls different electrical loads based on sensor readings and controller decisions. If sufficient solar power is available, the system prioritizes renewable energy usage. When renewable energy decreases, the controller shifts selected loads to battery or grid supply. This automatic switching ensures reliable and optimized power distribution.

### 2.8 Smart Grid Distribution and Load Operation

The managed electrical power is distributed to household or industrial loads connected within the smart grid network. The system ensures balanced power sharing between renewable energy sources, battery storage, and grid supply while maintaining continuous operation of connected devices and appliances.

### 2.9 System Performance and Energy Efficiency

The Smart Solar Grid with IoT Based Load Shifting continuously operates by optimizing solar energy utilization, minimizing grid dependency, and intelligently managing electrical loads. The system improves overall energy efficiency, reduces electricity wastage, lowers operational costs, and supports sustainable and eco-friendly smart grid applications through automated monitoring and intelligent control operation.

## II. RESULTS

### A. Solar Power Generation and Energy Monitoring Results

The solar photovoltaic (PV) panel successfully generated electrical energy under varying sunlight conditions. The generated DC power was monitored continuously using voltage and current sensors connected to the IoT-enabled controller. The battery storage unit effectively stored excess solar energy and supplied backup power during reduced solar generation periods. Real-time monitoring through the IoT platform showed stable voltage levels, efficient battery charging, and reliable power management throughout system operation.

### B. IoT-Based Load Shifting and Controller Results

The ESP8266/Arduino-based controller successfully monitored power availability, load demand, and battery status using connected sensors. Based on predefined load priorities and energy availability, the system automatically shifted non- critical loads to off-peak periods while maintaining uninterrupted operation of critical loads. The relay switching circuit operated accurately and efficiently, enabling intelligent load management. Real-time data such as voltage, current, power consumption, and load status were successfully transmitted to the IoT platform for remote monitoring and control.

### C. Smart Grid Performance and Energy Efficiency Results

The proposed smart solar grid system demonstrated efficient utilization of renewable energy and reduced dependence on conventional grid power. Load shifting improved overall energy management by minimizing peak-hour electricity consumption and balancing the connected loads effectively. The system operated reliably under different loading conditions and provided stable power distribution. Experimental results confirmed improved energy efficiency, effective automation, and enhanced smart grid performance through IoT-based monitoring and control.

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