Real - Time Energy Saver Using Microcontroller and Load Shifting

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DOI: 10.5281/zenodo.17338045

ABSTRACT

The rapid depletion of fossil fuels, coupled with rising energy demand and environmental concerns, has necessitated a transition toward renewable energy integration in modern power systems. Traditional centralized grids are increasingly inadequate to handle the variability and distributed nature of renewable sources such as solar and wind. The Smart Grid framework provides a foundation for decentralization, distributed generation, and active consumer participation. Within this framework, Demand Response (DR) has emerged as a key strategy to balance supply and demand by encouraging consumers to adjust their energy usage patterns. By shifting consumption away from peak hours and toward periods of lower tariffs or higher renewable availability, DR enhances grid reliability while providing economic benefits to consumers. This project focuses on implementing an Off-line Load Scheduling Algorithm for residential buildings equipped with renewable energy systems and utility grid connections.

Keyword: - Load Scheduling, Power Saver, Demand Based Load Shifting, ToU tariff, Flat-rate tariff.

1. PROBLEM FORMULATION

The rapid advancement in technology and the improvement in living standards have led to a significant increase in the use of electrical appliances in households and industries. While these appliances enhance comfort and convenience, their inefficient and unplanned usage often results in considerable energy wastage. As the number of devices in operation grows, so does the overall energy demand, placing additional stress on the power grid.

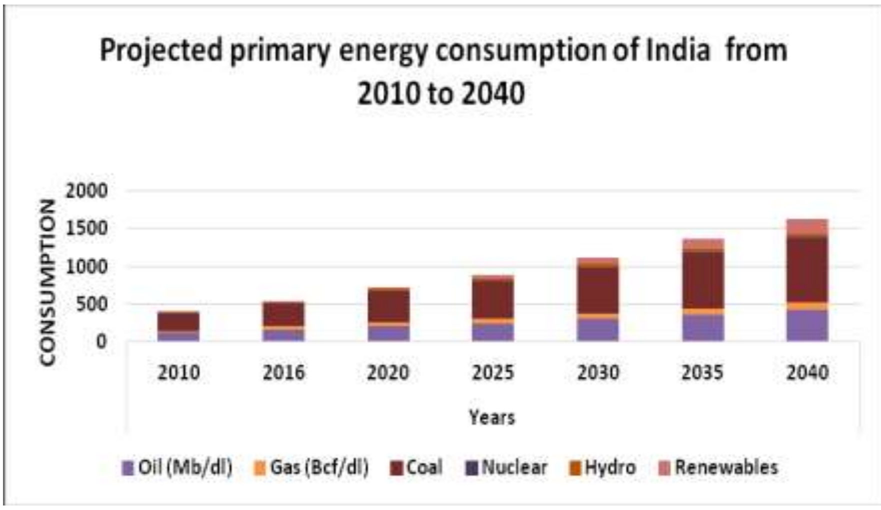
One of the major challenges faced by power systems today is grid overloading during peak hours. Excessive demand during these periods not only leads to higher operational costs but can also cause voltage instability or, in extreme cases, grid failure. Despite varying electricity tariffs throughout the day, most consumers continue to use electrical devices without considering time-based pricing, which results in higher energy bills and further strain on the grid.

To address these issues, there is a pressing need for an intelligent and systematic load scheduling mechanism that optimizes the use of electrical appliances. Such a system should aim to reduce peak-hour demand, minimize electricity costs for consumers, and maintain user comfort without compromising essential energy needs.

The proposed study focuses on developing a Real-Time Energy Saver using Microcontroller and Load Shifting. This system utilizes real-time monitoring and control techniques to schedule appliance operation based on demand, availability, and tariff structure, ultimately promoting efficient energy utilization and a more stable power distribution network.

2. OBJECTIVE

- To design and implement an Off-line Load Scheduling Algorithm for residential buildings with hybrid renewable energy systems (HRES).
- To minimize dependency on the utility grid during peak hours by shifting loads to off-peak periods.
- To reduce the overall cost of electricity consumption under both flat-rate and Time-of-Use (ToU) tariff structures.
- To evaluate the effectiveness of the algorithm in terms of load shifting, cost savings, and grid power reduction.



Graph -1: Projected Energy Consumption.

3. METHODOLOGY

The methodology adopted in this project involves the following steps:

3.1 Load Categorization

In order to achieve efficient energy management, all electrical appliances are categorized based on their operational flexibility and the possibility of load shifting. This classification enables the system to determine which appliances can be deferred or rescheduled without affecting user comfort. The loads are grouped into three main categories:

- Non-schedulable loads: These appliances are essential for immediate use and cannot be delayed without causing inconvenience. Examples include lights, fans, and televisions. Their operation depends directly on user demand and must be supplied with power as soon as they are switched on.
- Partially schedulable loads: These appliances can tolerate limited control or delay within specific operational boundaries. For instance, refrigerators, air conditioners, and laptops can be cycled or operated intermittently to balance energy use while maintaining desired performance levels.
- Fully schedulable loads: These loads can be completely shifted to non-peak hours or times of low tariff rates without affecting user convenience. Appliances such as washing machines, pool pumps, and dishwashers fall into this category. Their operation can be automatically scheduled based on energy availability, cost, or user-defined preferences.

3.2 Load Prioritization

Once the loads are categorized, they are further prioritized to ensure that essential appliances operate continuously, while flexible loads are managed strategically. The prioritization is based on the importance and urgency of the load, as well as the availability of renewable energy and tariff variations.

- High-priority loads: These are critical appliances that must operate immediately and are exempt from scheduling. Power is allocated to them on demand.
- Medium- and low-priority loads: These loads can be scheduled dynamically based on parameters such as renewable energy availability, grid load conditions, and time-of-use tariff rates. By deferring or adjusting the operation of these loads, the system minimizes energy costs and reduces the burden on the grid during peak demand periods.

3.3. Scheduling Algorithm

- **Flat-rate tariff:** Under flat-rate tariff, electricity cost does not depend on *when* or *how much* power you use at different times. So, cost optimization is not time-based, unlike in Time-of-Use (ToU) or Real-Time Pricing (RTP) systems. Instead, the focus is on operational efficiency and load prioritization, not cost variation. Avoid running unnecessary loads simultaneously. Use automation or timers to turn off idle devices.Even though tariff is flat, utility companies may penalize for excessive demand (kVAh or kW peaks). Load scheduling reduces this by staggering device operation. Distribute power evenly to avoid overload or tripping. Run non-critical loads when demand is lower.
- **ToU tariff:** Time-of-Use (ToU) tariff–based load scheduling is an effective energy management strategy that optimizes power consumption by aligning electrical load operation with dynamic tariff structures. In this approach, the electricity cost varies throughout the day according to predefined time slots categorized as peak, mid-peak, and off-peak periods. The scheduling algorithm intelligently controls the activation of various

electrical loads based on their flexibility, priority, and operational requirements to minimize total energy cost while ensuring user-defined constraints are satisfied. Deferrable loads, such as water pumps, washing machines, or electric vehicle chargers, are scheduled to operate during off-peak periods when electricity rates are lowest, while non-deferrable loads continue to operate as required. During high-tariff (peak) hours, low-priority or interruptible loads are delayed or temporarily turned off to avoid excessive energy expenditure and reduce grid stress.The ToU-based load scheduling system typically integrates a real-time clock, tariff database, and load controller module. The controller continuously monitors the current time, identifies the applicable tariff period, and dynamically adjusts load operations to achieve optimal performance. By redistributing power consumption to low-cost periods, this method not only **reduces the consumer's electricity bill** but also **enhances grid reliability and demand-side efficiency**. The system can further incorporate renewable energy sources or battery storage units to enhance flexibility and sustainability. Overall, ToU-based scheduling provides a practical and intelligent framework for **cost-effective, automated, and environmentally conscious energy utilization** in domestic, agricultural, and industrial applications.

4. TOOLS USING

4.1. Hardware Components

- Arduino Board (e.g., Arduino Uno, Mega, or Nano) – the central microcontroller for executing the scheduling algorithm.
- Relay Modules – to switch household appliances (fans, lights, pumps, etc.) ON/OFF based on scheduling.
- Real-Time Clock (RTC) Module (DS3231/DS1307) – to keep accurate time for scheduling loads at specific hours.
- LCD / OLED Display – to show load status, time, and energy usage.

4.2. Software Tools

- Arduino IDE – for coding and uploading the scheduling algorithm to the Arduino board.
- Proteus / Tinkercad / Fritzing – for circuit simulation and PCB design.

4.3. Programming & Algorithm Implementation

Load Scheduling Algorithm coded in C/C++ (Arduino language). Use arrays and priority queues to manage appliance categories (non-schedulable, partially schedulable, fully schedulable). Time-based decision-making using RTC module. Relay control logic to switch appliances ON/OFF according to tariff periods (flat-rate or ToU).

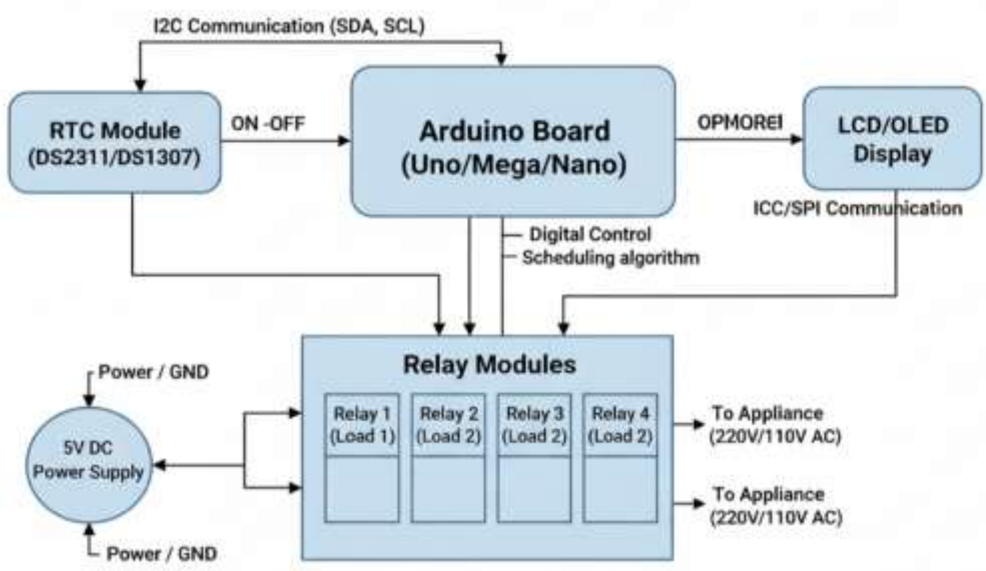


Diagram-1: Block Diagram of proposed system.

4.4. Testing & Validation Tools

- Multimeter & Oscilloscope – for electrical measurements.
- Serial Monitor (Arduino IDE) – for debugging and real-time data logging.

4. CONCLUSIONS

The proposed Off-line Load Scheduling Algorithm demonstrates the potential of consumer-side energy management in Smart Grids. By integrating renewable energy, tariff structures, and battery storage, the algorithm reduces peak demand, enhances renewable utilization, and minimizes electricity costs. This approach highlights the importance of consumer participation in achieving sustainable and decentralized energy systems.

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