

Grid Connected Energy System To Profit From Net Metering And Variable Rate Electricity

Mrs. S. Deepti¹, G. Hansika², J. Rupa³, D. Srilaxmi⁴

¹Associate Professor; Department Of Electrical And Electronics Engineering Bhoj Reddy Engineering College For Women Hyderabad India

^{2,3,4}B.Tech Students; Department Of Electrical And Electronics Engineering Bhoj Reddy Engineering College For Women Hyderabad India

Mail Id ; jonnalagaddarupareddy@gmail.com³

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Abstract

The rising demand for electricity, coupled with the growing adoption of net metering policies, necessitates efficient energy monitoring and management systems. This paper presents a grid-connected energy storage and monitoring system designed to optimize energy utilization and financial benefits under net metering schemes. The proposed system enables precise measurement, calculation, and display of both consumed and exported energy in a residential environment. The system uses a dual energy meter configuration to measure bidirectional energy flow: one meter tracks electricity supplied to the grid, while the other monitors electricity drawn from the utility. A microcontroller processes data from both meters, calculating net energy consumption and billing for each period. Stable operation is ensured through a regulated power supply and crystal oscillator. By providing real-time monitoring via an LCD display, the system enhances consumer awareness, promotes efficient energy usage, and ensures transparent billing. The proposed approach offers economic advantages to both consumers and utilities while improving system reliability and supporting renewable energy integration.

Keywords- Net Metering, Energy Monitoring, Grid-Connected System, Bidirectional Energy Measurement, Microcontroller, Renewable Energy, Energy Efficiency, Billing Accuracy

Introduction

The increasing reliance on electricity highlights the importance of efficient energy management. Net Energy Metering (NEM) is a billing arrangement that credits customers for surplus electricity generated by home energy systems, such as solar panels. Under NEM, energy exported to the grid offsets energy consumed from the utility, and the net consumption is used for billing. Global electricity demand continues to rise due to industrial growth and widespread use of electrical devices. Conventional energy sources, including oil, natural gas, and coal, account for approximately 80% of global energy production. However, these resources are finite, necessitating the adoption of alternative energy sources to mitigate potential energy crises.

The proposed system incorporates two main input blocks:

1. **Export Energy Meter:** Measures electricity supplied from the household to the grid, enabling billing of exported energy.
2. **Import Energy Meter:** Monitors electricity drawn from the utility, allowing accurate calculation of net consumption.

A microcontroller integrates data from both meters, calculates the net energy, and displays the net billing amount on an LCD. The system supports intelligent

power sharing and real-time monitoring, promoting energy efficiency and economic benefits.

Types of Embedded Systems

Embedded systems can be classified based on their operational characteristics, connectivity, and application requirements. Understanding these categories is essential for selecting the appropriate system for specific tasks.

Standalone Embedded Systems

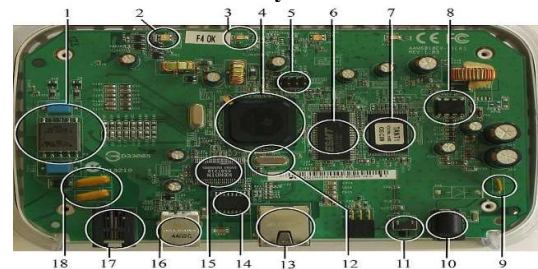


Fig 1: A modern example of embedded system

Standalone embedded systems function independently without requiring a host computer. They receive inputs from sensors, switches, or other devices, process the data internally using a microcontroller, and generate outputs through actuators, displays, or motors. These systems are

widely used in household appliances and consumer electronics, including microwave ovens, washing machines, air conditioners, and digital cameras. Their design allows continuous, autonomous operation, enhancing automation and efficiency in everyday applications.

Real-Time Embedded Systems

Real-time embedded systems are engineered to respond to inputs within strict time constraints. Failure to process information promptly can result in system malfunction or safety risks. These systems are critical in applications where timing precision and reliability are essential, such as automobile airbag systems, traffic signal control, industrial automation, and medical monitoring devices. Real-time systems ensure that tasks are executed immediately when triggered, making them indispensable in safety-critical environments.

Key Features:

- Immediate response to events
- Precise timing and high reliability
- Suitable for safety-critical and time-sensitive applications

Networked Embedded Systems



Fig 2: Networked embedded systems

Networked embedded systems are connected to other devices or networks to enable data communication and coordinated operation. They employ wired or wireless protocols such as Zigbee, Wi-Fi, or Bluetooth for connectivity. Applications include smart home automation, energy monitoring systems, wireless sensor networks, and industrial control systems. By enabling remote monitoring and control, these systems enhance efficiency, flexibility, and integration with intelligent infrastructures.

Key Features:

- Facilitates communication among multiple devices
- Enables remote monitoring and control
- Integrates with smart systems and networks

Hardware Components



Fig. 3 Energy Meter

An energy meter is a critical electrical device used to quantify the consumption of electrical energy in residential, commercial, and industrial settings. It measures energy in kilowatt-hours (kWh) and provides real-time monitoring, allowing electricity providers to calculate bills accurately. In grid-connected renewable energy systems, energy meters are especially important as they track both energy imported from and exported to the grid, facilitating net-metering applications. Typically, energy meters operate at 230V AC with a frequency of 50 Hz and produce pulse outputs—commonly 1600 or 3200 pulses per kWh—that interface with microcontrollers for automated monitoring. Connecting an energy meter involves linking its pulse output to an optocoupler, which isolates the high-voltage circuits from the microcontroller. The pulses are then interpreted to calculate power consumption, energy units, and associated costs. For example, a 100W load monitored by a 3200 pulses/kWh meter generates approximately 5.33 pulses per minute, translating into 2.4 kWh consumption over a day, which can then be converted into monetary units based on local tariffs.

LCD Display



Fig. 4 LCD display

Liquid Crystal Displays (LCDs) are widely used output devices in microcontroller systems, offering efficient visualization of information such as energy consumption, power generation, and system status. Standard LCD modules, such as 16x2 or 20x2 displays, can show multiple lines of characters and operate with 4-bit or 8-bit data buses. LCDs function by controlling light transmission through liquid crystals, with a backlight providing clarity. They require three control lines—Register Select (RS), Read/Write (RW), and Enable (EN)—in addition to the data bus lines. The RS line distinguishes between command and data input, RW specifies read or write

operations, and EN synchronizes data transfer. LCDs are suitable for embedded systems due to their low power consumption, lightweight structure, and clear visibility, making them ideal for displaying parameters like voltage, current, and energy flow in energy management systems.

PIC16F72 Microcontroller



Fig 5 PIC16F72 Microcontroller

The PIC16F72 is an 8-bit microcontroller commonly employed in embedded system applications for automation, energy monitoring, and control projects. Operating at 5V, it features 33 programmable I/O pins, 14 KB of flash memory, 368 bytes of RAM, and 256 bytes of EEPROM. It provides analog-to-digital conversion, serial communication interfaces, and low-power operation, making it suitable for battery-powered or low-energy systems. The microcontroller interacts with external components such as sensors, displays, relays, and communication modules through its PORTA, PORTB, and PORTC pins. Its EEPROM memory enables storage of calibration data or operational parameters, facilitating flexible system configuration and in-system programmability for iterative improvements in production.

Optocoupler



Fig 6 optocoupler

Optocouplers provide electrical isolation between high-voltage and low-voltage circuits, enhancing system safety and reducing noise interference. They comprise an LED and a photodetector within a single package, transmitting signals optically while preventing direct electrical contact. This galvanic isolation protects microcontrollers and sensitive electronics from transient voltages and ground loop disturbances. Common optocouplers, such as the PC817, operate with input currents of 5–20 mA and isolation voltages up to 5000V, making them

suitable for energy metering and control circuits in grid-connected systems.

Regulated Power Supply

A regulated power supply ensures a stable DC voltage to power microcontrollers, sensors, and control circuitry. In grid-connected systems, AC mains are stepped down via a transformer, rectified into DC through a bridge rectifier, filtered by capacitors to reduce ripple, and stabilized by voltage regulators such as the 7805. This reliable DC supply is critical for accurate energy measurement, control signal generation, and safe operation of low-voltage components. Specifications typically include a 230V AC input, a +5V DC regulated output, and a current capacity of up to 1A.

Solar Panel



Fig 7 Solar panel

Solar panels convert sunlight into DC electricity using photovoltaic cells. In grid-connected setups, this DC power is converted to AC through inverters for household use or for feeding surplus energy into the electrical grid. Net metering allows users to receive credits for exported electricity, thereby reducing energy costs. Typical small-scale panels operate at 12V with power ratings around 5W, employing monocrystalline cells for higher efficiency.

LED

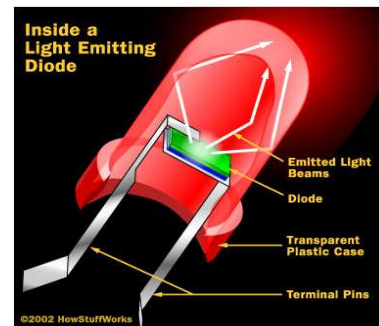


Fig 8 : Inside a LED

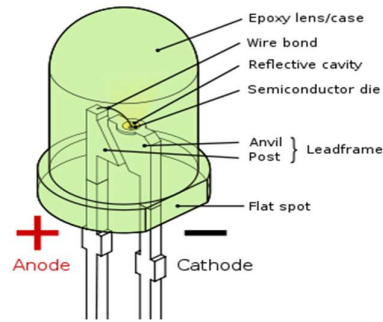


Fig 9 : Parts of a LED

Light-emitting diodes (LEDs) are semiconductor devices that emit light when forward-biased, a phenomenon known as electroluminescence. They offer high brightness, energy efficiency, long lifespan, and fast switching capability. LEDs are used both as indicators and for illumination, and their small size allows integration into displays and sensors. Typical specifications include forward voltages between 1.8–3.3V and operating currents of 10–20 mA.

Crystal Oscillator

Crystal oscillators generate stable and precise frequency signals using piezoelectric quartz crystals. The crystals vibrate at a defined resonant frequency when an electric field is applied, producing a highly accurate output used for clocking microcontrollers and timing circuits. Standard specifications include frequencies around 20 MHz for microcontroller applications, ensuring reliable operation of embedded systems.

Inverter

Inverters convert DC power from batteries or solar panels into AC suitable for household appliances. The process involves a control circuit generating switching signals, which are applied to MOSFETs or transistors. These switches create a pulsating current that is stepped up by a transformer to 110V or 230V AC. Depending on the design, inverters produce square wave, modified sine wave, or pure sine wave outputs, with components like capacitors, resistors, and diodes ensuring stable operation. Typical specifications include a 12V DC input, 230V AC output, and a power rating of 100W.

Software Requirements

The software implementation of the grid-connected energy monitoring system relies primarily on **Express PCB** for circuit design and the **PIC C compiler** for program development and microcontroller interfacing.

Express PCB

While breadboards provide flexibility during prototyping, the final design of a system benefits significantly from a professionally designed printed circuit board (PCB). Express PCB is a software tool specifically designed for creating PCBs that are

manufacturable by Express PCB company. The software is user-friendly but has limitations, including a limited part library, restricted file import/export options, and minimal professional CAD features. Despite these constraints, Express PCB allows designers to place components, traces, and pads efficiently, producing a durable, neat board suitable for embedded systems. The workspace can be customized according to user preferences, including unit selection (mm or inches) and layer visibility. Typical workflow involves placing components, routing traces, inserting corners for better connectivity, and finalizing the board layout by cropping to the desired dimensions.

PIC C Compiler

The PIC C compiler is used to develop, compile, and convert high-level Embedded C code into machine-readable hex files for the PIC16F73 microcontroller. Embedded C is essential for microcontroller programming because it enables precise control over hardware while maintaining the readability of high-level code. The compiler supports the standard C language constructs, I/O operations, bit manipulation, arrays, and pointers, but does not allow recursion due to the microcontroller's lack of stack memory. Separate compiler versions, namely PCB, PCM, and PCH, correspond to 12-bit, 14-bit, and 16-bit PIC architectures respectively. The compilation process involves creating a project folder, writing source code in .c files, and generating a .hex file after syntax verification. This hex file is then used for programming the microcontroller.

Compilation, Simulation, and Dumping

After writing the source code, the program is first compiled in the PIC C environment to check for syntax errors and generate the corresponding hex file. Simulation is performed using **Proteus software**, where the circuit is modeled, and the PIC16F73 is selected as the target device. All peripheral components relevant to the project are added to the simulation environment. Once the simulation validates the program's functionality, the hex file is transferred to the physical microcontroller using a programmer. The dumping process involves establishing communication between the programmer and the microcontroller, importing the compiled hex file, and writing it to the microcontroller's memory. Successful completion ensures that the microcontroller executes the program as designed.

Technical Architecture

The proposed system is a solar-based energy monitoring setup integrated with the utility grid, designed to optimize energy usage and capitalize on net metering and variable electricity tariffs. In this system, solar energy is first converted into electrical energy and supplied to an inverter, which transforms the generated DC power into AC power compatible with household loads. The converted AC power is

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measured through an energy meter to determine the energy generated by the solar source, and an AC load, such as a bulb, is connected to demonstrate its utilization. Simultaneously, grid-supplied electricity is monitored by a separate energy meter to measure energy consumption from or export to the grid. Both energy meter outputs pass through optocouplers, which provide electrical isolation between the high-voltage measurement circuits and the low-voltage control circuitry.

The optically isolated pulse signals are then transmitted to a PIC microcontroller, which serves as the central processing unit of the system. The microcontroller calculates energy consumption, generation, and net energy by interpreting the pulses from the energy meters. A regulated power supply ensures stable operation, while a crystal oscillator provides precise timing signals for accurate measurement and computation. A reset button is incorporated to restart the system when required. Processed information is presented on an LCD display, while LED indicators provide instant visual feedback on system status.

Circuit Architecture

The circuit architecture focuses on efficient solar energy utilization and economic optimization through net metering. Solar energy is first converted to DC voltage using a solar panel, with a capacitor employed to filter ripples and stabilize the voltage. A potentiometer allows for precise voltage regulation, and an LED provides a visual indication of operational status. The regulated DC supply drives a CD4047 IC configured in astable mode to generate square wave pulses, which form the basis of the inverter's operation.

Hardware Module Testing and Results

These pulses are amplified through resistors and transistors to drive a step-up transformer, which converts low-voltage DC pulses into high-voltage AC (230V), making the output suitable for household appliances and compatible with the utility grid. The system connects to a load to demonstrate usage and interfaces with the grid to facilitate bidirectional energy flow depending on generation and consumption conditions. Energy meters measure both imported and exported energy, producing pulses that are safely transmitted to the microcontroller via optocouplers. The microcontroller continuously monitors these pulses, calculates consumption, generation, and net energy, and displays real-time data on the LCD. By leveraging net metering, the system credits excess energy exported to the grid or draws energy when consumption exceeds solar generation. The integration of variable electricity tariffs enables users to strategically manage energy use, storage, and export, optimizing both operational efficiency and economic returns.

Applications

The grid-connected energy monitoring system has diverse applications. It is suitable for residential energy systems seeking to reduce grid dependency and electricity bills, commercial buildings aiming to manage peak demand efficiently, and industrial facilities with high power requirements. The system can support smart city infrastructure and decentralized energy generation and can be integrated into renewable microgrids for community-based energy management, promoting sustainable energy usage at multiple scales.

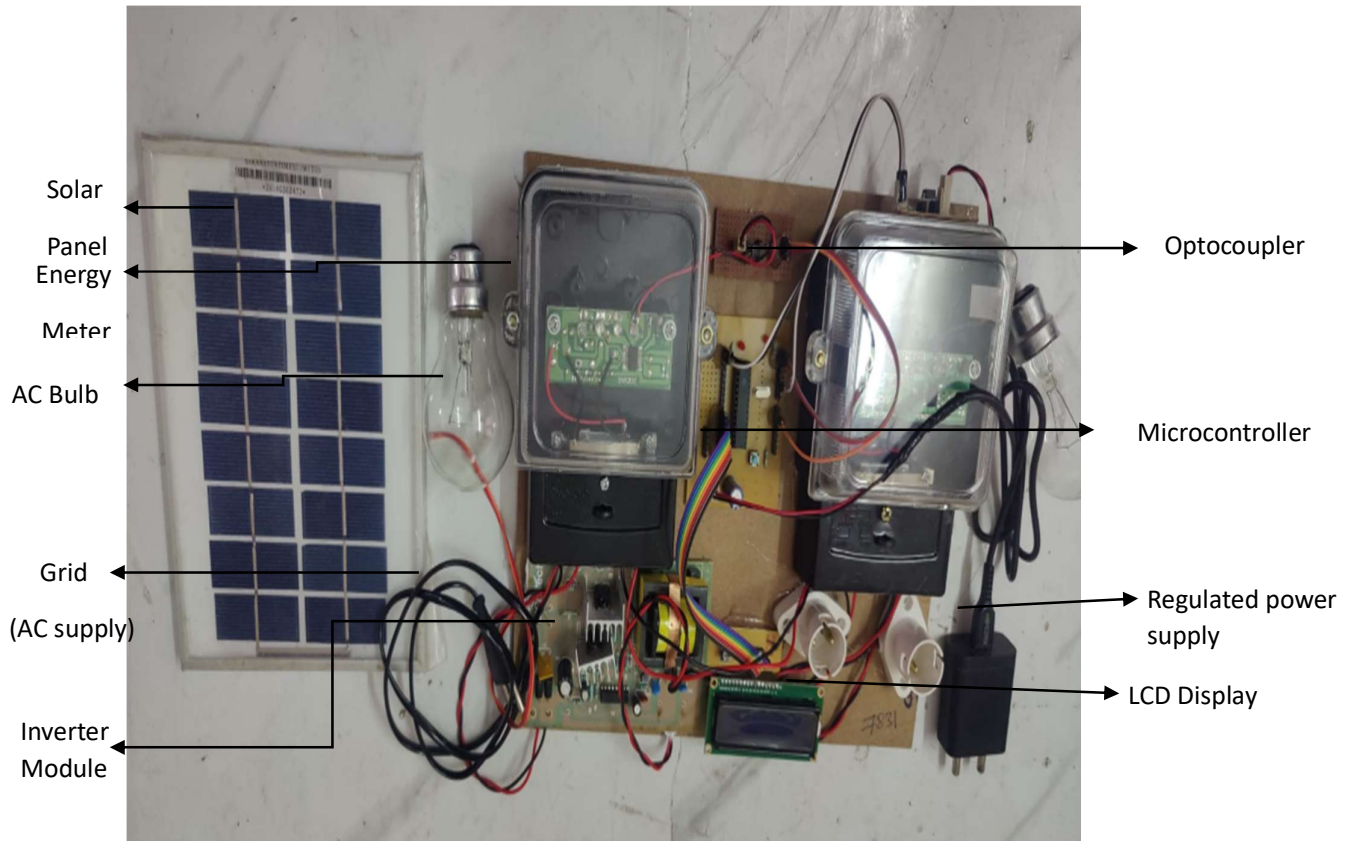


Fig 10; Hardware Module

The hardware module of the proposed grid-connected energy system consists of a solar panel, regulated power supply, microcontroller, energy meters, LCD display, and electrical loads. The solar panel serves as the primary energy source, converting sunlight into DC electrical energy, which can supply the household load and, if in surplus, export power to the utility grid. A transformer and rectifier circuit, combined with a voltage regulator, provide a stable DC supply for sensitive components, ensuring reliable operation. The microcontroller functions as the central processing unit, coordinating energy flow, processing measurement signals from energy meters, and controlling the LCD display to present real-time data. Energy meters track both imported and exported energy, facilitating net metering and demonstrating the system's ability to manage energy intelligently. Electrical loads, represented by bulbs, illustrate practical consumption, while optocouplers provide electrical isolation between high-voltage circuits and the low-voltage control system.

Operating Scenarios

The system was evaluated under three different operational scenarios to verify its performance in various energy flow conditions:

Case 1: Grid Energy Greater than Solar Generation

In this scenario, the energy supplied by the utility grid exceeds solar energy production. Experimental observations indicated that home energy generation was 0.0025 kWh per minute, equating to 45 kWh per month, whereas grid consumption reached 0.0053 kWh per minute, or 95.4 kWh per month. The system prioritized grid supply to meet household demand when solar generation was insufficient. The LCD display continuously monitored and presented solar generation, grid consumption, and net energy values. Based on variable electricity tariffs (₹4 per kWh normal, ₹8 per kWh peak, export rate ₹5 per kWh), the energy imported from the grid resulted in a monthly bill of ₹252 under the given conditions. This confirms the system's ability to accurately measure energy usage and optimize electricity costs.

Case 2: Grid Energy Less than Solar Generation

In the second scenario, solar generation exceeded grid consumption. Home energy remained 45 kWh per month, while grid energy consumption decreased to 27 kWh per month. Excess solar energy of 18 kWh was exported to the grid, which earned the user a credit of ₹90 at the export rate of ₹5 per kWh. The system successfully demonstrated energy prioritization from renewable sources, reducing dependency on the grid and enabling financial benefits through net metering. The LCD display

provided real-time monitoring of solar generation, grid consumption, and exported energy.

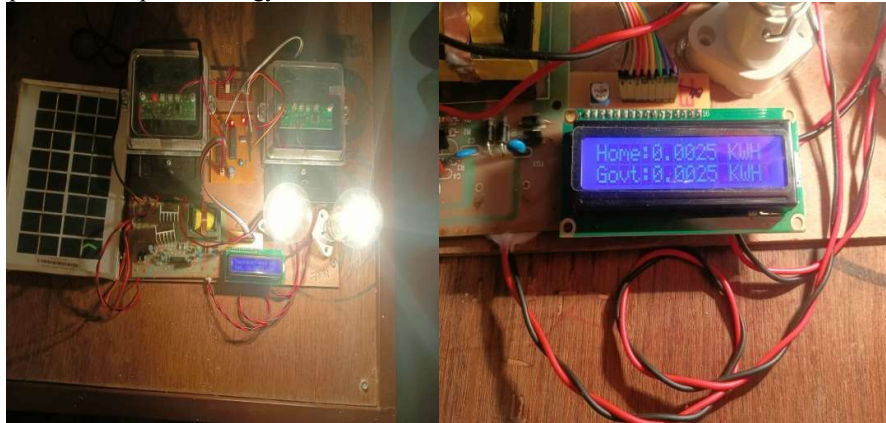


Fig 11 Experimental setup for grid energy=household load

In the final scenario, solar energy generation equaled household consumption, both measured at 45 kWh per month. In this balanced condition, no energy was imported or exported, resulting in a net energy of 0 kWh and zero cost. The LCD display confirmed the equilibrium, illustrating the system’s capability to maintain stable operation under balanced energy conditions and provide accurate real-time data.

Conclusion

The proposed grid-connected energy system effectively demonstrates the integration of solar energy with the utility grid, enabling efficient energy management through net metering. By exporting surplus solar energy to the grid and importing power when household demand exceeds generation, the system ensures continuous power supply while optimizing electricity costs. Real-time monitoring of energy consumption and generation allows users to accurately track energy usage, net energy flow, and associated financial benefits.

The study highlights the advantages of combining renewable energy sources with grid connectivity, emphasizing the potential for cost savings, improved energy efficiency, and reduced dependence on conventional power sources. The system successfully balances energy flow under varying operating conditions and provides a practical framework for smart energy management. This work serves as a functional prototype that can be adapted for larger-scale implementations, demonstrating how real-time, sustainable energy solutions can be applied in residential and commercial settings.

Future Scope

Several enhancements can be implemented to expand the capabilities of the proposed system:

- **Energy Storage Integration:** Incorporating advanced battery systems would enable storage of surplus energy, allowing usage during peak demand periods or power outages.

- **IoT and Artificial Intelligence:** Integration of IoT sensors and AI algorithms can enable remote real-time monitoring, predictive energy management, and intelligent load forecasting for optimal efficiency.
- **Dynamic Pricing Adaptation:** Automation based on time-of-use tariffs could maximize cost savings by prioritizing energy usage during off-peak periods.
- **Scalable Smart Grid Implementation:** Expanding the system for community or city-wide networks can facilitate decentralized renewable energy management and support smart grid initiatives.
- **Automation and Smart Billing:** Full automation of energy control, net metering, and billing processes would reduce manual intervention, improve efficiency, and enable energy trading with the utility grid.

The combination of renewable generation, intelligent energy management, and grid integration provides a sustainable pathway for energy-efficient homes, businesses, and larger-scale applications, promoting environmental benefits and long-term economic savings.

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