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

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Abstract
The growing demand for electrical energy and the widespread adoption of net metering policies require efficient systems capable of monitoring and managing bidirectional energy flow between consumers and the utility grid. This paper presents a grid-connected energy storage and monitoring system designed to maximize benefits from net metering and variable electricity tariffs. The proposed system enables accurate measurement, computation, and display of both energy consumption and energy export within a residential environment.The system utilizes a home grid configuration that connects household loads with the utility supply. Two energy meters are employed to perform bidirectional energy measurement. One meter records the electrical energy exported to the grid, while the second meter measures the energy imported from the utility mains. This dual-meter arrangement ensures reliable tracking of both energy flows.A microcontroller serves as the central processing unit, collecting data from both meters and calculating consumed and exported energy during each billing cycle. A regulated power supply and crystal oscillator provide stable system operation and timing accuracy. The processed information enables precise net energy computation and transparent billing. The calculated net units are displayed on an LCD in real time.The proposed system improves billing transparency, increases consumer awareness, and encourages efficient energy utilization. It also supports renewable energy integration and offers economic advantages for both consumers and utility providers.

Keywords— *Net Metering, Bidirectional Energy Measurement, Energy Monitoring System, Grid-Connected Systems, Renewable Energy Integration, Microcontroller-Based System, Smart Energy Management, Energy Billing Transparency.*

Introduction

Electric power plays a vital role in modern society, and the standard of living of a nation is closely linked to its energy consumption. Rapid industrialization and increased use of electrical appliances have significantly raised global electricity demand. Currently, a large portion of energy generation relies on conventional fossil fuels such as oil, coal, and natural gas. However, these resources are finite and contribute to environmental concerns. Therefore, integrating renewable energy sources with efficient energy management systems has become essential.Net Energy Metering (NEM) is a billing mechanism that allows consumers with renewable energy systems to export surplus electricity to the utility grid and receive credits. Under this arrangement, energy imported from the grid and energy exported to the grid are measured separately, and the net consumption is calculated at the end of the billing period.The proposed system implements a grid-connected energy monitoring solution using two energy meters and a microcontroller. One energy meter measures the electricity exported from the consumer's renewable system to the utility grid, while the second meter records energy drawn from the mains supply. The microcontroller processes both readings to determine total energy consumption and generation. The net payable units are computed by subtracting exported energy from consumed energy. This value is displayed on an LCD for user reference.

The primary objectives of the system are:

- Intelligent energy sharing with the utility grid
- Accurate net billing display after deducting exported energy
- Promotion of renewable energy usage
- Improved consumer awareness of energy utilization

Literature Survey

Net metering has gained significant attention in recent years as a practical approach for integrating distributed renewable energy sources with the utility grid. Standards defined by IEEE emphasize accurate measurement of both imported and exported electricity to ensure fair billing and efficient grid operation.

J. Smith et al. (2018) proposed a smart net-metering system using a microcontroller and bidirectional energy measurement. Their work demonstrated improved billing accuracy by recording both consumed and generated electricity, resulting in better energy management.

R. Kumar and S. Singh (2019) investigated a grid-connected solar photovoltaic system integrated with net metering. Their research showed that exporting excess solar energy during peak generation periods reduces consumer electricity costs and supports grid stability.

A. Verma and P. Sharma (2020) introduced an embedded energy monitoring system using sensors and controllers. Their design enabled real-time tracking of energy consumption and generation, allowing users to optimize energy usage.

Objective

The objective of this project is to design a grid-connected energy monitoring system capable of managing bidirectional energy flow between a household renewable energy source and the utility grid. The system employs two energy meters: one to measure exported energy and another to record imported energy from the mains supply. The readings from both meters are processed by a microcontroller to determine total units consumed and generated during a billing cycle.

The system calculates net energy by subtracting exported units from consumed units. The final value is displayed on an LCD for easy monitoring. By implementing this approach, the system reduces electricity costs, promotes renewable energy adoption, and enhances overall energy management. The proposed design contributes to sustainable power distribution and provides an economical solution for residential applications.

Embedded Systems

An embedded system is a specialized computing system designed to perform dedicated functions, often within real-time constraints. Unlike general-purpose computers, which support multiple applications, embedded systems are integrated into devices to carry out specific operations efficiently. These systems combine hardware and software components and are typically built around microcontrollers or digital signal processors. Embedded systems are widely used in everyday devices such as household appliances, industrial equipment, and communication systems.

can be broadly categorized based on functionality and operational requirements. Standalone embedded systems operate independently without external host computers. Real-time embedded systems perform tasks within strict timing constraints, ensuring prompt responses. Networked embedded systems communicate with other devices through wired or wireless networks, enabling data exchange and remote monitoring. Mobile embedded systems are designed for portable battery-powered devices, focusing on compactness and low power consumption. These classifications help in understanding the architecture and application scope of embedded system designs.

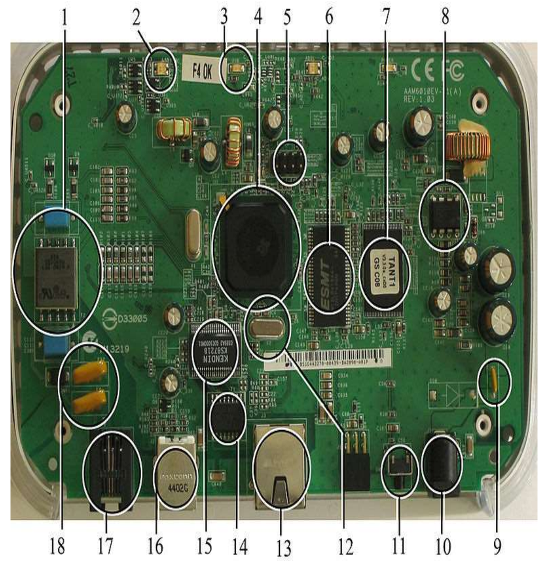

Fig 1: A modern example of embedded system

Standalone embedded systems function independently by receiving input from sensors or user interfaces, processing the data through a microcontroller, and generating output through displays or actuators. These systems are commonly found in consumer electronics such as microwave ovens, washing machines, and air conditioners. Real-time embedded systems, on the other hand, operate within strict time limits where delayed responses can lead to system failure. Applications such as automobile airbags, traffic control systems, and industrial automation rely heavily on real-time processing. Networked embedded systems communicate with other devices using protocols such as Zigbee, Wi-Fi, or Bluetooth, allowing remote monitoring and control. Examples include smart energy meters and home automation systems. Mobile embedded systems are designed for portable electronics such as smartphones, tablets, and portable medical devices, emphasizing low power consumption and efficient processing.

Hardware Components

Energy Meter

An energy meter is an electrical instrument used to measure the amount of electrical energy consumed over time, typically expressed in kilowatt-hours. It continuously records power usage of connected loads, and the accumulated readings are used for billing purposes. In grid-connected renewable energy systems, energy meters play a crucial role in measuring both imported and exported electricity. This bidirectional measurement is essential for net-metering applications where consumers receive credits for surplus energy supplied to the grid.

Fig. 2 Energy Meter

The energy meter provides pulse outputs proportional to energy consumption, which can be interfaced with a microcontroller for digital processing. Typical specifications include 230 V AC input, 50 Hz operating frequency, pulse output ranging from 1600 to 3200 pulses per kilowatt-hour, and rated current between 5 A and 30 A. By counting pulses generated by the meter, the microcontroller calculates total energy usage and exported energy accurately, enabling real-time monitoring and billing computation.

LCD Display

A liquid crystal display is widely used in embedded systems to present information such as system status, energy consumption, and calculated billing values. LCD modules such as 16×2 or 20×2 displays are commonly used because of their low power consumption and ease of interfacing with microcontrollers. The display operates by controlling liquid crystal alignment between transparent electrodes, allowing characters to be formed when electrical signals are applied.

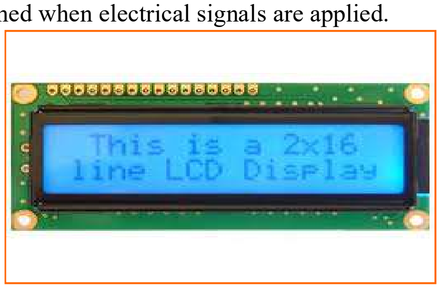

Fig. 3 LCD display

The LCD uses control pins such as Register Select, Read/Write, and Enable, along with data lines for communication with the microcontroller. It can operate in either 4-bit or 8-bit mode, depending on the available I/O pins. In the proposed system, the LCD displays real-time energy consumption, exported energy, and net billing values, providing users with clear monitoring capability.

PIC16F72 Microcontroller

The PIC16F72 microcontroller is an 8-bit device commonly used in embedded applications due to its reliability and low power consumption. It includes digital input/output ports, timers, memory modules, and analog-to-digital conversion capability. The microcontroller processes signals from energy meters, calculates energy units, and controls output devices such as LCD displays.

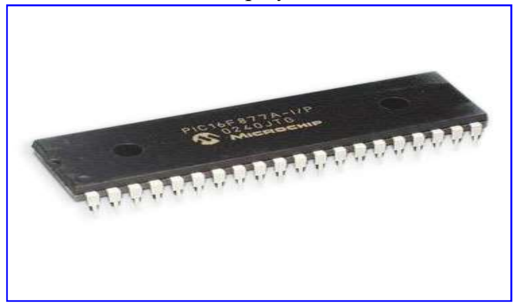

Fig 4 PIC16F72 Microcontroller

Operating at up to 20 MHz, the microcontroller provides sufficient processing capability for energy monitoring applications. It contains multiple I/O ports, EEPROM memory for storing parameters, and oscillator pins for clock generation. The PIC16F72 serves as the central control unit of the system, coordinating data acquisition, computation, and display operations.

Optocoupler

An optocoupler is used to provide electrical isolation between high-voltage circuits and low-voltage control circuits. It consists of an LED and a phototransistor enclosed within a single package. When current flows through the LED, light is emitted and detected by the phototransistor, allowing signal transmission without direct electrical connection. This isolation protects sensitive microcontroller circuits from voltage spikes and noise. Optocouplers such as PC817 are commonly used in energy meter interfacing to safely transfer pulse signals to the microcontroller.

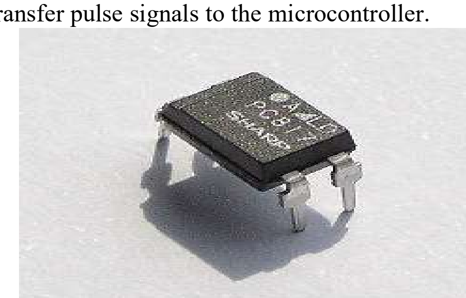

Fig 5o ptocoupler

Regulated Power Supply

A regulated power supply provides stable DC voltage required for embedded system operation. The AC mains supply is first stepped down using a transformer, then rectified using a bridge rectifier. Filter capacitors smooth the pulsating DC voltage, and a voltage regulator such as 7805 produces a constant 5 V output. This regulated supply powers the microcontroller, sensors, and display units.

Stable voltage ensures accurate measurement and reliable system performance.

Solar Panel

A solar panel converts sunlight into electrical energy using photovoltaic cells. The generated DC power is converted into AC through an inverter for use in household appliances or export to the utility grid. In a net-metering system, excess solar energy is supplied to the grid, and energy credits are accumulated. Solar panels help reduce electricity costs and promote renewable energy utilization.

LED

A light-emitting diode is used as an indicator in embedded systems. It operates based on electroluminescence, where electrons recombine with holes in a semiconductor material to emit light. LEDs offer advantages such as low power consumption, long life, and high reliability. In this system, LEDs indicate power status and operational conditions.

Crystal Oscillator

A crystal oscillator provides a stable clock signal for microcontroller operation. It uses the piezoelectric effect of quartz crystals to generate precise frequency oscillations. These clock pulses determine the execution speed of instructions and ensure accurate timing in the system.

Fig 6 Crystal oscillator

Inverter

An inverter converts DC power from batteries or solar panels into AC power suitable for household loads. It uses an oscillator circuit, switching devices, and a transformer to generate alternating voltage. The inverter enables solar energy utilization and allows excess energy to be fed back to the grid in net-metering applications.

Battery (12V DC)
↓
Oscillator / Control Circuit
↓
Switching Transistors or MOSFETs
↓
Step-Up Transformer
↓
AC Output (110V / 220V)

Fig 7 Block Diagram of an inverter

SOFTWARE REQUIREMENTS

The proposed grid-connected energy monitoring system is implemented using specialized software tools for circuit design, program development, and simulation. ExpressPCB software is used for printed circuit board (PCB) design, while the PIC C compiler is utilized for writing, compiling, and generating executable code for the microcontroller. These software tools collectively support the development of both hardware and firmware components of the system.

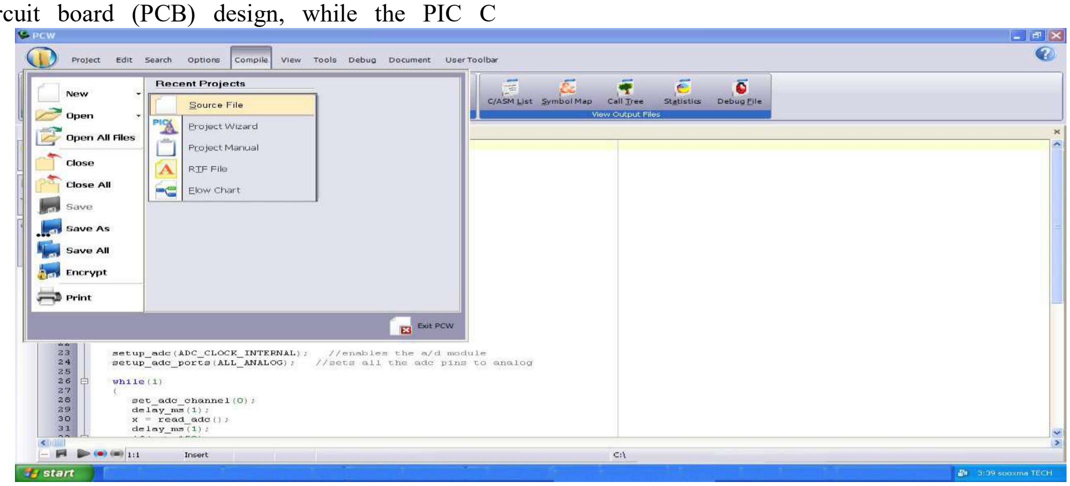

Fig 8: Picture of opening a new file using PIC C compiler

ExpressPCB is primarily employed to design the PCB layout of the embedded hardware. During the prototyping phase, breadboards provide flexibility for testing; however, for final implementation, a properly designed PCB ensures reliability, mechanical stability, and reduced wiring complexity. ExpressPCB offers a simple user interface that allows designers to place components, route traces, and define board dimensions. Although the software has certain limitations, such as a restricted component library and lack of advanced export options, it remains suitable for educational and prototype-level PCB development. The design process begins by configuring workspace units, selecting appropriate layers, and positioning components according to circuit requirements. Traces are then routed between components, and the board size is adjusted to meet physical constraints. This PCB layout is subsequently used for fabrication and hardware implementation.

The PIC C compiler is used to develop firmware for the microcontroller using Embedded C language. The compiler converts high-level source code into machine-readable hexadecimal (.hex) format, which is later programmed into the microcontroller. The compiler supports standard C constructs along with microcontroller-specific features such as register manipulation, bit operations, and peripheral control. In embedded systems, the program runs continuously without an operating system; therefore, the firmware is structured around an infinite loop that performs real-time monitoring and control. The header file corresponding to the selected microcontroller is included to access hardware registers and peripherals. This approach simplifies firmware development while ensuring efficient execution.

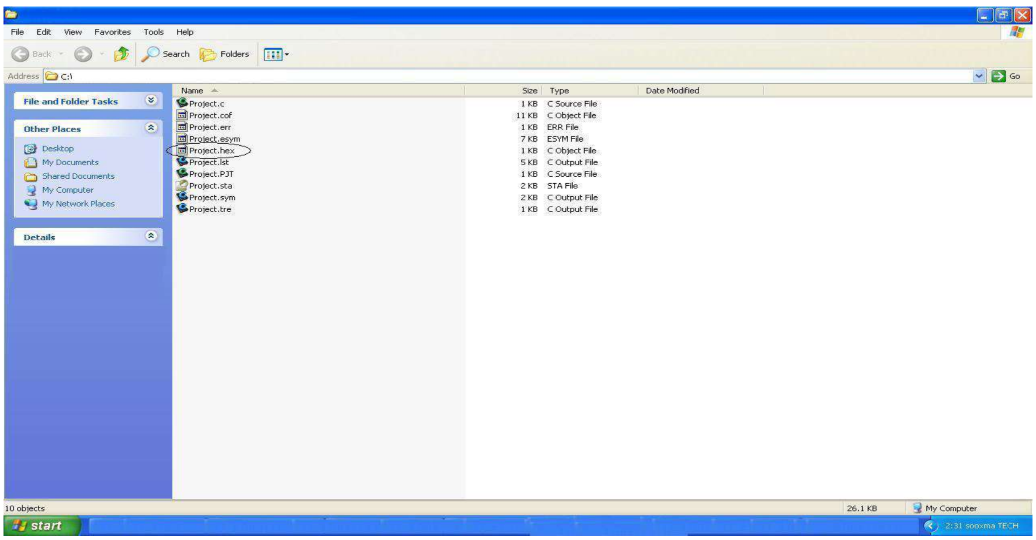

Fig 9: Picture of .hex file existing using PIC C compiler

The software development process involves three main stages: compilation, simulation, and program dumping. In the compilation stage, the Embedded C source code is written and compiled using the PIC C compiler. Syntax errors are corrected, and a hexadecimal file is generated automatically after successful compilation. During simulation, the circuit is designed using Proteus software, where the microcontroller and other components are interconnected virtually. The generated hex file is loaded into the simulated microcontroller, allowing verification of system behavior before hardware implementation. Once simulation results are satisfactory, the hex file is programmed into the physical microcontroller using a hardware programmer. This process ensures accurate firmware execution and minimizes hardware debugging efforts.

The developed firmware performs real-time monitoring of energy consumption and generation. The microcontroller receives pulse signals from two energy meters representing imported and exported electrical energy. These pulses are counted using internal timers and converted into energy values in kilowatt-hours (kWh). The system continuously calculates total energy consumed, energy exported, and net energy balance. The calculated values are displayed on an LCD module for user monitoring. If the consumed energy exceeds generated energy, the system indicates that the consumer must pay for the difference. Conversely, if generated energy is higher, the system indicates that energy credits are earned. This continuous processing enables intelligent energy management and supports net metering functionality.

Technical Architecture

The technical architecture of the proposed system is based on a grid-connected solar energy monitoring framework. Solar energy generated by the photovoltaic panel is first converted from DC to AC using an inverter so that it can power AC loads and interact with the utility grid. The generated AC power is passed through an energy meter to measure solar energy production. Simultaneously, the grid supply is connected to another energy meter to monitor energy drawn from or supplied to the utility grid. The outputs of both energy meters are interfaced to the microcontroller through optocouplers, which provide electrical isolation between high-voltage and low-voltage circuits.

The PIC microcontroller acts as the central processing unit, receiving pulse inputs from both energy meters and calculating energy parameters. A regulated power supply provides stable DC voltage for operation, while a crystal oscillator ensures precise timing. The processed data is displayed on an LCD module, and LED indicators provide visual system status. This architecture enables bidirectional energy monitoring and accurate net metering calculations.

The system offers several advantages, including reduced electricity cost, efficient energy utilization, real-time monitoring, and promotion of renewable energy usage. It also supports grid stability by feeding surplus energy back to the utility. However, certain limitations exist, such as high initial installation cost, absence of energy storage, and dependence on grid availability. Despite these challenges, the system demonstrates practical applicability in residential, commercial, and industrial energy management scenarios.

Hardware Module Testing And Results

The hardware module of the proposed system consists of a solar panel, power supply unit, microcontroller, energy meters, LCD display, optocoupler, and load. The solar panel generates DC power, which is utilized by the load and interfaced with the grid. The microcontroller processes energy measurements and displays system parameters on the LCD. Energy meters measure both imported and exported energy, enabling implementation of net metering. The system prioritizes solar energy usage and draws power from the grid when necessary.Three operating conditions were analyzed to evaluate system performance. In the first case, grid energy consumption exceeded solar generation. The measured values indicated higher dependence on grid supply, resulting in electricity billing for the consumer. In the second case, solar generation exceeded grid consumption, and surplus energy was exported to the grid, generating credits for the user. In the third case, solar generation equaled load demand, resulting in balanced operation with zero billing. These results confirm that the system accurately monitors energy flow and supports net metering calculations under different conditions.The case study analysis demonstrates efficient utilization of solar energy. When consumption is higher than generation, the system imports energy from the grid. When generation exceeds consumption, excess energy is exported. When both values are equal, the system operates in a balanced state. This validates the functionality of the proposed energy monitoring system.

Conclusion

The proposed grid-connected energy system successfully demonstrates efficient utilization of solar energy in combination with the utility grid using net metering. The system enables bidirectional energy monitoring, allowing excess energy to be exported and additional energy to be imported when required. Real-time monitoring and calculation improve transparency and promote effective energy management. The implementation highlights the benefits of renewable energy integration and variable rate electricity in reducing operational costs and improving energy efficiency. The system serves as a practical prototype for smart energy management applications.

Future Scope

Enhancements may include integration of battery storage to store surplus energy for later use, incorporation of IoT-based remote monitoring, and implementation of artificial intelligence for predictive energy management. Dynamic pricing algorithms can be added to optimize energy usage based on tariff variations. The system can also be expanded for large-scale smart grid applications and automated billing mechanisms. These improvements will further enhance system performance and support sustainable energy solutions.

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