SMART BIDIRECTIONAL ENERGY METER FOR A GRID-INTERFACED ELECTRIC VEHICLE CHARGER

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ABSTRACT

Electric Vehicle (EV) has been given considerable attention due to their attractive properties of reducing the fuel consumption and the gas emission. The energy during EV batteries charging and discharging can be calculated via smart meter, bidirectional communication and remote control can be achieved between EV and the grid. In this paper, a smart energy meter for EV is presented where the EV acts as a smart grid application. When the EV is connected to the grid, the meter measures and displays the battery voltage, current and the power. Additionally it displays the direction of the battery current whether it is in charging or discharging mode and the power flows from grid to vehicle (G2V) or from vehicle to grid (V2G). The data is displayed on LCD shield in addition to a remote computer via a ZigBee wireless connection. A practical prototype using an Arduino and ZigBee wireless communication is implemented to verify the proposed system performance.

Keywords: Smart energy meter, distributed generation, electric vehicle, energy efficiency.

INTRODUCTION

Electric vehicle (EV) has been given considerable attention due to their attractive properties of reducing gasoline consumption and the gas emission if compared to conventional vehicles. Power electronics converters can be used to operate the EV as a distributed generation (DG) unit to supply energy to the grid or loads [1]. In this case, a bidirectional smart energy meter can be used to measure the battery charging and discharging data such as voltage, current, and active and reactive power.

Recently, the concept of smart grid is growing which features higher utilization of power grid, demand reduction, and extensive usage of renewable energy source. Smart grids are used to accomplish an advanced power system with automatic monitoring, diagnosing, and repairing functions [2]-[5]. Hence, a smart energy meter is required to monitor different electrical quantities and communicate with the control center. There are many kinds of wireless network standards. ZigBee wireless communication complies with IEEE 802.15.4 standard. It provides a Low-Rate Wireless Area Personal Network (LR-WPAN). ZigBee has been designed to utilize general purpose protocol, low-power, and low cost consumption [6]-[8].

Real time monitoring of electricity parameters like voltage, current, real and reactive power of the significant devices in a home is important for the control and optimization of the energy usage of those devices.

Smart power meter based on ZigBee communication has been proposed in [9] for the Advanced Metering Infrastructure (AMI) of smart grid. They proposed a dsPIC30F based power meter with the capability of outage recording. However, that system is not intended for the EV.

Another related design based on double MSP430 is proposed in [10] without accounting the energy monitoring system essential for home management system (HMS).

The wireless communication system based on XBee (ZigBee) module. These devices are especially suitable for low cost and low–power wireless communication system. The proposed wireless smart metering system design focused mainly on the collection of electric data such as voltage, current, frequency, power, energy, and sending these information via ZigBee wireless communication to the monitoring unit [11]-[12]. It can capture and communicate these information on a real-time basis to enable constant monitoring of the system status and decision making at the central computer. Control command from the central computer can also reach to the remote end via the identical ZigBee based wireless communication interface which enables the use of smart plugs in addition to the smart meter to control the operation of the load in connect/ disconnect basis [11-13].

If the EVs are considered a DG, there should have a bi-directional smart meter which not only measure energy charged vehicle but also measure energy supplied to grid. According to the difference of phase angle between the current and the voltage waveform in the electric grid, the energy consuming direction can be judged [11-13].

In this paper, a smart power meter, bidirectional communication and remote control are achieved between electric vehicle and the grid. In addition, the smart meter is able to measure voltage and current, active and reactive power, and other electric parameters all this is displayed on a LCD shield. Also all this are be displayed on computer using wireless connection (ZigBee).

PROPOSED SMART POWER METER HARDWARE SETUP

The smart meter transmitter module is shown in Fig. 1. It measures both the current and voltage of the test circuit using instrument transformers, the test circuit characteristics can be measured non- invasively.

The resulting are fed into an LM741P op amp configured as a summer circuit to scale the signals down to a 0-5v logic level. This provides an interface into the Atmel Arduino microprocessor. The functional specification for the Smart Meter required it to measure a circuit operating at no more than 12v AC, in order to mitigate the potential for hazardous electric shocks. In order to measure a voltage of such a circuit, a transformer was used to provide electrical isolation from the primary circuit.

The configuration of the voltage transformer and the op-amp as the voltage from the voltage transformer oscillates from a positive voltage to a negative voltage; it must have an offset added to it to allow it to interface to the op-amp, which can only measure voltages within its voltage supply range of 0-5v.To achieve this, the op-amp is configured as a summer circuit which sums together the voltages present at its + input. One of the input voltages is the signal from the voltage transformer. The voltage emanates from the voltage transformer's center-tap and is halved using a voltage divider circuit, lowering it.

The Arduino Uno is a microcontroller board based on the ATmega328. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button.

The smart meter receiver module block diagram are shown in Fig. 2.Wireless Link XBee and XBee-PRO ZB embedded RF modules provide cost-effective wireless connectivity to devices in ZigBee mesh networks. Utilizing the ZigBee PRO feature Set, these modules are interoperable with other ZigBee devices, including devices from other vendors [8], [11].

Programmable versions of the XBee-PRO ZB module make customizing ZigBee applications easy. Programming directly on the module eliminates the need for a separate processor. Because the wireless software is isolated, applications can be developed with no risk to RF performance or security.

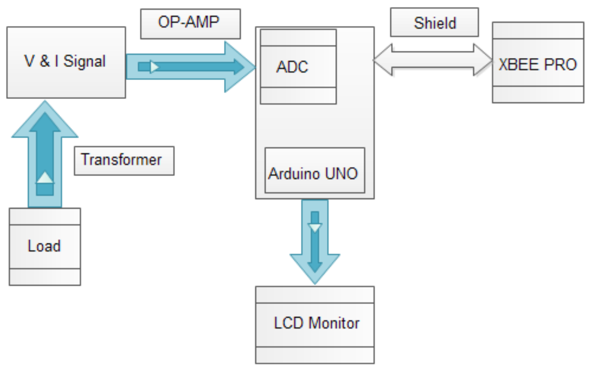


Fig. 1. The smart meter transmitter module

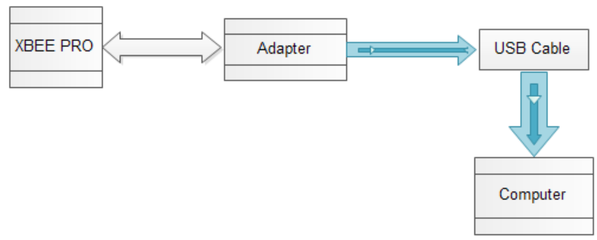


Fig 2. The smart meter receiver module

The Xbee shield allows an Arduino board to communicate wirelessly using Zigbee. It is based on the Xbee module from MaxStream. The module can communicate up to 100 feet indoors or 300 feet outdoors (with line-of-sight).

It can be used as a serial/usb replacement or you can put it into a command mode and configure it for a variety of broadcast and mesh networking options. The shields breaks out each of the Xbee's pins to a through-hole solder pad. It also provides female pin headers for use of digital pins 2 to 7 and the analog inputs, which are covered by the shield (digital pins 8 to 13 are not obstructed by the shield, so you can use the headers on the board itself). Regular USB cable used to interface between the Arduino and the computer

PROPOSED SMART POWER METER SOFTWARE SETUP

The software has been coded in C. Although the programming environment for Alf and Vegard RISC processor (AVR) microcontrollers, is geared towards assembly language, the freely-available GNU Compiler Collection (GCC) compiler for AVR Studio allows programming in the higher-level C language. This is highly desirable as the complexity of the network stack requires modularization of the software and this is better achieved in C than in assembly.

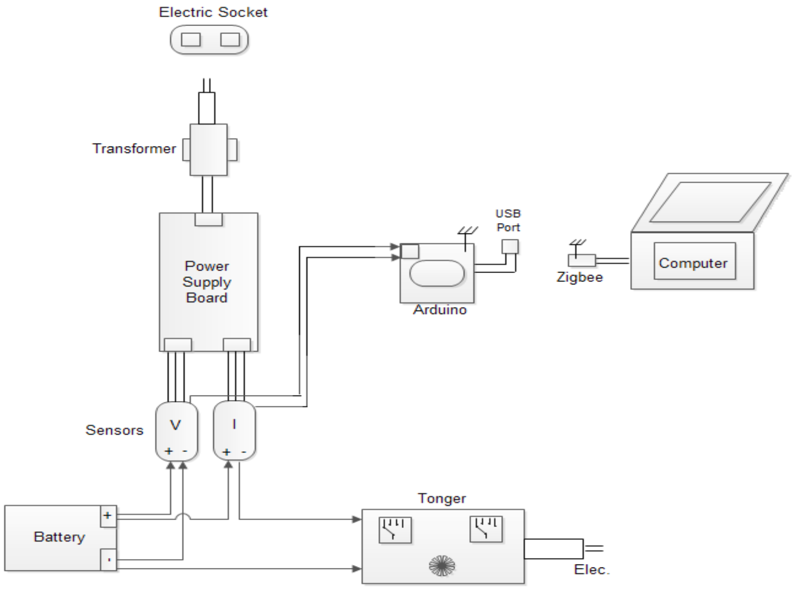


Fig 3. The smart meter block diagram setup

Each node commences with an initialization routine which configures the relevant IO pins, on-board features, interrupts, off-board chips, etc. Secondly, the nodes will initialize the network discovery and association procedure to attempt to register in the same Personal Area Network (PAN).

Once this is successful, each node will remain in a listening state until a frame is received, at which point the network stack state machine will be called. The state machine will pull apart the various sub-frames and strip away the protocol layers in order to recognize the packet and respond according to stack rules or pass application layer data up to the application layer level. TX initialization routine commences upon power on and begins configuring the registers required for the Smart Meter operation:

i. Initialize USART link (baud rate, stop bits, etc.)
ii. Reset XBee-PRO ZB S2B chip (sends it into Power On state)
iii. Initialize SPI interface
iv. State transition to TRX_OFF
v. Initialize counters (comparator number and enable)
vi. Set global interrupts enabled
vii. Set counter interrupt enabled
viii. Write to XBee-PRO ZB S2B; initialize interrupts for TRX_END events
ix. State transition to PLL_ON
x. State transition to TX_ARET_ON
xi. Configure Analog to Digital Converter ADC (channel select, mode select, and pre-scale clock)
xii. Start ADC
xiii. Initialize source Medium Access Control (MAC) layer address and network
xiv. Configure Clear Channel Assessment (CCA) attributes for Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA)

Once initialization is complete, the TX node will check to see if it has registered in a PAN. If it has not, it will initiate a network discovery request according to the association procedure outlined in the previous section. The RX node has a very similar software structure to that of the TX node. After the initialization function has been completed, the node changes into the RX_AACK state to wait for any incoming packets.

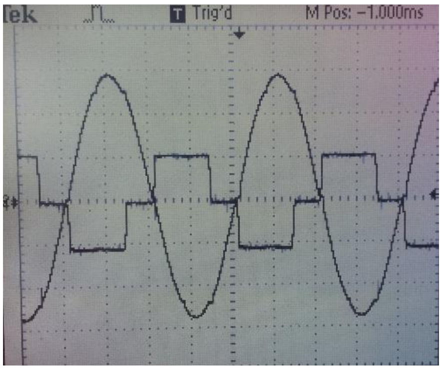
The node waits until it receives a network discovery request from any available TX nodes. If it does, it initiates the beacon notify function which sends out a MAC layer beacon approximately every second for a predetermined amount of time or until a network join request is received. If a network join request is received, the stack checks to see if the request is from a node which is already a member of the neighbor table. If it is, the request is denied. If it is not, the request is successful and a network join response is transmitted to the TX node.

THE PROPOSED SYSTEM WITH EXPERIMENTAL SETUP

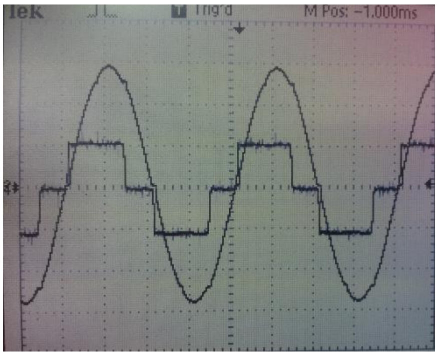
A laboratory prototype for the system shown in Fig. 3 is implemented to verify the proposed technique experimentally. In this setup system the electric grid connected to the EV through power supply board and toner which charges the battery of the EV. The voltage and the current are sensed using a sensors then feed into a signal condition circuit then to A/D circuit to an Arduino board which are programed to use the phase shift and sinusoidal wave to measure battery voltage, voltage, current, active power, reactive power and the energy direction.

All of this data are displayed on LCD monitor.
Also all this are be displayed on computer using Xbee shield and wireless connection ZigBee. The computer are used to display, record and analyze this data. It allows the data to be send through bi-direction communication of the ZigBee.

The smart meter measuring voltage and current direction; V2G are shown in Fig. 4.The smart meter measuring voltage and current direction; V2G are shown in Fig. 5. The phase shift between the voltage and the currant in used to determine the direction in addition to active and reactive power.



Time scale: 5 ms/div, ch1: 100 V/div, ch2: 2 a/div
Fig. 4. smart meter measuring voltage and current direction; V2G



Time scale: 5 ms/div, ch1: 100 V/div, ch2: 2 a/div
Fig. 5. smart meter measuring voltage and current direction; G2V

CONCLUSIONS

In this paper, A ZigBee based smart meter has been designed. This system can enable the user to monitor the electricity parameters like the battery voltage, voltage, current, frequency, active power, reactive power and the energy direction. All of this data are displayed on LCD monitor. Also all this are be displayed on computer using Xbee shield and wireless connection ZigBee which can send these information on a real-time basis to enable constant monitoring of the system status.

A smart meter applied to V2G is proposed. The smart meter has bi-direction measure and bi-direction communication compare to traditional meter. It can judge the energy consuming direction of a system by the different phase between the current and the voltage waveform in the electric net. It can calculate the energy direction flows from grid to vehicle (G2V) or from vehicle to grid (V2G).

The smart meter is the interface between the grid and electric vehicle. A practical prototype using an Arduino and ZigBee wireless communication is implemented to verify the proposed system performance.

APPENDIX

Fig 6. Smart meter measuring voltage and current direction; V2G

Fig 7. Smart meter shows current direction; G2V

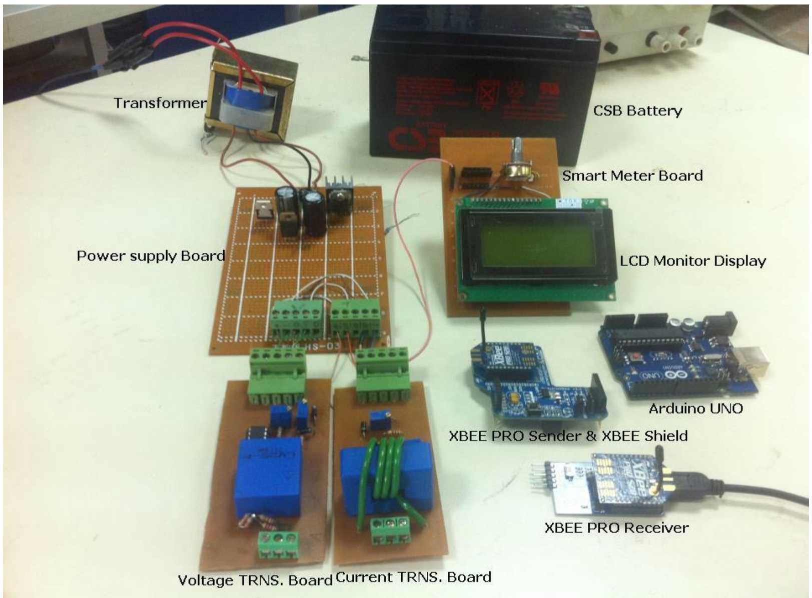


Fig 8. Test setup photography

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