Energy Management through SSM protocol

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Abstract — ***Electricity demand in India exceeds the availability, both in terms of base-load energy and peak availability. The efficient use of energy is of prime importance to the utilities or industry. Judicious electric power consumption is linked to precious natural resource utilization as well as environmental sustainability. Applying computing, control equipment and techniques is one of the most cost-effective and significant opportunities for large energy users to reduce their energy cost and improve profits. There are essentially two approaches to electrical energy management. First approach is from the supply / utility end (Supply Side Management or SSM) and the other is from the consumer end (Demand Side Management or DSM). This work is based on Supply Side Management (SSM) protocol and consists of design, fabrication and testing of a control device that will be able to automatically regulate the power flow to an individual consumer's premise. Overuse of electricity (above the connected load or contracted demand) is monitored by this control device by the individual consumers. The work specially emphasizes on contracted demand of every consumer and tries to restrict the use of electricity within the contracted level. This control unit incorporates both software and hardware work and at present is designed for 1 kW contracted demand. The device is tested in laboratory and reveals its potential use in the field.***

Keywords: Supply Side Management, load management, contracted demand, connected load, control unit

1. Introduction

India's energy demand is increasing rapidly with the intensive growth of economy. In recent years availability of power in India has both increased and improved but demand has consistently outstripped supply and substantial energy and peak shortages prevailed in 2009-10. There are also various estimates of 25000 to 35000 MW of power being produced by diesel generation to meet the deficits [1]. India is the world's fifth largest electricity generator with total installed capacity of 2, 28,722 MW. Out of this, 90,062 MW is from state owned utilities, 72,927 MW is from privately owned utilities and 65,733 MW is from centrally owned utilities. The pace of investment from private players is increasing considerably, which shows an encouraging prospect for the electricity sector. India's energy demand has been growing rapidly in the last two decades. This demand has been boosted by industrial growth as well as rise in domestic consumption. On the other hand, supply of energy too has grown but has been outstripped by demand. India derives most of its electricity from fossil fuels; primarily from coal (20,381 MW and 59% of total capacity).

Currently, India has a total 1,55,969 MW of installed capacity on thermal, 39,788 MW of installed capacity on hydro, 28,184 MW of installed capacity on Renewable Energy Sources (RES) and 4,780 MW of installed capacity on nuclear sources [2]. The electricity demand in India exceeds the availability, both in terms of base load and peak load energy. The base- load and peak-load deficit are 8.5 % and 10.6% respectively during the year 2010 -11 [3]. Because of insufficiency in fuel supply, the country is facing severe power shortage. In this scenario, efficient use of energy, its conversion and utilizations are the viable alternatives available to the utilities or industry to overcome the demand-supply gap to a great extent.

Electrical energy management may be implemented on the supply side or demand side or both. Demand-side management measures take advantage of opportunities to increase the efficiency of energy service delivery; these opportunities are not being fully taken advantage of in the market. To make use of DSM measures requires special programs that try to mobilize cost-effective savings in electricity and peak demand. These programs help overcome various barriers that prevent many cost effective DSM measures from being adopted; these barriers exist even in countries with fully developed market economies. Without DSM programs, these energy and peak demand savings would not occur or would materialize only after significant delay, and in any case could not be relied upon, forcing utilities to construct expensive back-up capacity and causing higher energy rates. Numerous studies in many countries have found that cost-effective DSM programs can reduce electricity use and peak demand by approximately 20% to 40%. DSM benefits households, enterprises, utilities, and society. This process reduces customer energy bills, the need for power plant, transmission, and distribution construction, maintenance and equipment replacement costs, local air pollution. Demand Side Management (DSM) involves actions at the level of end users such as use of efficient appliances, use of less energy during peak hours or shifting of demand from peak to off-peak times etc. DSM is a very effective way to manage the efficient utilization of energy [4].

Supply Side Management (SSM) refers to efficient operations in electricity generation, transmission, and distribution. It is also based on the mixing of various energy resources for electricity generation and proper management of base-load and peak-load. Electric power supply system comprises of electricity generation units, high-voltage transmission lines through which electricity is transported over long distances. In local level, substations and distribution lines delivers the electricity to the consumer and control centre to coordinate the operation of the systems. Mohamed and Khan [5] reviewed the various options for electrical energy management both at the utility and consumer side. This study concludes that three main methods, (i) direct load control, (ii) interruptible load control and (iii) time-of-use are widely used for supply side electrical energy management. In case of demand side management, various energy efficient practices are followed to reduce the electrical energy consumption at the user end. Load shedding is a common practice followed by utility to manage the specific loads when supply is lower than the demand. The electricity demand in the peak hours is much higher than the rest of the day. It is also true that the supply side is limited in its production, transmission and distribution network. Hence, shifting of loads from peak to off-peak period or complete cut-off of the loads is the less expensive solution to load management. Load management can be implemented at both supply and demand side. Distributed Interruptible Load Shedding (DILS) scheme splits every user's load into interruptible and uninterruptible parts [6]. Hence, at peak load condition, when supply is lower than the demand, utility can only use the load shedding scheme for the interruptible loads. This scheme can be implemented to industrial as well as domestic customers. Banerjee [7] has done an analysis on load management in the Indian power sector using US experience. This study reveals that the direct load control of agricultural pumps, commercial air conditioners and interruptible or time-of-use tariffs in the industrial sector are useful options for India for better load management. It is also important for the utility to have an accurate demand calculation of its consumer. Microcontroller-based digital energy meters are now widely used to monitor the energy consumption (kWh) and maximum demand (kW) [8]. This type of monitoring helps the utility for proper billing of the energy consumption at individual premises. The energy billing through this type of metering helps the energy distribution companies to improve metering and billing accuracy and efficiency.

The electricity billing by the utilities for medium and large consumers in High Tension (HT) category depends on capacity (demand), actual energy consumption and also the reactive energy (kVAR) drawn by the consumers. In case of domestic customers, the billing is primarily based on connected load (kW) or contracted demand and the actual energy consumption by the consumers. In addition of these, other fixed and variable charges are also there for both industrial and residential consumers. The utilities use the tariff structure to influence the end users for better load management like time-of-day tariff, penalties on lower power factor, concession on higher power factor, penalties on exceeding permitted maximum demand etc. Load management is a powerful mechanism of efficient operation from utilities perspective. A consumer normally executes a contract with the utility for a certain amount of connected load (maximum demand) at a fixed tariff rate. The connected load is generally based on the total load requirements at the end users. In case of residential consumers, the connected load is generally 1, 2, 3 and 4 kW depending on the numbers and types of electrical load present in the premises. The utilities charge a fixed tariff for a contracted demand apart from the other charges. The present connected load charges are INR 30/kW for domestic customer and INR 110/kW for commercial customer. However, no control mechanism is in place by which the utility can monitor the additional demand over the connected load by the consumers. Hence, if the customer is using beyond the contracted demand or connected load, the utility faces over demand in the grid or can face problems related to grid stability. It is also important to mention that the utility is losing the revenue due to overuse from the connected load by the customer. Stability of a power system is indicated by the status of voltage and frequency. A power system is considered normal, if these two parameters remain within specified limits during operation. A power system becomes unstable when voltage and frequency change beyond the limits [6].

In this work, a microcontroller based single-phase digital control mechanism is designed to regulate the power flow to the individual consumer from the supply side by using a PIC microcontroller. This device can be placed close to the electric supply input point of the customer. This device will monitor the load of the customer and if the load exceeds the connected load (contracted demand), the device will cut OFF the customer. As and when, the users will reduce the load below its pre-set value; the device will automatically start supplying power to the user. This type of controller has been selected because of its performance, efficiency and design flexibility. Operating software has been developed in C-language and compiled by MikroC compiler. The proposed device has been developed and tested in the laboratory (for contracted demand 1 kW). The results from the control unit are compared with the measured results.

2. System Developement

The system architecture of microcontroller-based control unit is given in the Fig.1. The system consists of voltage and current sensing elements, Microcontroller, Precision rectifier, sample and hold circuitry, buzzer system, Relay and Liquid Crystal Display (LCD) [8]. A 230V, 50 Hz supply is provided to the control device. The current sensor of the device senses the magnitude of current which is passing through and gives a signal in the form of a small voltage. This signal is then amplified and fed to a precision rectifier circuit. Also one step-down transformer (9V-0-9V) is used to sense the voltage. Voltage output from the transformer is given to the precision rectifier circuit and then given to a sample-and-hold circuit. These two outputs, one from precision rectifier and one from sample-and-hold circuit are analog quantities and they are given to the microcontroller (PIC16F877A) which has inbuilt ADC to convert it to digital form. The microcontroller (PIC16F877A) will sense both the current and voltage used by the consumer and if the current and voltage limits are exceeded then the electronic switch will close for a certain time, which is set by the supplier. This means that the whole power supply to the consumer gets switched OFF. After the preset time, the microcontroller (PIC16F877A) will process again to check the limits of current and voltage. If it is found that the current is equal to or below the given limit (the limit which approaches the exceeding limit) then the load will not be switched OFF. However, if it is exceeded then the load needs to be reduced to prevent the whole load to remain switched off by the electronic switch. A +5V power supply is added for the Microcontroller (PIC16F877A) to actuate it and the precision rectifier, Amplifier and sample-and-hold circuitry needs both +5V and -5V both power supplies.

2.1 Hardware Architecture For Control Unit

The hardware architecture of Microcontroller-based digital control system is shown in the Fig. 2. The power consumption is being regulated by using the sensors (current and voltage) and Microcontroller (PIC16F877A) to prevent the use of power beyond the contracted demand. The Microcontroller based digital control system can be divided into nine parts as voltage sensor, current sensor, amplifier circuitry, precision rectifier circuitry, sample-and-hold circuitry, microcontroller, relay control unit, display unit and power supply unit. The hardware descriptions of nine parts are presented below.

a. Voltage Sensor

A step-down transformer is used for sensing the AC voltage. The input from the AC mains is stepped down through a 9V-0-9V transformer. The voltage from the secondary terminals of the transformer is rectified by a precision rectifier. The output is fed to a linear voltage divider circuit (a 100K trim pot). This voltage is fed to the microcontroller PIC16F877A.

b. Current Sensor

For sensing the AC current, one current sensor is used. This is also called Hall Effect sensor. This current sensor consists of a precise, low-temperature drift linear Hall sensor IC with temperature compensation circuit and a current path with 0.4 mΩ typi cal internal conductor resistance. This extremely low-resistance can effectively reduce power loss, operating temperature and increase the reliability. Applied current flowing through conduction path generates a magnetic field which is sensed by the integrated Hall IC and converted into a proportional voltage. The Hall element is constructed from a thin sheet of conductive material with output connections perpendicular to the direction of current flow. It responds with an output voltage proportional to the magnetic field strength when subjected to a magnetic field. The voltage output is very small (µV) and requires additional electronics to achieve useful voltage levels.

c. Amplifier circuit

An amplifier is an electronic device that increases the voltage, current, or power of a signal. Amplifiers are used in wireless communications and broadcasting, and in audio equipment of all kinds. In this particular work, the voltage output of the current sensor is very small (µV) and requires additional electronics to achieve useful voltage levels. Hence, one Op-Amp (LM324) is used. The gain of the amplifier is nearly seven.

d. Precision Rectifier circuit

The signal processing applications with very low voltage, current and power levels require rectifier circuits. The ordinary diodes cannot rectify voltages below the cut in voltage of the diode. The precision rectifier is a small signal rectifier which is capable of rectifying signals of very low peaks. LM324 Op-Amp is used for rectifying purpose.

e. Sample-and-hold circuitry

A sample and hold circuit is a circuit which samples an input signal and holds onto its last sampled value until the input is sampled again. Sample-and-hold circuit is used to sample an analog signal and to store its value for some length of time (for digital code conversion). For a rapidly varying analog signal, it periodically samples the signal and holds the amplitude of each sampled signal at the input of the ADC for a sufficient time to allow accurate conversion. The ADC needs to have a stable signal in order to accurately perform a conversion. Sample and hold circuits are commonly used in analogue to digital converts, communication circuits, PWM circuits etc. LF398 is used for sample and hold purpose.

f. Microcontroller

PIC microcontroller (PIC16F877A) has inbuilt ADC so that this controller can convert the analog data to digital data. Voltage and current inputs going through rectification and sample-and-hold circuitry are given to the PIN 2 and 3 of microcontroller. The microcontroller will sense both the current and voltage, as given by the supplier (utility grid) and if the current and voltage limits exceed then the electronic switch will close for a certain time set by the supplier. This means that the whole power supply gets switched OFF. After sometime, as set in the controller, the microcontroller will check again to see the limits of current and voltage. If the load consumption is equal or below the given limit then the load will not be interrupted. But, if it is exceeding the set limit then the load needs to be reduced to prevent the whole load switched OFF by the electronic switch.

g. Relay control unit and Buzzer system

One 12V relay is used for switching ON or OFF of the connected load. The device does not respond if the power flowing through it is within the preset limit. If the power flow approaches the preset limit it gives a continuous intermittent *beeps* with a buzzer connected in PIN 21 of PIC16F877A (100 ms intervals) to warn the consumer to be vigilant and if the power flow exceeds the preset limit, the device responds by switching OFF the load from the supply instantaneously. Once switched OFF the load will remain OFF for a preset time (10 sec, which can be increased) as a punitive measure. The device in the meantime will monitor the status of the load and if is still more than the set value it will keep the load switched OFF for another 10 sec. The process may continue indefinitely. If the load is restored to within the set limit, the load will be switched ON and the system will function normally.

h. Display unit

The liquid crystal display controller displays alphanumeric characters and symbols. It can be configured to drive a dot-matrix liquid crystal display under the control of microcontroller. In this case, LCD is mainly used to display voltage, current and energy consumption of the load.

i. Power supply unit

Every electronic circuit needs appropriate power supply for its operation. Basically Microcontrollers, Op-Amps, Liquid crystal display and relays operate on ±5 volts DC supply. The present set-up utilizes a ±5 volt DC power supply.

2.2 Control Unit Software Development

The system software is implemented in C language and the developed code is edited, compiled with MikroC software. The flowchart of the algorithm is shown is Figure

3. The sequential steps in the algorithm for the control unit are as follows.

1. Start
2. Initialize the display.
3. Check the voltage, current and phase difference of voltage and current i.e. power factor
4. Calculate the power P=VI cosϕ
5. Display V=, I=, P=. (Voltage in volts, Current in amp, Power in watts)
6. Switch on the loads.
7. Check the power whether it is beyond the contracted demand or not.
   a. If it exceeds the contracted demand then the control unit gives a long beep sound and switch OFF the load for some time (Set by supplier). After the pre-set time, it will check the power again and if load is regulated by the consumer i.e. if power consumed is below the contracted demand it will allow the power flow and go to step 7b.
   b. If it is below the contracted demand, but close to it the control unit gives a small beep sound at small regular intervals and the consumer continues to receive power. These bip sounds indicate power consumed approaches the contracted demand.
8. Go to step 3.

3. Results And Analysis

The control unit has been tested in the laboratory. The control unit is designed and tested, at present, for a low power of 1 kW for convenience. However, this can be readily enhanced to 5 kW with 20A maximum rating of the current sensor. In the control unit, the power is shown on the Liquid Crystal Display. Current sensor and voltage sensor outputs are checked and calibrated using DSO. Sensor outputs for different loads are linear. Data Analysis of Current Sensor Output and Power displayed for a particular load on the control unit is shown in Table 1and Table 2 respectively. The results shown in Table2 are expected energy output in watts. It is seen that beyond 1 kW, this control unit switch OFF the loads for 10 sec by giving a long and continuous beep sound. It checks the power again after 10 sec, if it is regulated by the consumer (before 10 sec elapses) switches ON the load. After crossing 550W, it gives a regular but intermittent beep sound till the limit of 1 kW is reached. If power consumed by the consumer is less than 550W the control unit permits power flow without any restriction. The device is found to be working reliably as per design and in-built logic. It has also fast response

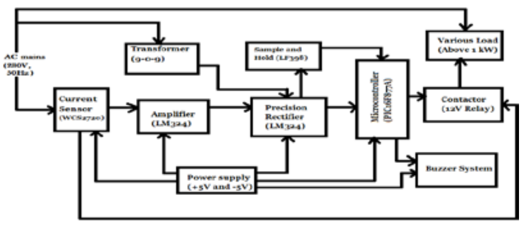

Figure 1: Architecture of the control unit

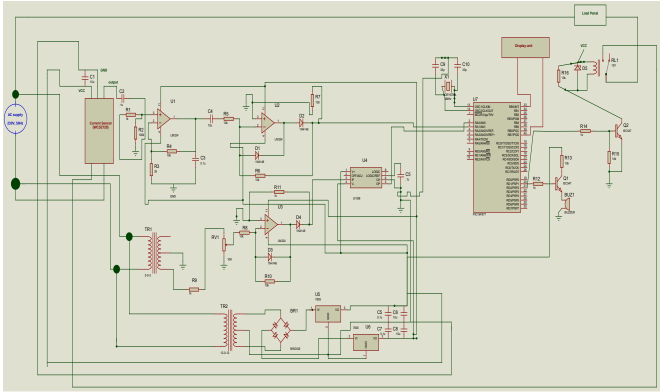

Figure 2: Hardware design of the control unit

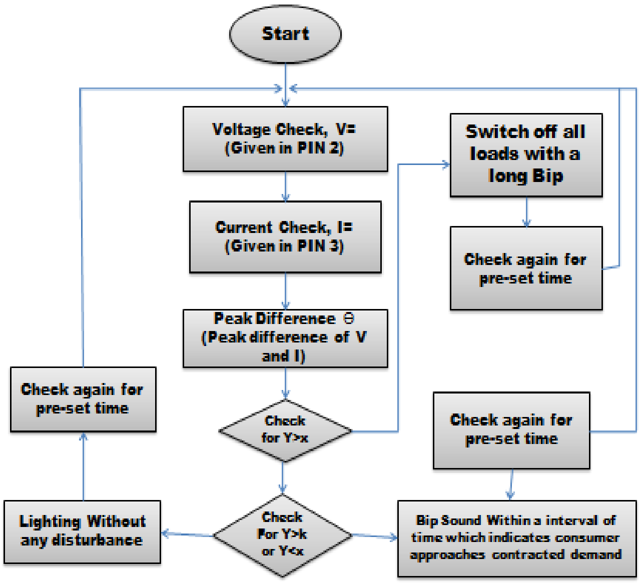

Figure 3: Flow chart for the control unit

Table 1: Data Analysis Of Current Sensor Output

Resistive Loads (Watt)s	Output Voltages (Volts)
60	0.018
100	0.03
160	0.05
220	0.07
300	0.1
400	0.13
500	0.16
560	0.18
620	0.2
680	0.22
800	0.26
900	0.3
1000	0.34
1100	0.38
1200	0.42
1300	0.44

1500	0.5
1600	0.52
1800	0.58
2000	0.6

Table 2: Power Displayed On Lcd And Status Of Buzzer

Power readings (W)		Audio signal	Power switching status
Rated power at 230V	Control unit display power at 228V		
25	23	No sound	ON
100	97	No sound	ON
125	120	No sound	ON
200	195	No sound	ON
225	220	No sound	ON
325	320	No sound	ON
400	385	No sound	ON
500	484	No sound	ON
550	530	Bip sound with interval	ON
575	568	Bip sound with interval	ON
625	618	Bip sound with interval	ON
1000	987	Long bip sound	OFF
400	385	No sound	ON

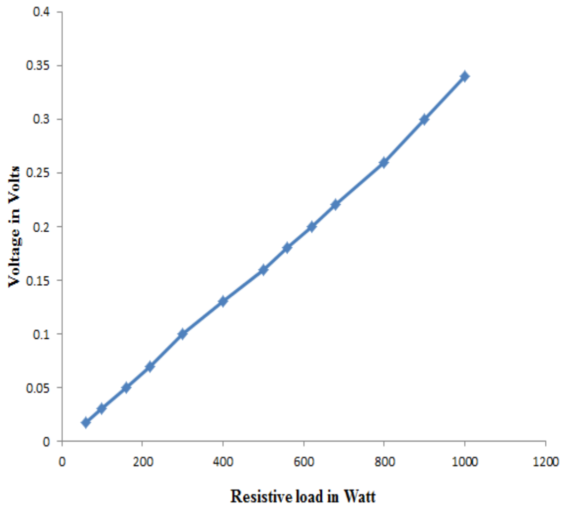

Figure 3: Resistive load versus voltage curve

4 .Conclusion

The energy management device which has been designed, built and tested for 1 kW load can be made part of the domestic supply system and with enhanced load capacity by incorporating the same hardware and software protocols.

With addition of pulse -operated switching from the supply end, the device can set remotely to control the energy levels to the consumer s in consonance with the energy availability and realize real time management of electric power within the framework of a smart grid.

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