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Full Length Research Paper

A smart energy management system for monitoring and controlling time of power consumption

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Energy resources and their management is one of the prime challenges to the world especially low economy developing countries like Malaysia where the major contribution to energy generation is based on imports setting a considerable weight on the country economy. This overwhelming is causing affliction to policy makers and researchers. Domestic energy landscape has changed significantly over the years. From being an energy rich country a decade ago, Malaysia is slow and will soon be joining other countries that have to rely on imports in order to meet domestic demand. Hence, proper management of energy is a crucial issue that needs to be addressed to support the economy towards a higher growth trajectory. A holistic approach addressing the issues of energy supply, demand and pricing needs to be undertaken. In this research, a feedback and goal setting method is introduced in order to manage the high rise in peak demand. To obtain and monitor the desired mechanism, a high-tech system is proposed that involves some means of metering, display and communication layer having a live contact with the utility. A new package price is introduced here that might be of great user interest. This design is having an ability to be very effective in terms of electrical peak load management and a cost effective solution for different categories of users.

Key words: Electric power management, digital power monitoring, GSM-SMS technology.

INTRODUCTION

In traditional monitoring, human labor that is, a line man plays a significant role in collecting and managing field data. However, due to the size increase of consumption areas, this kind of manual practice is considered time consuming and labor intensive. As the Malaysia economy sector is recovering from the financial and economic crisis, resurgence in energy demand is expected. Within the last three years, the energy generating capacity (increases according to the energy demand) has increased almost 20%, from 13,000 MW in the year 2000 to 15,500 MW in the year 2003. The energy generating capacity is further expected to increase to 22,000 MW by the year 2010 (Thaddeus, 2002). In order to meet the increasing demand, energy supply infrastructure will need to be continuously developed and at the same time, being very capital intensive. Consequently, this will impose tremendous pressure on the natural resources, particularly for developing countries like Malaysia. At the same time, it is clear that the current patterns of growth, resource use and environmental degradation cannot extend indefinitely into the future (Abdul, 2004). The dramatic increase in local energy statics shows that the demand can not be fulfilled blindly as energy resources will be one of the major issues in future worst than as it is now for some countries including developing countries even.

The available energy resources needed to be managed on short and long term basis. The peak electricity in afternoon is one of the common problems that add up to the existing problems. Meanwhile, the growing demand for new power plants in a situation where generation is already depending mainly on importing coal is a serious issue to be addressed. Generation of power plants is directly related to the peak energy demand and solving

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this issue can result in reduction of this demand for time being at least; that is delaying the urgent installation of a power station. An overview of local energy statistics shows that the major contribution of electricity generation is from thermal plants mainly depending on imported coal. This year, the price for import of coal will be close to 1000M $ which is 3 times greater than 2006 that was 316M $. Results from the study shows that CO_2 emission from coal fired power plants will grow at 4.1% per year to reach 98 million tons in Malaysia (Martunus et al., 2008). The main focus of this paper is on developing a new intelligent power monitoring system. The package of designed embedded system consists of the advanced control technique comprising of two parts; slave part which is controlled by high-tech controller and 'master part' which is actually being dedicated to handle a particular task which may require very powerful processors having some element of extensibility or programmability (Wolf, 2000). In this work, we will consider, more specifically, real-time embedded systems used in a communication intensive environment which have some peculiarities that may be considered when we are developing new applications. For real-time constraints, we mean that a real-time system must satisfy explicit (bounded) response-time constraints or its correctness may be compromised, risking severe consequences including failure. In these systems, the response time is as important as the correctness of the outputs. A real-time system does not necessarily need to be fast; it must simply produce correct responses within a definite time limit.

A real-time embedded system usually monitors on the environment where the embedded system is installed; and if it does not respond in time to a request, the result can be disastrous (Laplante, 1997). Slave part, mounted on the 'user location' containing 32 bit MCU (Jivan, 2002) integrating sensing devices, UN limited range GSM Modems modules and display section for user. This system would be able to expect the time as well position to display on the LCD at every defined user locations. The software part includes the monitor and IDE parts. A graphical user interface (GUI) and software management packages are also developed to monitor and maintain the system. MPLAB has been selected for as the IDE and C18 as the compiler for the advanced controller unit; so both the hardware and software solutions are integrated in the proposed system to make it most reliable and user friendly. This required core software used for programming the setup and creating a replica of the real network. The sensed inputs are being applied to high-tech chip, whose job is to continuously produce correspondent outputs and display it. Individual unit is connected to master node using a wireless connection; this master node containing network operating centre (NOC) and automated monitoring server. The technique applied to minimize the peak energy consumption is the pre-defined variable energy packages resulting in motivating user to change his consumption habits.

The algorithm proving to be real application of embedded systems for monitoring in power system networks.

RELATED WORK AND CONTRIBUTIONS

History of embedded system

The 'history of embedded system' goes way back to the sixties. However, the system developed those days could not penetrate themselves for the common man due to their prohibitively high cost and limited portability. An article from 'embedded technology journal' quotes: "with the attributes mentioned in previous heading, it is clear that such a system could have been developed with only the advent of microprocessors; to briefly trace the history of embedded systems architectures, we have moved rapidly from system-in-chassis to system-on-board, then into system-on-chip (SoC) integration over the past decade. Each time we have integrated, our power density has increased as our form factor shrank. Interestingly, today, embedded systems have more in common with supercomputers than with commonly desktop and laptop machines." It is further analyzed that both supercomputer and embedded computer have hit the wall of diminishing returns on single thread, Van Neumann processors and have moved into the domain of multi core and alternative processing. It has been reported that, the first embedded system to be produced in large quantities was the Autonetics D-17 guidance computer which was used in Minutemen Missile released in 1961. It was built from discrete transistor logic and had a hard disk for main memory. The real era of embedded dominance took off in 1962, with the foundation of the PC/104 Consortium by Ampro, RTD and other manufactures. The group established a format for Intel microprocessors based on a motherboard approximately 4 inches square and just under an inch high. The board was stackable, allowing a very powerful computer to be assembled in a box approximately 4 inches square or even less.

The embedded systems design considers the systems characteristics and restrictions that are fundamental for an efficient system function. As a result, low power design of communication intensive real-time embedded systems must consider the environment and application constraints to optimize the system's design (Wolf, 2000) such as real-time responsiveness and intensive execution of communication tasks. The author has described an electric power energy monitoring system in a university using an Intranet. By using the 'intranet', electric data of every point can be collected comparatively easily. This system was a healthy contribution in early 21st century. But this system only refers to the monitoring of electrical parameters. There is no way out given for the controlling or balancing the demand curve (Takeshi, 2006). “Large-size display panel” installed within the campus itself is not an attractive and cost effective approach. Now the trend in world is more towards a smart and cheap technology. In Victoria, Australia, increasing summer electricity demand peaks by air conditioning caused extra investments on

low use plants. Introduction of smart meters to customers was seen as a mechanism to link wholesale and retail markets. The government changed legislation as instigated by the Essential Services Commission of Victoria. Installation started in 2006 for dedicated categories; in 2013, about one million smart meters should be installed (Ofgem, 2006). Chia-Hung proposed a system for monitoring and control using PLC technology. According to him, home power consumption tends to grow in proportion to the increase in the number of large-sized electric home appliances (Chia-Hung, 2008). An embedded system without any new additional wiring has been developed for home power management. By using power line communication (PLC) technology, electric home appliances can be controlled and monitored through domestic power lines. We describe a PPCOM (PLC power-controlled outlet module) which integrates the multiple AC power sockets, the power measuring module, the PLC module and a microcontroller into a power outlet to switch the power of the sockets on/off and to measure the power consumption of plugged-in electric home appliances. We have also designed an embedded home server which supports the ‘web page’ user interface, thus allowing the user to easily control and monitor the electric home appliances by means of the ‘internet’.

In addition, the field experiments reported have demonstrated that our design can be practically implemented and provides adequate results. It must be recognized that power cables were never designed for carrying data signals and power line channel is a very harsh, noisy and nonlinear transmission medium. The main problem that has to be considered in PLC involves the inter symbol interference (ISI) which is generated by multi-path propagation effects and its resulting delay spread. Nor’aisah Sudin presented her model, describing the transmission of metering data using a fiber cable (Nor Aishah et al., 2008). The prototype is integrated with an interval meter, Mk 6 Genius electric meter that is capable of register the energy consumption in a specified period of time through an optical serial communication probe that is IEC1107 FLAGTM compatible to a central computer for processing. The serial port analog to digital converter was used in the communication system and attached to the computer through RS-232 interface. The computer will then display the electrical consumption pricing in a display panel. Microsoft visual C++. 3ET is used as the development platform specifically for the data processing and user interface design. The prototype was meant to compensate the current system and able to provide accurate, reliable and instantaneous meter reading and displays the users’ electrical consumption in terms of price unit. But as an analyst to me, it is not a wise solution. Too expensive as it need a huge cost of installation for physical media and there will be more problems rather that comforts, system will need more man power for maintenance and security of this dispatched media. There will be losses of data in case of any breakdown and there is no backup system.

A recent research in India shows that embedded system has become very popular in monitoring and control systems. A. Goswami designed experimental modal for monitoring and controlling temperature and light using a simple micro controller shows the accuracy in results obtained in this process. The accuracy indicates how closely the sensor can measure the actual or real world parameter value. The more accurate a sensor is, better it will perform. The writer used the micro controller not a very much updated, and the system was not capable for offline analysis of data (Goswami et al., 2009). Muhammad Mehroze Abdullah proposed a ‘smart demand-side energy management based on cellular technology’ stating that, detailed information about consumption of electricity is not provided to users and network operators which is prime wastage of electricity (Mehroz et al., 2009). The writer did not clearly explain the standard of communication used; also cost effectiveness of the system is still a question mark. The system proposed is designed for individual and no enough focus on overall system operation; how this system can affect the peak load demand.

Energy overview for Malaysia

To meet increasing requirement of electrical load highly requires new generation, making current resources more efficient and output oriented. Sometime, upgrading or replacing the transmission lines is also necessary. Replacing some of the infra structure needs 10 to 15 years; while peak demand is projected to increase over the next 10 years by 19%, meanwhile transmission miles are projected to increase less than 7%. This gap is a red zone resulting into huge crises strongly needs some management to minimize this gap until requirement is fully achieved (U.S department of Energy, 2008). Taiwan is also a developing country and its electricity statistics are having few similarities with Malaysian energy profile mentioned as follows:

i) The lack of indigenous energy resources: dependence on imported energy resources;
ii) The use of fossil fuels as the primary energy sources;
iii) Current limited utilization of renewable energy: despite ongoing development, the utilization of renewable energy is presently limited due to technical constraints, high unit cost and comparative instability. The cost of renewable energy is still too expensive to be widely applicable for

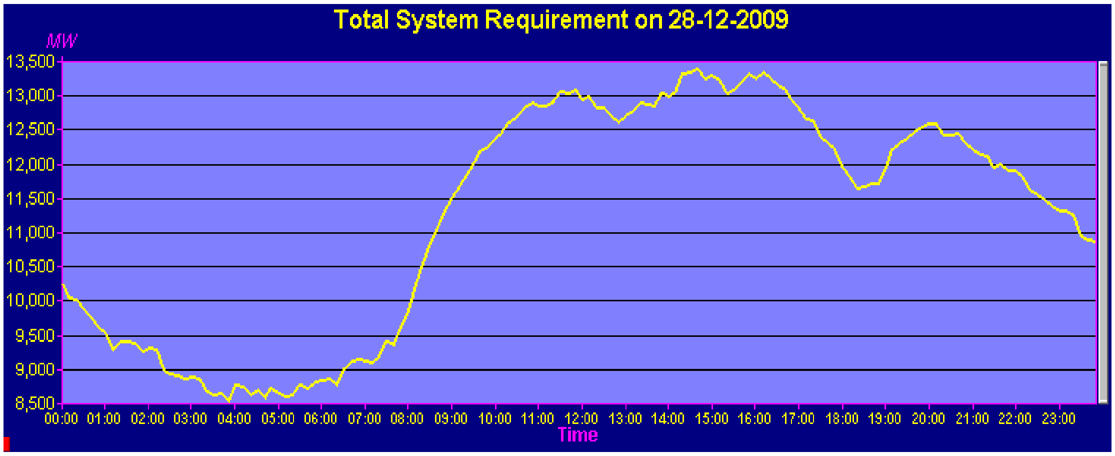


Figure 1. High rise in peak also showing off-time and peak times recorded on December 2009, recorded at national load dispatching center (NLDC) Malaysia (taken from the system).

domestic power generations.The authorities in Taiwan set an implementation plan for short time management of electricity, mainly focusing on creating awareness among users by providing the actual awareness among them using different mean (Yun-Hsun, 2009). According to authorities, all sectors need to be addressed to manage this growing challenge through public awareness campaign. This campaign consisted of awareness by training and motivating the consumers through different means like print and electronic media, seminar and advertisements etc. But there is no way out to get feedback and follow up after this huge campaign. This awareness scheme even having motivation among users, but there is no practicable system to control the peak load problem. There is no clear way to see how effective this system is? Our algorithm offers using some source of energy monitoring device to get actual consumption awareness, surely resulting in positive achievements.

Designed pro-type is highly target oriented and successful in achieving the EMS (energy management system) and it proved to be very convenient in real time pricing.

System design and description

Figure 2 shows the system flow diagram between vendor and user followed by some stages, feedback and monitoring to make sure implementation of the packages is provided.

Hardware implementation

The remote node can be selectively configured to provide master-slave topology, or to form stand-alone, that is, digital power monitoring system. In the left side of Figure 1, the ‘current transformer’ acts as a front-end signal acquisition system, as it provide main input signal to be processed. This signal is digitized in current to voltage convertor amplifier circuit. This signal is processed in controller according to highly pre-defined program and output through MAX232, a level shifter IC is sent to GSM modem for further operation (Figure 3). The job of micro controller is to perform all calculation based on I and V pulses and to calculate amount of energy used according to a pre-defined equation, and to generate cost for this consumption taking in consideration the defined electricity packages, that is, real time monitoring and calculation. GSM modem supported by AT commands is connected to micro controller to transmit data according to pre-described time period to central base station. GSM modem use SMS technology. To send or receive any SMS or to display any SMS in the inbox which is actually the information of the consumption, there are some specific commands (Figures 4 and 5).

At central node

Hardware section

Hugely designed data base, having capability of updating with any information received, this system is intelligent enough to make implementation of any operation and to detect any fault. The information is received at GSM end which is forwarded to ‘main brain’ of the system, immediately updated in MDMS (metering data management section). The central process is also connected to NOC (network operating center). Load control devices majorly related to future enhancement, to use efficiently back up resources like standby generator, batteries, fly wheels etc. Also it aims to make intelligent protection system, capable to detect any fault and heal it

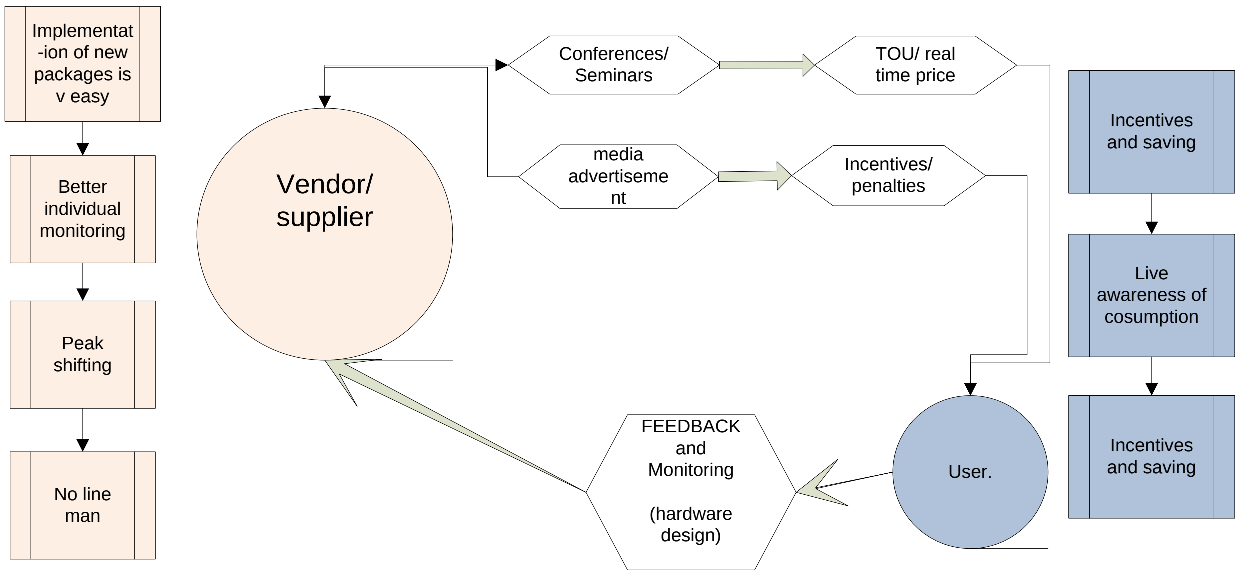


Figure 2. System flow diagram between vendor and user is followed by some stages, feedback and monitoring is to make sure implementation of the packages is provided.

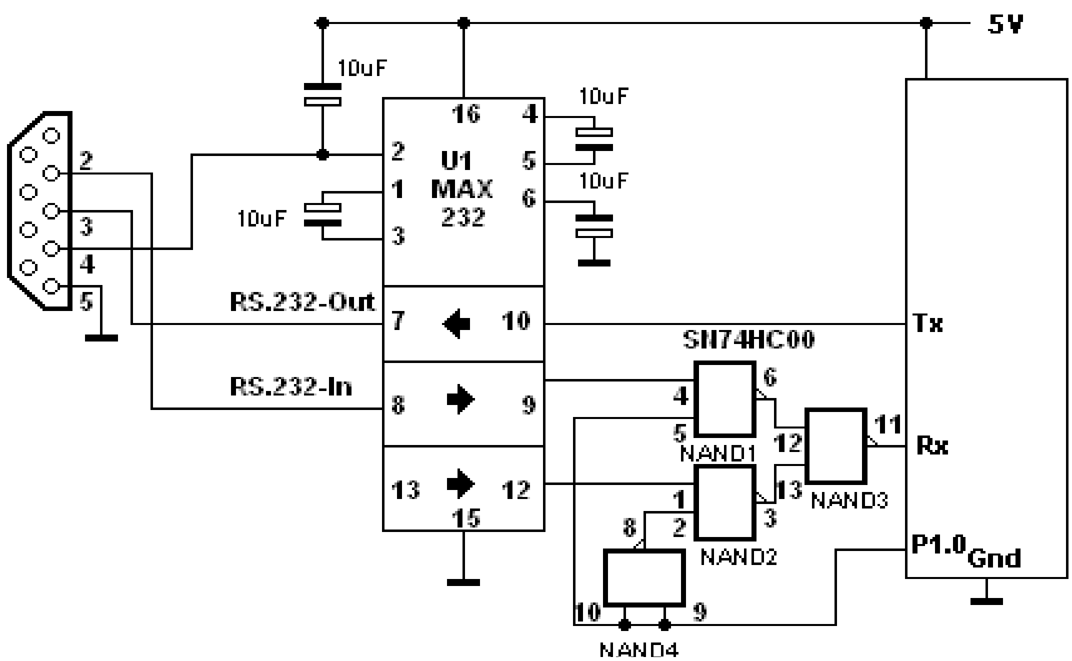


Figure 3. GSM pin connection to microcontroller.

before it affects the system.

Software section

As discussed, the prototyped central Node has two types of operating modes, ‘stand-alone’ and ‘slave-master’. Thus it has separate program for each mode of operation. It is apparent that both modes require certain common basic support functions and accordingly, the software should be structured modularly. So these supporting routines can be incorporated into any of the programs as a common operational approach to allow minimal power consumption. Any decision for shut down, implementation of a new package, updating and calculation of information, managing all history, uploading

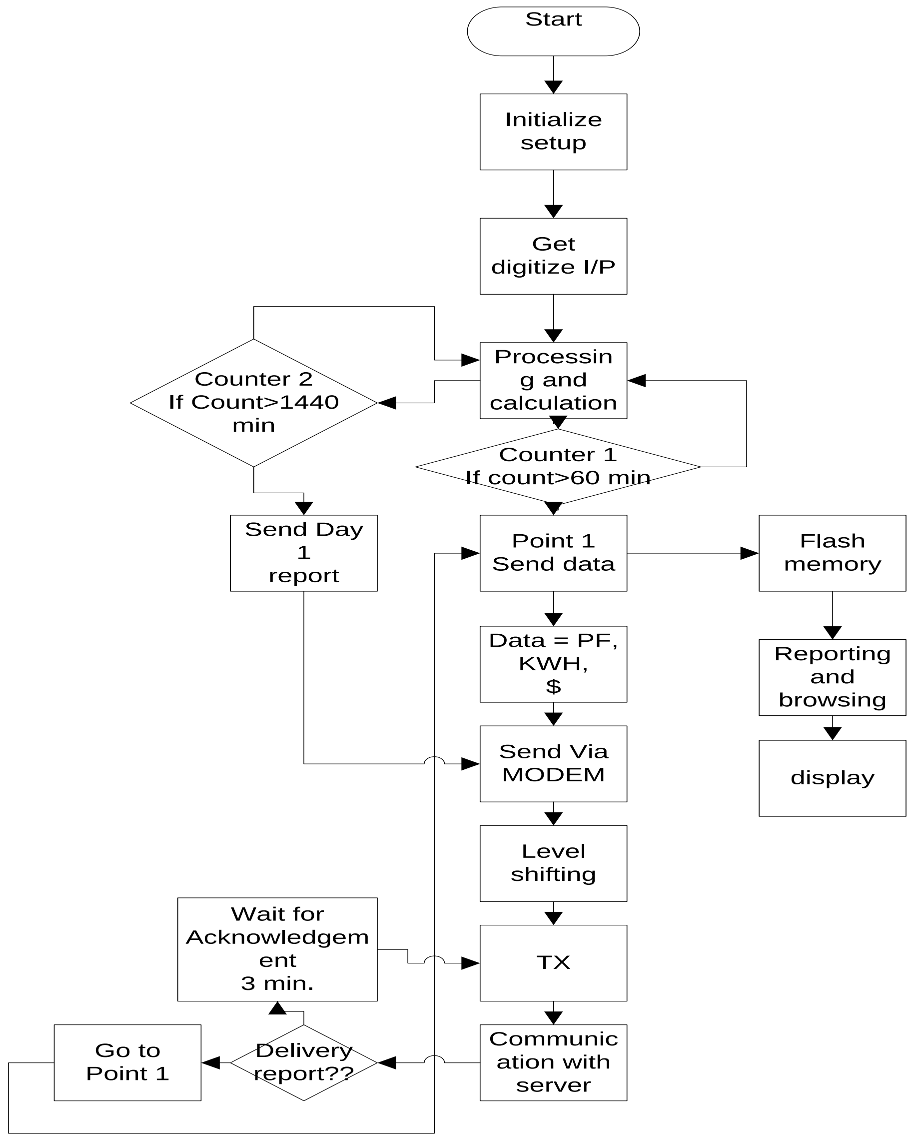


Figure 4. System flow chart showing mechanism of operation for energy detective.

the pre-paid units requires a highly designed data base. Security measures for data base are an issue that strongly needs high level programming. This central node has two types of jobs to perform, firstly management of all history and currently receiving information; secondly, control and monitoring ready to make any decision in case of any situation. SO it needs two separate protocols to define these jobs (Figure 6).

The connections

In this part, there are three key modules: MCU: PIC32MX320, TA-1311 current sensor and the advanced wireless: GSM module MOD-9001D. The MCU of the embedded gateway is 32 bits MCU produced by MICROCHIP, designed to provide a cost-effective and high performance microcontroller solution for general applications. To reduce total system cost with maximum efficiency, it also provides the following: speed 80 MHz, 1.56 DMIPS/MHz, 32-bit MIPS M4K core, 2-channel UART with handshake, system manager (chip select logic, FP/EDO/SDRAM controller), I/O ports, RTC, IIC-BUS interface and so on. For sensing input, TA 1311 is selected; the TA1X11 series of PCB mounted miniature current transformers are designed specifically for integration into products which require exceptionally accurate primary signal transformation while exposed to harsh environmental operating conditions. This is specially designed for applications that require exceptional accuracy with minimal phase angle error. The main connections are shown in Figure 7. The MCU

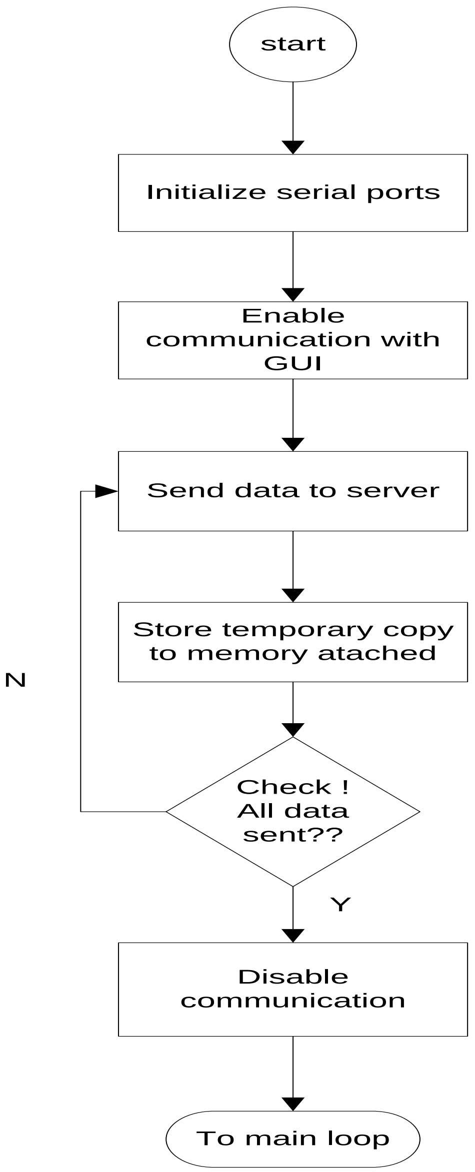


Figure 5. System flow chart description at remote end, calculation and transmission of information.

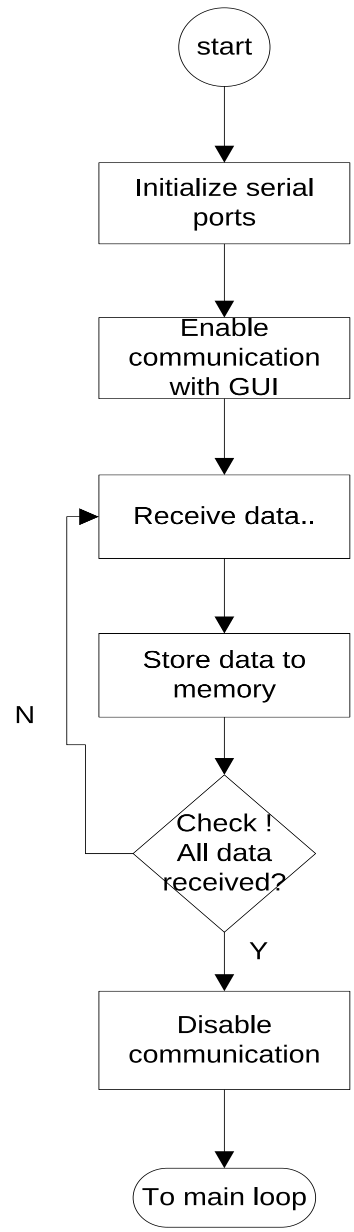


Figure 6. The sequence of instruction flow in central node.

module has two Rx/Tx channels. One is specified for the GSM and the other one is reserved for the transceiver (XStream RF modules). We only need the MCU RxD/TxD to connect with TXD1/RXD1 of GSM; next is to connect the remaining RxD/TxD with the wireless; although it is kept pending for the enhancement stage will be used as a backup and also to save SMS cost in small clusters. Regarding display, the graphical LCD is selected.

The main concept is designed via core programming to provide maximum benefits to the users. The facilities contain the current consumption detail and price, history of consumption, current package running and information about peak/off peak time (Figure 7).

RESULTS AND DISCUSSION

The system is based on a hypothesis, “an affective visual feedback and variable time pricing, compromising of penalties and incentives to user will help in a new habit formation avoiding systems to get any failure in peak time, also postpone new generation investments for long time”.

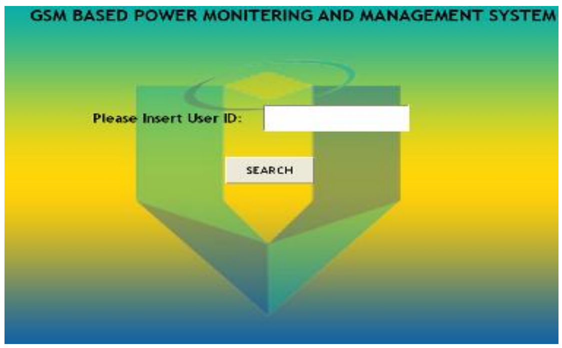
To implement and ensure the variable price packaging, the designed algorithm is proved to be effective on initial level. The targets given to the user are almost achieved, even sometime the average use is more than previous history, but peak is having a considerable difference.

Figure 7. The system hardware pictures. Left side is the receiver and the right side is the transmitter module attached with meter.

To get more facts and results, the system needed to be launched on a comparatively large scale (Figure 8). Among a survey in a town are in Kuantan city, maximum people are satisfied to install this proposed system at even their own expenses, as it seemed to be very helpful in terms of financial saving using incentive and cheap price packages. Few of the users are having a view that this system will only contribute to more troubles in terms of visual and audio alarms and having technicalities inside it. But this number is less than 15% (Table 1). As a manipulation check, an analysis of variance was conducted on the amount of electricity consumed during the month of April 2010 for the type of comparison feedback (self, social or both); X implied goal and usage level (high or low). The only significant effect was the main effect of usage for low-level and high-level users (Figure 9). The primary objective of the present investigation was to propose, implement and evaluate comparatively the two programs designed to publicly commit commercial-residential users to energy conservation. The first one is old electromechanical meter and monitoring by line man and the new one is author's proposed system where all operation is carried out automatically. It had been assumed that a powerful commitment intervention in which users was: a) acknowledged for their participation in a community energy conservation program; and b) motivated to protect a positive community image by change of habits following through with a public commitment to conserve energy, would lead to greater achievements of energy conservation.

The results of the present evaluative investigation were inconsistent with this hypothesis. What emerged instead was the finding that the mild commitment intervention led to greater levels of electricity conservation than did the strong commitment intervention. The monitoring system itself proved to be very efficient and effective. Many conceptual explanations exist for why the stronger, and theoretically, the most powerful intervention strategy were less effective in the present experimental context. Designed prototype on initial level is giving precise and accurate values of consumption. The message delivery delay is a problem yet to be solved and cost per SMS is also issue that is cost oriented. The structured post experimental data obtained from owners (Table 2) also revealed some perceptual responses that were inconsistent with the outcome measures. This data is used in many type of analysis that was not possible before. Service provider can have a live look on system individual demand and supply can see the sudden rise and also it is very easy to implement any new package. The overall peak seems to be reduced considerably. Maximum care was taken in both the selection of subjects and the design of the experiment in order to assure ecological validity accuracy and precision of values. Some issues like delay in message delivery also needed to resolve yet, but this is a system error happening. However, without using a larger sample or an extensive cross section sampling, effects of group differences cannot be ruled out; neither can ecological validity be assured without replicating the results in a field study. Nonetheless, the robustness of the results should encourage researchers to join in a more extensive investigation of the links between motivation and goal-setting in the energy conservation domain. It is becoming important to have such a system which helps to manage

(a)



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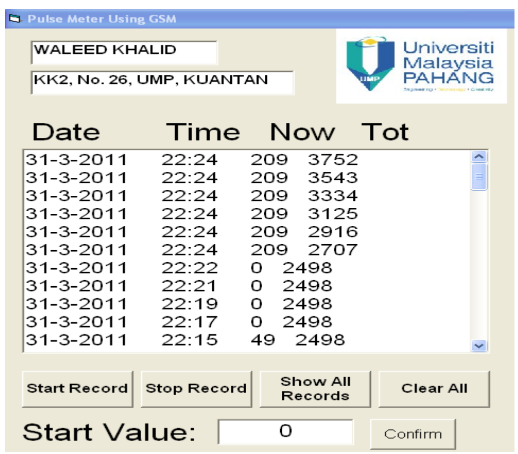

(c)

Figure 8. An instantaneous value recorded at GUI: according to a calculation equation pre defined in the system.

Table 1. A survey conducted in Bukit Istana, a town area to get feedback about our proposed algorithm.

Description	Number
Total number of users interviewed	120
Number of users ready to adopt proposed solution (conditional)	41%
Number of users ready to adopt proposed solution (un-conditional)	23%
Number of response user.	11%
Number of user against the new algorithm.	25%
Reason for being against: in their view it will just increasing complications, and will provide no benefit.	

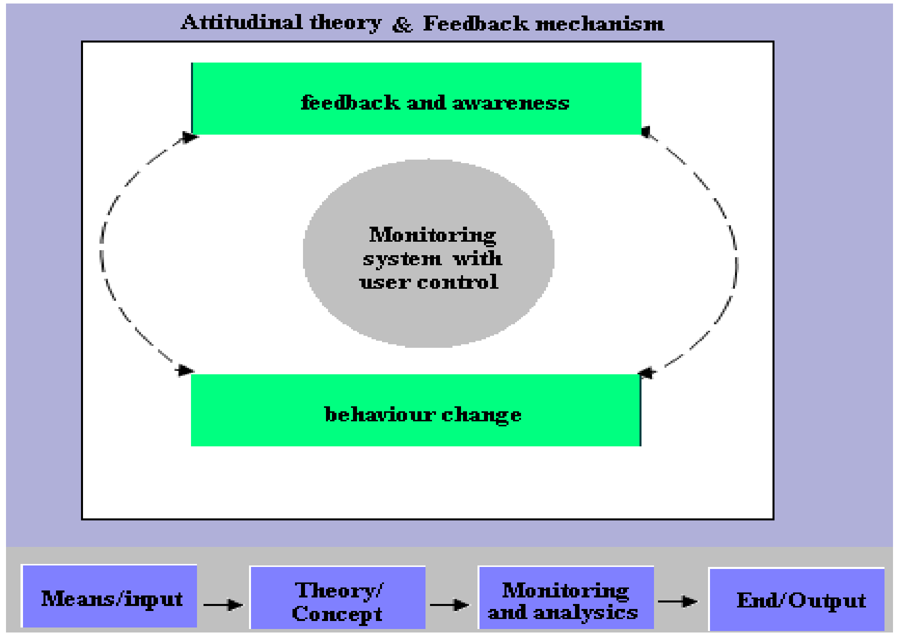

Figure 9. Electricity consumption feedback conceptual framework.

Table 2. Data collected from precise monitoring of a single home user.

Date/time	12:00am-1:00 AM	2:00 AM	3:00 AM	4:00 AM	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM
1-Mar-11	83	57	82	63	85	80	71	78	490	493	768	706
2-Mar-11	61	70	70	85	78	65	80	81	390	454	805	997
3-Mar-11	56	76	81	66	64	67	77	75	393	521	818	807
4-Mar-11	79	86	86	86	55	61	63	81	332	372	885	700
5-Mar-11	71	63	85	62	83	74	84	74	542	576	807	741
6-Mar-11	56	57	71	71	61	57	82	65	539	410	934	781
7-Mar-11	75	57	74	86	74	58	81	60	409	505	995	767
8-Mar-11	55	54	67	63	82	67	54	85	494	407	965	751
9-Mar-11	70	76	85	55	57	78	83	79	532	557	985	971
10-Mar-11	69	57	86	61	64	69	62	64	403	366	943	731
11-Mar-11	61	69	69	62	83	62	65	62	324	437	753	701
12-Mar-11	78	77	66	54	61	66	65	83	328	487	742	888
13-Mar-11	66	84	78	65	67	81	59	67	499	491	771	794

Table 2. Continues.

1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	11:00 PM	12:00 AM	Total
911	800	701	851	924	541	559	437	547	531	80	75	9842
876	756	741	950	865	458	420	633	401	545	80	71	9522
804	702	967	791	807	583	620	571	473	553	84	89	10421
959	849	795	869	898	410	488	526	491	557	81	72	10394
981	933	752	995	882	418	482	486	542	553	76	70	10414
857	921	766	883	897	418	405	425	499	553	93	92	9817
767	896	970	879	895	579	493	568	544	509	93	72	10307
771	700	853	996	954	527	516	577	514	618	73	72	10597
777	905	706	939	794	510	434	514	531	543	98	73	9839
832	750	936	797	944	550	401	540	435	421	98	85	9952
742	983	982	914	863	417	617	613	525	409	69	72	10106
704	837	740	988	807	552	507	592	583	422	77	69	9853
863	895	958	753	893	536	454	621	439	452	95	86	10487
881	915	926	726	949	513	422	422	578	562	84	74	10372
917	711	892	850	739	583	597	546	474	464	91	82	10198
1000	760	771	761	996	590	461	431	605	526	77	98	10089
803	895	767	976	743	487	556	550	476	550	72	76	10061
966	885	791	734	893	502	480	590	542	530	88	93	10293
914	771	939	756	808	476	503	577	540	442	69	80	9949
977	894	908	945	969	535	461	613	437	497	70	97	10818

consumption on the basis of real time pricing, with a secure and live mentoring device friendly to both user and supplier, especially in case of developing countries because smart grid concept is no doubt the overall solution but it is not feasible for low budget economies. Smart grid technology is still new and has yet to develop acceptable standards.

Our algorithm offers using some source of energy monitoring device to get actual consumption awareness; surely resulting in positive achievements. Designed pro-type is highly target oriented and successful in achieving the EMS (energy management system) and it proved to be very convenient in real time pricing. The prototype is tested for a few users for defined time and after peer monitoring, it showed a healthy response in order to achieve targets.

Conclusion

It is therefore concluded that product-integrated energy feedback with a planned motivation to users, when coupled with a means for the user to set an energy conservation goal, offers a convenient and highly successful means to save energy. Even though for some users, the average use of energy when calculated is slightly more than that calculated earlier; the peak is still having good marginal progress. Few complaints also received about technical difficulties of system, but these were less than 10%. Till this time, only prototype of system is installed and examined for a limited number of users only, more detailed study needs a wide network with more efficient monitoring system which is in phase of development, especially to avoid calculation, need monitoring and analyzing software later on. The technique presented in this work provides a very highly technical monitoring means for the digital measurement of electrical energy, which may be used over a wide range of energy measurement. The results obtained exhibited linear behavior over the range used. The apparatus gave good results under various loading conditions and with a power factor ranging from low to high values.

Actual use and result of this system will be obtained after implementation to a specific area, but estimated accounts will be eliminated and customers will pay only for what they actually use.

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