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DEMAND SIDE MANGEMENT FOR MICROGRIDS THROUGH SMART METERS

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ABSTRACT
Microgrid is a small scale power system consisting of distributed small power facilities such as solar power, wind power and micro-turbines. The microgrid has been researched and encouraged actively in many countries, because of some merits such as an eco-friendly system, good quality power supply and energy security. Microgrid power generation satisfies the power requirement of considerable number of consumers during the islanded operation. During this off grid time of operation a Demand Side Management (DSM) system can be used for better power distribution among the consumers. DSM promotes the efficient usage of power, while focusing on the network stability and reliability. Because it monitors the real time power consumption of users and automatically distribute the excess power of the system while controlling the power usage of the users to keep the network stability. The authors have developed few smart meter units, robust communication system and a main server to help to transmit the real time information to the consumer as well as to the main control unit which runs the DSM program.

KEY WORDS
Demand side management, microgrid, smart meter

1. Introduction

The emerging potential of Distributed generation (DG) can be realized by taking a system approach that views local generation and loads as a subsystem or a "micro grid" [1]. This subsystem method allows for local dispatch control of DG and reduces dependency on a central dispatch. Once a disturbance takes place, the DG and the associated local loads can separate from the utility and isolate the local loads from the disturbance, providing a high level of service, with minimum effect to the stability of the transmission grid's integrity. These capabilities of intentional islanding of Micro Grids provide local reliability than the legacy systems can provide [2], [3].

A microgrid is a small scale power system consisting of distributed small power facilities such as solar power, wind power and micro-turbines. Due to merits such as an eco-friendly system and energy security, the microgrid has been researched and encouraged actively in many countries. For commercialization, the effective operation for the microgrid is very important.

The emerging Information and Communication Technologies (ICT) are used to advance the existing power grid to a Smart Grid. Intelligent devices such as Wireless sensor networks and the communication between them provide a good platform for monitoring and controlling the Smart Grid [4].

During the islanded operation of a grid connected microgrid power generation satisfies the power requirement of considerable number of off-grid consumers. Therefore consumers are limited to a low power usage. In the traditional Grid, consumers would not get real time feedback about their usage and they can learn the amount of their usage by monthly bill only. But in the islanded mode of a Micro Grid, if one or more consumers go for a higher usage during peak hours, the total system can gets trip due to high demand and low generation. Intelligent DSM can be used as a solution to the above typical problem [5][6].

A DSM system can be used for better power distribution among the consumers which is not in use nowadays. However wireless Sensor Networks for Smart Home Energy Management in Smart Grids has developed in several ways [7][8]. DSM promotes the efficient usage of power, while focusing on the network stability and reliability. Because it monitors the real time power consumption of users and automatically distribute the excess power of the system while controlling the power usage of the users to keep the network stability.

The authors have developed few smart meter units, robust communication system and a main server to help to transmit the real time information to the consumer as well as to the main control unit which runs the DSM program. The developed controlling system automatically identifies the critical situations during peak hours and excess energy in off-peak hours and sends messages to the customers by mentioning how the power could be used while indicating the critical levels.

Rest of the paper is organized as follows. Section 2 discusses the system overview used by the authors. Section 3 describes the system implementation and section 4 gives a brief of demand side management and finally the conclusions are given in Section 5.

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2. Microgrid and Demand Side Management

Almost all large power systems in the world are relying on centralized electricity generation such as large-scale hydro, coal, and natural gas and nuclear power plants. Long-distance, high-voltage transmission lines carried the power to the customers from centralized sources where in Sri Lanka hydro power stations are gathered in up country while thermal generation is gathered around Colombo except few thermal plants outside Colombo. However, the growing demand for clean, reliable and affordable electricity generation is changing this existing scenario. On the other hand, the aging centralized energy infrastructure, which can be more vulnerable with the increasing power demand, requires innovative and economical solutions as the construction of new transmission facilities is highly constrained by the environmental and economic considerations. Many countries in the world have responded to these demands with suitable policy adjustments that encourage distributed and renewable energy generation. As a result, the share of renewable and efficient DGs is rapidly increasing. The Sri Lanka Energy Authority (SEA) has proposed renewable energy targets to meet the policy target of generating 10% of power from non-conventional renewable sources by 2015.

In this context the power systems have to become smarter, more reliable and more robust in taking on renewable energy sources without losing stability and efficiency. Smarter microgrids are an answer to this situation. Their capability to house local embedded generators as distributed generation and be locally controlled offers various advantages over legacy systems in order to realize the potential of such smarter systems, a high degree of distributed control is required [9]. The traditional power grid has experienced several blackouts in Sri Lanka with the lack of smarter micro grid. Matching the demand during an islanded operation is a very critical in terms of controlling the stability. Therefore monitoring and automation of the microgrid is essential and Demand side energy management (DSEM) is becoming one of the significant research topics [10], [11].

3. Related Work

The authors have partially implemented a microgrid test bed and final outlook would be as shown in the Fig. 1.

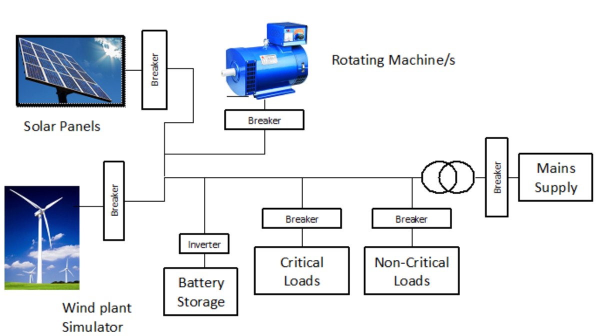

Fig. 1. Proposed microgrid test bed

The DSM and the control system proposed by the authors [12] are going to implemented on this microgrid test bed. In this section, briefly describe the main components of the implemented DSM system and how it's function. Energy meter is the basic equipment which is required to measure the power consumed by the customer. It can measure the real time power consumption while displaying on the LCD screen. Fig. 2 shows the functional block diagram of the smart meter.

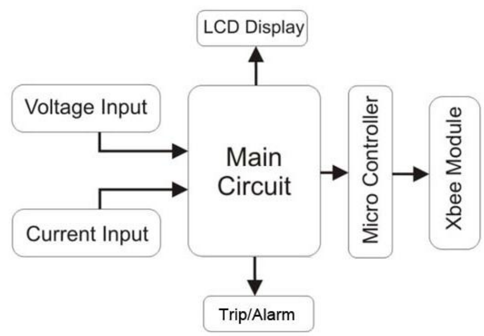

Fig. 2. Functional block diagram of the smart meter

Smart meters send the real time power consumption details of each consumer to the central server through wireless communication. The controlling process runs according to the gathered information and the same time update the web site. The implemented system overview is shown in the Fig. 3.

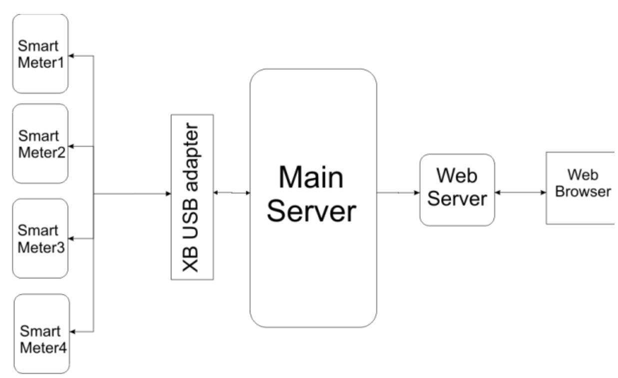

Fig. 3. System overview

As seen on the Fig. 4, the data fed from the smart meters stored in the internal database. The main server accesses those data to monitor the system status and it feeds the web server using html post method. The web server is developed using Google apps [13] and it is hosted in the Google app store. Web server consists of email gateway to generate the email notifications to the users and a web application which acts as a main user interface.

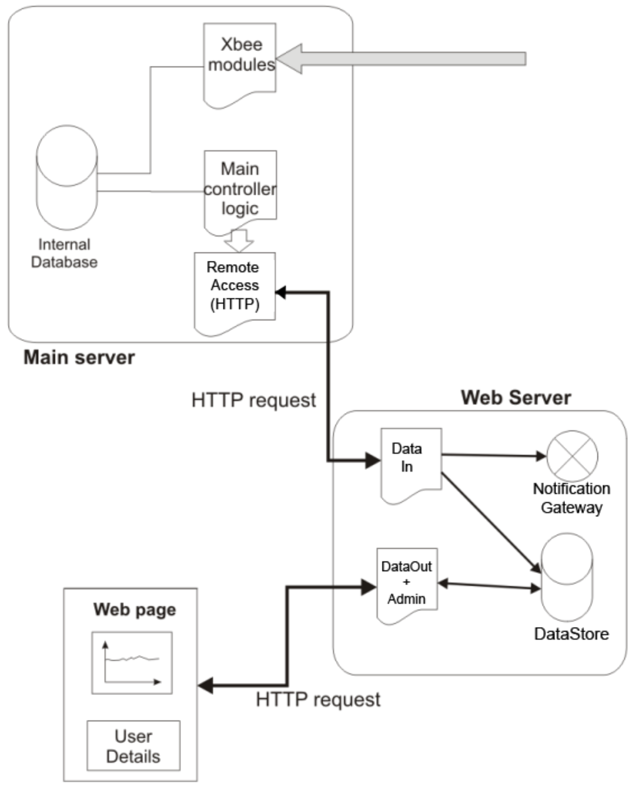

Fig. 4.Virtual data flow of the system

4. System Implementation

This section briefly describes the each component of the implemented system including the smart meter, communication modules, and the main server.

4.1. Smart Meter

Smart meter is used to calculate the real time power consumption and send those stats to the main server. An energy measuring IC (ADE 7758) was used to acquire the electricity usage. This meter is used to take readings from the consumer end and generation end. Since ADE 7758 is three phase energy metering IC with a serial interface, it can be used for both single and three phase systems to calculate the power. The required parameters like power, voltage can be extracted by reading this IC [14].

Smart meter mainly consists of ADE 7758 micro controller, LCD display and Xbee module. Inputs to the meter are taken from voltage divider and current transformer (CT) which has turns ratio 1800:1. The LCD display shows the present power usage and important messages to the consumer which are generated by the system. The accuracy of the smart meter is 1W, since the project mainly emphasizes the demand side management not the accuracy of the meter readings. Developed smart meter is shown in Fig. 5.

Fig.5. Smart Meter

4.2 Communication

GPRS module, Power Line carrier module and Xbee wireless module can be used for wireless communication. Even though GPRS module can send data to long distance, the operating cost was considered as in the higher side. Also signal losses can cause severe problems to the continuous operation of the system when using the GPRS technology. Power Line Carrier method was also discarded because of the signal distortion that can be happen when communicating through power lines. Communicating through wireless Xbee module was selected as the best option for wireless communication, because of its capability of robust operation in harsh environments, low cost, ease of operation and low power consumption.

There are two types of Xbee series, namely series 1 and series 2. Series 1 use a microchip made by Freescale to provide simple, standards-based point-to-point communications, as well as a proprietary implementation of mesh networking. The Series 2 uses a microchip from Ember networks that enables several different flavours of standards-based ZigBee mesh networking. Mesh networking is the heart of creating robust sensor networks, the systems that can generate immensely rich data sets or support intricate human-scale interactions. Authors have used series two Xbee module over series 1 because of the low power consumption, higher range and capability of creating mesh networks. The main limitation is these Xbee modules supports only up to 120 m line of sight communication. Xbee Pro modules support up to 1.6 km but those are relatively expensive. This proximity drawback is self-surmounted by the Series 2 modules' inherited quality of data packet hopping.

4.3 Main Server

This sub system is responsible for handling the main control operations of the Smart grid. It is implemented using the JAVA language and maintains separate database to store the data. MYSQL database is used for this purpose. One process of the server retrieves the data from Xbee modules and stores them in the database while another process do the control operations. The server observes the current generation level and the demand levels of the users and provides instructions to the meters in order to gain the optimized operation of the smart grid. The power usage quota is given to each individual user according the nature of the system. If a user is exceeding that usage quota, alarm signal is sent to that user to trigger the alarm circuit, which is the part of the meter. Furthermore the SMS and email notifications are also sent to let the user know that the system is going to be unstable. If that condition prevails, the tripping signal is sent, to cut off the user from the micro grid for the sake of system stability.

The main server (Fig. 6) consists of several packages to cater the needs of the system. They are XBeeCom, DBServices, Management, MeterService, RemoteResponse and RemoteAccess. Data transferring processes of the main server is shown in fig. 5. XbeeCom class handles the all the network related activities like fetching the data from the Xbee modules and sending the control instructions to the remote modules via Xbee devices. So the Xbee object is accessed throughout the central server program execution. So it is wise to keep one Xbee object and share it with the method calls. That is how the singleton pattern comes into the scene. The singleton class used in this package is XbeeServiceFactory. It creates a single Xbee object and allows the XbeeCom class to use it as required. DBServices package handles all the data storing activities since the meter readings are stored in the database for processing and further referential activities. MySQL database is used for this purpose. MySQLCon class is used for handle this activities. RemoteResponse and RemoteRequest classes handle the connection with the web server. It transmits and receives the data using the http post method.

MeterService package consists of two classes named Meter and MeterBench. Meter class was used to model the real meter, and MeterBench is singleton class which provides all meter related data and methods to the required processes.

Management package is the heart of the main server. Logic for demand side management was implemented in this class. After processing the requirements of the system, unit quota for each user of the micro grid is generated.

When developing the main server and the web server, focus was to develop the units as modular system, so the whole system will adhere to the Object Oriented Principles. In order to store and process the data, the data structures like HashMap, HashSet are used.

4.4 Web Server

The web server is a java Google app engine application which is also compatible with the other types of java servers. Web server operation is divided into two parts as Usage Data Handling (UDH) and User Management (UM). In UDH, Google app store is used to store the usage data. This data is updated real-time via a java Servlet interface which is communicated via html post methods that are generated by the main server. This data is used for notification generation. Afterword, the data is released via a web application. A java Servlet interface is used for this purpose. For User Management, a full featured user management system is built and a web interface for user management is given. In this, the data to connect with the users like Email addresses, phone numbers and data relevant to the power usage like devices used are collected. Furthermore, this will provides an intuitive interface for administrators to manage the user data.

4.5 Web Application

The web application can be considered as the main user interface of the system. Through this web application, power usage data and current user stats are provided. Power usage data will be shown in the graphical form and the data are updated real time. The Ajax technique will be used for the Web Server and Client Program.

Furthermore the instructions, notifications and ability to update user preferences, are given to the user via the web Application (Fig. 7).

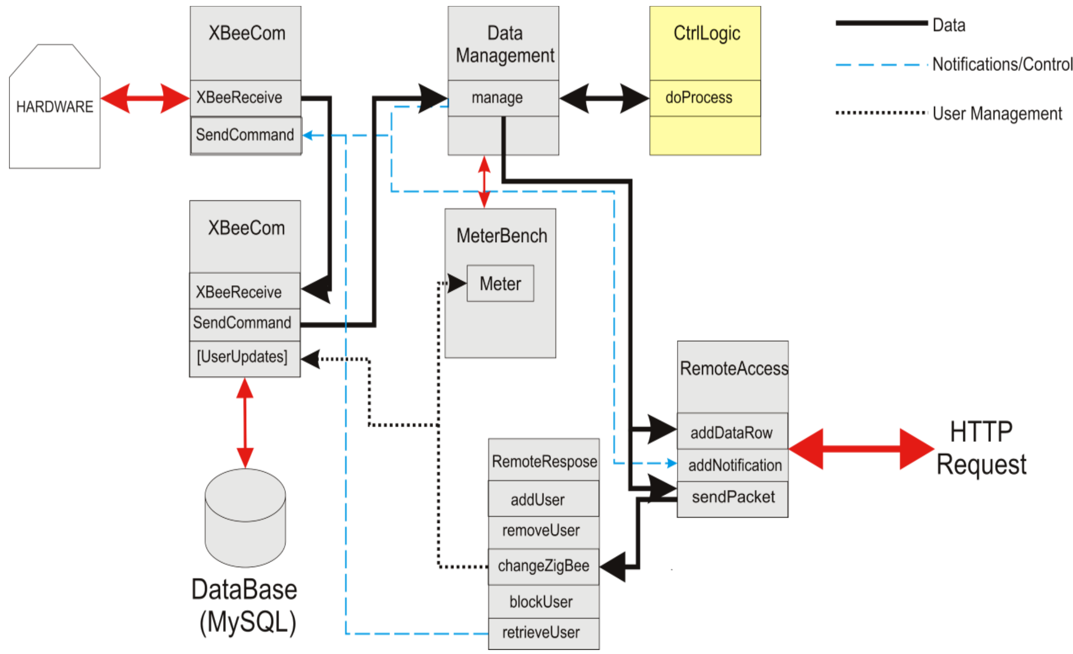

Fig.6. Data transfer of the main server

Fig. 7 Web user interface (Web UI)

4.6 Special developing techniques used

It is a good practice to create the project with a room for customization and extensions. Since the Google app engine is used as the web server, to make the server applicable to the other types of servers, the requirement of customization was highlighted. Furthermore, to have a room for extensions was too highlighted as the project's main functions like notification interface and control plug-ins are follow the plug-in architecture.

In order to meet those requirements, the dynamic binding technique is used. In this, the required class is created with the implementation of relevant interface inside the class hierarchy, but not use directly. The class's package and class name is configured in the relevant section in the config.xml. If the configuration is correct, the program automatically takes the relevant object to the runtime on demand. This way the developer can create and modify the relevant classes without affecting the already running classes. The downside is, if and only if the class is not properly configured, the runtime can issue the exception complaining the class cannot be loaded. This technique is used in plug-in situations for the extensibility and other situations for configurability.

4.7 Demand side management

Proper control logic is needed to give power quotas to the individual users in order to optimize the power usage of the system. We have developed an algorithm to calculate the usage limits of the users.

Authors have defined some parameters to model the algorithm. Number of generators (g) and Number of static users (s) are defined. The term static user is used to identify the critical users like hospitals, who are unable to disengage from the system unless in a very critical situation. Number of dynamic users (d) is defined to identify non critical users. Maximum allowable step (C_{max}) is identified as the maximum load, which a user can attach to the system in an instance. Safety multiplier (n) is taken because there might be a situation that more than one component starts at a particular movement. In order to prevent the unstability occur in the system in this situations, a constant is defined and used in the calculations. By using 2 as this constant, the n-1 stability can be achieved. Finally a reserved margin (R) is used the generation.

Let the generation of ith generator be $U_{g,i}$.

Then total usage

$$G_{total} = \sum U_{g,i} \qquad (1)$$

Let usage of i[th] static user and i[th] dynamic user be $U_{s.i}$ and $U_{d,i}$ respectively.
Same as the above,

$$U_S = \sum U_{s,i} \quad (2)$$

And

$$U_D = \sum U_{d,i} \quad (3)$$

Since the reserve margin is R

$$Alowable\ to\ use = G_{total} - R \quad (4)$$

The static usage is not controllable. Therefore, allowable usage for non dynamic users,

$$(D_{allowable}) = G_{total} - R - U_S \quad (5)$$

Since the total dynamic usage is U_D,

$$Excesspowerinsystem$$
$$Excess\ power\ (e) = G_{total} - R - U_S - U_D \quad (6)$$

Furthermore, dynamic user quota $Q_{p,d}$ is given by

$$Q_{pd} = \frac{G_{total} - R - U_s}{d} \quad (7)$$

After calculating the above parameters, the usage limits of each user are calculated as described in the following paragraph.

If the excess energy of the system is more than the maximum allowable step times safety multiplier , then it implements the system is having a considerable amount of excess energy. Therefore, the allowable limits of all the users are increased by the maximum allowable step.
Let allowable amount for one user be $U_{allowable}$

$$(e > nC_{max}) \rightarrow U_{allowable\ ,i} = U_i + C_{max} \quad (8)$$

If above condition is not satisfied, following condition is used. If the relevant user's usage is more than $Q_{p,d}$ that means the user consumes more than the quota. Then the relevant user's allowable limit is set to be his current usage.

$$(e < nC_{max} \& U_i > Q_{p,d}) \rightarrow U_{allowable\ ,i} = U_i (9)$$

If the user's consumption is lower than the quota, the user is allowed to go up to the quota.

$$(e < nC_{max} \& U_i < Q_{p,d}) \rightarrow U_{allowable\ ,i} = Q_{p,d} \quad (10)$$

If the total dynamic usage exceeds the total dynamic allowable, the system takes the power from the Reserved. That means the system should immediately fill the reserved energy. In order to do so, the system issues the requests to the most consuming dynamic user to decrease their power usage. Since, the relevant user always uses more than the quota, it is ethical to consider as a warning level.

$$(D_{allow} < U_D) \rightarrow U_{allow\ ,i,max} = U_i - C_{max} \ (11)$$

Ultimately, in low power consuming situations the system encourages any user to use the excess power and in the high consumption situations, the system forces all the users to use a same amount of power.
This is the proposed logic for the system. Since the dynamic binding feature implemented in the system, the system administrators or developers can use there own logic without dificulties. However, the system administrator or developer should take the responsibility of the circumstants which are arrises by their logic .

4. Conclusion

Smart metering is versatile for the micro grids because of its advanced metering techniques, robust communications capability and process automation capabilities. The main advantage of the smart metering is its reliability. Apart from the raw micro grid, it not only optimizes the usage of generated power among the system users, but also provides adequate warning massages about growing problems. As a result of that efficiency of the whole system increases. Another plus point of smart metering is safety. Since it is an autonomous process, normal operations of the grid does not affect to the grid workers or to the public.

The main disadvantage of this system is, it relies on the central server. If the central server crashes, the whole system will get crashed. But this scenario can be avoided by using the distributed server system. One of the foreseen fact is the devices can be developed to gain the direct demand side management. That is direct control of household appliances through smart meters. Another fact to be stated is, as the data transmission plays a vital role, enhancing the data security is crucial. That can be achieved by using data encryption, digital certificates and intruder detection systems. Those can be stated as the future enhancements of the project.

Members have successfully developed the meters circuits, mesh network among the meters, central server and web server. Finally system is able to perform processes which were expected in the scope.

Implementation of the smart metering system seems complex process. Because of the prevailing analog meters should be replaced with the digital smart metering devices and need to develop communication infrastructure. But using power line carriers as a communication medium might reduce the burden but it has its own disadvantages. Apart from these facts reliability, efficiency and other added beneficial factors will drive the appeal of smart metering system to the micro girds.

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