AGENT-BASED SIMULATION FOR MICRO GRID ENERGY MANAGEMENT SYSTEM

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ABSTRACT

The aim of this study was to to develop energy management system of the 120 kWp microgrid system. The microgird system was installed at School of Renewable Energy Technology (SERT), Naresuan University. The system are consist of 120 kW multi-crystalline PV array, 2 set of 60 kW PV inverters, 150 kW battery inverter, 100 kW diesel engine generator, 200 kWh battery bank, static var generator for maintain power stable and controll unit. The microgrid can check the system and system information through the central control unit only at the microgrid's equipment building. It is inconvenient to manage microgrid system.

The microgrid system have a lot of data in each day. For long term data management process the data from the microgrid system can become larger day by day and have too much information. Many data are inconvenience to utilize. To solve this problem, a proper database system manager needs to be developed by using computer software agent technology call agent base technology. The microgrid energy management system is used to present all information in the system and to inform the system administrator in any status of the microgrid system. The system administrator can use data and simulation result from energy management system to estimate system performance and to set the production plan for matching the load demand with renewable energy resources. The system administrator can easily control and operate the microgrid system. The advantage of developing microgrid energy management system are easy to access the microgrid system from everywhere in every time and

used space to storage every data smaller than 11 times by convert XLS file to SQL file format. And in case of system error, the energy management system can show system alarm to system administrator by system result report. The simulated annual average performance ratio and the actual annual average performance ratio are 76.50 % and 73.45% respectively. That higher the annual average performance ratio 3.05 %.

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CHAPTER I

INTRODUCTION

Rational for the study

Presently, the problem of global warming is on the rise because of the excessive use of fossil energy. This affects the environment negatively and is not sustainable. So, the use of alternative energy is increasingly becoming necessary while renewable energy sources such as solar energy, wind power, biomass, hydropower etc, are gaining popularity. Because of this, the technologies of renewable energy and other alternative energy are advancing faster recently than in the past and we have more technological options in renewable energy. When these renewable energy sources are connected together, we can get a continuous supply of energy as it comes from more than one source. But the efficiency of each renewable energy technology is different.

The concept of bringing these renewable energy sources connected to each other makes up the new network of renewable energy, called a micro-grid, in some countries also called a smart grid. The idea is that each renewable energy source produces electricity and then sends electrical energy into the main transmission lines (National Grid), to supply the power in the main system. In this way, smaller electric generating stations can serve to boost the power of the main system. The interconnection of these systems needs to use an energy management system (EMS) to manage power demand and supply data.

The School of Renewable Energy Technology (SERT), Nareasuan University, Phitsanulok, Thailand is home to the largest energy park in Thailand. SERT has installed electricity generation systems of various kinds of renewable sources. In December 2008, SERT installed a PV Micro Grid System (MGS) with the objective to demonstrate the use of an electricity network connected from a small renewable energy source to the national grid. This MGS includes the solar cell system with a battery backup and diesel engine generator. It supplies directly to the load and if there is no load in operation, then it sends electricity to the grid.

The main generator of SERT's microgrid is PV generator. Electricity from PV generator depend on solar irradiant that are uncontrollable and there are difficult to manage system stability and system efficiency not optimize. Now a day, utilization factor of the system (solar fraction) is about 50 % . We can improve it by use energy balance solution such as add PV module, add battery storage. But this solution need more budget to investment. Or we can use computer software to manage the best production plan for highest performance. And data from the micro-grid system records are becoming larger day by day and are not used. System has too much data but we cannot select only the data we need. The concept of the software agent can solve this problem. The software agent is a computer program that works as a representative (agent) of us to identify the information we need. Agent-Based technology or Multi Agent System (MAS) are the names of software agent technology that we used in this research.

SERT's micro-grid system has no energy management system (EMS) to manage data from it. So, this research needs an EMS so that it can be used to forecast the power from the system and all data can be displayed on the internet and not only at the micro-grid equipment building. This research will develop an EMS for retrieving and managing data in the micro-grid system at SERT. It is expected that development of such an EMS will help to manage data easily and conveniently and it will be the guideline to apply to the energy management systems in other types of microgrid systems or other renewable energy systems. If we have the necessary information from EMS, we will make the best decisions for making the best energy production plan.

Purpose of the study

To develop an agent-based simulation function for micro grid energy management systems.

Scope of the study

This research will be evaluate on the energy management system of SERT's 120 kW. PV micro grid system. This system was installed at Energy Park, School of Renewable Energy Technology, Naresuan University.

Benefit of the study

1. To increase system performance (Performance Ratio) of microgrid system.
2. To increase renewable energy fraction (Solar fraction) of microgrid system.
3. To decrease energy loss of microgrid system.

CHAPTER II

LITERATURE REVIEWS

Microgrid

Microgrid system can be defined as a group of Distributed Energy Resources (DER) and loads functioning as a single controllable system that reacts to central control command signals and supplies both power and heat to its regional area. Moreover, it is also defined as an independent low-voltage distribution system that has a squad of DER with energy storages and microsources such as PV, wind, microturbine, CHP, fuel cell, etc. Microgrid system is not only providing power to its local area, but also exchanging power with national power grid when its power generation is insufficient or surpass its load.

Normally, microgrid system has 5 main components as follows:

1. Distributed generation or microsources
2. Loads
3. Energy storage system
4. Controller
5. Point of common coupling

There are two common operation modes of microgrid system that are grid connected mode and island mode. In the recent decades, the fraction of renewable energy in the world energy consumption is continuously increasing in high rate and becoming a significant energy resource of the world. From this point, integrating renewable energy with microgrid concept is an important objective that has been researched and developed in many countries such as Germany, US, Japan, etc. In the present day, most of microgrid system has main or support generator that uses renewable energy in generation. However, just only controllable energy resources such as fossil fuel, biomass, biogas, hydro, etc. are used in primary generator because it is uncomplicated controlling with high security and stability of power generation from these energy resources. In the different way, uncontrollable energy resources such as solar, wind, etc. is always used in secondary generator because it is complex controlling with acceptable security and stability. When consider to uncontrollable energy resources, it shows that the potential of these energy resources is high and scattering in every part of the world. In some areas, the potential of controllable energy resources is limited and it is difficult to import from other areas. In this case, uncontrollable energy resources are the alternative energy resources for using as energy resources of main generator in microgrid system

FIPA

The Foundation for Intelligent Physical Agents (FIPA) is an international organization that is dedicated to promoting the industry of intelligent agents by openly developing specifications supporting interoperability among agents and agent based applications. This occurs through open collaboration among its member organizations, which are companies and universities that are active in the field of agents. FIPA makes the results of its activities available to all interested parties and intends to contribute its results to the appropriate formal standards bodies where appropriate.

The members of FIPA are individually and collectively committed to open competition in the development of agent based applications, services and equipment. Membership in FIPA is open to any corporation and individual firm, partnership, governmental body or international organization without restriction. In particular, members are not bound to implement or use specific agent-based standards, recommendations and FIPA specifications by virtue of their participation in FIPA.

The FIPA specifications are developed through direct involvement of the FIPA membership. The status of a specification can be either Preliminary, Experimental, Standard, Deprecated or Obsolete. More detail about the process of specification may be found in the FIPA Document Policy and the FIPA Specifications Policy. A complete overview of the FIPA specifications and their current status may be found on the FIPA Web site.

FIPA is a non-profit association registered in Geneva, Switzerland. As of June 2002, the 56 members of FIPA represented many countries worldwide. Further information about FIPA as an organization, membership information, FIPA specifications and upcoming meetings may be found on the FIPA Web site at http://www.fipa.org/.

SQL (Structured Query Language)

SQL was originated in 1970's in IBM's San Jose laboratory where it was used as the relational database language for System-R DBMS. Successful outcome of this project at 1979, made SQL becoming popular among many RDBMS vendors. As a result many relational DBMS came to the market such as Oracle by Relational Software (1979), INGRES from Rational Technology (1981), IDM from Britton-Lee (1982), DG/SQL from Data General Corporation (1984) and Sybase from Sybase Inc.

SQL received certification from American National Standard Institute (ANSI) and from International Standard Organization (ISO) in 1986. There are number of advantages in using a standardized relational language such as reduced training costs, application portability, application longevity, reduced dependence on a single vendor and cross-system communication. Disadvantages of such language are loss of application portability due to addition of special SQL features by the vendor and also it is difficult to fix any deficiencies in the standard.

There are three types of SQL commands

1. Data definition language (DDL) - these commands are issued to create, alter or delete tables. Usually these commands can be executed by database administrator only to prevent any accidental or deliberate damage to the database.

2. Data manipulation language (DML) - these commands are used to insert, update, delete or query data from tables.

3. Data control language (DCL) - these commands are used to grant various access privileges of the database structure to users. Only the database administrator can execute these commands.

RDBMS

RDBMS stands for Relational Database Management System. RDBMS data is structured in database tables, fields and records. Each RDBMS table consists of database table rows. Each database table row consists of one or more database table fields. RDBMS store the data into collection of tables, which might be related by common fields (database table columns). RDBMS also provide relational operators to manipulate the data stored into the database tables. Most RDBMS use SQL as database query language. Edgar Codd introduced the relational database model. Many modern DBMS do not conform to the Codd's definition of a RDBMS, but nonetheless they are still considered to be RDBMS. The most popular RDBMS are MS SQL Server, DB2, Oracle and MySQL.

PHP

PHP is a server-side scripting language designed for web development but also used as a general-purpose programming language. PHP is now installed on more than 244 million websites and 2.1 million web servers. Originally created by Rasmus Lerdorf in 1995, the reference implementation of PHP is now produced by The PHP Group. While PHP originally stood for Personal Home Page, it now stands for PHP: Hypertext Preprocessor, a recursive acronym. PHP code is interpreted by a web server with a PHP processor module, which generates the resulting web page: PHP commands can be embedded directly into an HTML source document rather than calling an external file to process data. It has also evolved to include a command-line interface capability and can be used in standalone graphical applications.

PHP is free software released under the PHP License, which is incompatible with the GNU General Public License (GPL) due to restrictions on the usage of the term PHP. PHP can be deployed on most web servers and also as a standalone shell on almost every operating system and platform, free of charge.

Agent based Management Reference Model [1]

Agent based management provides the normative framework within which FIPA agents exist and operate. It establishes the logical reference model for the creation, registration, location, communication, migration and retirement of agents.

The entities contained in the reference model are logical capability sets (that is, services) and do not imply any physical configuration. Additionally, the implementation details of individual APs and agents are the design choices of the individual agent system developers.

The agent management reference model consists of the following logical components, each representing a capability set these can be combined in physical implementations of APs.

An agent is a computational process that implements the autonomous, communicating functionality of an application. Agents communicate using an Agent Communication Language. An Agent is the fundamental actor on an AP which combines one or more service capabilities, as published in a service description, into a unified and integrated execution model. An agent must have at least one owner, for example, based on organizational affiliation or human user ownership, and an agent must support at least one notion of identity. This notion of identity is the Agent Identifier (AID) that labels an agent so that it may be distinguished unambiguously within the Agent Universe. An agent may be registered at a number of transport addresses at which it can be contacted.

A Directory Facilitator (DF) is an optional component of the AP, but if it is present, it must be implemented as a DF service. The DF provides yellow pages services to other agents. Agents may register their services with the DF or query the DF to find out what services are offered by other agents. Multiple DFs may exist within an AP and may be federated. The DF is a reification of the Agent Directory Service in [FIPA00001].

An Agent Management System (AMS) is a mandatory component of the AP. The AMS exerts supervisory control over access to and use of the AP. Only one AMS will exist in a single AP. The AMS maintains a directory of AIDs which contain transport addresses (amongst other things) for agents registered with the AP. The AMS offers white pages services to other agents. Each agent must register with an AMS in order to get a valid 131 AID. The AMS is a reification of the Agent Directory Service in [FIPA00001].

An Message Transport Service (MTS) is the default communication method between agents on different AP. An Agent Platform (AP) provides the physical infrastructure in which agents can be deployed. The AP consists of the machine(s), operating system, agent support software, FIPA agent management components (DF, AMS and MTS) and agents. The internal design of an AP is an issue for agent system developers and is not a subject of standardization within FIPA. AP's and the agents which are native to those APs, either by creation directly within or migration to the AP, may use any proprietary method of inter-communication. It should be noted that the concept of an AP does not mean that all agents resident on an AP have to be co-located on the same host computer. FIPA envisages a variety of different APs from single processes containing lightweight agent threads, to fully distributed APs built around proprietary or open middleware standards. FIPA is concerned only with how communication is carried out between agents who are native to the AP and agents outside the AP. Agents are free to exchange messages directly by any means that they can support.

Software describes all non-agent, executable collections of instructions accessible through an agent. Agents may access software, for example, to add new services, acquire new communications protocols, acquire new security protocols/ algorithms, acquire new negotiation protocols, access tools which support migration, etc.

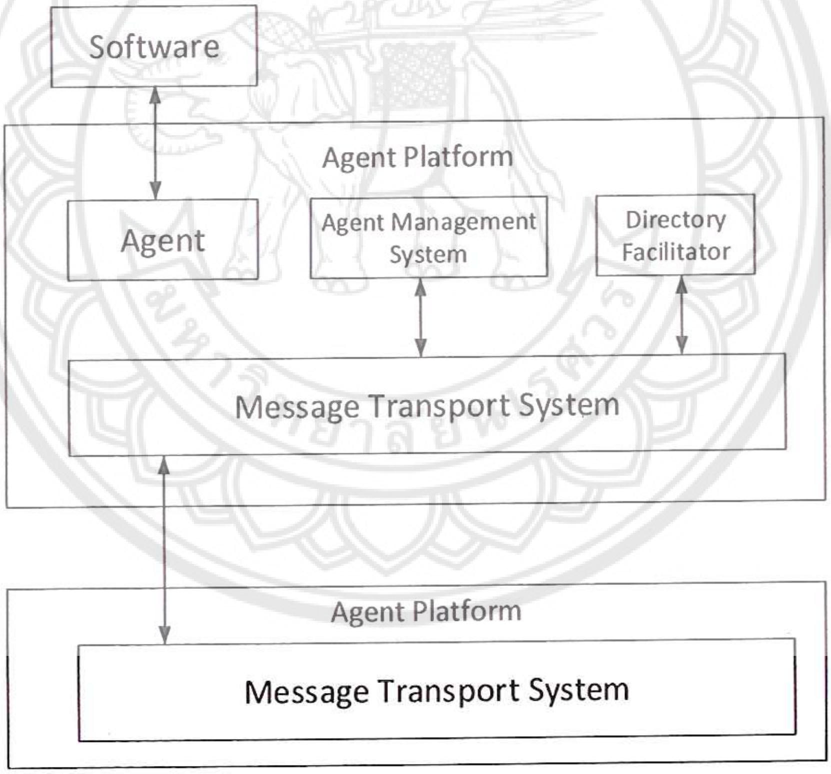


Figure 1 Agent based Management Reference Model

Formula and equation to calculate parameter in this research [2]

The technical analysis processes of International Energy Agency Photovoltaic Power Systems (IEA PVPS) Task 2 – Performance, reliability and analysis of Photovoltaic Systems that based on EU guidelines and IEC 61724 standard are used to evaluate the efficiency and performance of PV generator in this research. The important parameters and equations for analysis are presented as follows

$$Y_A = E_{A,d} / P_0 \tag{1}$$

Y_A = Array yield (h / d)
$E_{A,d}$ = Array output energy per day (kWh)
P_0 = Nominal power or module power at STC (kW)

$$Y_f = E_{use,PV,day} / P_0 \tag{2}$$

Y_f = Final yield (h / d)
$E_{use,PV,day}$ = $F_A \times E_{use}$
$E_{use,PV,day}$ = Direct PV energy contribution to E_{use} (kWh)

$$F_A = E_A / E_{in} \tag{3}$$

F_A = Fraction of total system input energy contributed by PV array
E_A = Arrey output energy
E_{in} = Total system input energy

$$E_{in} = E_A + E_{BU} + E_{FU} + E_{FS} \tag{4}$$

E_{in} = Total system input energy (kWh)
E_A = Arrey output energy (kWh)
E_{BU} = Energy from back-up system (kWh)
E_{FU} = Net energy from utility grid (kWh)

E_{FS} = Net energy from storage (kWh)

$$E_{use} = E_L + E_{TU} \tag{5}$$

E_{use} = Useful Energy supplied by the system (kWh)

E_L = Energy from PV to loads (kWh)

E_{TU} = Net energy to utility grid (kWh)

$$Y_r = \int_{day} G_I \, dt / G_{STC} \tag{6}$$

Y_r = Reference yield (h / d)

G_I = Global irradiance in the array plane (W/m^2)

G_{STC} = Global irradiance at standard test conditions (W/m^2)

$$L_c = Y_r - Y_A \tag{7}$$

L_c = Array capture losses (h / d)

$$L_s = Y_A - Y_f \tag{8}$$

L_s = System losses (h / d)

$$PR = Y_f / Y_r \tag{9}$$

PR = Performance ratio

$$\eta_{A,mean} = E_A / E_{S,A} \tag{10}$$

$\eta_{A,mean}$ = Mean array efficiency

$$E_{S,A} = H_I \times A_A \quad (11)$$

$E_{S,A}$ = Total solar energy on array plane (kWh)

H_I = Global irradiation in the plane of the array (kWh/m^2)

A_A = Array area (m^2)

$$\eta_{tot} = E_{use,PV} / E_{S,A} \quad (12)$$

η_{tot} = Overall PV plant efficiency

CERTS Microgrid Test-Bed

The CERTS microgrid test-bed is located at Columgus, ohio and it is operated by American Electric Power. It consists of three feeders and one of them is connected with two convertor based sources driven by Natural gas. Second feeder is powered by the same kind of source and other feeder is connected to the utility grid but it can also be powered by distributed generator when static switch is closed. Load banks and fault load points are implemented at each point along the feeders. Communication is done by Ethernet connection in between Energy Management System (EMS) and at dynamic operation communication network is not used. So power sources are operated in distributed autonomous control with plug and play capabilities. There is no central controller implemented in CERT testbed. Droop characteristics of each source are controlled by the real power vs frequency droop and the voltage is maintained using the reactive power vs voltage droop and providing the local stability insure there is no circulating reactive current between sources. The thyristor base static switch is used to control islanding conditions of the microgrid at any disturbance. IEEE P1547 Standard series say that distributed resources should be islanded at any disturbance of the system. In CERT microgrid that can be achieve through the static switch and then distributed resources are islanded and those are operated to serve local loads. Load bank at utility side from the static switch is operated by utility grid. Natural gas driven sources are fairly controllable than other sources like wind power and solar PV. Storage elements are more dominant when there is more intermittent energy sources are connected in to the system.

Review of related research

Hatziargyriou N. D., Dimeas A., Tsikalakis A. G., Pecas Lopes J. A. and Kariniotakis G. [3] describes the main functions required by the MGCC for the efficient MG participation in future real-time markets following different policies. The open market prices and bids coming both from DG sources and loads are considered. The functions developed allow coordinated management of the MG micro-sources, in order to achieve decrease in their operating costs and making MG a viable future power system prospect. The closed-loop price signal control technique and data flow between MGCC and LC are showed in figure 2.

This paper describes the energy market base controlling technique that is a member of power management controlling technique group.

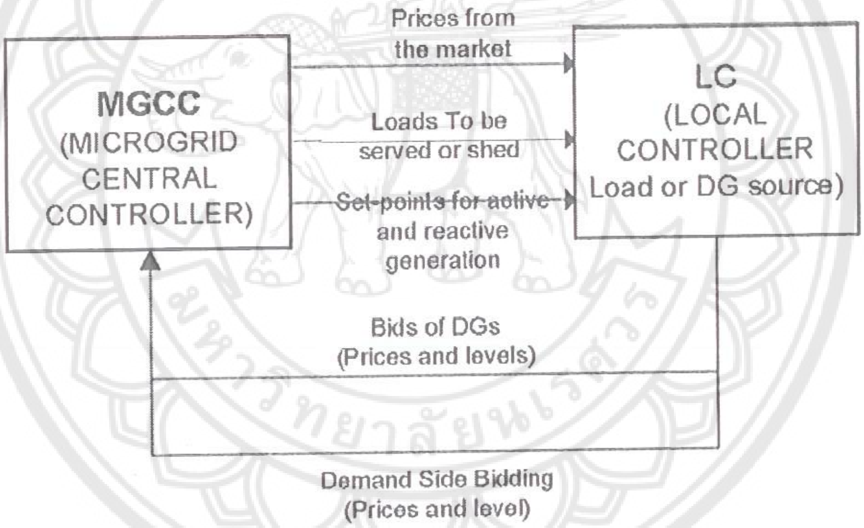


Figure 2 The closed-loop price signal control technique and data flow between MGCC and LC

Funabashi T., Fujita G., Koyanagi K. and Yokoyama R. [4] present control system, operation planning is realized based on generation and load forecasting by using artificial neural network and fuzzy systems. The flowchart of load forecast is displayed in figure 3.Unit commitment of generations includes start/stop of power generations and energy storages. Load following function is accomplished by an adaptive control system based on conventional PI control scheme. To include, in a flexible manner, new generations or loads into the microgrid, multi-agent technologies might be applied. The block diagram of microgrid control using multi-agent system is present in figure 4. The control system can contribute to efficient operation of DGs and stable power supply for customers.

This paper describes the load and generation forecast technique that is members of forecast controlling technique group, the communication controlling technique that is a member of generation controlling technique group, and local base controlling technique that is a member of power management controlling technique group.

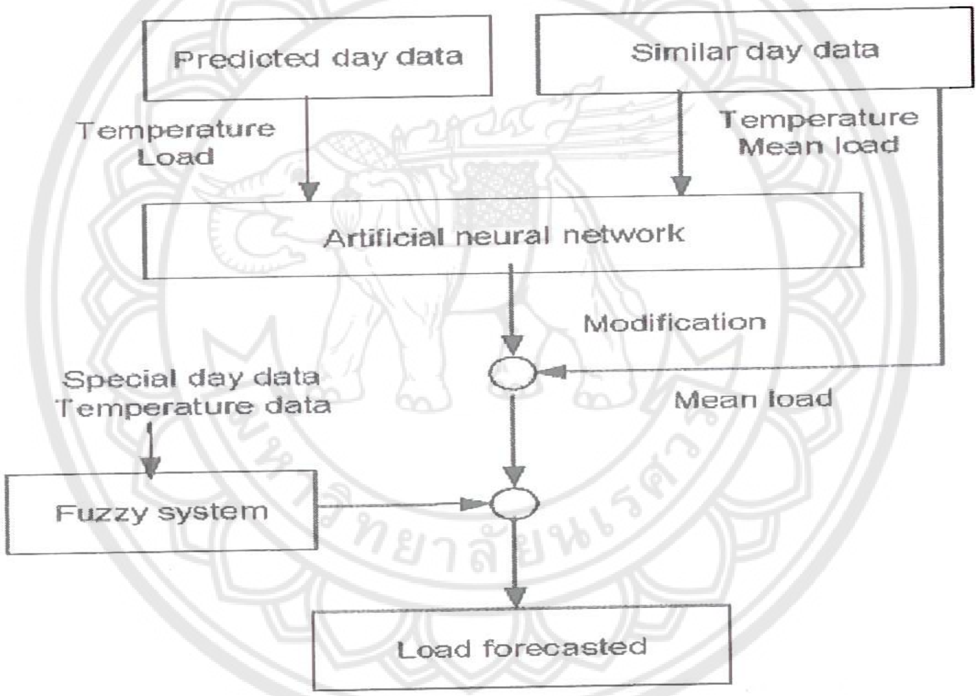


Figure 3 The flowchart of load forecast

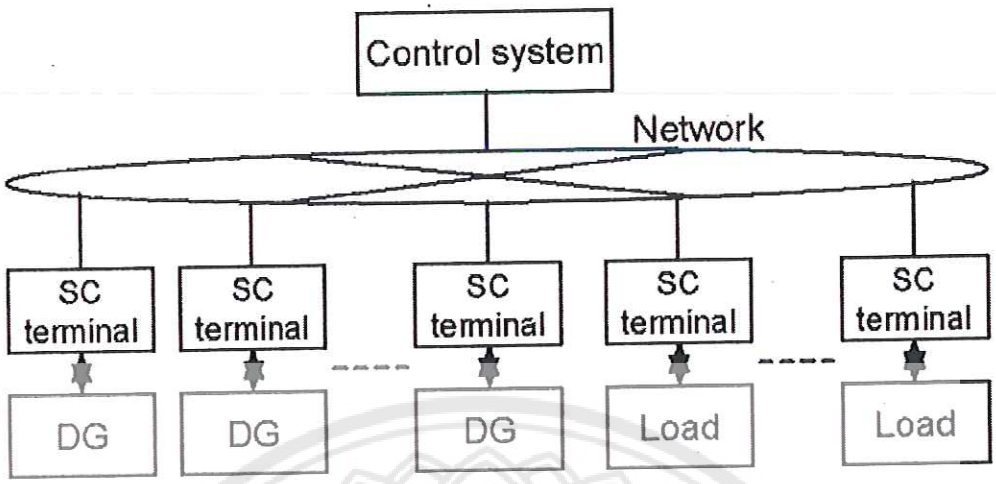


Figure 4 The block diagram of Microgrid control using multi-agent system

Funabashi T. and Yokoyama R. [5] present three field tests of MG in Japan. The MG sites are in Aomori, Aichi, and Kyoto that have total DER capacity 710, 2400, and 750 l& respectively. The microgrid configuration is showed in figure 5. The control systems of the MGs are based on generation and load that forecasting by using neural network and fuzzy systems. The test results, these MG contribute to efficient operation of DGs and stable power supply for customers. The load and supply profile of MG in Japan is displayed in figure 6.

This paper describes the load and generation forecast technique that is a member of forecast contolling technique group, and local base controlling technique that is a member of power management controlling technique group.

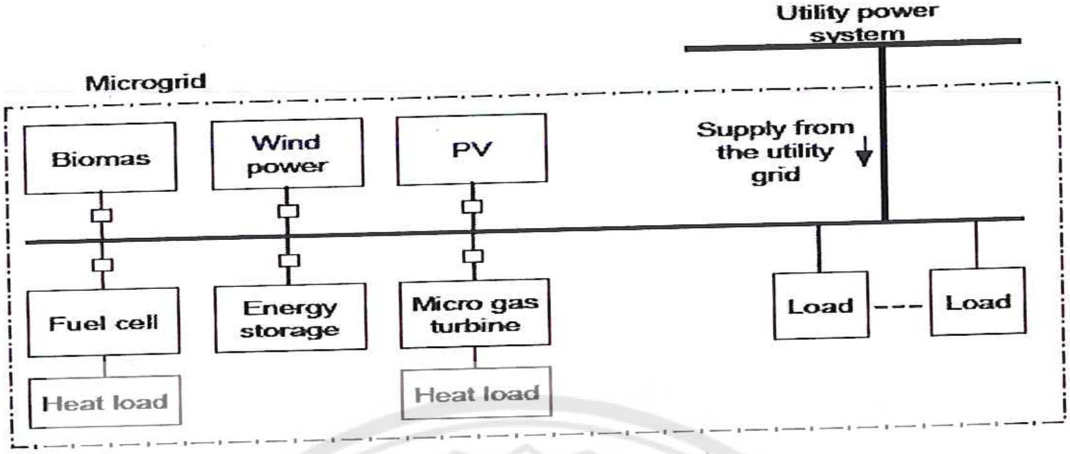


Figure 5 The microgrid configuration

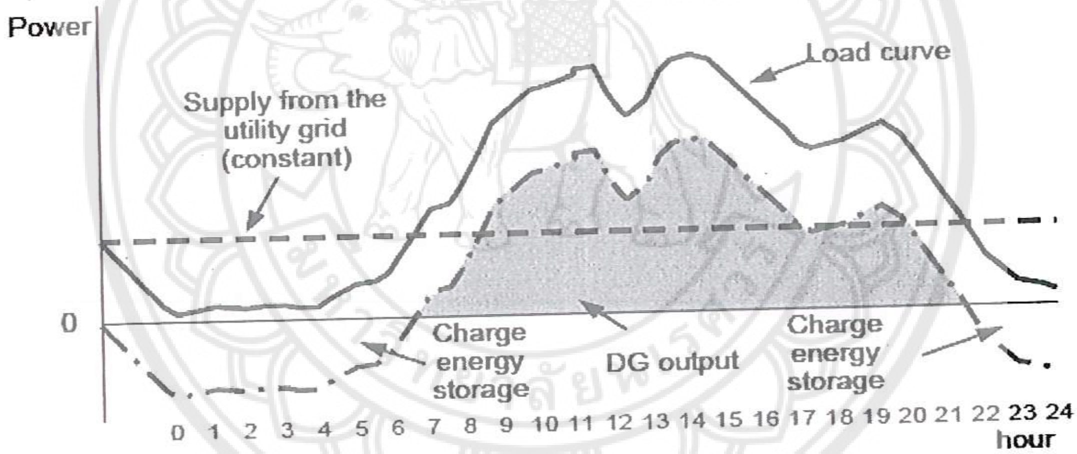


Figure 6 The load and supply profile of MG in Japan

Stevens J., Klapp D.A. and Volikommer H.T. [6] describe field testing of the CERTS MG concepts in an actual hardware installation. The tests cover different scenarios of step load changes and transitions from utility-tied to islanded operation. The tests show that the control algorithms of CERTS MG perform robustly during a variety of transient events such as separation from the utility power system and step load changes while the MG is islanded and able to control either the power output of the individual DGs, or the power flow in the circuit that the DGs are connected to. CERTS Microgrid test bed is showed in figure 7

This paper describes the frequency/voltage droop controlling technique that is a member of generation controlling technique group and local base controlling technique that is a member of power management controlling technique group.

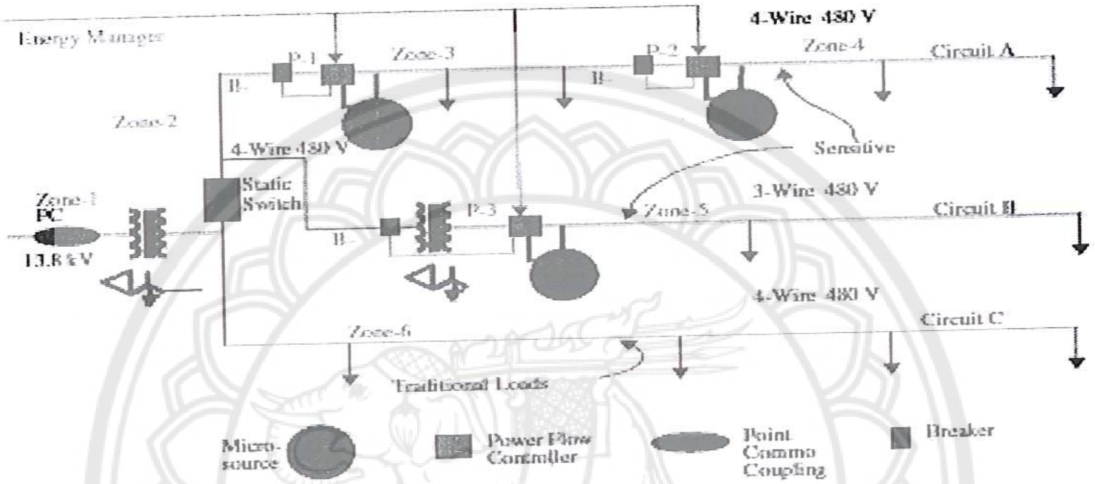


Figure 7 CERTS Microgrid test bed

Celik [7] studied the measure of energy contribution (WF) of WG(s) in stand-alone or hybrid-wind systems with battery storage. It has been studied on a yearly basis. An 8-year long measurement of hourly wind speed data from five different locations throughout the world has been used to determine the yearly WF curves through simulations. Based on the simulated WF curves, a simplified algorithm was derived from estimating the yearly WF for a stand-alone and/or hybrid-wind system. The novel method requires the Weibul wind speed distribution parameters on a yearly basis and the ELR, BLR and some coefficients as input. The output is the yearly WF value. As the comparison of the results from the simplified model with those from the simulation procedure showed, the yearly WF can be predicted with very high accuracy. This approach does not only eliminate the requirement of detailed and complex simulation programs, but it also makes it possible to estimate WF in cases where the measured hour-by-hour wind speed data does not exist. Considering the limited number of sizing and design algorithms for autonomous WESs, either standalone or hybrid, it is safe to say that such simplified algorithms are of a vital importance if WESs are to be alternative to traditional energy systems.

Dimeas and Hatziargyriou [8] designed an agent based operation of a micro grid. The main focus so far has been on the communication of an agent that controls a production unit with its market environment. Preliminary results have shown the feasibility of this approach. Work is in progress in order to build controllable loads linked to the Consumption Unit agents. The most efficient and cheap method to achieve this is by using a PLC (Programmable Logical Controller). The Consumption Unit agent will have measurements in order to estimate the consumption and to make more realistic bids. Furthermore, this agent will have the ability to control the load and to limit it according to the market status or the Micro Grid security. In addition, more sophisticated market operations are tested in order to reveal potential technical problems, like the one presented before (keeping the power at a certain level).

School of Renewable Energy Technology (SERT) Micro grid – Thailand [9]

School of Renewable Energy Technology (SERT) and New Energy and Industrial Technology Development Organization (NEDO) have cooperated for construct the micro grid system in the area of SERT, Naresuan University. The objectives of this system are studying and developing the micro grid system for controlling logic concept for electrical stabilization. The micro gird system, it consist of 120 kW multi-crystalline PV array, 2 set of 60 kW PV inverters, 150 kW battery inverter, 100 kW diesel engine generator, 200 kWh battery bank, static var generator for maintain power stable and controlling unit.

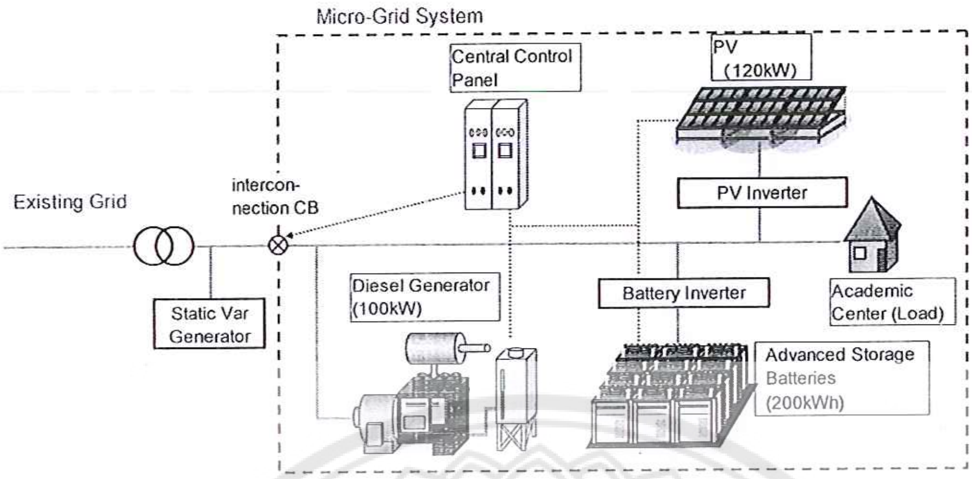


Figure 8 SERT's microgrid system

Data collection of SERT microgrid

The data collection system in SERT microgrid collects the important parameters such as solar irradiance, ambient temperature, module temperature, PV output voltage, PV output current, inverter output voltage, inverter output current, and inverter output power from the sensors that installed in PV generator. The data collection system collects these significant parameters every minute during PV microgrid system operation. The collected data is transferred to graphic operation terminal (GOT) 1000 for displaying and storing in its compact flash memory. The data that stored in the compact flash memory is downloaded to the computer every week for using in system performance evaluation.

Table 1 Microgrid Battery voltage setting

Power	Definition	Time	Action
305 V.	Over voltage.	50 sec.	bat inv trip
300 V.	Over voltage.	1 min.	bat inv trip
290 V.	Over voltage.	3 min.	bat inv trip
280 V.	Over voltage.	5 min.	bat inv trip
185 V	Low voltage	1 min.	alarm

Table 2 Battery SOC setting

SOC	Definition	Action
90%	Upper limit	-
88%	PV output restrain level	-
85%	upper reference	release PV restrain
60%	reference SOC	-
50%	Lower reference	DG stop
32%	DG start	-
30%	Lower limit	-

Logenthiran T, Srinivasan D and Khambadkone A. [10] developed a multi-agent system for energy resource scheduling of an islanded power system with distributed resources, which consists of integrated micro grids and lumped loads. Distributed intelligent multi-agent technology is applied to make the power system more reliable, efficient and capable of exploiting and integrating alternative sources of energy. The algorithm behind the proposed energy resource scheduling has three stages. The first stage is to schedule each micro grid individually to satisfy its internal demand. The next stage involves finding the best possible bids for exporting power to the network and competes in a whole sale energy market. The final stage is to reschedule each micro grid individually to satisfy the total demand, which is the addition of internal demand and the demand from the results of the whole sale energy market simulation. The simulation results of a power system with distributed resources comprising three micro grids and five lumped loads show that the proposed multi-agent system allows efficient management of micro-sources with minimum operational cost. The case studies demonstrate that the system is successfully monitored, controlled and operated by means of the developed multi-agent system.

Laboratory-scale micro grid system at National Technical University of Athens (NTUA) [11] NTUA micro grid test system shown in Figure 11 comprises of two PV generators, one wind turbine, battery energy storage, controllable loads and a controlled interconnection to the local LV grid. Generators are connected to the AC grid via fast-acting inverters. The battery is connected via a bi-directional PWM voltage source converter, which regulates the voltage and frequency when the system operates in the island mode.

The battery inverter operates in voltage control mode (regulating the magnitude and phase/ frequency of its output voltage). When the micro grid operates in parallel to the grid, the inverter follows the grid. The system is built on the Java Agent Development Framework (Jade) 3.0 platform, thus communication language could be either XML or SL. Operation planning of this test micro grid is done using a Multi Agent System (MAS), which consists of four agents:

1. Production Unit: Responsible to control the inverter of the battery. The main tasks are to control the overall status of the batteries and to adjust the power flow depending on the market prices.

2. Consumption Unit: Represents the controllable loads in the system. It knows the current demand and makes estimations of the energy demand for the next 15 min. At every 15 min it makes bids to the available Production Units in order to cover the estimated demand.

3. Power System: Represents the main grid to which the micro grid is connected. According to the market model adopted, the Power System Agent announces the selling and buying prices. It does not participate in the market operation since it is obliged to buy or sell any amount of energy asked for.

4. Micro grid Central Control (MGCC): MGCC is responsible to announce the beginning and the end of a negotiation for a specific period and to record the final power exchanges between the agents in every period.

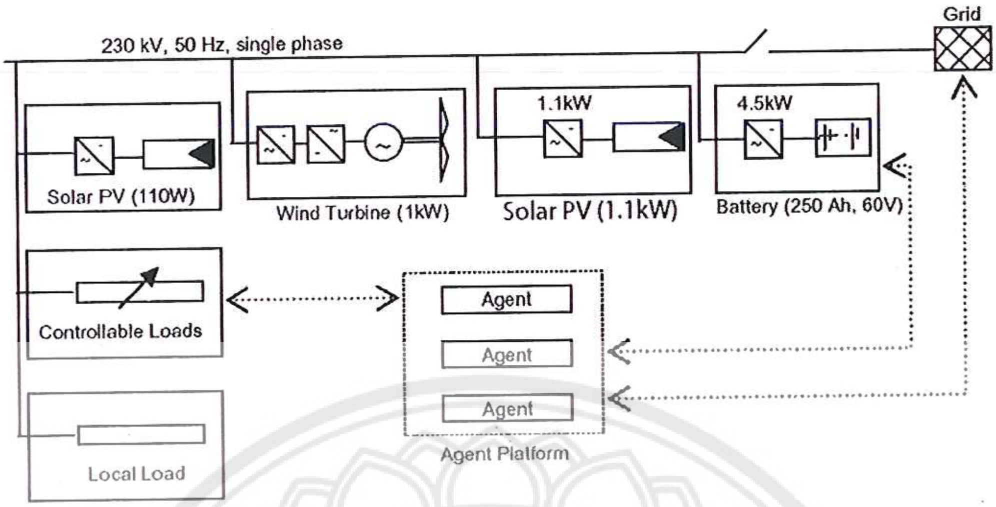


Figure 9 The laboratory microgrid facility at NTUA

Oyarzabal J., Jimeno J., Ruela J., Engler A. and Hardt C. [12] reports a Micro Grid Management System based on intelligent software agent technologies and its application to the effective management of generation & storage devices connected to a LV network forming a micro grid. The micro grid, defined as a set of generation, storage and load systems electrically connected and complemented by a communication system, is successfully monitored, controlled and operated by means of the developed software. The software modular architecture enables additional services for advanced control, such as the deployed generation secondary control system. The effectiveness and applicability of the introduced software has been evaluated by a twofold strategy: on one hand, the management system has been tested on a laboratory environment where real generation, storage and load devices are being monitored and controlled, while on the other hand, performance and scalability issues related to the agent framework have been assessed.

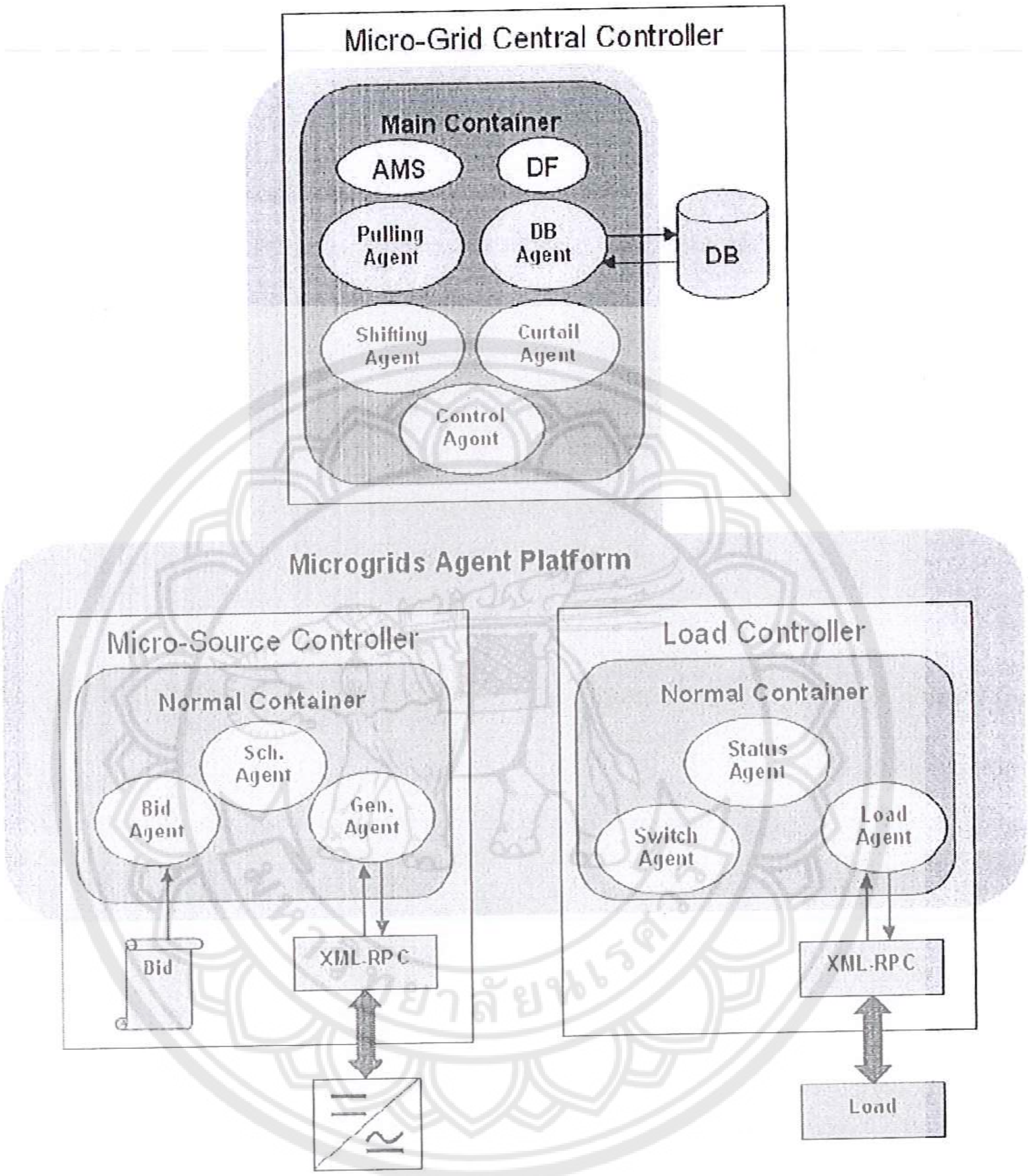


Figure 10 Management system architecture.

Rudd, Catterson and McArthur [13] develop an online condition monitoring systems are used to prolong the life of electrical power equipment by continually monitoring for any signs of faults, name "Condition Monitoring Multi-Agent System (COMMAS)". To be of most use, a condition monitoring system should be flexible enough to accommodate various sensors and different data interpretation techniques. To provide such flexibility this system proposes an agent-based architecture, where autonomous modules (agents) perform separate parts of the data management and interpretation tasks. This means that only the agents associated with required tasks need to be deployed. This system presents an example of a flexible agent-based system that can be used to diagnose defects in a power transformer using data from various sensors.

The agent-based architecture also provides an extensible framework to integrate different types of data interpretation. This paper shows this by detailing the addition of further interpretation agents for pattern recognition, diagnosis and learning. One employs a knowledge-based approach to diagnose defects in transformers, based on fundamental partial discharge behaviors. Other agents provide on-line learning of the plant behaviors, automatically identifying normal and abnormal modes, leading to advanced anomaly detection capabilities.

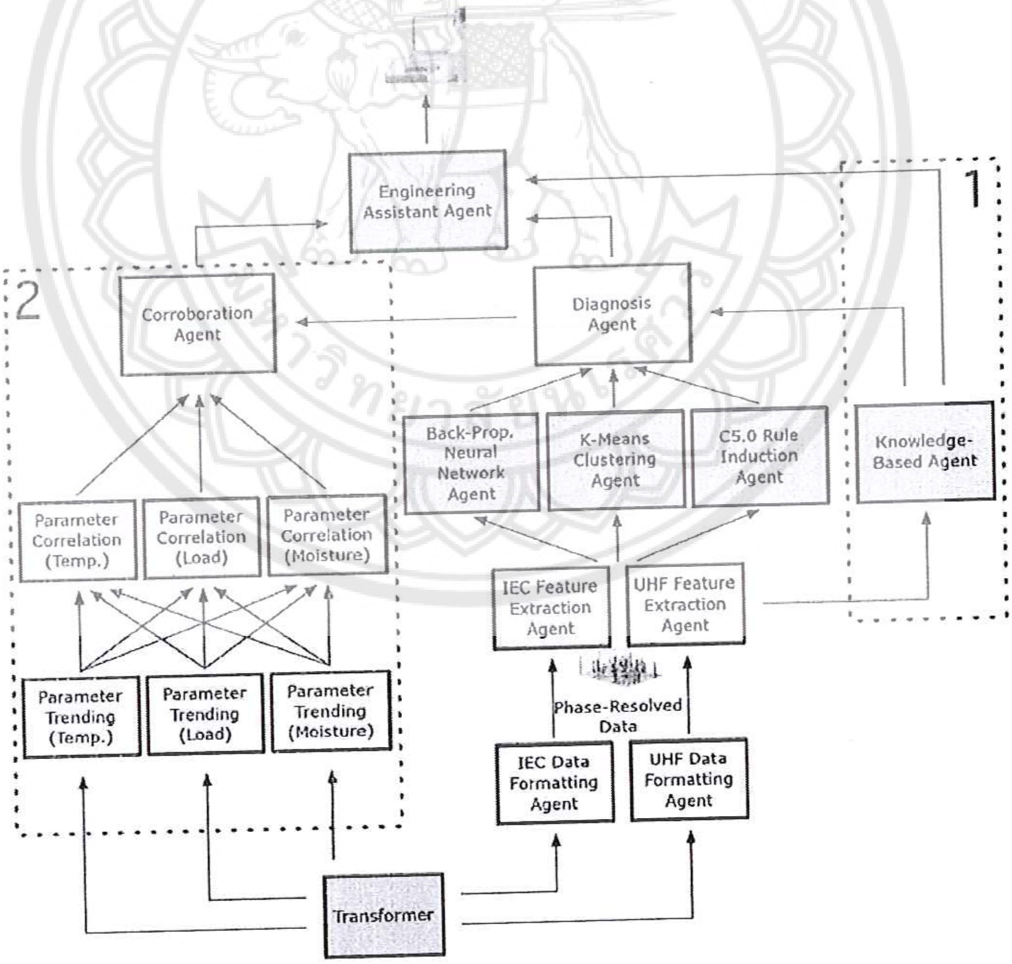


Figure 11 COMMAS Architecture

Manika Nakaththalage Suranjith Ariyasinghe, Kullappu Thantrige Manjula Udayanga Hemapala [14] The scares of conventional energy resources and negative environmental impact of non renewable energy recourses are accelerating the technologies for new non conventional environment friendly energy options. Most of utility the grids are saturated with bulk energy resources but there are plenty of available small scale energy resources distributed around regions. Most of them are identified as wind, photo voltaic (PV), solar thermal and waste heat from industries and cooling tower of combined cycle power plants. It is difficult to gain full potential from these renewable energy resources as when they are connected to the power system individually, it leads to hindering the system stability. Microgrid is an attractive option to harness the benefits offered by distributed generation, eliminating constraints on high penetration of Distributed Energy Resources (DER). The microgrid provides an interface between central grid and micro devices to overcome these individual integration issues. So microgrid should capable to address those issues to optimize grid stability and power quality. Control system of the microgrid can be discriminated as voltage and frequency control, power flow balancing, load sharing, and protection as well as islanding and resynchronization. This research is focused on design and development of a microgrid test-bed for experimenting several kinds of microgrid topologies and coordination of individual components with a well defined energy management scheme.

N. W. A. Lidula and A. D. Rajpakshe [15] The Residential Microgrid of Am Steinweg in Stutensee. This microgrid system is connected to the medium voltage (20 kV) network through a 400 kVA transformer. Distributed energy sources used in this microgrid is CHP at 28 kW and PV systems at 35 kW and storages are battery bank with 880 Ah. 100 kW bidirectional inverters are used at battery banks to convert energy. The maximum power through the transformer is 150 kW [21]. After reviewing of several published research papers, Table 1 has formulated with the available microgrid test beds. According to the findings most of the test-beds are equipped with solar PV, Solar thermal, wind and CHP. But uses of micro or mini hydros are rare. Therefore the authors are specifically looking in that area as it is more important in countries like Sri Lanka. Sri Lanka has good potential of micro and mini hydro schemes which are currently serving for rural areas.

Table 3 Type of microgrid operation systems

No.	Region	places	Centralized	Autonomous	Agent based
1	Asia	Aichi, Japan	X	-	-
2	Asia	Kyoto Eco-Energy, Japan	X	-	-
3	Asia	Hachinohe, Japan	X	-	-
4	Asia	CRIEPI, Japan	X	-	-
5	Asia	Sendai, Japan	X	-	-
6	Asia	HFUT, China	-	-	X
7	Asia	Lab-scale, China	X	-	-
8	Asia	IET, India	X	-	-
9	Asia	SERT, Thailand	X	-	-
10	Europe	Bronsbergen, Netherland	X	-	-
11	Europe	DeMoTec, German	X	-	-
12	Europe	Kythnos, Greece	X	-	-
13	Europe	Am Steinweg, German	-	-	X
14	Europe	NTUA, Greece	-	-	X
15	Europe	CESIRICERCA, Italy	-	-	X
16	Europe	Uni. Of Manchester, UK	X	-	-
17	North America	Boston Bar, Canada	-	X	-
18	North America	Boralex, Canada	-	X	-
19	North America	CERTS, US	-	X	-
20	North America	UW, US	-	X	-

The operation system of microgrid power plant separate into three type such as Centralized microgrid operation system, Autonomous microgrid operation system and Agent-based microgrid operation system.

Centralized microgrid operation system

Centralized microgrid operation system is a normal operation system for microgrid power plant. All function of power plant can be operate by manual using PLC (Programmable Logic Control) or SCADA (Supervisory Control and Data Acquisition) that install at control station. And operating with coded signals over communication channels to provide control remote equipment.

Autonomous microgrid operation system

Autonomous microgrid operation system is the operation system that have automatic function to operate power plant by using embedded controllers within autonomous system, A basis for autonomous operation system is distributed sensor or actuator systems. By sharing information among microgrid power plant and used computerize to operate equipment.

Agent-based microgrid operation system

Agent-based microgrid operation system is the operation system that smarter than Autonomous control system. It can operate all function of power plant by using software agent to think and making decision to operate system by using information from environment and other agent in the system for higher performance.

From table 3. Show surveyed result from 20 microgrid power plant around the world, in Asia, Europe and North America. Founded only four microgrid power plant that used agent based in operation system include of Am Steinweg microgrid power plant, Germany. National Technical University of Athens (NTUA), Greece. CESI RICERCA, Italy and only one in Asia at HFUT, China.

Mostly microgrid power plant include SERT used centralized operation system.

CHAPTER III

RESEARCH METHODOLOGY

In this research will evaluate the energy management system (EMS) for SERT's 120 kW microgrid that install at School of Renewable Energy Technology (SERT), Naresuan University. There are 5 main steps of the dissertation methodology as following.

1. Reviewing literatures.
2. Design EMS, database and agent based.
3. Developing database.
4. Developing Agent-based Software.
5. Developing Energy management system.
6. System analyze.

In this research, database and EMS will developed by using RDBMS theory (Relational database management system) and develop a software agent by using an agent-based modeling. They are the technologies to use in developing a model for forecasting the future results. Also, we will develop a database by using SQL (Structured Query Language) and develop an EMS by using PHP language and use ODBC (Open Database Connectivity) to connect the EMS and the database.

And when database, EMS and agent-based model were developed, the system administrator can use a software agent to retrieve some necessary data from the database to analyze. Microgrid energy management system was consider the energy management concept as follows:

System efficiency, Energy loss and Utilization factor (Solar fraction) The software agent will simulate and forecast the necessary data such as, PV energy power, PV voltage and current, Load demand (academic center), Performance ratio, Array yield, Final yield, Array capture loss, System loss and Solar fraction

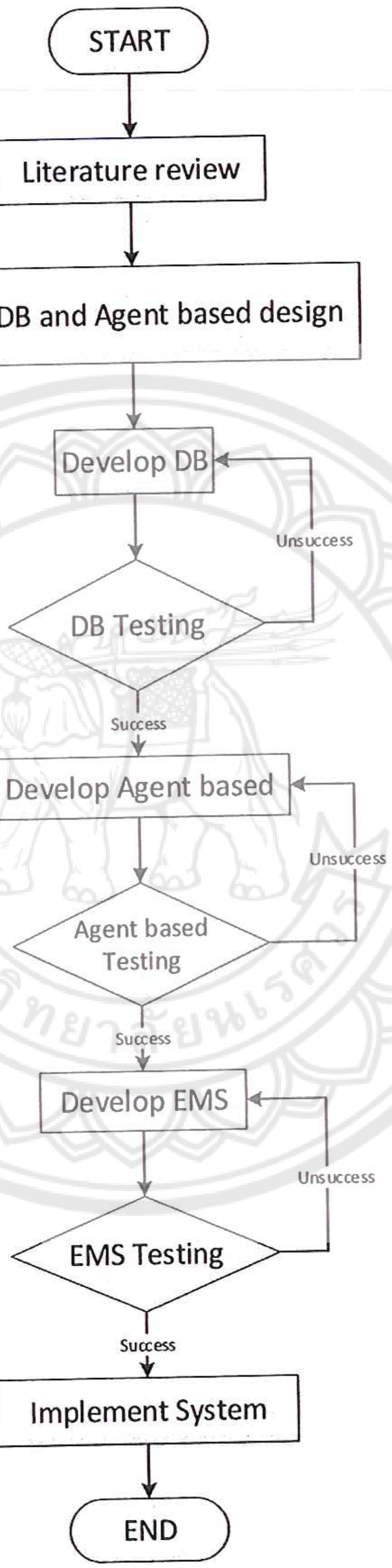


Figure 12 Flow chart of dissertation methodology

Parameters and equations used in Performance evaluation procedure

Input parameter such as Solar irradiance, Ambient temperature, Module temperature, PV output voltage, PV output current, Inverter output voltage, Inverter output current and Inverter output power

Governing equations, The technical analysis processes of International Energy Agency Photovoltaic Power Systems (IEA PVPS) Task 2–Performance, Reliability and Analysis of Photovoltaic Systems that based on EU guidelines and IEC 61724 standard are used to evaluate the efficiency and performance of PV generator in this research. The important parameters and equations for analysis are presented as follows:

Performance ratio

$$PR = Y_f / Y_r \tag{1}$$

Where

PR = Performance ratio

Y_f = Final yield (h / d)

Y_r = Reference yield (h / d)

Final PV system yield (Final yield)

$$Y_f = E_{use,PV,day} / P_0 \tag{2}$$

Where

Y_f = Final yield (h / d)

$E_{use,PV,day}$ = $F_A \times E_{use}$

$E_{use,PV,day}$ = Direct PV energy contribution to E_{use} (kWh)

Energy from PV array (Array yield)

$$Y_A = E_{A,d} / P_0 \tag{3}$$

Where

Y_A = Array yield (h / d)

$E_{A,d}$ = Array output energy per day (kWh)

P_0 = Nominal power or module power at STC (kW)

Reference yield

$$Y_r = \int_{day} G_I \, dt / G_{STC} \tag{4}$$

Where

Y_r = Reference yield (h / d)

G_I = Global irradiance in the array plane (W/m^2)

G_{STC} = Global irradiance at standard test conditions (W/m^2)

Solar Fraction

$$F_A = E_A / E_{in} \tag{5}$$

Where

F_A = Fraction of total system input energy contributed by PV array

E_A = Arrey output energy

E_{in} = Total system input energy

Total system input energy

$$E_{in} = E_A + E_{BU} + E_{FU} + E_{FS} \qquad (6)$$

Where

E_{in} = Total system input energy (kWh)

E_A = Arrey output energy (kWh)

E_{BU} = Energy from back-up system (kWh)

E_{FU} = Net energy from utility grid (kWh)

E_{FS} = Net energy from storage (kWh)

Useful Energy supplied by the system

$$E_{use} = E_L + E_{TU} \qquad (7)$$

Where

E_{use} = Useful Energy supplied by the system (kWh)

E_L = Energy from PV to loads (kWh)

E_{TU} = Net energy to utility grid (kWh)

Array capture losses

$$L_c = Y_r - Y_A \qquad (8)$$

Where

L_c = Array capture losses (h / d)

Y_r = Reference yield (h / d)

Y_A = Array yield (h / d)

System losses

$$L_s = Y_A - Y_f \tag{9}$$

Where

L_s = System losses (h / d)

Y_A = Array yield (h / d)

Y_f = Final yield (h / d)

Mean array efficiency

$$\eta_{A,mean} = E_A / E_{S,A} \tag{10}$$

Where

$\eta_{A,mean}$ = Mean array efficiency

E_A = Array output energy per day (kWh)

$E_{S,A}$ = Total solar energy on array plane (kWh)

Total solar energy on array plane

$$E_{S,A} = H_I \times A_A \tag{11}$$

Where

$E_{S,A}$ = Total solar energy on array plane (kWh)

H_I = Global irradiation in the plane of the array (kWh/m^2)

A_A = Array area (m^2)

Overall PV plant efficiency

$$\eta_{tot} = E_{use,PV} / E_{S,A} \tag{12}$$

Where

η_{tot} = Overall PV plant efficiency

E_{use} = Useful Energy supplied by the system (kWh)

$E_{S,A}$ = Total solar energy on array plane (kWh)

PV equation

$$P_{PV} = \begin{cases} P_{stc}\frac{G_{ING}}{G_{STC}}(1 + k(T_c - T_r)) & (G_{ING} > C) \\ 0 & (G_{ING} \le C) \end{cases} \tag{13}$$

Where

P_{PV} = the output power of the module at irradiance GING;

P_{STC} = the module maximum power at the standard condition;

G_{ING} = the incident irradiance;

G_{STC} = the standard irradiance of 1000w/m2;

k = the temperature coefficient of power;

T_c = the cell temperature;

T_r = the reference temperature 25 (C;

C = a threshold value constant according to the performance of the PV cell.

Battery equation

$$SOC = 1 - \frac{Q_d}{C_{bat}} \tag{14}$$

Where

SOC = battery state of charge

Q_d = quantity of charge missing in the battery

C_{batt} = battery capacity

EMS equation

$$E = \{(PV + Bat + DG) - load\} \tag{15}$$

Where

E = energy supply to grid/load (+,-) (kWh)

PV = energy from PV (kWh)

Bat = energy from battery (kWh)

DG = energy from diesel generator (kWh)

Load = energy supply to load (kWh)

When the EMS have summary data from the agent-bases, the system administrator will use it in a decision support process for power plant planning. The analyzed data will show as follows:

1. Energy production from a micro grid power plant.
2. Energy that supplies the load.
3. Load demand
4. Energy loss in system.
5. Solar fraction.

Lastly, when the system administrator have the analyzed data, the system administrator can bring it to compare with the data from the system without an EMS agent-base. Afterwards, the research can concluded.

The results from the EMS can be displayed on the internet through PC, tablet, laptop, smart phone and other mobile devices.

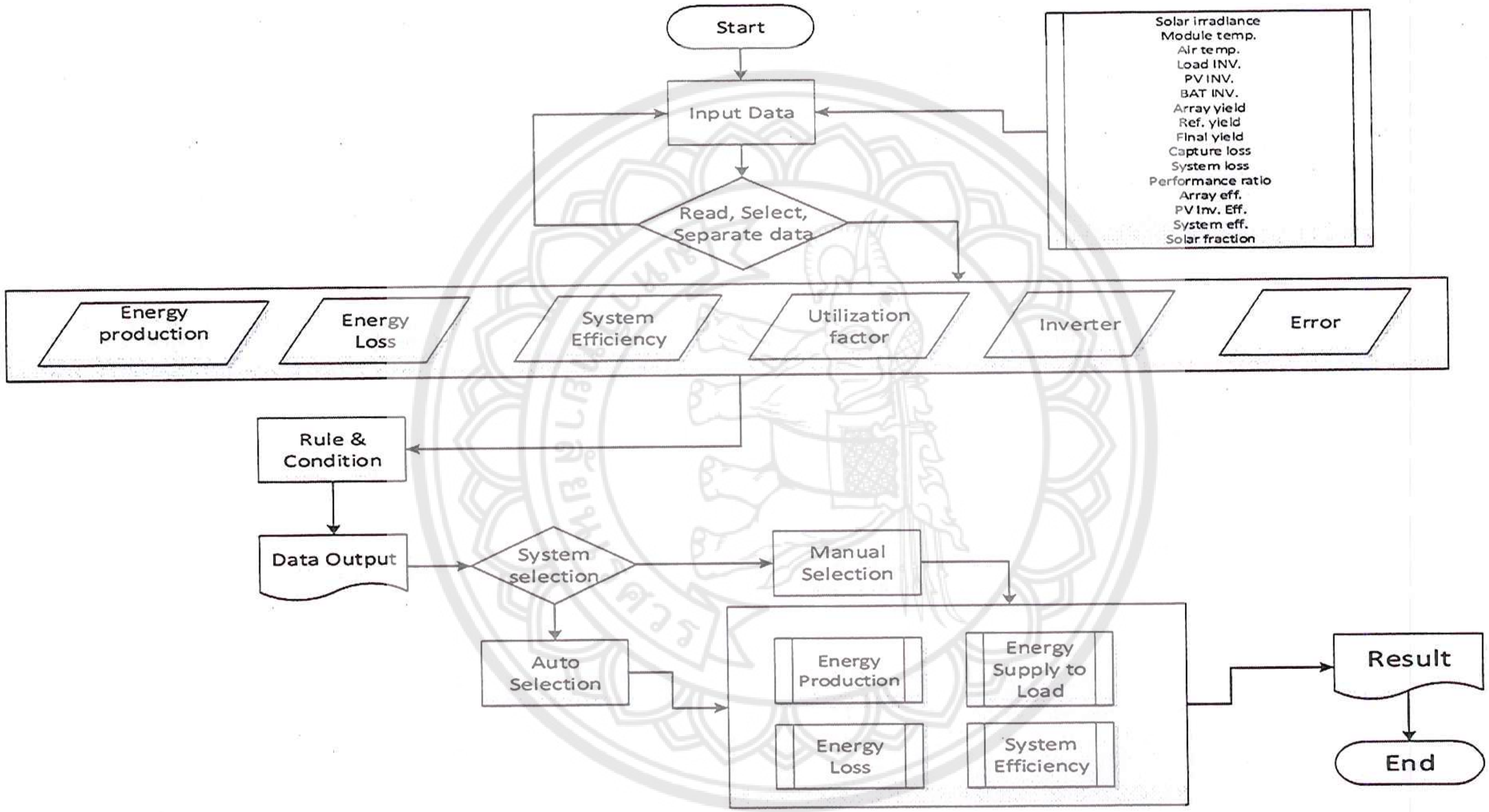


Figure 13 Flow chart of the simulation

Software

1. PHP : Hypertext Preprocessor is free software released under the PHP License, which is incompatible with the GNU General Public License (GPL). PHP can be deployed on most web servers and also as a standalone shell on almost every operating system and platform, PHP is freeware.

2. SQL(MySQL) : MySQL is a relational database management system (RDBMS) and most popular open source database, MySQL

3. ODBC : (Open Database Connectivity) is a standard programming language for accessing database management systems (DBMS). This connector is free of charge.

4. Windows server 2003 enterprise is a server operating system produced by Microsoft

EMS design

The energy management system design for operate over the internet by personal computer, laptop computer, tablet, smart phone or other mobile devices. It have three main function such as system report, system monitor and system simulation. As show in figure 15.

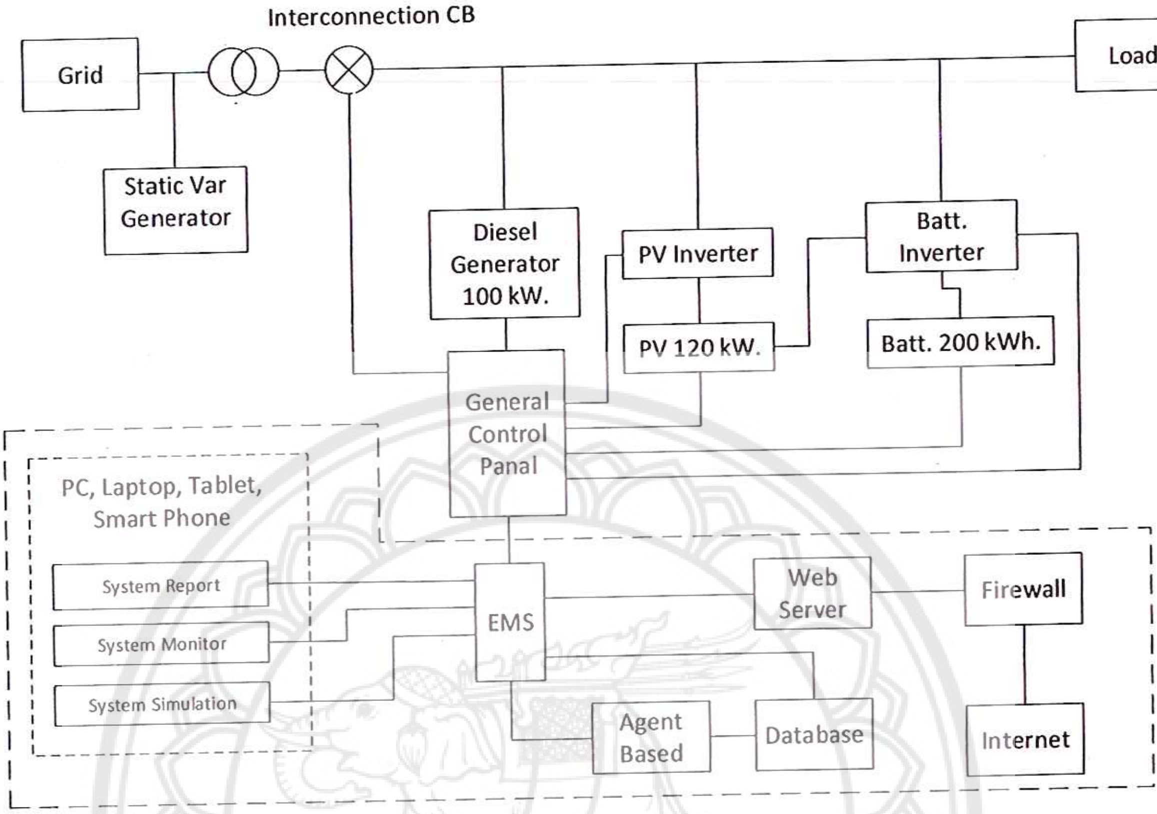


Figure 14 EMS diagram

Developing software process diagram

Waterfall model is a model to explain develop program computer system process. Waterfall model starting from the top-down hierarchy. In Each step, if not complete, can return to the previous step. Start from search for system requirement, do data analysis, system design, coding program, testing program and implement system. As show in figure 16.

Agent based design

Agent based design from FIPA's Agent based management reference model in figure 16. Each agent compose of four module such as data collecting module for collect data from database, decision making module to make decision from condition rule, action module to take action by condition rule and get/store data from environment to data collecting module and last, communication module to connect with other agents. Agent based design as show in figure 17.

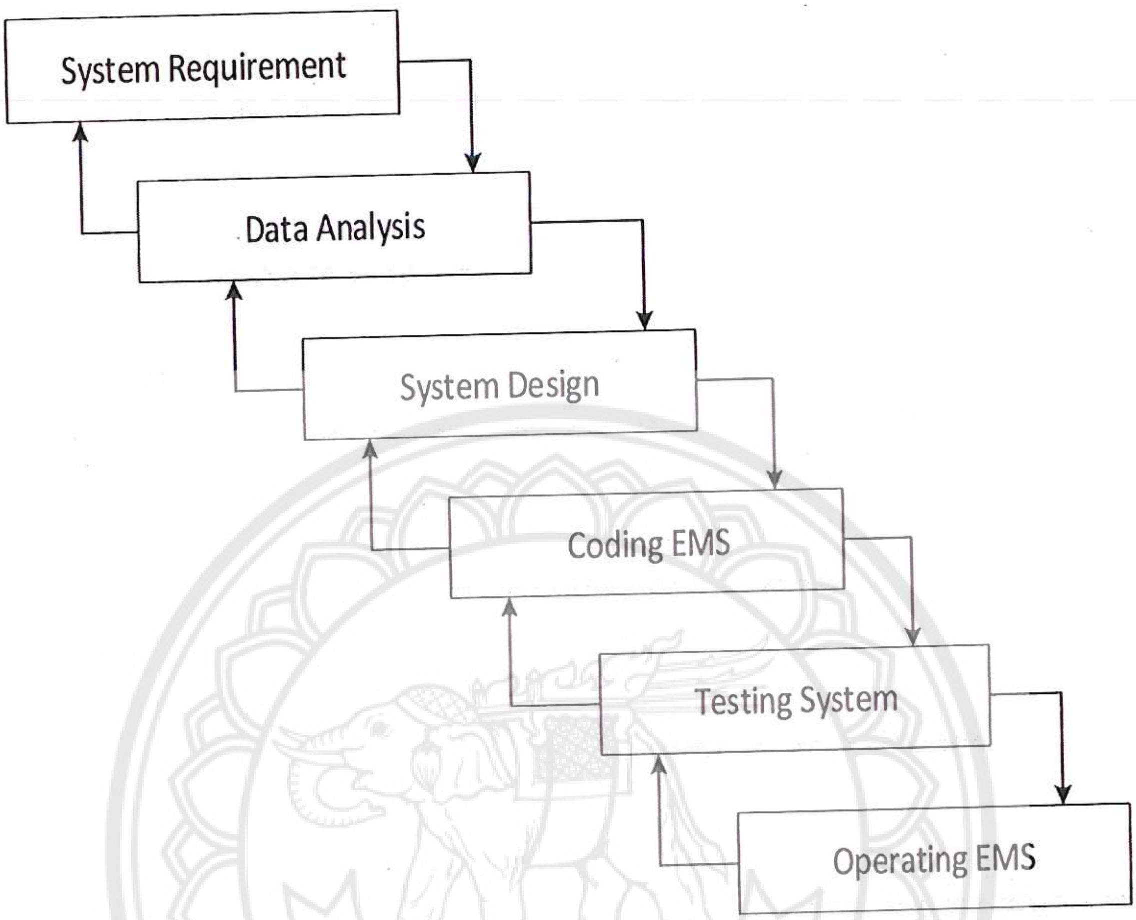


Figure 15 Developing software process diagram: Waterfall model

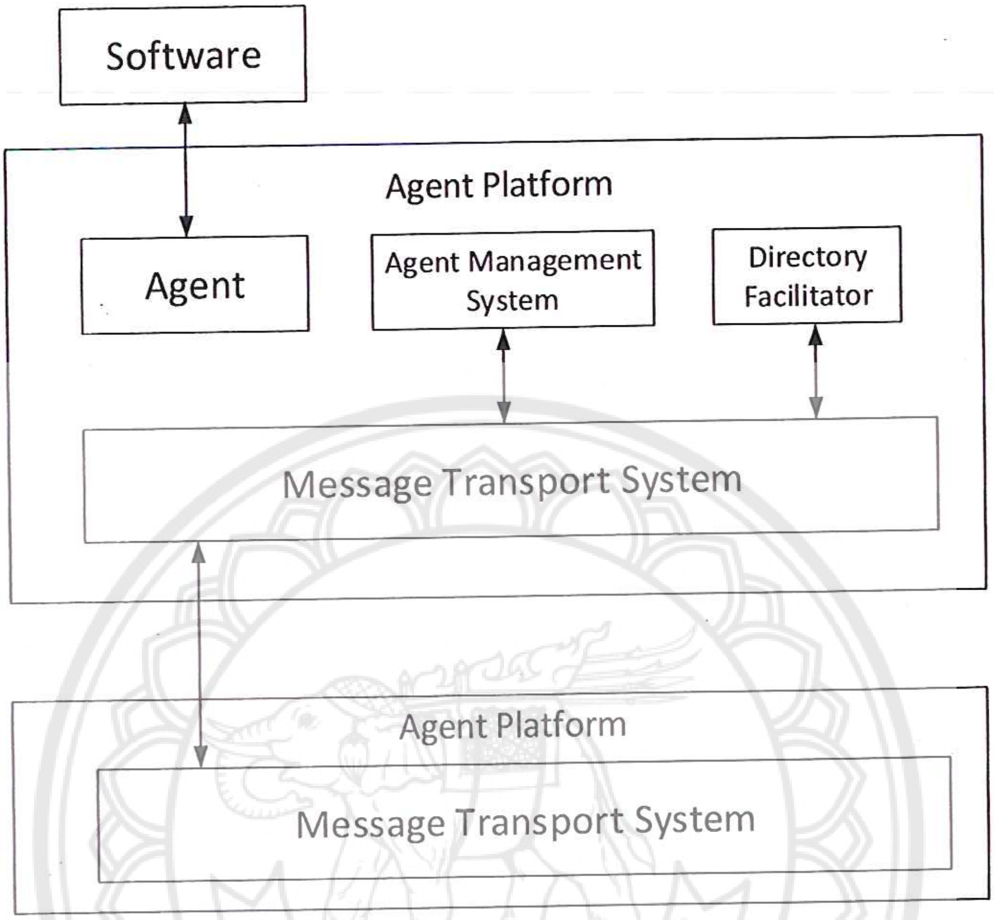


Figure 16 FIPA's Agent based management reference model

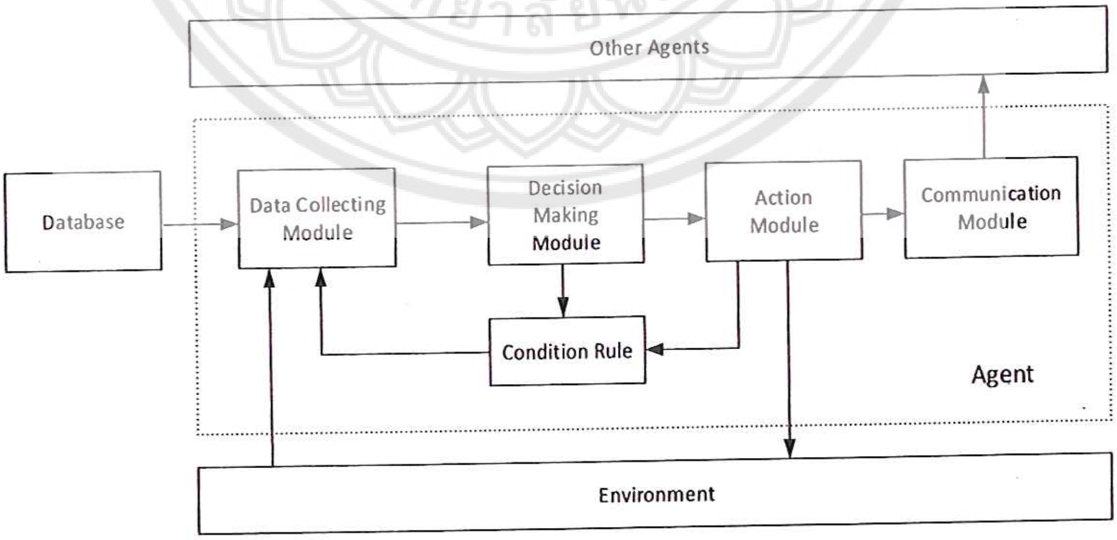


Figure 17 Agent based design for EMS

Database design

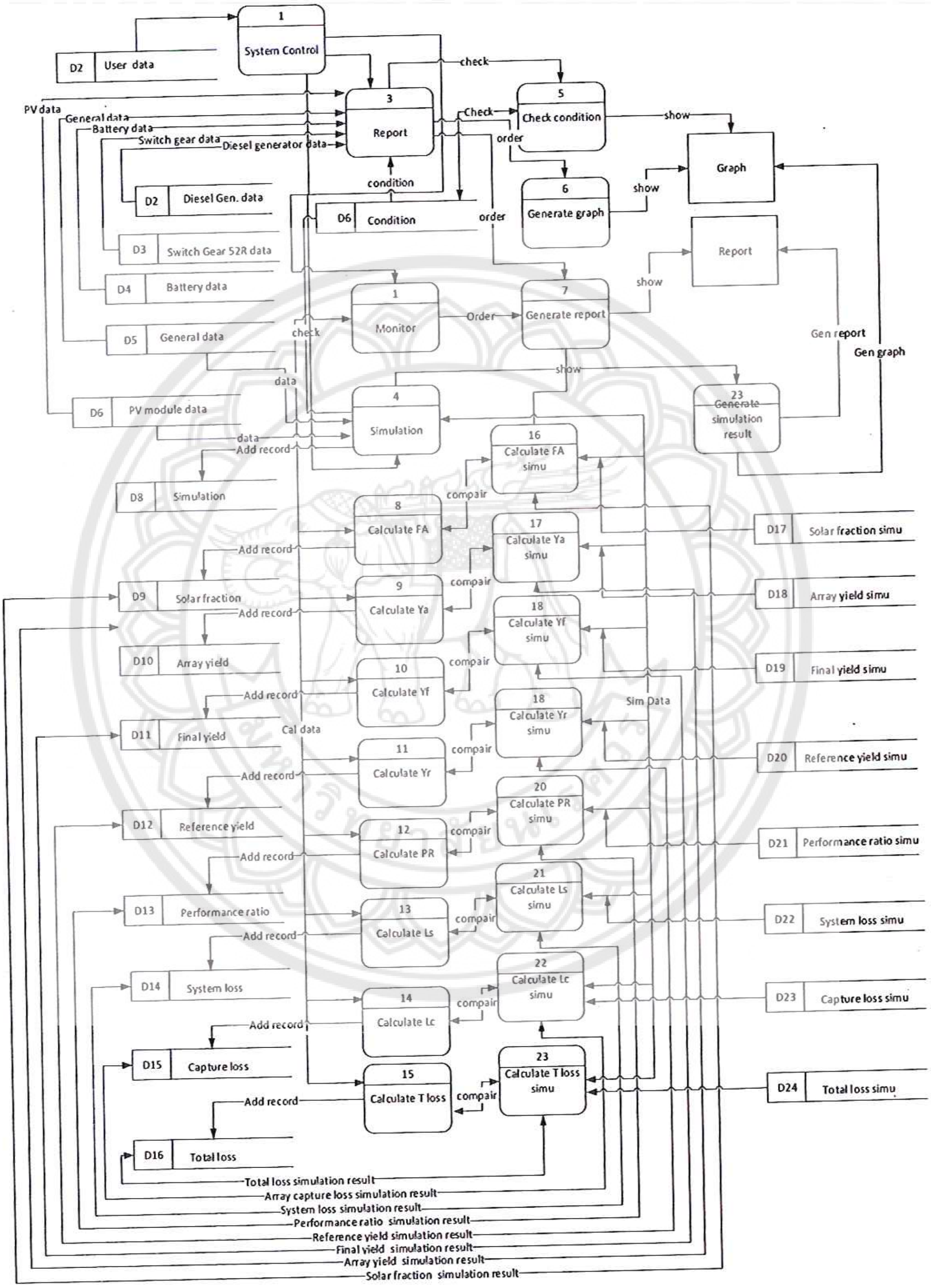


Figure 18 EMS data flow diagram.

From figure 18 EMS data flow diagram have 24 process and 24 data store. All process such as system control, monitor, report, simulation, check condition, generate graph, generate report, calculate solar fraction (FA), calculate array yield (Ya), calculate final yield (Yf), calculate reference yield (Yr), calculate performance ratio (PR), calculate system loss (Ls), calculate array capture loss (Lc), calculate total loss (Tloss), calculate simulation solar fraction (FA), calculate simulation array yield (Ya-simu), calculate simulation final yield (Yf-simu), calculate simulation reference yield (Yr-simu), calculate simulation performance ratio (PR-simu), calculate simulation system loss (Ls-simu), calculate simulation array capture loss (Lc-simu), calculate simulation total loss (Tloss-simu). And all of data store such as user data, diesel generator data, switch gear 52R data, battery data, general data, condition, simulation, solar fraction, array yield, final yield, reference yield, performance ratio, system loss. Capture loss, total loss, simulation solar fraction, simulation array yield, simulation final yield, simulation reference yield, simulation performance ratio, simulation system loss. simulation Capture loss and simulation total loss.

Data Overview

SERT's Micro grid System use Mitsubishi's PLC (GOT1000) that connects from 30 Data logger in system. And each data logger will record 8,005 data witch make the system have 240,150 records per day.

All data can separate to 5 groups

1. General information
2. Data from PV modules
3. Data from Battery & Inverter
4. Data from Switch GEAR 52R
5. Data from Diesel Generator

System Parameter

General Information Parameter data, index and size of storage show in table 4.

Table 4 General Information Parameter

Index	Datail	Size
A	Daily logging data	5
N	Quantity of Solar Radiation	5
O	Outside Temperature	2
X	Transformer Panel MCCB1 Open	1
AZ	Manipulative Value of Inverter Output W	5
BA	Manipulative Value of Inverter Output Var	5
BO	Manipulative P Value to Adjust	3
BP	Manipulative Q Value to Adjust	3
BQ	Local Control Use 1:Use	1
BR	Local Control Device Fault	1
CJ	Operation Mode (RMOTE/MANUAL (LOCAL)) 1:REMOTE	1
CL	SVG Operation 1:Run	1
DH	Main Load(Academic Center) Wh(Lower part)	5
DI	Main Load(Academic Center) Wh(Upper part)	5
DJ	52R Close 1:Close	1
DK	MCCB1 Close 1:Close	1
DL	MCCB2 Close 1:Close	1
DM	SGP Failure (Integrated Alarm)	3
DN	House Consuming Wh (Lower part)	5
DO	House Consuming Wh (Upper part)	5
DP	PTP Failure (Integrated Alarm)	3
DQ	Manipulative Interconnection Point Power	5
DR	Manipulative Interconnection Point P Factor	5
DS	PV_HIT Wh (Present 30m Value)	5
DT	PV_HIT Wh1 (30m Later Value)	5
DU	PV_HIT Wh1 (60m Later Value)	5

Table 4 (cont.)

Index	Datail	Size
DV	Load_HIT Wh (Present 30m Value)	5
DW	Load_HIT Wh1 (30m Later Value)	5
DX	Load_HIT Wh1 (60m Later Value)	5
DY	PV Stop Instruction	3

Data from PV modules parameter, index and size of storage show in table 5.

Table 5 Data from PV modules

Index	Datail	Size
B	PV Inverter Output Active Power	3
C	PV Inverter Output Reactive Power	3
D	PV Inverter Output Current(AC) R Phase	5
E	PV Inverter Output Current(AC) S Phase	5
F	PV Inverter Output Current(AC) T Phase	5
G	PV Inverter Output Current(AC) N Phase	5
H	PV Inverter Output Wh(Lower part)	5
I	PV Inverter Output Wh (Upper part)	5
J	NO.1 PV Inverter Input Voltage(DC)	5
K	NO.1 PV Inverter Input Current(DC)	5
L	NO.2 PV Inverter Input Voltage(DC)	5
M	NO.2 PV Inverter Input Current(DC)	5
P	Manipulative Reduced Value of NO.1 PV Out. W	5
Q	Manipulative Reduced Value of NO.2 PV Out. W	5
R	NO.1 PV Operation Status 1:Ope	5
S	NO.2 PV Operation Status 1:Ope	5

Table 5 (cont.)

Index	Datail	Size
T	NO.1 PV INV. Integrated Alarm(Inv. Abnormality)	5
U	NO.2 PV INV. Integrated Alarm(Inv. Abnormality)	5
V	NO.1 PV INV. Integrated Alarm(Grid Abnormality)	5
W	NO.2 PV INV. Integrated Alarm(Grid Abnormality)	5
Y	PV Module Temperature 1	3
Z	PV Module Temperature 2	3
AA	PV Module Temperature 3	3
AB	PV Module Temperature 4	3

Data from Battery & Inverter parameter, index and size of storage show in table 6.

Table 6 Data from Battery & Inverter

Index	Datail	Size
AC	BAT Inverter Output Active Power	3
AD	BAT Inverter Output Reactive Power	3
AE	BAT Inverter Output Voltage (AC) R Phase	5
AF	BAT Inverter Output Current (AC) R Phase	5
AG	BAT Inverter Output Current (AC) S Phase	5
AH	BAT Inverter Output Current (AC) T Phase	5
AI	BAT Inverter Output Current (AC) N Phase	5
AJ	BAT Inverter Output Frequency	5
AK	BAT Inverter Charge Wh(AC)(Lower part)	5
AL	BAT Inverter Charge Wh(AC)(Upper part)	5
AM	BAT Inverter discharge Wh(AC)(Lower part)	5
AN	BAT Inverter Discharge Wh(AC)(Upper part)	5

Table 6 (cont.)

Index	Datail	Size
AO	Bat Inverter Input Voltage(DC)	3
AP	Bat Inverter Input Current(DC)	3
AQ	BAT Inverter Charge Wh(DC)(Lower part)	5
AR	BAT Inverter Charge Wh(DC)(Upper part)	5
AS	BAT Inverter discharge Wh(DC)(Lower part)	5
AT	BAT Inverter Discharge Wh(DC)(Upper part)	5
AU	BAT State of Charge(SOC)	3
AV	BAT Inverter Charge Wh(Lower part)	5
AW	BAT Inverter Charge Wh(Upper part)	5
AX	BAT Inverter Discharge Wh(Lower part)	5
AY	BAT Inverter Discharge Wh(Upper part)	5
BB	BAT Inverter Grid Connected Operation 1:Connect	1
BC	BAT Inverter PQ Control Mode	1
BD	BAT Inverter Device Fault	1
BE	Battery Temperature 1	3
BF	Battery Temperature 2	3
BG	Battery Temperature 3	3
BH	Battery Temperature 4	3

Data from Switch GEAR 52R parameter, index and size of storage show in table 7.

Table 7 Data from Switch GEAR 52R

Index	Datail	Size
BI	52R Secondary(Bus) R Phase Voltage	5
BJ	52R Secondary(Bus) S Phase Voltage	5
BK	52R Secondary(Bus) T Phase Voltage	5
BL	52R Secondary(Bus) Active Power	3
BM	52R Secondary(Bus) Reactive Power	3
BN	52R Secondary(Bus) Frequency	5
CM	52R Primary (P System Side) Active Power	3
CN	52R Primary (P System Side) Reactive Power	3
CO	52R Primary (P System Side) Voltage (R Phase)	5
CP	52R Primary (P System Side) Voltage (S Phase)	5
CQ	52R Primary (P System Side) Voltage (T Phase)	5
CR	52R Primary (P System Side) Current (R Phase)	5
CS	52R Primary (P System Side) Current (S Phase)	5
CT	52R Primary (P System Side) Current (T Phase)	5
CU	52R Primary (P System Side) Frequency	5
CV	52R Primary(P System Side) Transmission Wh(L part)	5
CW	52R Primary(P System Side) Transmission Wh(U part)	5
CX	52R Primary(P System Side) Transmission Wh(L part)	5
CY	52R Primary(P System Side) Transmission Wh(U part)	5
CZ	52R Primary (Bus Side) Voltage (R Phase)	5
DA	52R Primary (Bus Side) Voltage (S Phase)	5
DB	52R Primary (Bus Side) Voltage (T Phase)	5
DC	52R Primary (Bus Side) Current (R Phase)	5
DD	52R Primary (Bus Side) Current (S Phase)	5
DE	52R Primary (Bus Side) Current (T Phase)	5
DF	52R Primary (Bus Side) Current (N Phase)	5
DG	52R Primary (Bus Side) Frequency	5

Data from Diesel Generator parameter, index and size of storage show in table 8.

Table 8 Data from Diesel Generator

Index	Datail	Size
BS	Generator Active Power	3
BT	Generator Reactive Power	3
BU	Generator Voltage(RS Phase)	5
BV	Generator Current(R Phase)	5
BW	Generator Current(S Phase)	5
BX	Generator Current(T Phase)	5
BY	Generator Frequency	5
BZ	Generator Wh(Lower part)	5
CA	Generator Wh(Upper part)	5
CB	Generator Power Factor	3
CC	Stator Temperature	3
CD	Bearing Temperature	3
CE	Rotation Speed of Engine	5
CF	Lubricant Oil Entrance Pressure	3
CG	Cooling Water Outlet Temperature	3
CH	Operation Time	3
CI	DG Connecting CB(52G)	3
CK	DG Integrated Alarm 1:Fault	1

EMS process

EMS process diagram as show in figure 19. It have three main module, monitoring module, decision making module and simulation module. Monitoring module get data from RDBMS. To generate monitoring result. Decision making module get data from RDBMS. And condition rule to generate status and system report. Simulation module get data from RDBMS. And condition rule from decision making module agent to generate simulation result such as solar radiation, module/array temperature, ambient temperature load, PV output power, array yield, final yield, renewable energy fraction, array capture loss, system loss and total loss.

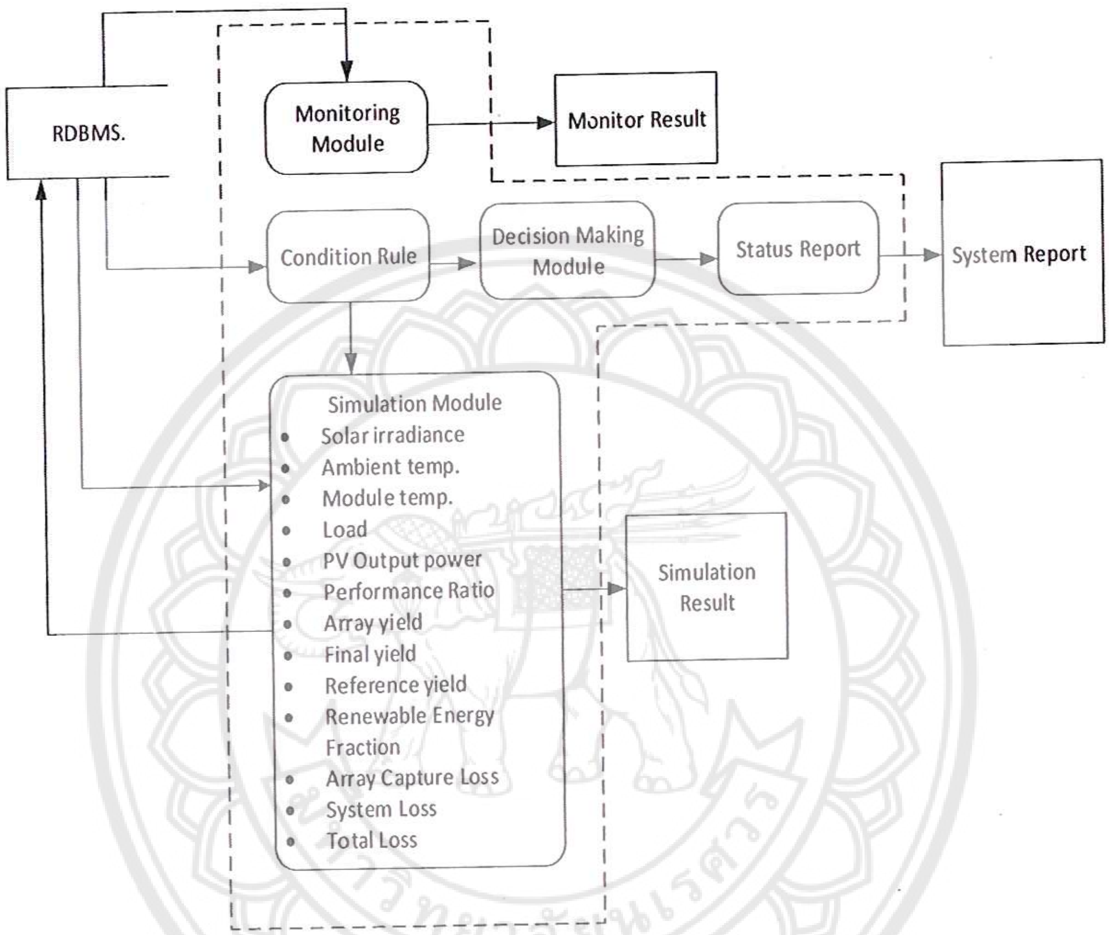


Figure 19 EMS process diagram.

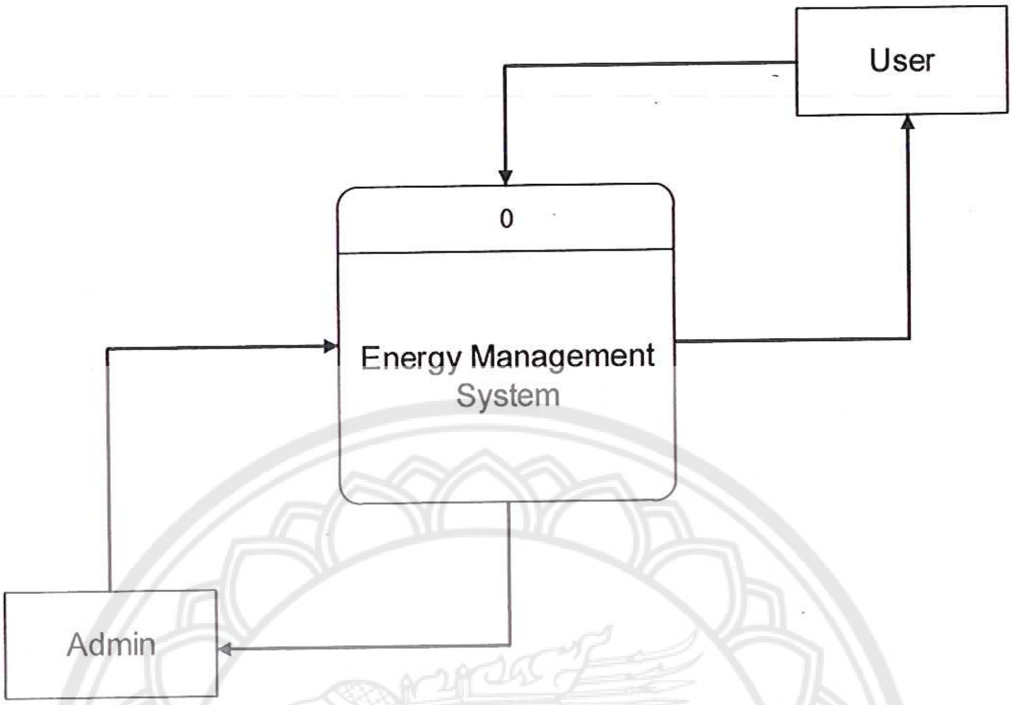


Figure 20 Context Diagram : DFD Level 0

From figure 20 show context diagram or data flow diagram level 0 of EMS system consist of system administrator and system user are connect with EMS.

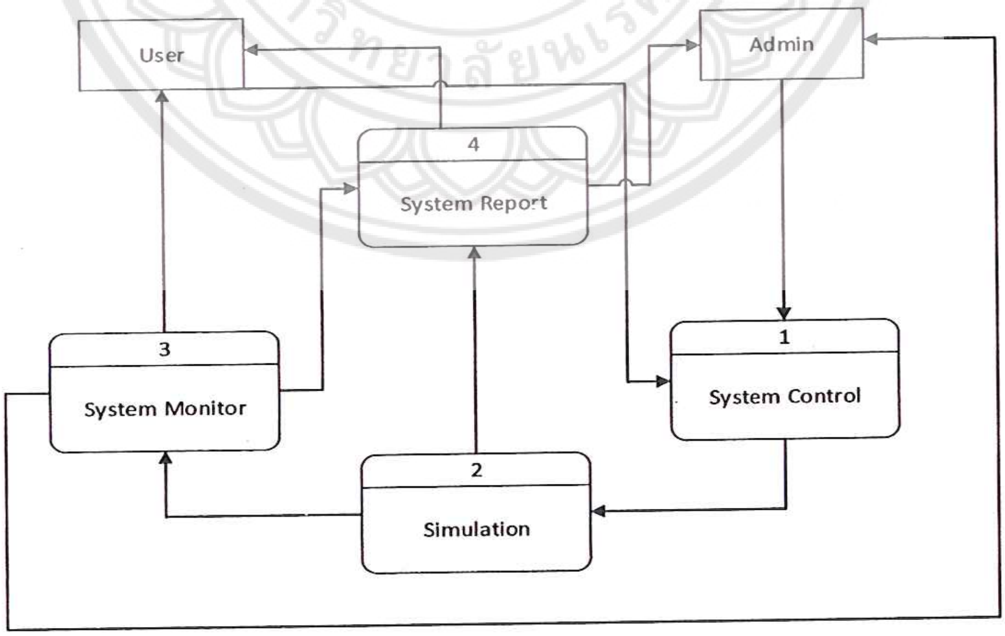


Figure 21 DFD Level 1

From figure 21 show data flow diagram level 1 of EMS system consist of four main process, system control, simulation, system monitor and system report. System administrator and system user are connect with EMS.

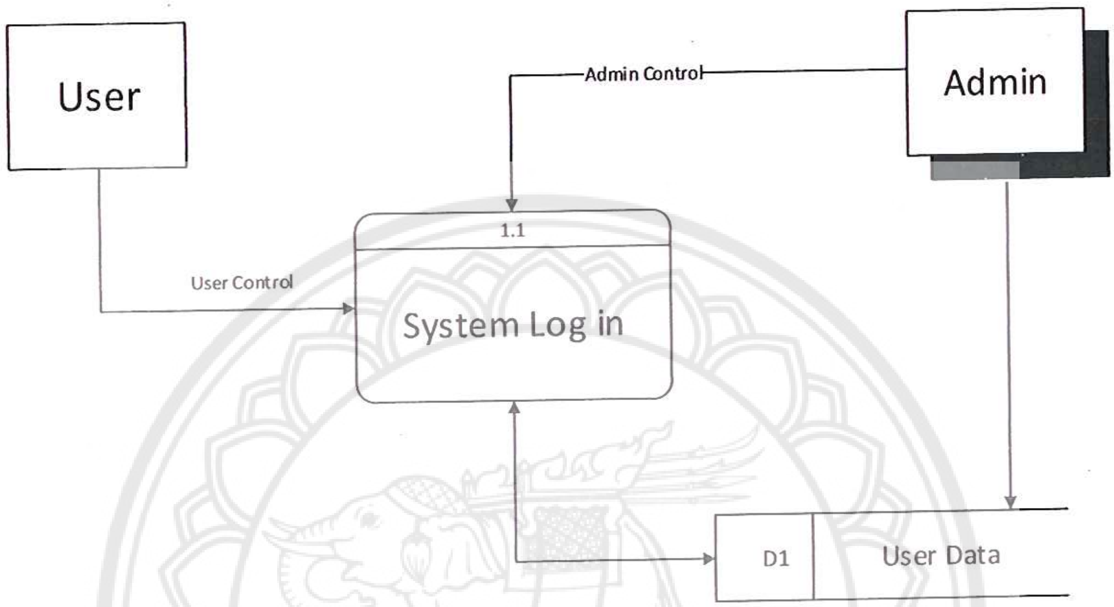


Figure 22 DFD Level 1 Process 1: System control

From figure 22 show data flow diagram level 1, Process 1, System control. To login in to EMS by System administrator and system user. System administrator get data to add user into EMS from user data store.

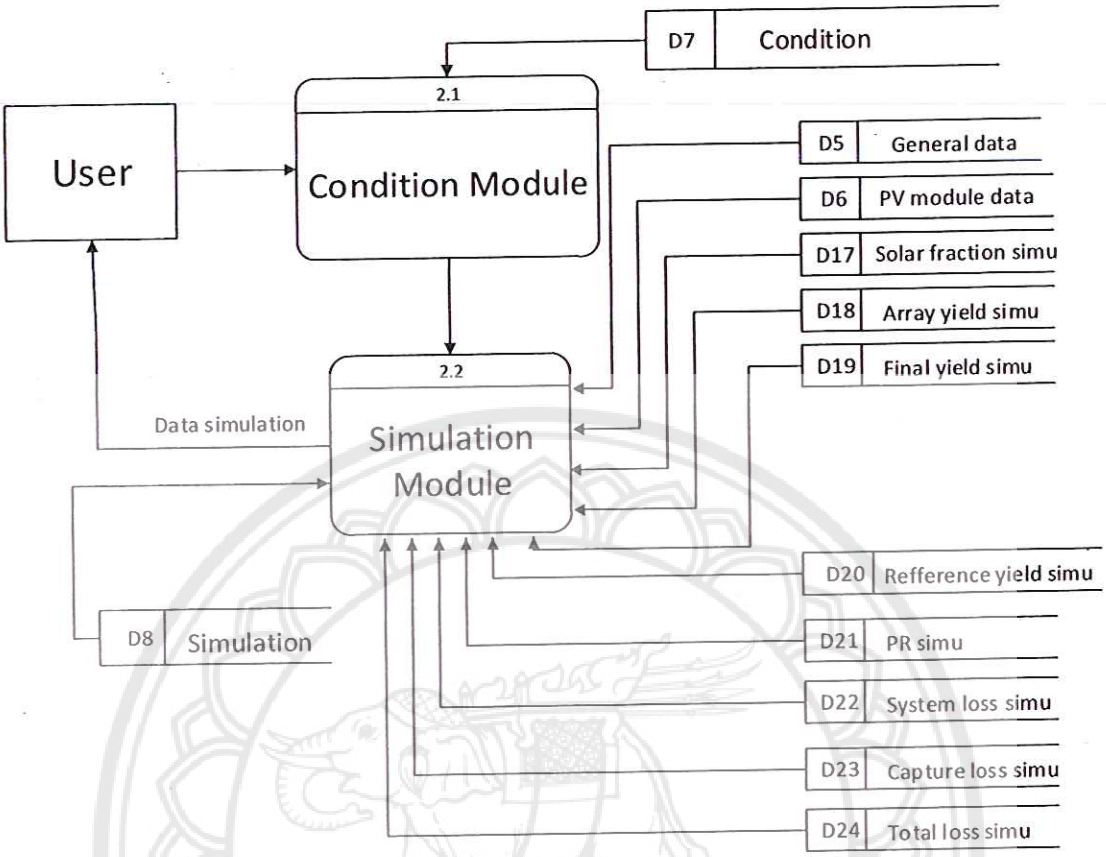


Figure 23 DFD Level 1 Process 2: Data management

From figure 23 show data flow diagram level 1, Process 2, Data management. Consist of two agent, condition module and simulation module. Condition module get data from condition data store to make decisions and send to simulation module. Simulation module get data from data store such as general data, PV module data, simulation data store, simulation solar fraction, simulation array yield, simulation final yield, simulation reference yield, simulation performance ratio, simulation system loss, simulation Capture loss and simulation total loss.

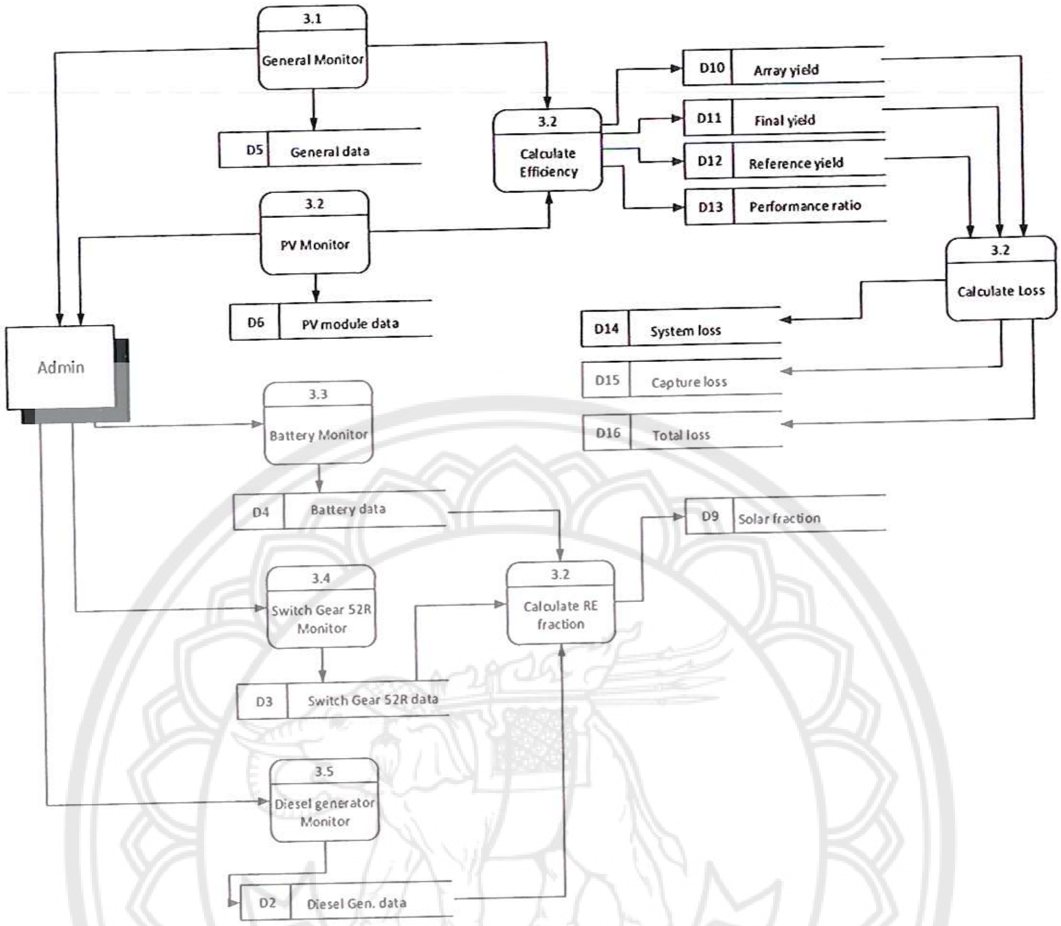


Figure 24 DFD Level 1 Process 3: Monitoring

From figure 24 show data flow diagram level 1, Process 3, Monitoring. This agent consist of eight agent process such as general monitor, PV monitor, battery monitor, switch gear 52R monitor, diesel generator monitor, calculate efficiency, calculate RE fraction and calculate loss. General monitor agent get data from general data store, PV monitor agent get data from PV module data store, battery monitor agent get data from battery data store, switch gear 52R monitor agent get data from switch gear 52R data store, diesel generator monitor agent get data from diesel generator data store. Calculate efficiency agent get data from array yield data store, final yield data store, reference yield data store and performance ratio data store. Calculate RE fraction agent get data from solar fraction data store. And calculate loss agent get data from system loss data store, capture loss data store and total loss data store.

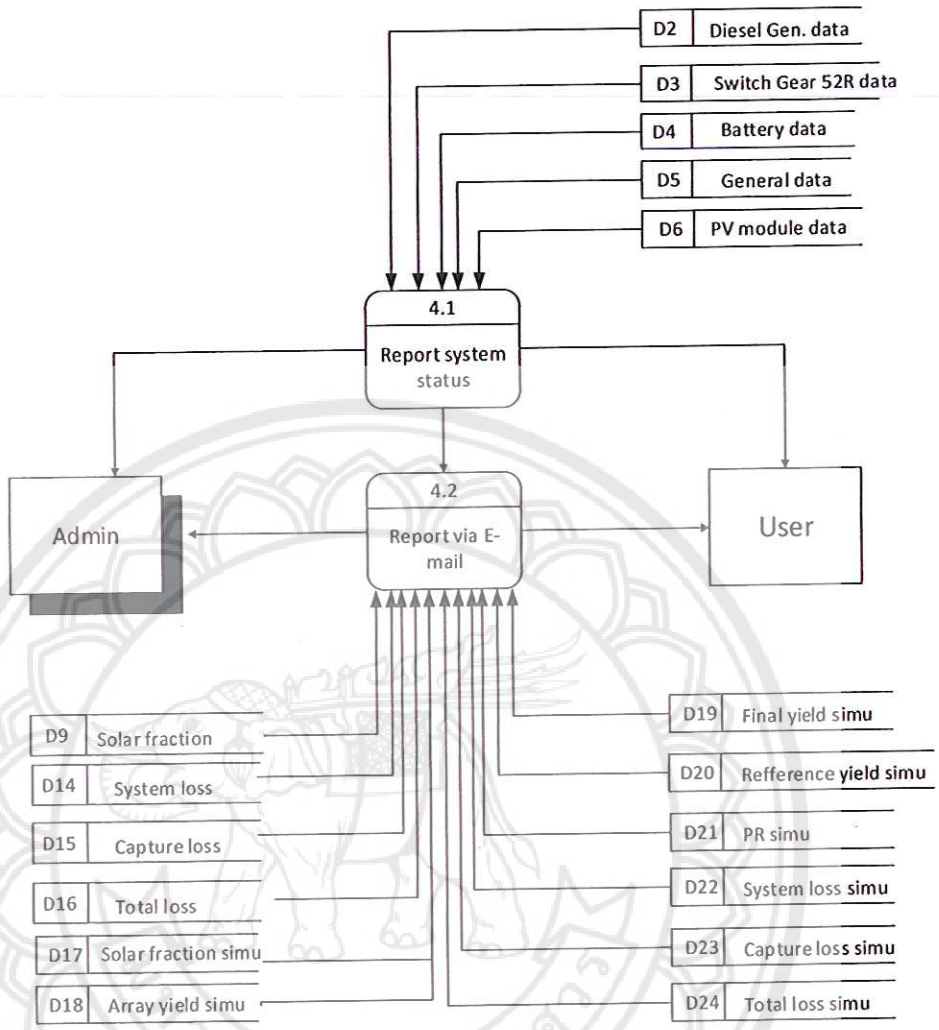


Figure 25 DFD Level 1 Process 4: Reporting

From figure 25 show data flow diagram level 1, Process 4, reporting. This process consist of two agent, report system status agent and report via e-mail agent. Report system status agent get data from general data store, switch gear 52R data store, battery data store, PV module data store and general data store. Report via e-mail agent get data from performance ratio data store, solar fraction simulation data store, capture loss simulation data store, total loss simulation data store, array yield simulation data store, final yield simulation data store, reference yield simulation data store, performance ratio simulation data store

CHAPTER IV

RESULT AND DISCUSTION

Agent based microgrid management system evaluation result

After implement Agent based microgrid management system. The result is presented as follows.

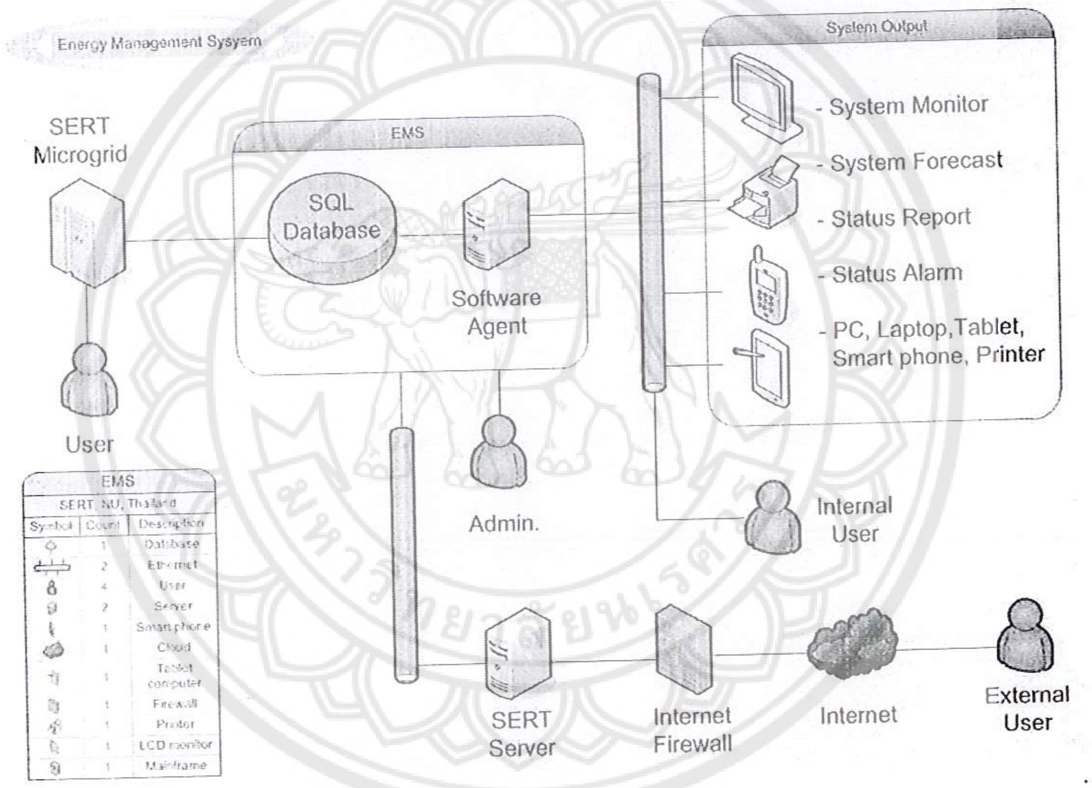


Figure 26 Design of SERT's micro grid energy management system

SERT's micro grid energy management system (EMS) install on SERT server behind internet firewall. System user such as system administrator, internal user and normal user can operate EMS through the internet via personal computer, laptop computer, tablet, smart phone and other mobile device. SERT's micro grid energy management system have four main function such as system control, data management, system monitoring and system reporting. An EMS consist of SQL RDBMS and software agent operate by php.

1. System management interface

Figure 27 show the system management function use to login to Agent based microgrid management system by user such as system administrator and normal user. User must be have user name and password to login EMS.

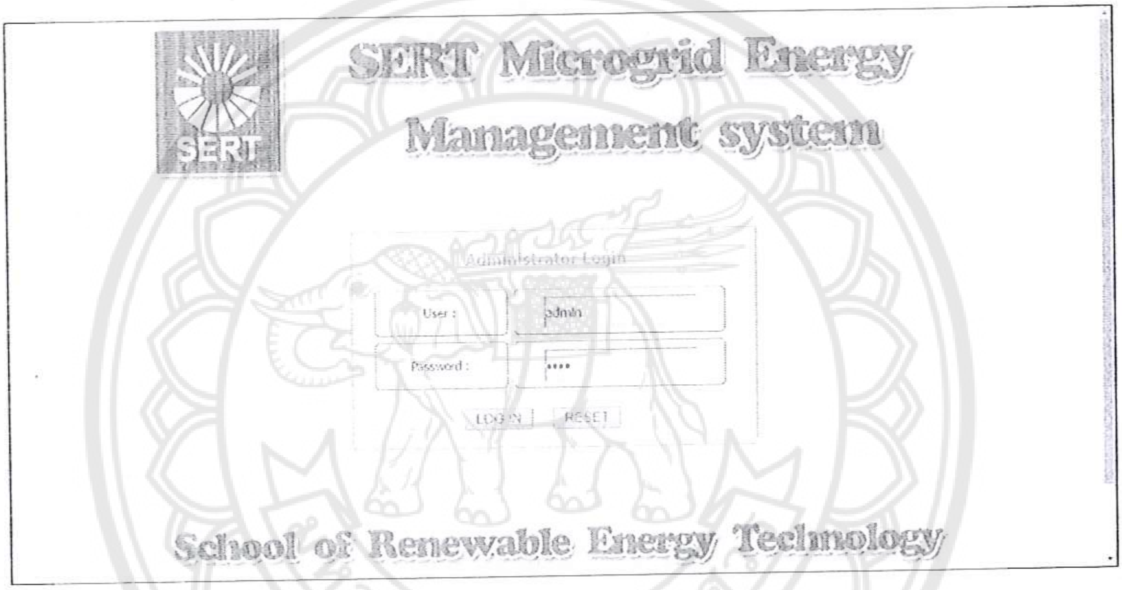


Figure 27 Login window

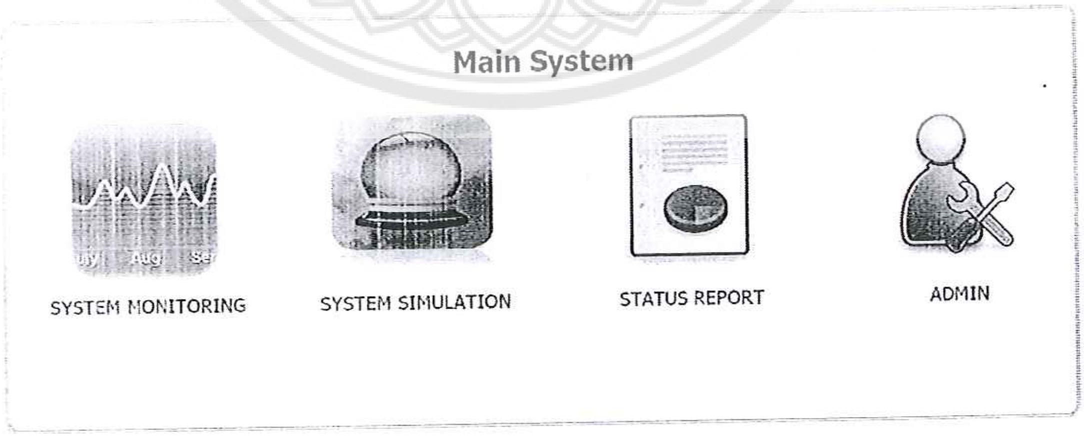


Figure 28 Main function

From figure 28 show main function of EMS after login process complete. The main function such as system monitoring, system simulation, system status report and admin control function.

Admin tool

Figure 29 Add user function

From figure 29 show add user function. This function can operate by system administrator only.

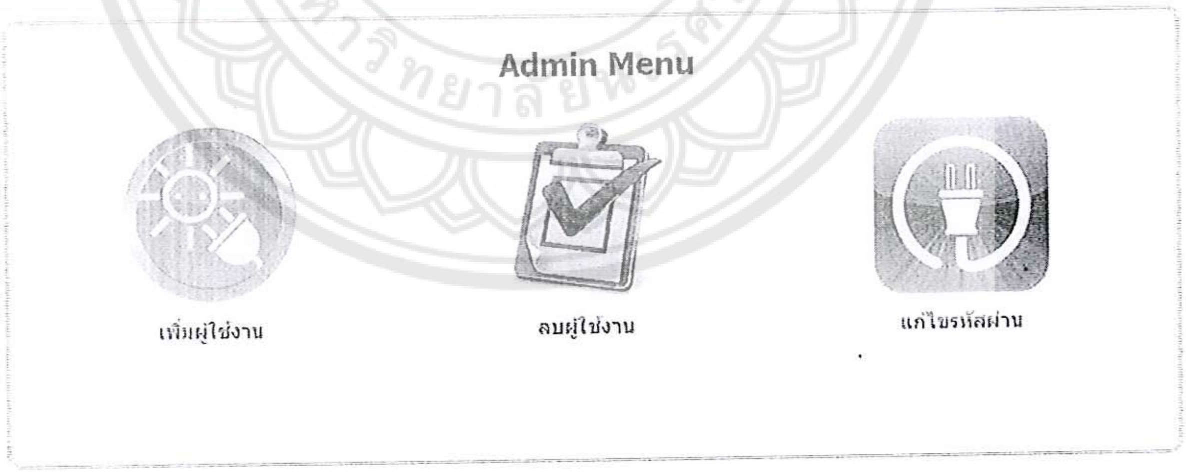


Figure 30 Function of administrator menu. Add user, delete user and change password

Figure 30 show function of system administrator menu. Include of Add user, delete user and change password.

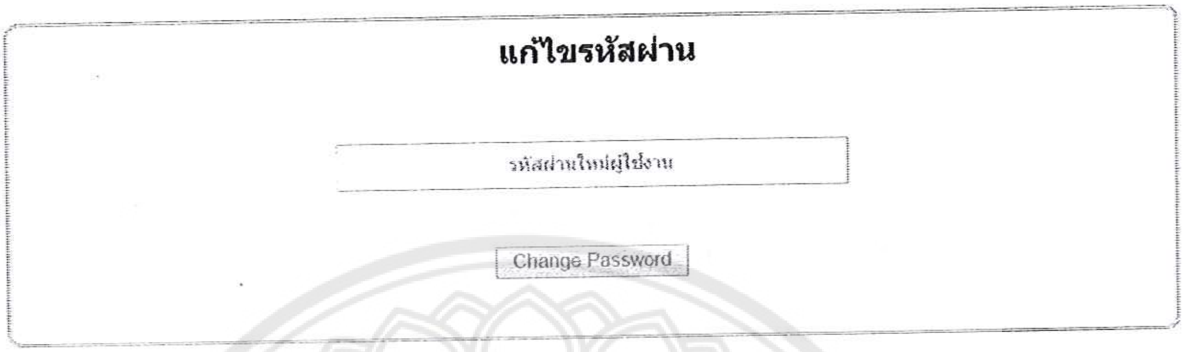


Figure 31 change password function

Figure 31 show change password function. This function can operate by system administrator only.

Figure 32 delete user function

Figure 32 show delete user function. This function can operate by system administrator only.

Monitoring

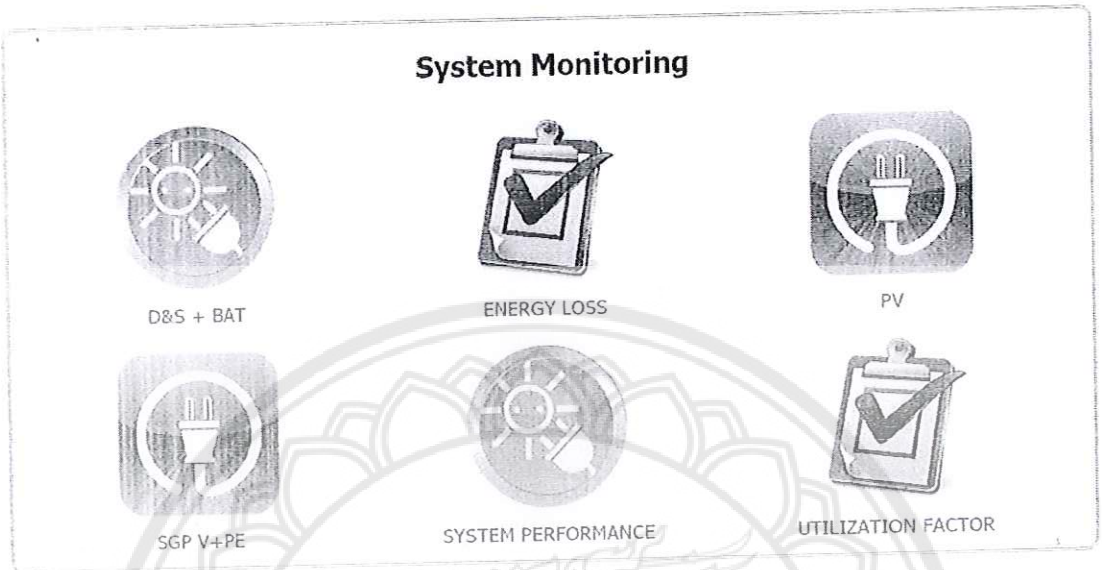


Figure 33 System monitoring function

Figure 33 show all of System monitoring function. Consist of Demand and supply and battery monitor, energy loss monitor, PV system monitor, switch gear and power monitor, system performance monitor and utilization factor monitor. System monitoring function can be operate by both type of user. System administrator and normal user.

Demand and Supply and battery

Figure 34–36 show monitoring menu of Demand and Supply and battery separate by daily, monthly and season. Data that can be monitor such as photovoltaic and diesel generator generation power, battery inverter output power, system load, battery inverter input voltage(DC), battery inverter input current(DC), battery inverter input power(DC), battery inverter output power, interconnection sending power, interconnection breaker stste and battery stage of charge(SOC).

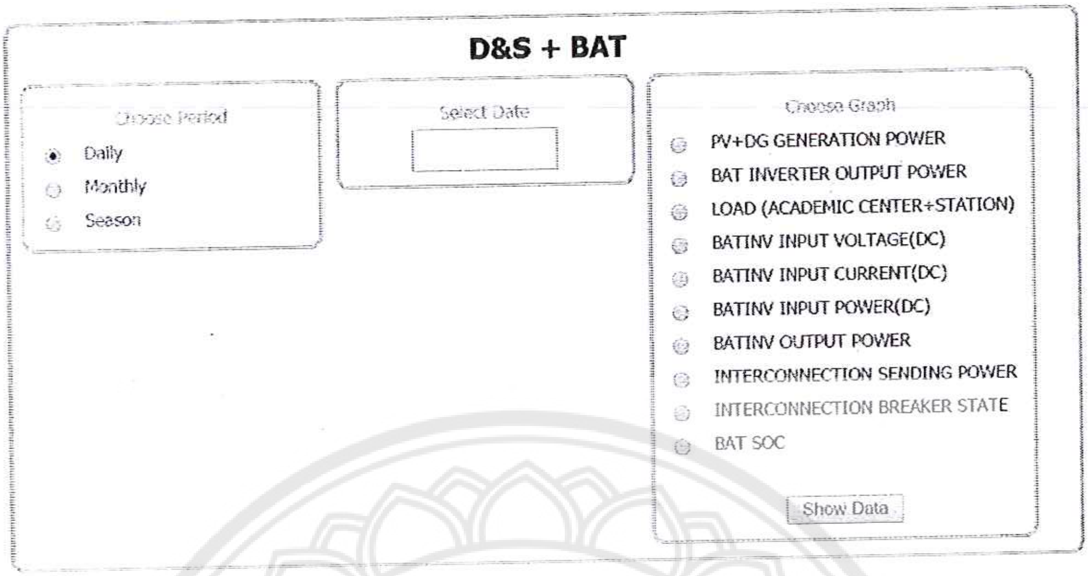


Figure 34 Demand and Supply and battery detail data select by daily

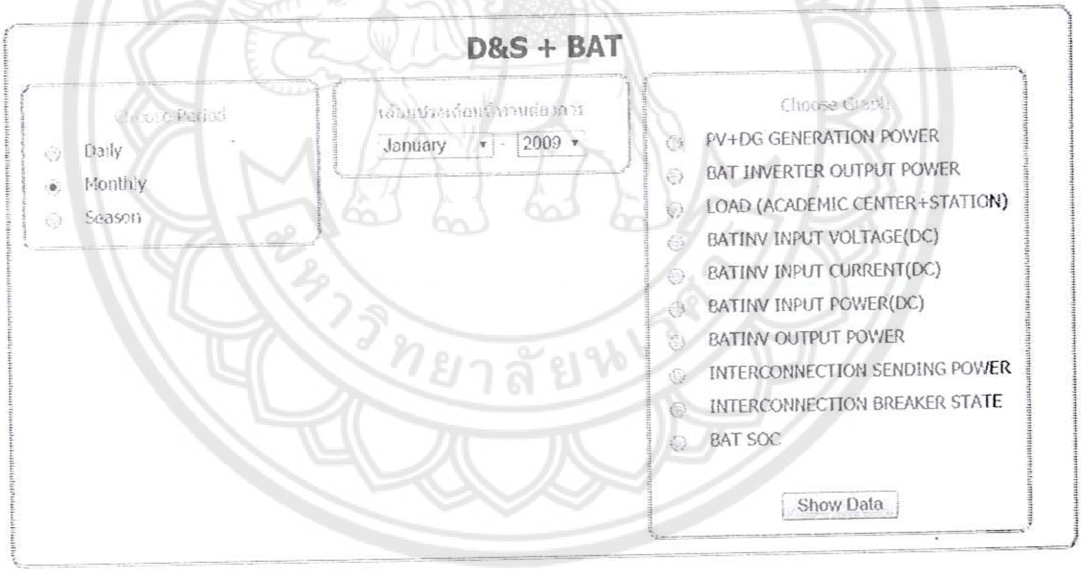


Figure 35 Demand and Supply and battery detail data select by month

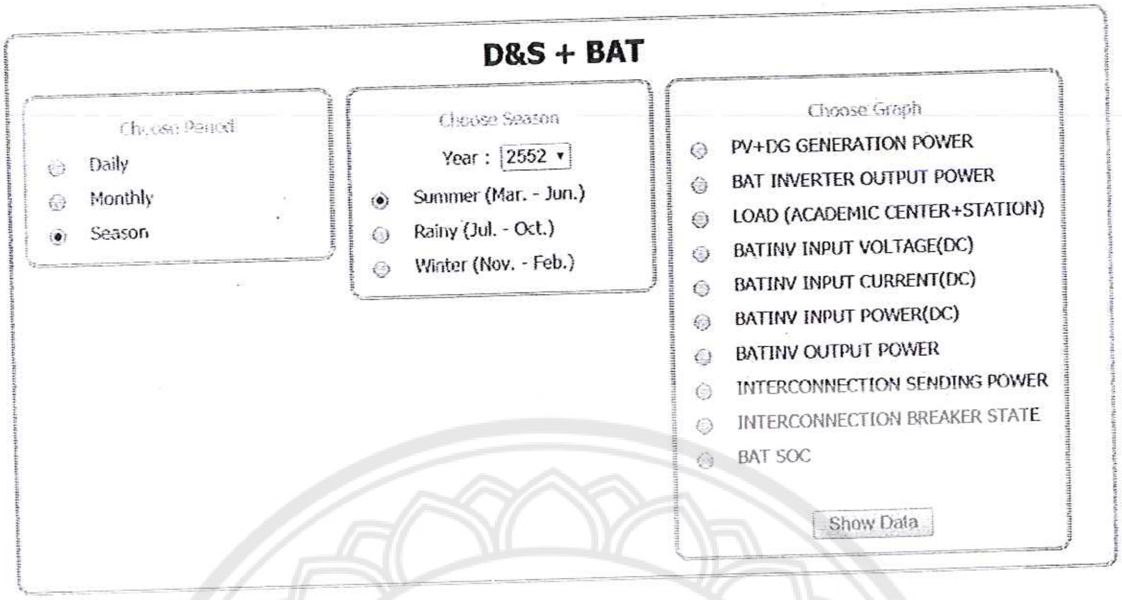


Figure 36 Demand and Supply and battery detail data select by season

PV

Figure 32–34 show monitoring menu of photovoltaic (PV) data separate by daily, monthly and season. Data that can be monitor such as solar radiation, PV voltage and current number 1, PV voltage and current number 2, PV inverter input power(number 1 + number 2), PV module temperature and ambient temperature and PV inverter output power(number 1 + number 2).

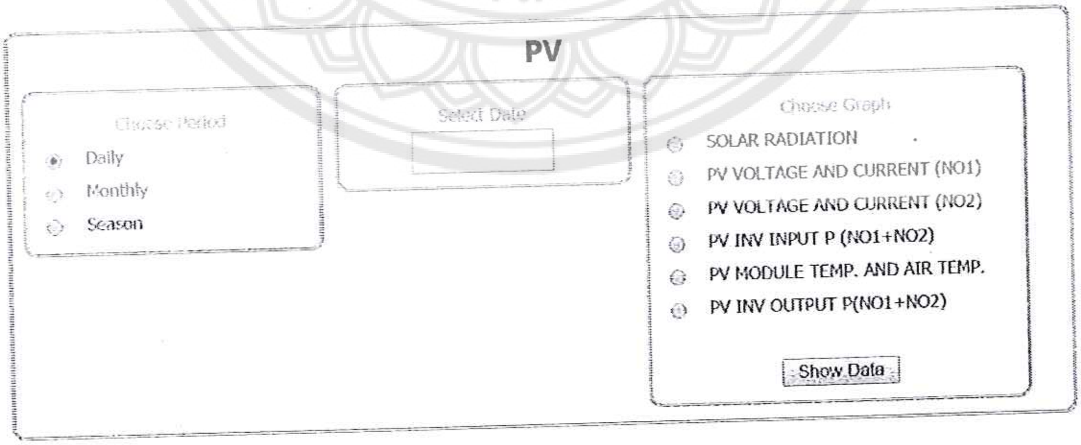


Figure 37 PV daily

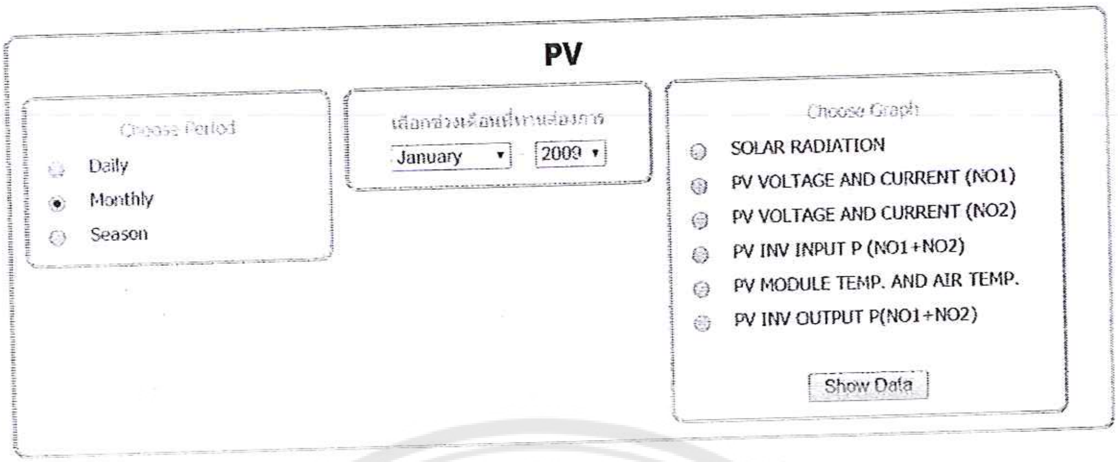


Figure 38 PV monthly

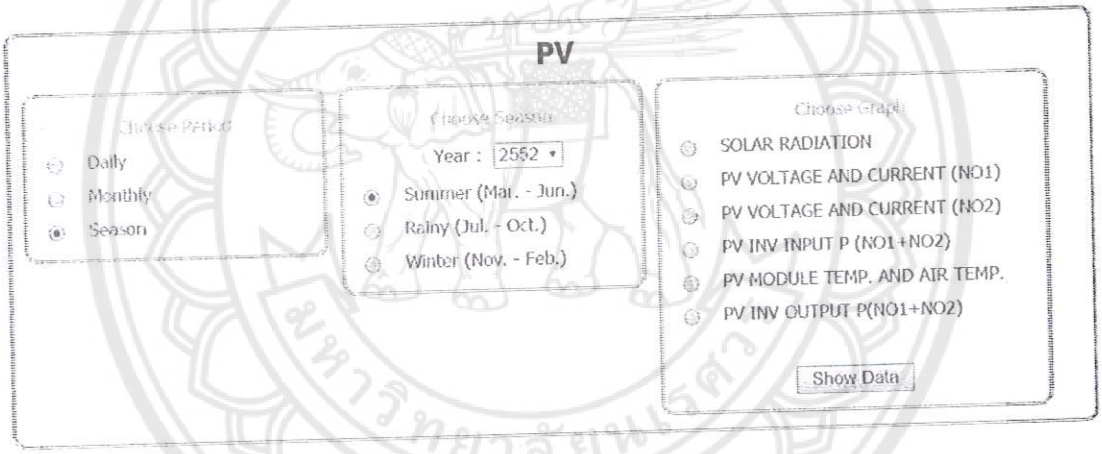


Figure 39 PV season

Energy loss

Figure 40–45 show monitoring menu of energy loss data separate by daily, monthly and season. Data that can be monitor such as array capture loss, system loss and total loss.

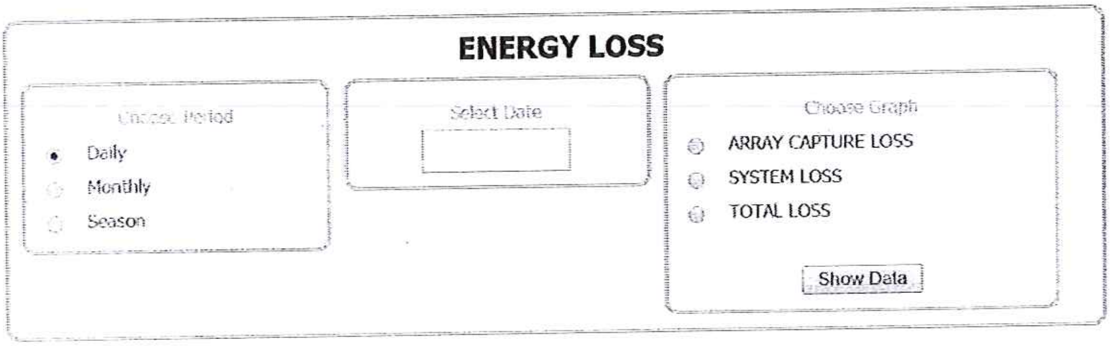


Figure 40 Energy loss daily

Figure 41 Energy loss monthly

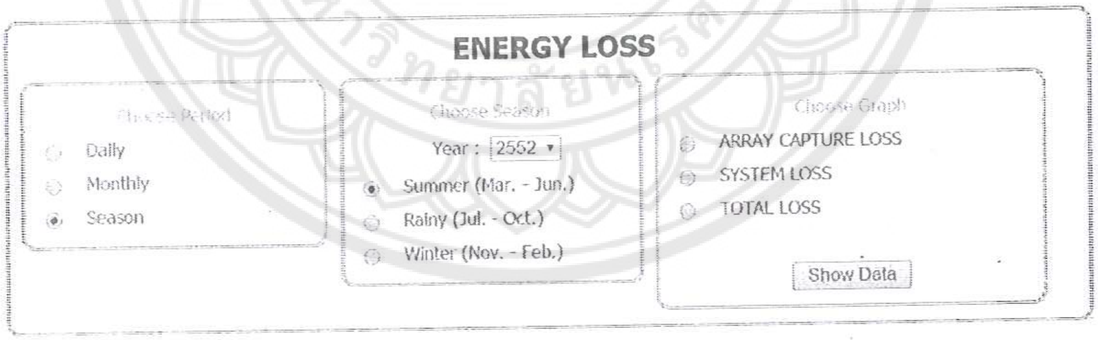


Figure 42 Energy loss season

SGP and power energy

Figure 43–45 show monitoring menu of switch gear 52R and power energy, data separate by daily, monthly and season. Data that can be monitor such as power system side voltage, microgrid side voltage, power system side frequency, microgrid side frequency, switch gear state and interconnection power factor.

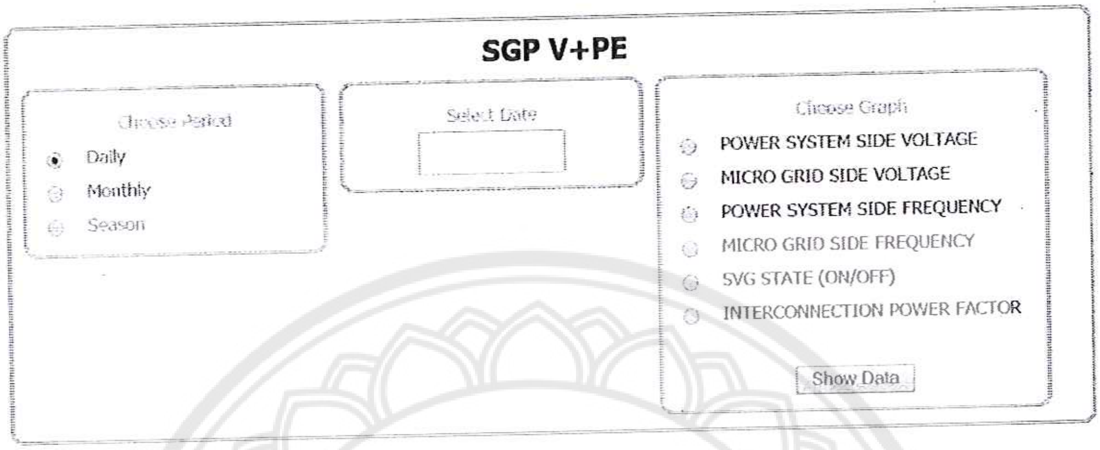


Figure 43 SGP power daily

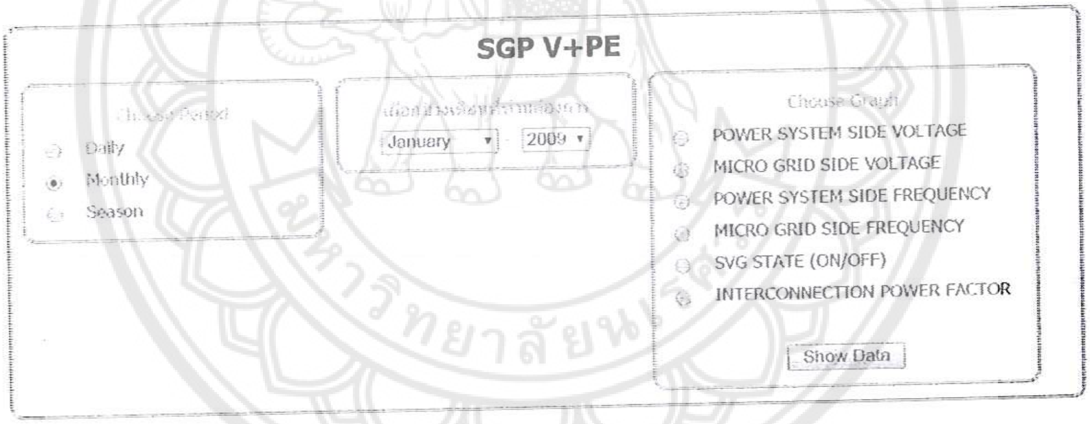


Figure 44 SGP power monthly

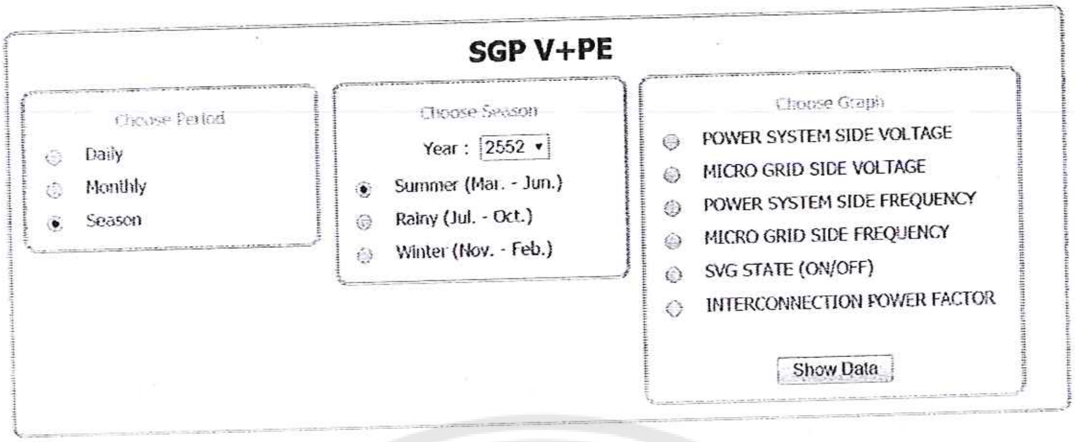


Figure 45 SGP power season

System performance

Figure 46–48 show monitoring menu of system performance, data separate by daily, monthly and season. Data that can be monitor such as performance ratio, array yield, final yield and reference yield.

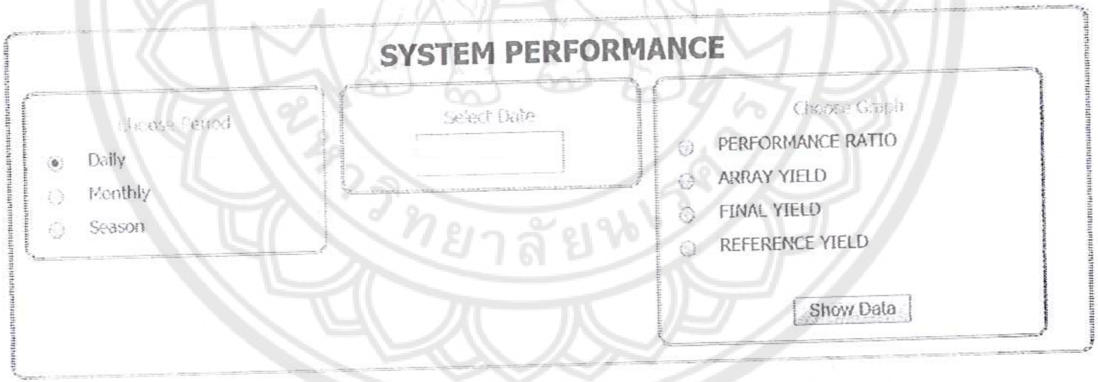


Figure 46 System performance daily

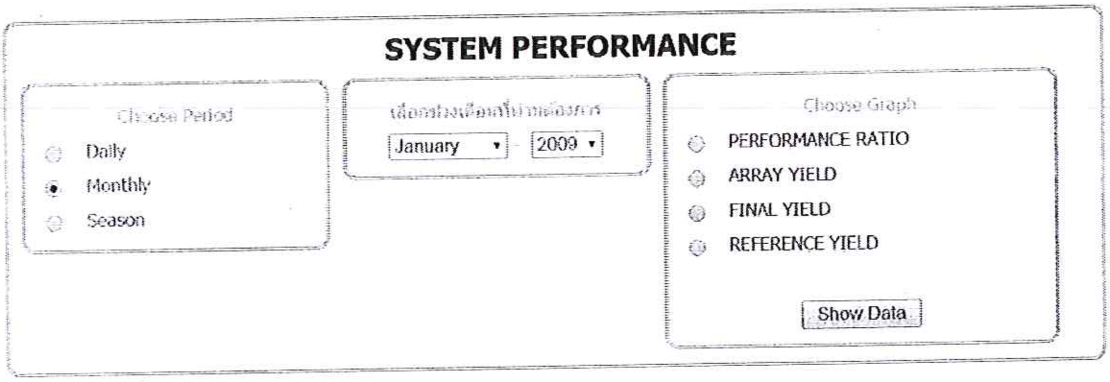


Figure 47 System performance monthly

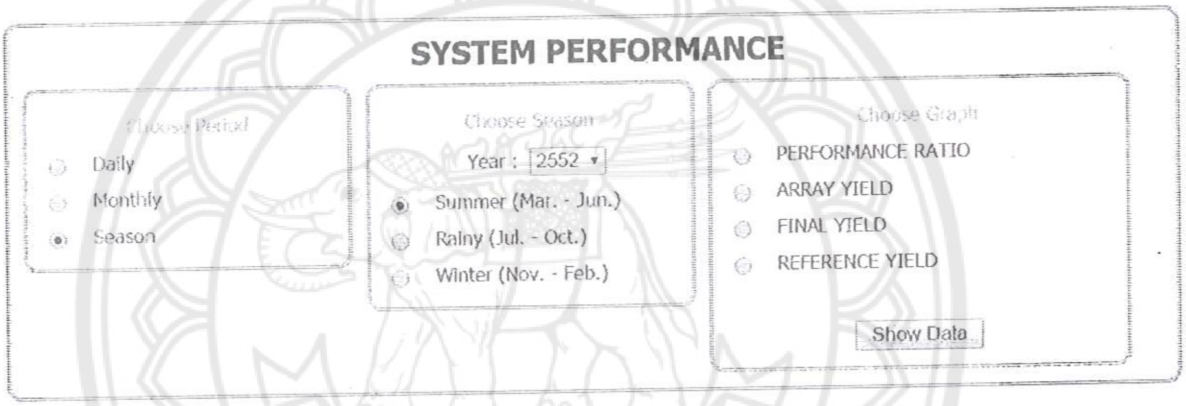


Figure 48 System performance season

Utilization factor (Solar fraction)

Figure 49–51 show monitoring menu of Utilization factor (Solar fraction), data separate by daily, monthly and season. Data that can be monitor such as Solar fraction.

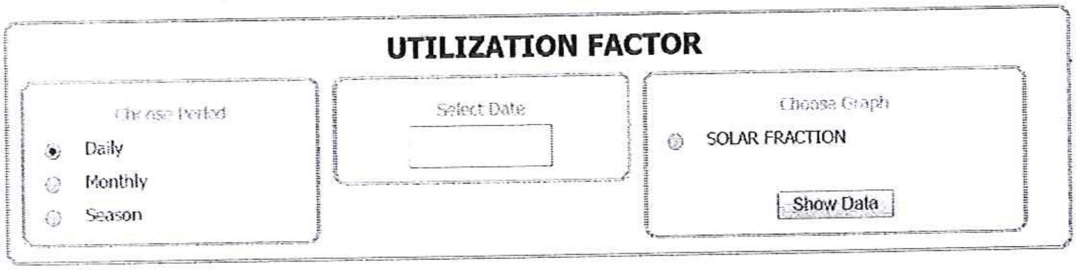


Figure 49 Utilization factor (Solar fraction) daily

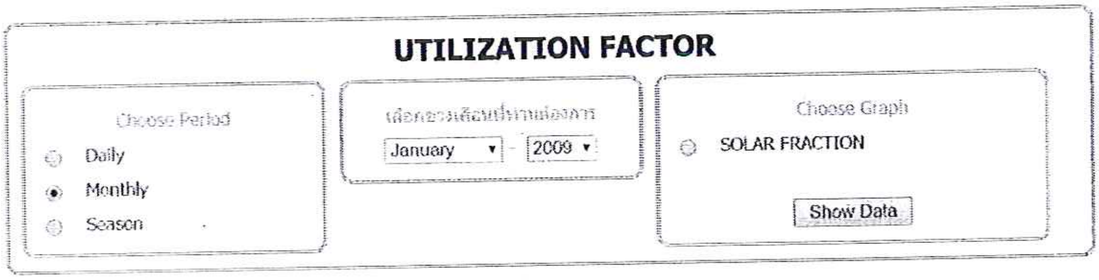


Figure 50 Utilization factor (Solar fraction) monthly

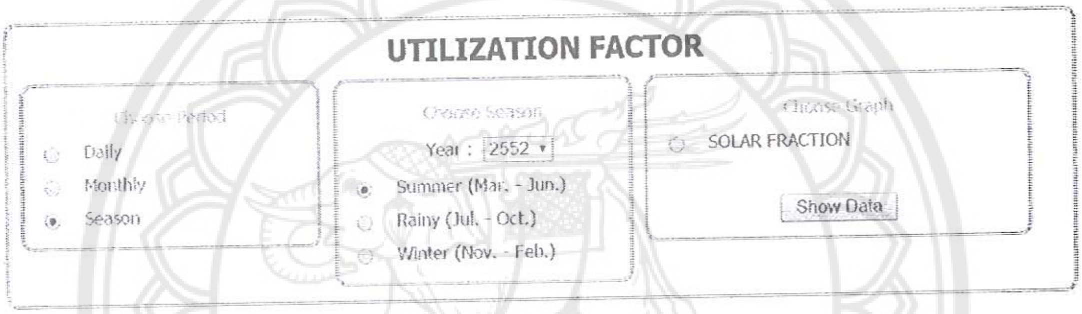


Figure 51 Utilization factor (Solar fraction) season

Result from system monitoring

The Agent based microgrid management system get every parameter from the microgrid system, including the data as follows.

Data from PV generator include of solar irradiance, PV output voltage, PV output current, PV module temperature, ambient temperature, PV inverter output voltage, PV inverter output current, PV inverter output power, PV inverter output reactive power and PV inverter output frequency.

Data from diesel engine generator include of generator output voltage, generator output current, generator output power, generator output reactive power and generator output frequency.

Data from battery and inverter include of battery input voltage, battery output voltage, battery input current, battery output current, battery temperature, battery inverter input voltage, battery inverter output voltage, battery inverter input current, battery inverter output current, battery inverter input power, battery inverter output power, battery inverter input reactive power, battery inverter output reactive power and battery inverter output frequency.

Data from switch gear 52R and load include of existing grid voltage, microgrid voltage, microgrid imported current, microgrid exported current, microgrid imported power, microgrid exported power, existing grid frequency, microgrid frequency , and interconnection PF.

After implement Agent based microgrid management system, the system can generate result as follows.

Result from PV group result include of Solar radiation, PV voltage and current, PV inverter input power, PV inverter output power, PV module temperature and ambient temperature, PV inverter efficiency, PV generation efficiency and PV inverter generation efficiency.

Result from Demand and supply group result include of PV and diesel generation power, battery inverter output power, interconnection sending power, load and interconnection breaker state.

Result from Battery group include of battery inverter input voltage, battery inverter input current, battery inverter input power, battery inverter efficiency and battery SOC.

Result from Switch gear 52R group include of power system side voltage, microgrid side voltage, power system side frequency, microgrid side frequency, switch gear state and interconnection power factor.

And all of result can separate into three groups. The result can group by date by month and by season.

Result by date (daily result), the system can show all day data. Every day in year.

Result by month, the system can generate result of the month and show separate in each month. January, February, March, April, May, June, July, August, September, October, November and December

Result by season, the system can generate result and group by four months for season. Such as, March, April, May and June are summer season. July, August, September and October are rainy season. November, December, January and February are winter season.

Daily result

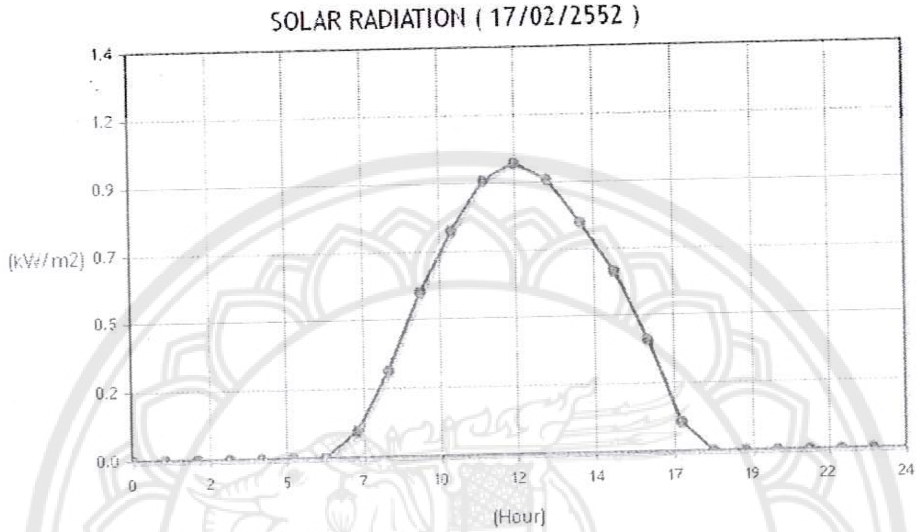


Figure 52 Daily solar radiation

In this figure represents sample result of daily solar radiation starting from sun rise at 06.00 and increasing until peak point at 12.00. It got peak power about 1.0 kW. And drop out until sun set at 18.00.

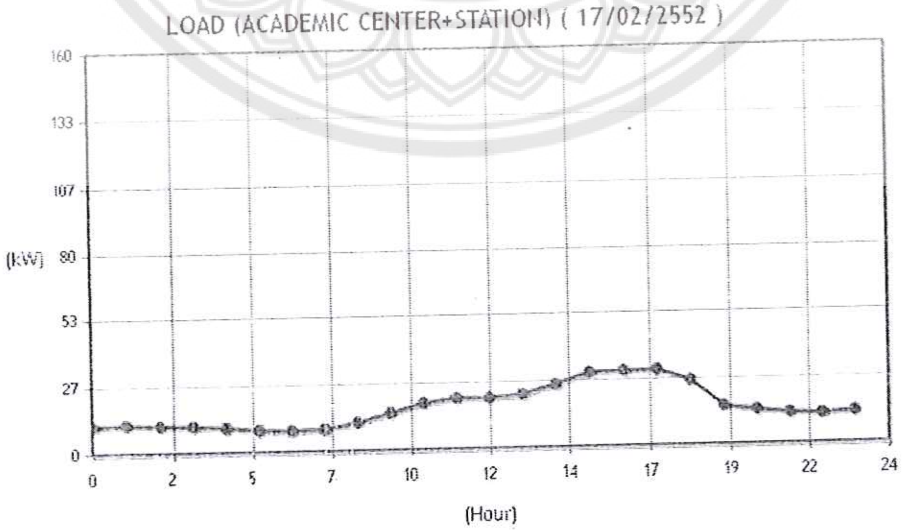


Figure 53 Daily load (academic center and station)

In this figure represents sample result of daily load of PVMG system starting from work time at 08.00 and increasing until peak point in afternoon. It used peak power about 30 kW. And drop out until work end at 19.00.

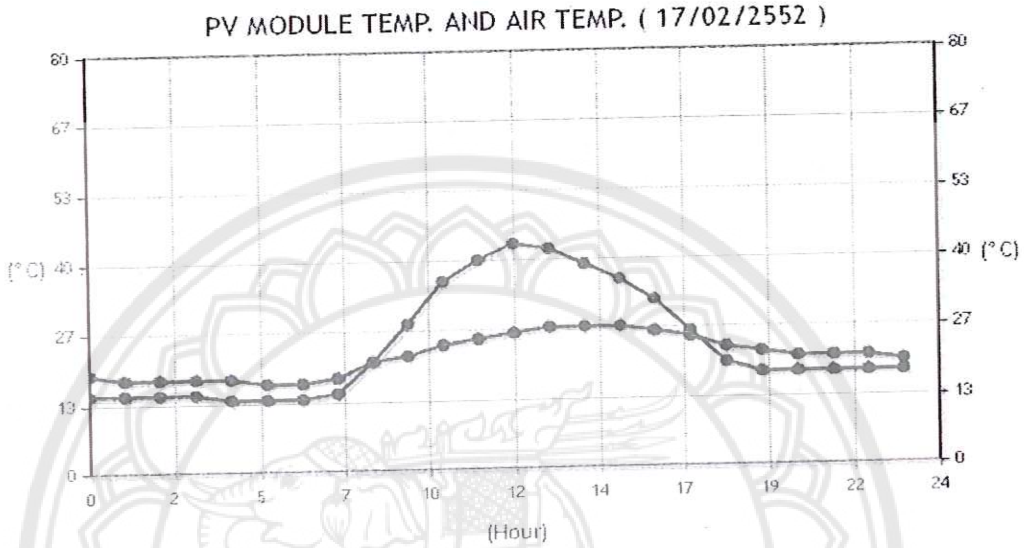


Figure 54 Daily PV module temperature.

In this figure represents sample result of daily PV module temperature and air temperature starting from 06.00 and increasing until peak point at 12.00. PV module peak temperature about 43 degree celsius. And drop out until 19.00. And peak air temperature is about 27 degree Celsius at 13.00.

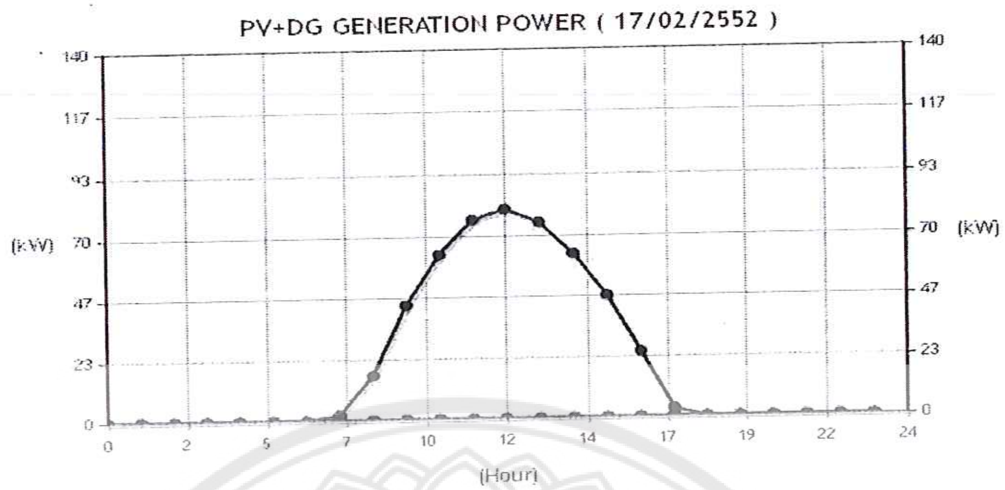


Figure 55 Daily PV and diesel generator power

In this figure represents sample result of daily PV and diesel generator power starting from sun rise at 06.00 and increasing until peak point at 12.00. It got peak power about 80 kW. And drop out until sun set at 18.00. And diesel generator did not start.

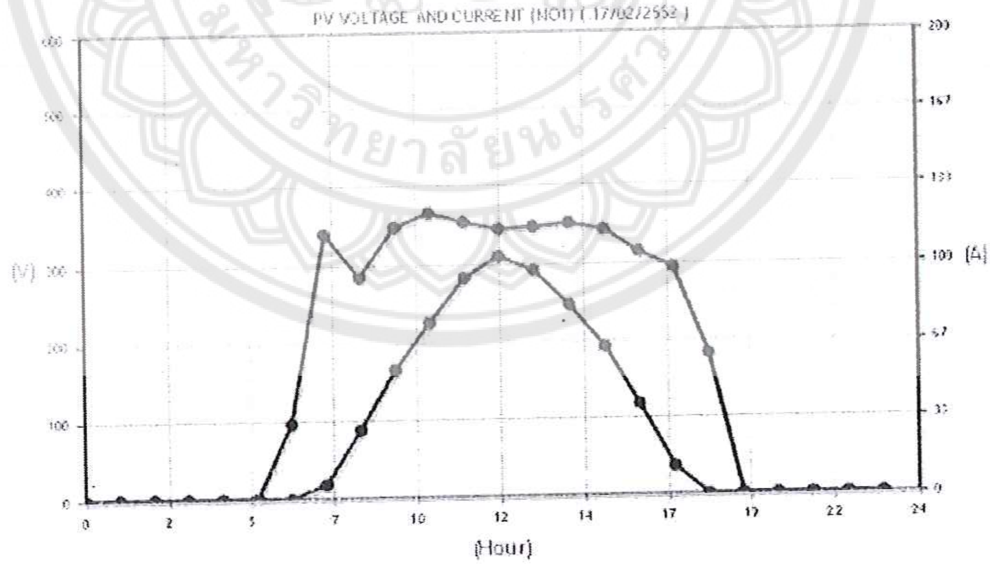


Figure 56 Daily PV voltage and current 1

In this figure represents sample result of daily solar radiation starting from sun rise at 06.00 and increasing until peak point at 12.00. It got peak power about 1.0 kW. And drop out until sun set at 18.00.

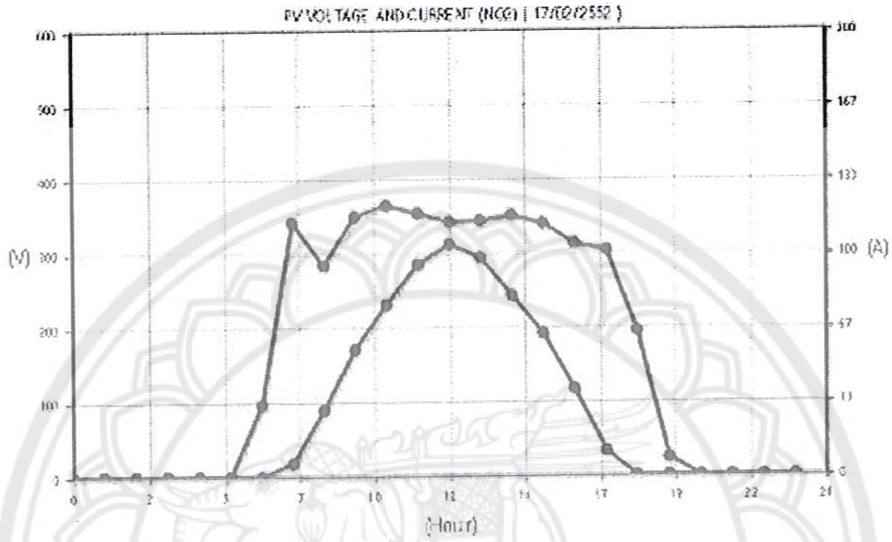


Figure 57 Daily PV voltage and current 2

In this figure represents sample result of daily solar radiation starting from sun rise at 06.00 and increasing until peak point at 12.00. It got peak power about 1.0 kW. And drop out until sun set at 18.00.

In this figure represents sample result of daily PV voltage and current from sun rise at 06.00 until sun set at 19.00. PV voltage is about 350 volt. And peak PV current is about 110 amp.

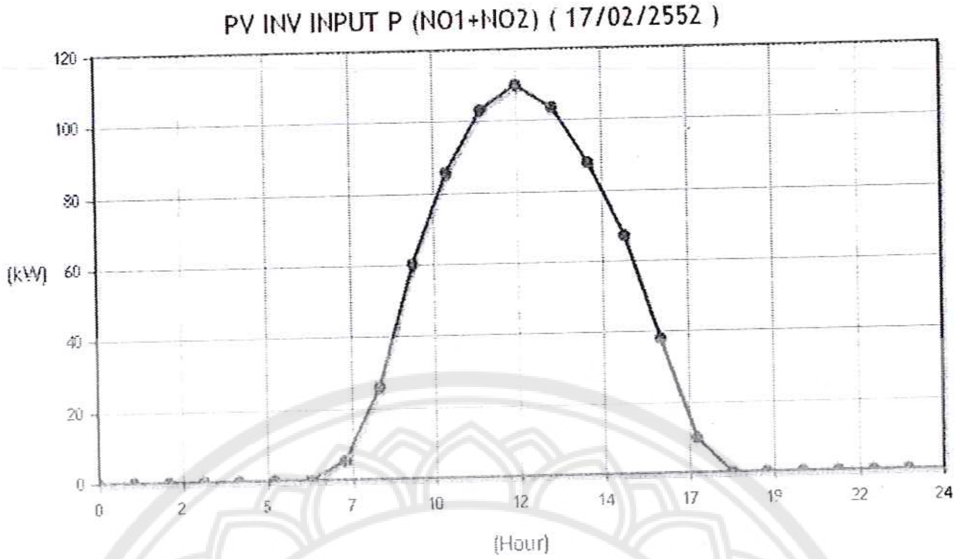


Figure 58 Daily PV inverter input power

In this figure represents sample result of daily PV inverter input power starting from sun rise at 06.00 and increasing until peak point at 12.00. It got peak power about 110 kW. And drop out until sun set at 18.00.

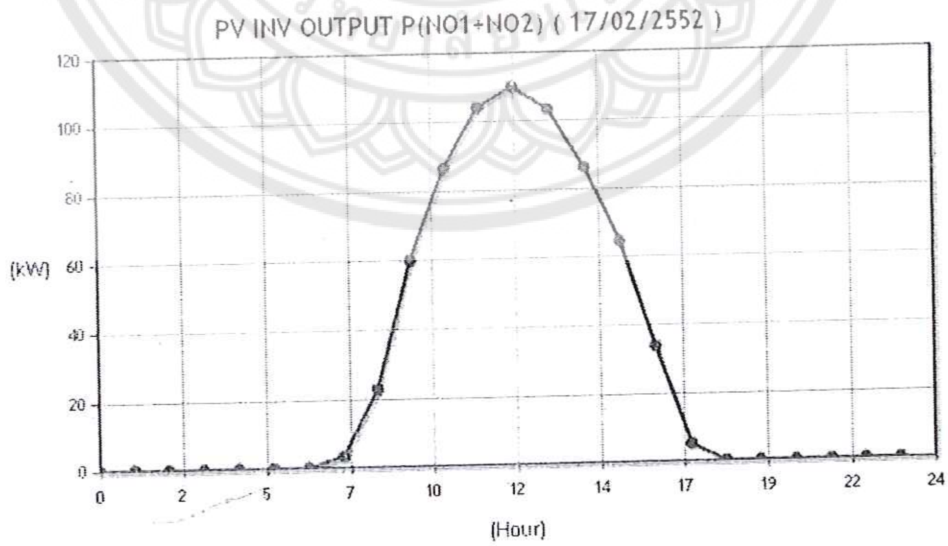


Figure 59 Daily PV inverter output power

In this figure represents sample result of daily PV inverter input power starting from sun rise at 06.00 and increasing until peak point at 12.00. It got peak power about 110 kW. And drop out until sun set at 18.00.

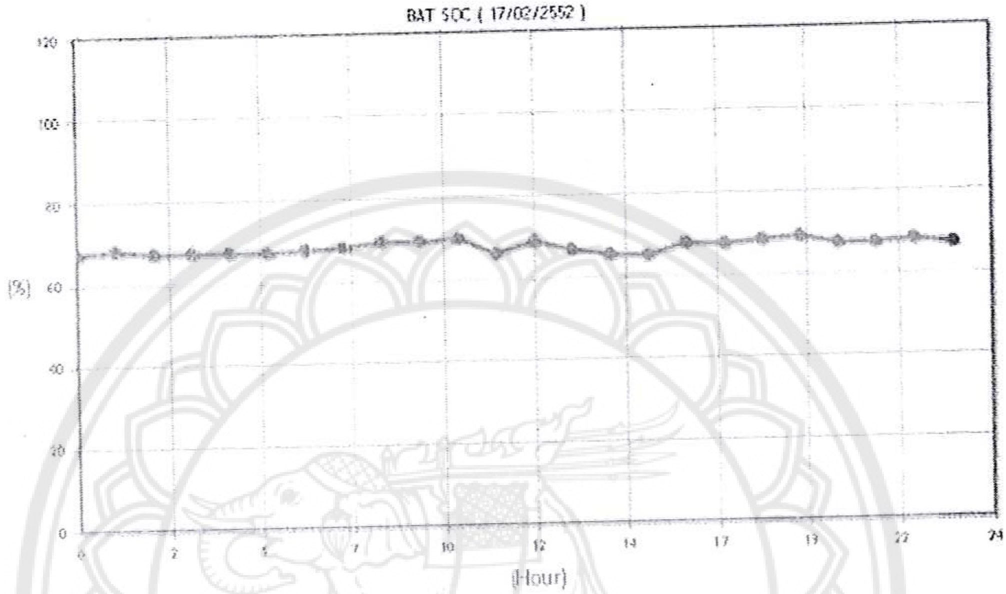


Figure 60 Daily battery SOC

In this figure represents sample result of daily battery stage of charge is about 68 % all day.

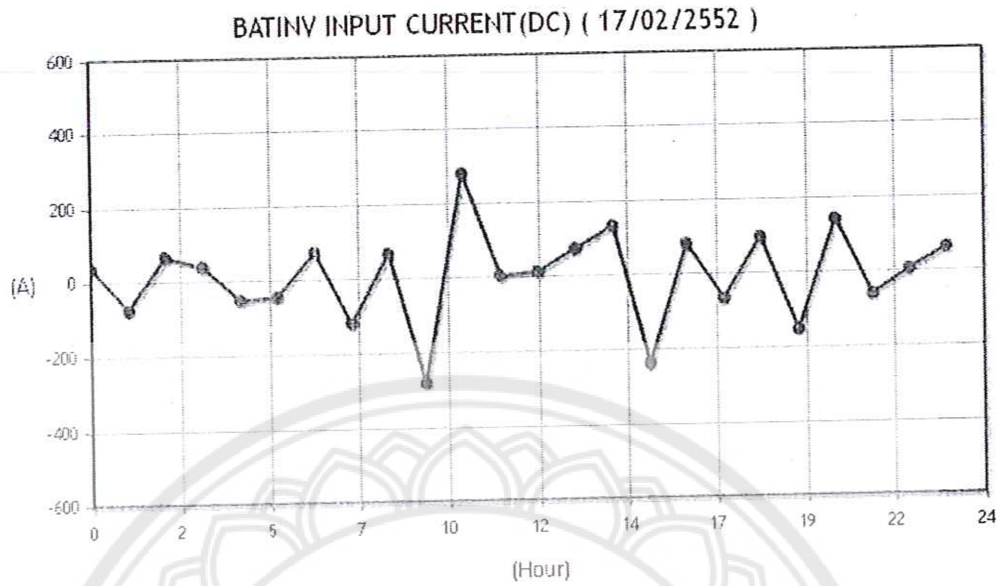


Figure 61 Daily battery inverter input current

In this figure represents sample result of daily Daily battery inverter input current.

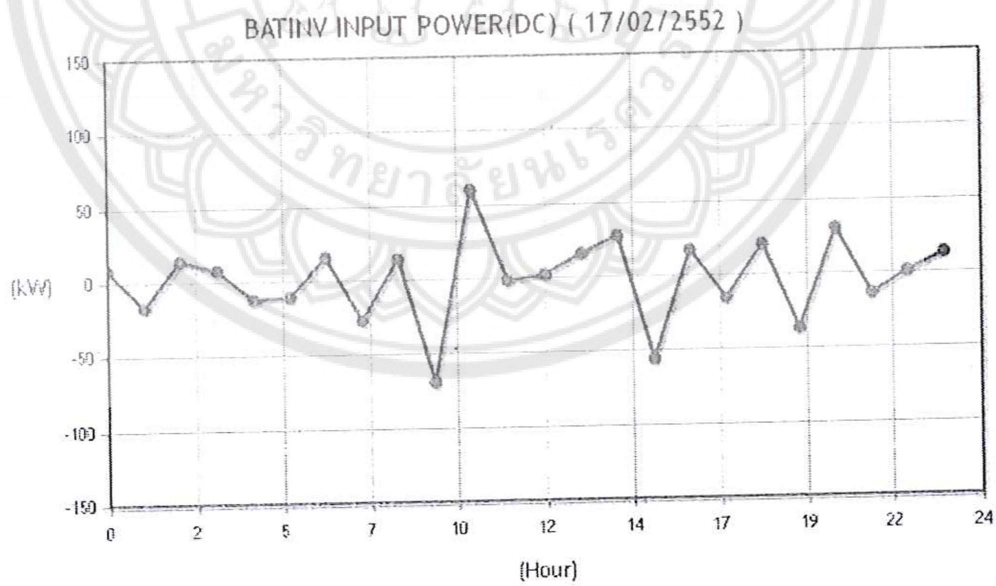


Figure 62 Daily battery inverter input power

In this figure represents sample result of daily Daily battery inverter input power.

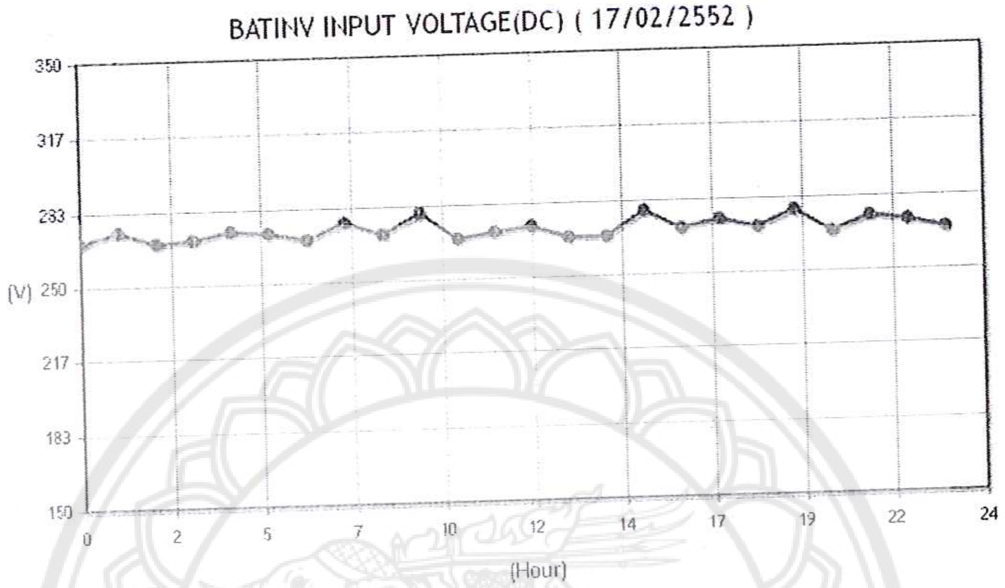
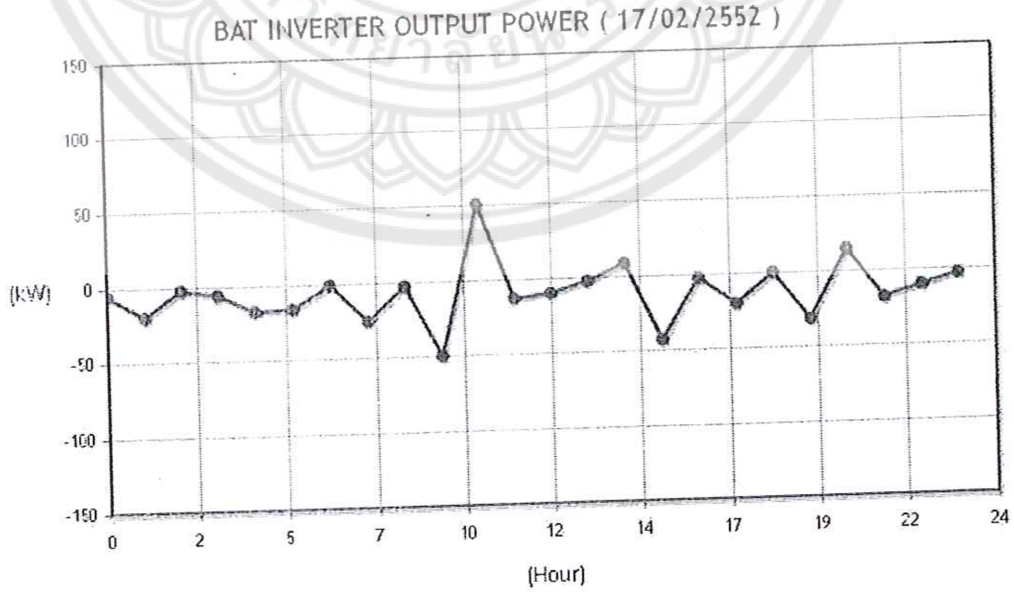


Figure 63 Daily battery inverter input voltage

In this figure represents sample result of daily Daily battery inverter input



voltage.

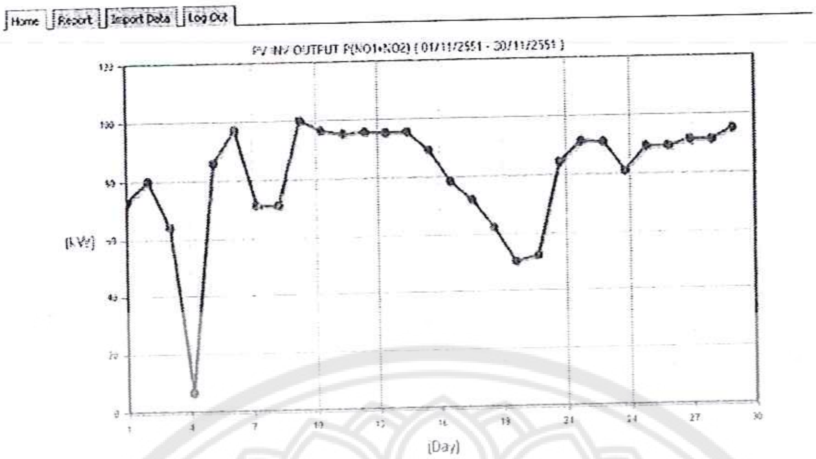
Figure 64 Daily battery inverter output power

In this figure represents sample result of daily Daily battery inverter output power.

Monthly results

In this figure 60-71 represents sample monthly result. In each figure separate results by days in the month. The sample results are include of Monthly PV inverter output power (November 2008), Monthly PV inverter output power (December 2008), Monthly PV inverter output power (January 2009), Monthly PV inverter output power (February 2009), Monthly PV inverter output power (March 2009), Monthly PV inverter output power (April 2009), Monthly PV inverter output power (May 2009), Monthly PV inverter output power (June 2009), Monthly PV inverter output power (July 2009), Monthly PV inverter output power (August 2009), Monthly PV inverter output power (September 2009) and Monthly PV inverter output power (October 2009).

ระบบการนำข้อมูลเข้า



ข้อมูลจริงจากกราฟ

ลำดับที่	วันที่ - เวลา	ค่าพลังงานที่ใช้ (หน่วย : (kW))
1	01/11/2551	0.00
2	02/11/2551	72.92
3	03/11/2551	80.07
4	04/11/2551	63.93
5	05/11/2551	6.46
6	06/11/2551	85.87
7	07/11/2551	97.05
8	08/11/2551	71.23
9	09/11/2551	71.13
10	10/11/2551	100.00
11	11/11/2551	96.33
12	12/11/2551	95.18
13	13/11/2551	95.68
14	14/11/2551	95.32
15	15/11/2551	95.46
16	16/11/2551	89.15
17	17/11/2551	78.41
18	18/11/2551	71.87
19	19/11/2551	62.20
20	20/11/2551	50.25
21	21/11/2551	52.17
22	22/11/2551	84.32
23	23/11/2551	91.36
24	24/11/2551	90.98
25	25/11/2551	91.08
26	26/11/2551	89.33
27	27/11/2551	89.32
28	28/11/2551	91.44
29	29/11/2551	91.36
30	30/11/2551	95.01

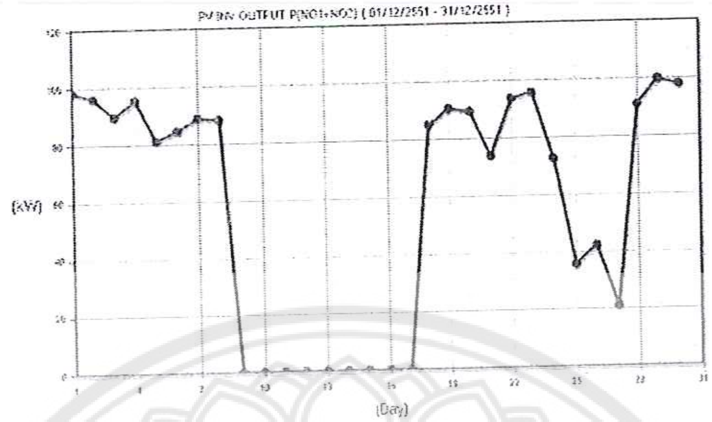
รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV INV OUTPUT P(NO1+NO2) - ระหว่างวันที่ 01/11/2551 ถึง 30/11/2551

Figure 65 Monthly PV inverter output power (November 2008)

ระบบการนำข้อมูลเข้า

Home | Report | Import Data | Log Out



ข้อมูลจริงจากกราฟ

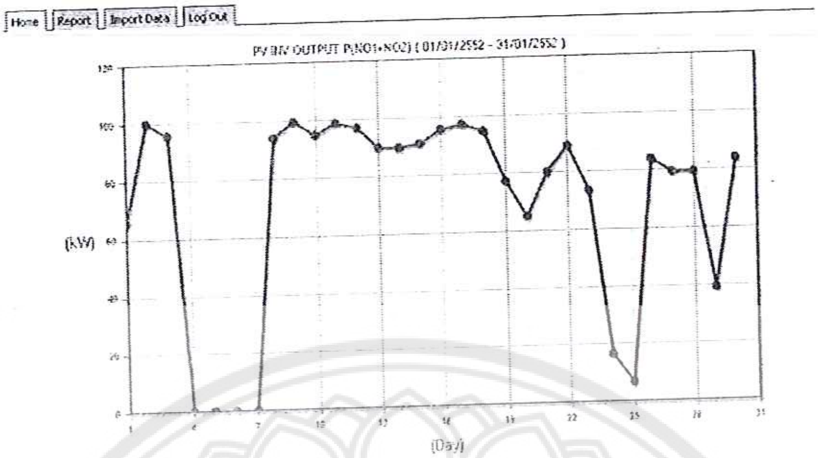
ลำดับที่	วันที่ - เวลา	ค่ากำลังงานที่ใช้ (หน่วย : (kW))
1	01/12/2551	100.00
2	02/12/2551	98.31
3	03/12/2551	96.09
4	04/12/2551	89.70
5	05/12/2551	95.33
6	06/12/2551	81.19
7	07/12/2551	84.53
8	08/12/2551	88.98
9	09/12/2551	88.42
10	10/12/2551	0.00
11	11/12/2551	0.00
12	12/12/2551	0.00
13	13/12/2551	0.00
14	14/12/2551	0.00
15	15/12/2551	0.00
16	16/12/2551	0.00
17	17/12/2551	0.00
18	18/12/2551	0.00
19	19/12/2551	85.06
20	20/12/2551	90.70
21	21/12/2551	89.50
22	22/12/2551	73.84
23	23/12/2551	93.90
24	24/12/2551	95.81
25	25/12/2551	72.69
26	26/12/2551	35.66
27	27/12/2551	42.08
28	28/12/2551	20.91
29	29/12/2551	91.09
30	30/12/2551	99.93
31	31/12/2551	98.00

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV INV OUTPUT P(NO1+NO2) - ระหว่างวันที่ 01/12/2551 ถึง 31/12/2551

Figure 66 Monthly PV inverter output power (December 2008)

ระบบการนำข้อมูลเข้า



ข้อมูลจริงจากกราฟ

1	01/01/2552	93.11
2	02/01/2552	65.33
3	03/01/2552	100.00
4	04/01/2552	95.65
5	05/01/2552	0.00
6	06/01/2552	0.00
7	07/01/2552	0.00
8	08/01/2552	0.00
9	09/01/2552	94.19
10	10/01/2552	99.62
11	11/01/2552	94.84
12	12/01/2552	98.78
13	13/01/2552	97.06
14	14/01/2552	90.00
15	15/01/2552	89.75
16	16/01/2552	90.93
17	17/01/2552	95.71
18	18/01/2552	97.26
19	19/01/2552	94.84
20	20/01/2552	77.27
21	21/01/2552	64.85
22	22/01/2552	80.87
23	23/01/2552	85.01
24	24/01/2552	73.30
25	25/01/2552	16.36
26	26/01/2552	6.61
27	27/01/2552	83.84
28	28/01/2552	79.29
29	29/01/2552	79.32
30	30/01/2552	39.22
31	31/01/2552	83.63

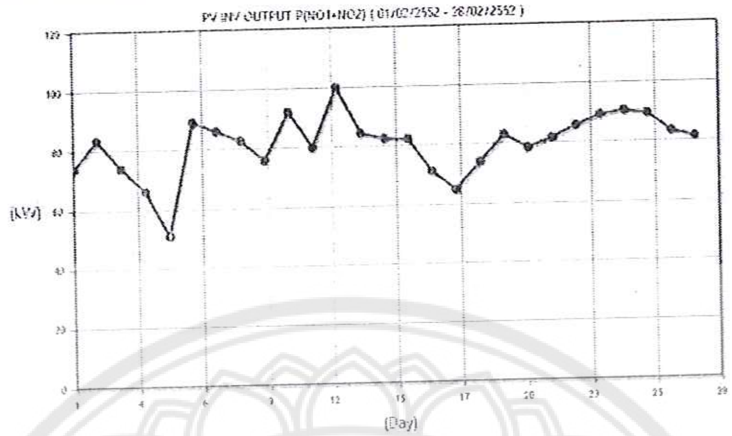
รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV INV OUTPUT P(NO1+NO2) - ระหว่างวันที่ 01/01/2552 ถึง 31/01/2552

Figure 67 Monthly PV inverter output power (January 2009)

ระบบการนำข้อมูลเข้า

Home | Report | Import Data | Log Out



ข้อมูลจริงจากกราฟ

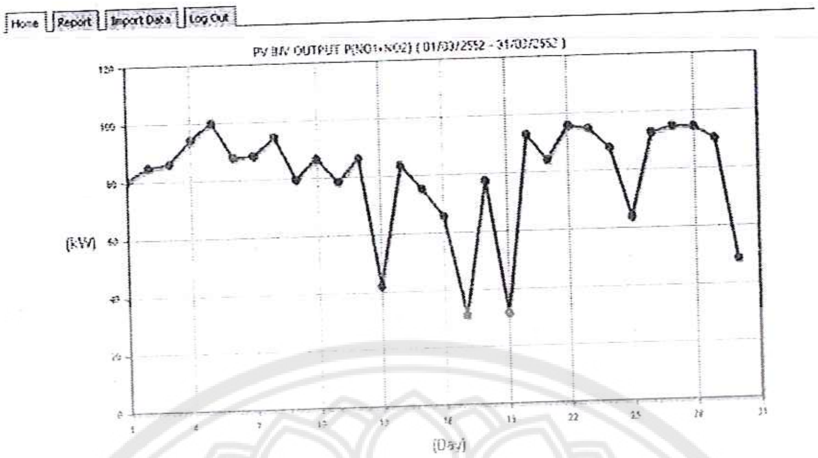
เลขที่	วันที่ - เวลา	ค่าพลังงานที่ใช้ (หน่วย : (kW))
1	01/02/2552	73.85
2	02/02/2552	73.73
3	03/02/2552	83.33
4	04/02/2552	73.79
5	05/02/2552	65.92
6	06/02/2552	50.75
7	07/02/2552	83.13
8	08/02/2552	65.99
9	09/02/2552	82.67
10	10/02/2552	75.81
11	11/02/2552	92.04
12	12/02/2552	73.95
13	13/02/2552	100.00
14	14/02/2552	84.41
15	15/02/2552	82.52
16	16/02/2552	82.19
17	17/02/2552	71.09
18	18/02/2552	64.56
19	19/02/2552	73.96
20	20/02/2552	83.10
21	21/02/2552	78.38
22	22/02/2552	81.69
23	23/02/2552	85.70
24	24/02/2552	89.13
25	25/02/2552	90.41
26	26/02/2552	89.43
27	27/02/2552	83.41
28	28/02/2552	81.49

รายละเอียดของข้อมูล

I. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV INV OUTPUT P(NO1+NO2) - ระหว่างวันที่ 01/02/2552 ถึง 28/02/2552

Figure 68 Monthly PV inverter output power (February 2009)

ระบบการนำข้อมูลเข้า



ข้อมูลจริงจากกราฟ

เลขที่	วันที่ - เวลา	ค่าพลังงานที่ใช้ (หน่วย : (kW))
1	01/03/2552	74.96
2	02/03/2552	80.56
3	03/03/2552	84.91
4	04/03/2552	86.00
5	05/03/2552	94.11
6	06/03/2552	100.00
7	07/03/2552	87.80
8	08/03/2552	88.19
9	09/03/2552	94.55
10	10/03/2552	79.69
11	11/03/2552	86.68
12	12/03/2552	78.63
13	13/03/2552	86.41
14	14/03/2552	41.86
15	15/03/2552	83.49
16	16/03/2552	75.26
17	17/03/2552	65.50
18	18/03/2552	30.92
19	19/03/2552	77.53
20	20/03/2552	31.28
21	21/03/2552	93.00
22	22/03/2552	84.14
23	23/03/2552	95.86
24	24/03/2552	94.62
25	25/03/2552	87.84
26	26/03/2552	63.62
27	27/03/2552	92.83
28	28/03/2552	94.76
29	29/03/2552	94.55
30	30/03/2552	90.42
31	31/03/2552	48.39

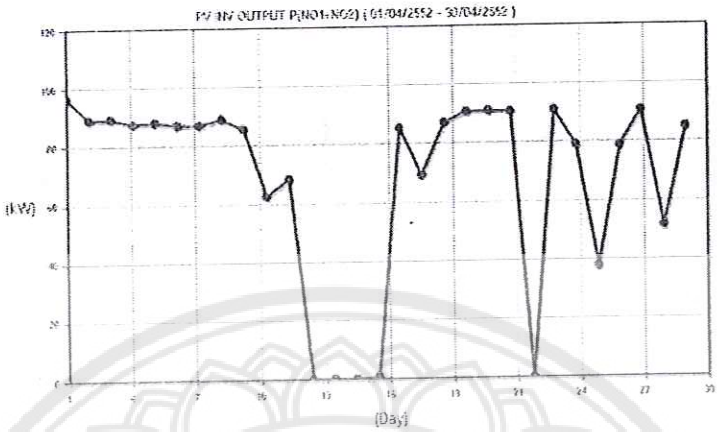
รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV INV OUTPUT P(NO1+NO2) - ระหว่างวันที่ 01/03/2552 ถึง 31/03/2552

Figure 69 Monthly PV inverter output power (March 2009)

ระบบการนำข้อมูลเข้า

Home | Report | Import Data | Log Out



ข้อมูลจริงจากกราฟ

เลขที่	วันที่ - เวลา	ค่าพลังงานที่ใช้ (หน่วย : (kW))
1	01/04/2552	100.00
2	02/04/2552	96.32
3	03/04/2552	69.14
4	04/04/2552	69.29
5	05/04/2552	87.59
6	06/04/2552	88.11
7	07/04/2552	87.05
8	08/04/2552	87.04
9	09/04/2552	69.06
10	10/04/2552	85.54
11	11/04/2552	62.36
12	12/04/2552	69.26
13	13/04/2552	0.00
14	14/04/2552	0.00
15	15/04/2552	0.00
16	16/04/2552	0.71
17	17/04/2552	85.41
18	18/04/2552	69.20
19	19/04/2552	87.19
20	20/04/2552	90.70
21	21/04/2552	90.94
22	22/04/2552	90.70
23	23/04/2552	0.00
24	24/04/2552	91.11
25	25/04/2552	79.12
26	26/04/2552	37.54
27	27/04/2552	78.85
28	28/04/2552	90.80
29	29/04/2552	51.32
30	30/04/2552	85.15

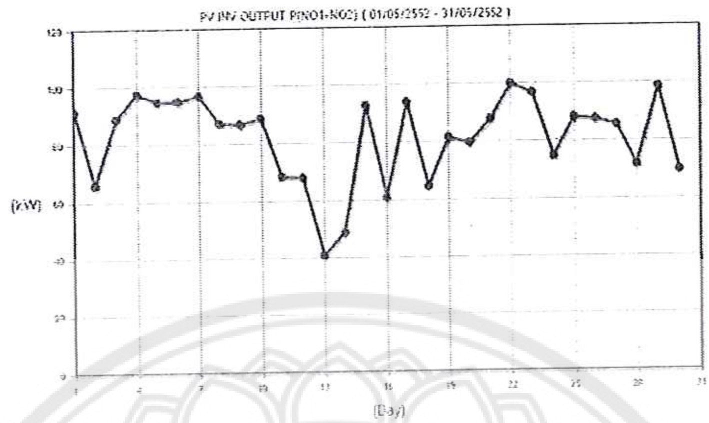
รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV INV OUTPUT P(NO1+NO2) - ระหว่างวันที่ 01/04/2552 ถึง 30/04/2552

Figure 70 Monthly PV inverter output power (April 2009)

ระบบการนำข้อมูลเข้า

Home | Report | Import Data | Log Out



ข้อมูลจริงจากกราฟ

ครั้งที่	วันที่ - เวลา	ค่าพลังงานที่ใช้ (หน่วย : (kW))
1	01/05/2552	85.67
2	02/05/2552	91.73
3	03/05/2552	65.67
4	04/05/2552	89.88
5	05/05/2552	97.48
6	06/05/2552	94.74
7	07/05/2552	94.88
8	08/05/2552	96.75
9	09/05/2552	87.11
10	10/05/2552	86.71
11	11/05/2552	89.61
12	12/05/2552	68.39
13	13/05/2552	67.83
14	14/05/2552	40.74
15	15/05/2552	48.70
16	16/05/2552	92.81
17	17/05/2552	60.69
18	18/05/2552	93.91
19	19/05/2552	64.58
20	20/05/2552	81.46
21	21/05/2552	79.61
22	22/05/2552	87.76
23	23/05/2552	100.00
24	24/05/2552	96.84
25	25/05/2552	74.62
26	26/05/2552	88.18
27	27/05/2552	87.53
28	28/05/2552	85.53
29	29/05/2552	71.65
30	30/05/2552	98.65
31	31/05/2552	69.71

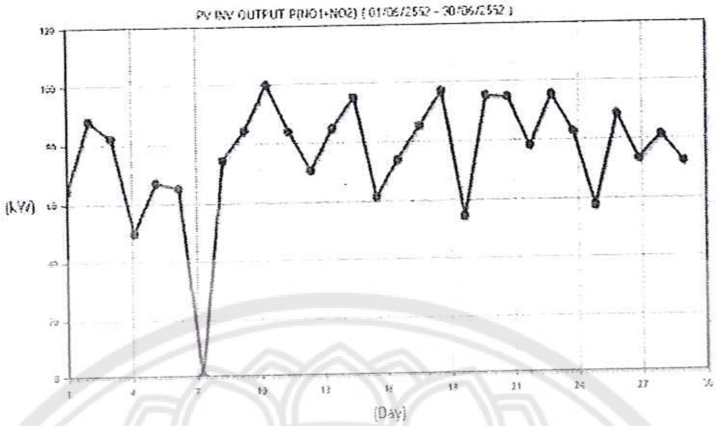
รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV INV OUTPUT P(NO1+NO2) - ระหว่างวันที่ 01/05/2552 ถึง 31/05/2552

Figure 71 Monthly PV inverter output power (May 2009)

ระบบการนำข้อมูลเข้า

Home | Report | Import Data | Log Out



ข้อมูลจริงจากกราฟ

เลขที่	วันที่ - เวลา	ค่ากำลังงานที่ใช้ (หน่วย : (KW))
1	01/06/2552	71.98
2	02/06/2552	64.35
3	03/06/2552	88.14
4	04/06/2552	82.14
5	05/06/2552	49.58
6	06/06/2552	66.92
7	07/06/2552	65.01
8	08/06/2552	0.00
9	09/06/2552	74.32
10	10/06/2552	84.48
11	11/06/2552	100.00
12	12/06/2552	83.80
13	13/06/2552	70.49
14	14/06/2552	64.85
15	15/06/2552	95.30
16	16/06/2552	61.20
17	17/06/2552	73.84
18	18/06/2552	85.43
19	19/06/2552	97.15
20	20/06/2552	54.13
21	21/06/2552	95.48
22	22/06/2552	94.97
23	23/06/2552	78.11
24	24/06/2552	95.54
25	25/06/2552	82.83
26	26/06/2552	57.35
27	27/06/2552	88.71
28	28/06/2552	73.32
29	29/06/2552	81.47
30	30/06/2552	72.37

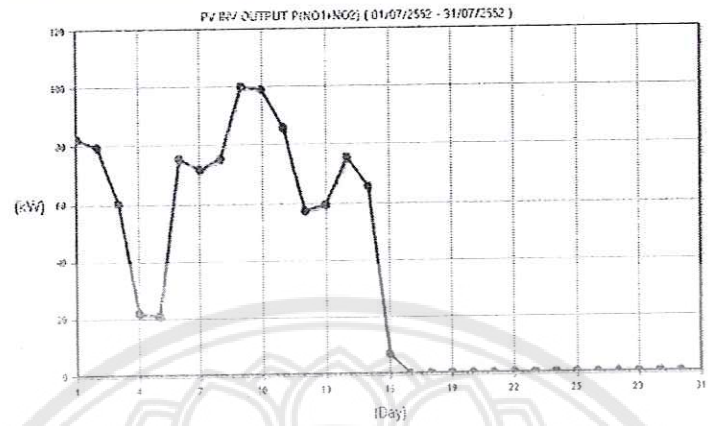
รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV INV OUTPUT P(NO1+NO2) - ระหว่างวันที่ 01/06/2552 ถึง 30/06/2552

Figure 72 Monthly PV inverter output power (June 2009)

ระบบการนำข้อมูลเข้า

Home | Report | Import Data | Log Out



ข้อมูลจริงจากกราฟ

เลขที่	วันที่ - เวลา	ค่าพลังงานที่ใช้ (หน่วย : (kW))
1	01/07/2552	76.66
2	02/07/2552	82.35
3	03/07/2552	79.44
4	04/07/2552	60.36
5	05/07/2552	21.65
6	06/07/2552	20.89
7	07/07/2552	75.48
8	08/07/2552	71.96
9	09/07/2552	75.54
10	10/07/2552	100.00
11	11/07/2552	98.93
12	12/07/2552	85.74
13	13/07/2552	57.15
14	14/07/2552	59.31
15	15/07/2552	75.65
16	16/07/2552	65.54
17	17/07/2552	6.78
18	18/07/2552	0.00
19	19/07/2552	0.00
20	20/07/2552	0.00
21	21/07/2552	0.00
22	22/07/2552	0.00
23	23/07/2552	0.00
24	24/07/2552	0.00
25	25/07/2552	0.00
26	26/07/2552	0.00
27	27/07/2552	0.00
28	28/07/2552	0.00
29	29/07/2552	0.00
30	30/07/2552	0.00
31	31/07/2552	0.00

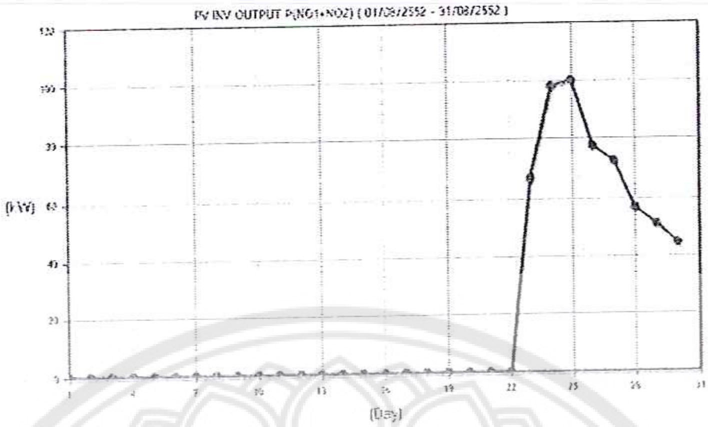
รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV INV OUTPUT P(NO1+NO2) - ระหว่างวันที่ 01/07/2552 ถึง 31/07/2552

Figure 73 Monthly PV inverter output power (July 2009)

ระบบการนำข้อมูลเข้า

Home | Report | Import Data | Log Out



ข้อมูลจริงจากกราฟ

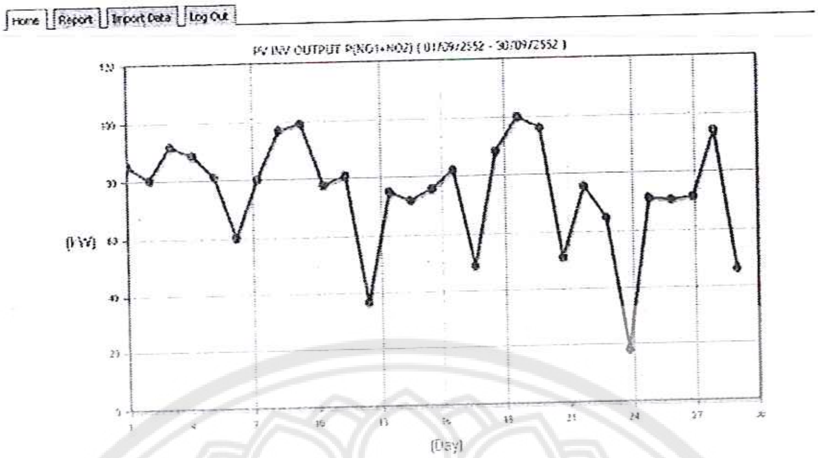
ลำดับ	วันที่ - เวลา	ค่าเฉลี่ยกำลังที่ใช้ (หน่วย : (kW))
1	01/08/2552	0.00
2	02/08/2552	0.00
3	03/08/2552	0.00
4	04/08/2552	0.00
5	05/08/2552	0.00
6	06/08/2552	0.00
7	07/08/2552	0.00
8	08/08/2552	0.00
9	09/08/2552	0.00
10	10/08/2552	0.00
11	11/08/2552	0.00
12	12/08/2552	0.00
13	13/08/2552	0.00
14	14/08/2552	0.00
15	15/08/2552	0.00
16	16/08/2552	0.00
17	17/08/2552	0.00
18	18/08/2552	0.00
19	19/08/2552	0.00
20	20/08/2552	0.00
21	21/08/2552	0.00
22	22/08/2552	0.00
23	23/08/2552	0.00
24	24/08/2552	66.66
25	25/08/2552	98.10
26	26/08/2552	100.00
27	27/08/2552	77.43
28	28/08/2552	72.24
29	29/08/2552	56.73
30	30/08/2552	50.57
31	31/08/2552	44.59

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV INV OUTPUT P(NO1+NO2) - ระหว่างวันที่ 01/08/2552 ถึง 31/08/2552

Figure 74 Monthly PV inverter output power (August 2009)

ระบบการนำข้อมูลเข้า



ข้อมูลจริงจากกราฟ

เลขที่	วันที่ - เวลา	ค่าพลังงานที่ใช้ (หน่วย : (kW))
1	01/09/2552	72.87
2	02/09/2552	85.22
3	03/09/2552	80.42
4	04/09/2552	91.73
5	05/09/2552	88.53
6	06/09/2552	81.23
7	07/09/2552	59.84
8	08/09/2552	80.46
9	09/09/2552	96.94
10	10/09/2552	99.00
11	11/09/2552	77.73
12	12/09/2552	80.85
13	13/09/2552	36.29
14	14/09/2552	74.97
15	15/09/2552	71.87
16	16/09/2552	75.71
17	17/09/2552	82.19
18	18/09/2552	48.56
19	19/09/2552	88.46
20	20/09/2552	100.00
21	21/09/2552	96.12
22	22/09/2552	50.89
23	23/09/2552	75.55
24	24/09/2552	64.56
25	25/09/2552	17.83
26	26/09/2552	71.13
27	27/09/2552	70.44
28	28/09/2552	71.38
29	29/09/2552	94.07
30	30/09/2552	46.03

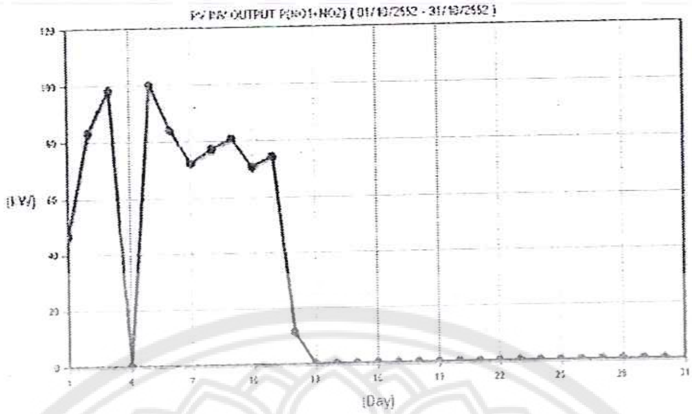
รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV INV OUTPUT P(NO1+NO2) - ระหว่างวันที่ 01/09/2552 ถึง 30/09/2552

Figure 75 Monthly PV inverter output power (September 2009)

ระบบการนำข้อมูลเข้า

Home | Report | Import Data | Log Out



ข้อมูลจริงจากกราฟ

เลขที่	วันที่ - เวลา	ค่าพลังงานที่ใช้ (หน่วย : kW)
1	01/10/2552	26.13
2	02/10/2552	46.60
3	03/10/2552	83.15
4	04/10/2552	99.16
5	05/10/2552	0.00
6	06/10/2552	100.00
7	07/10/2552	83.60
8	08/10/2552	72.11
9	09/10/2552	77.13
10	10/10/2552	80.73
11	11/10/2552	70.82
12	12/10/2552	74.32
13	13/10/2552	11.46
14	14/10/2552	0.00
15	15/10/2552	0.00
16	16/10/2552	0.00
17	17/10/2552	0.00
18	18/10/2552	0.00
19	19/10/2552	0.00
20	20/10/2552	0.00
21	21/10/2552	0.00
22	22/10/2552	0.00
23	23/10/2552	0.00
24	24/10/2552	0.00
25	25/10/2552	0.00
26	26/10/2552	0.00
27	27/10/2552	0.00
28	28/10/2552	0.00
29	29/10/2552	0.00
30	30/10/2552	0.00
31	31/10/2552	0.00

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV INV OUTPUT P(NO1+NO2) - ระหว่างวันที่ 01/10/2552 ถึง 31/10/2552

Figure 76 Monthly PV inverter output power (October 2009)

Season results

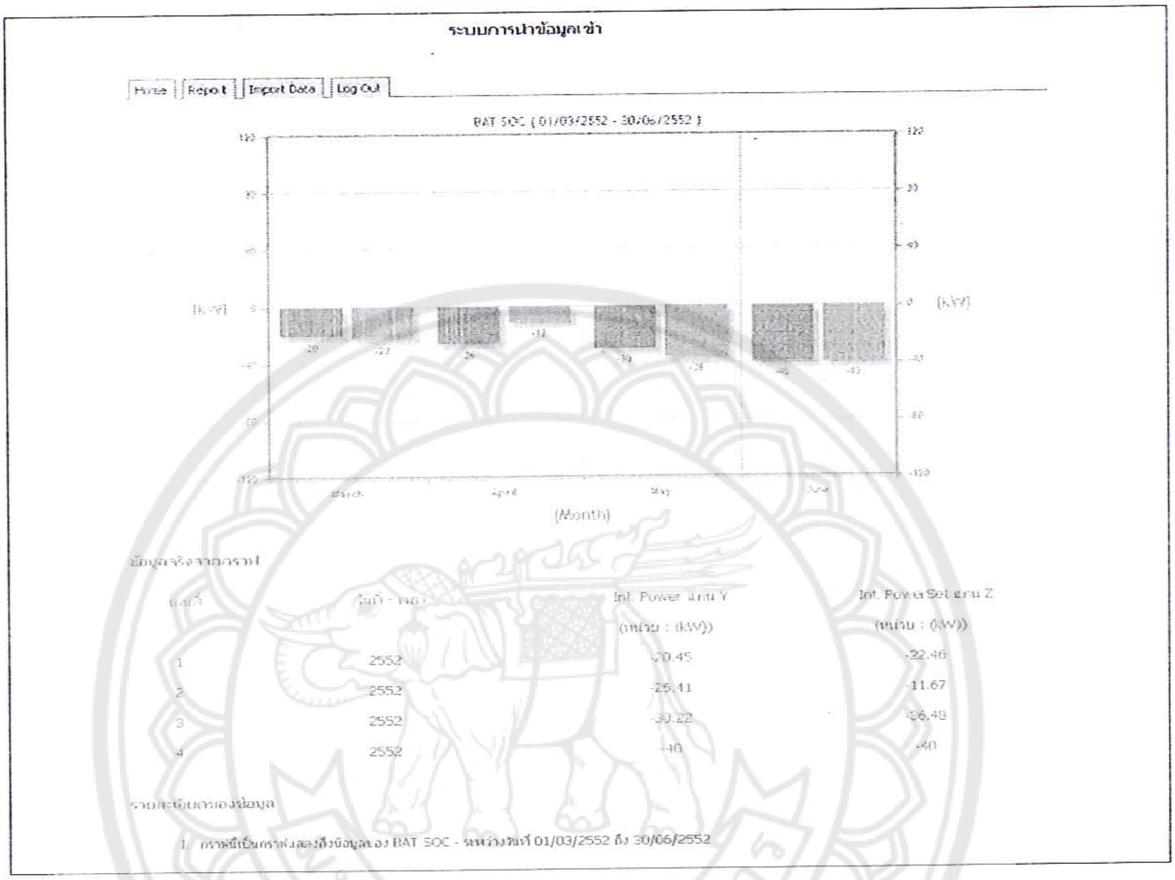
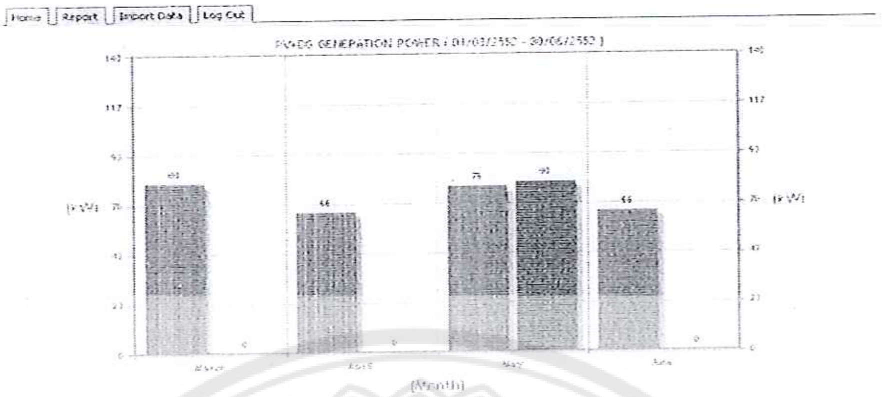


Figure 77 Summer Battery SOC (March - June 2009)

ระบบการนำข้อมูลเข้า



ข้อมูลจริงจากกราฟ

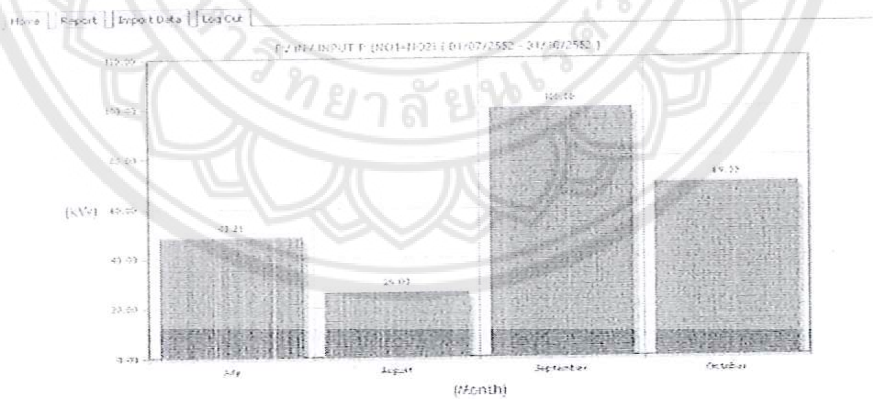
ลำดับ	วันที่ - เวลา	PV แกน Y (หน่วย : (kW))	DG แกน Z (หน่วย : (kW))
1	2552	80	0
2	2552	66	0
3	2552	76	90
4	2552	66	0

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV+DG GENERATION POWER - ระหว่างวันที่ 01/03/2552 ถึง 30/06/2552

Figure 78 Summer PV and diesel generation power (March - June 2009)

ระบบการนำข้อมูลเข้า



ข้อมูลจริงจากกราฟ

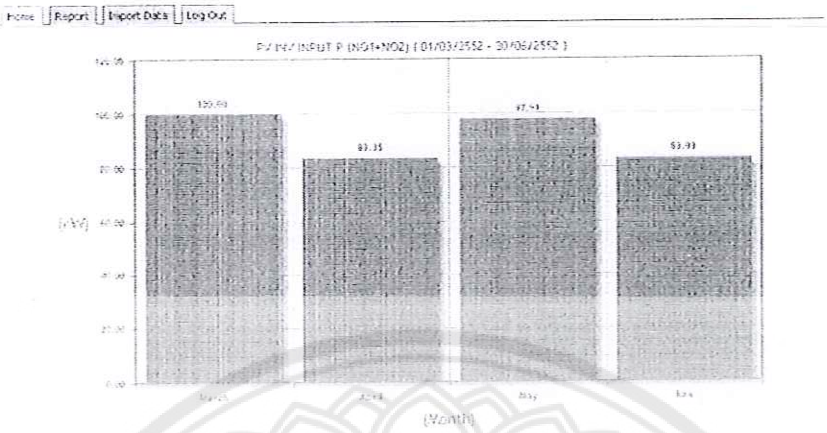
ลำดับ	วันที่ - เวลา	ค่าพลังงานที่ใช้ (หน่วย : (kW))
1	2552	49.21
2	2552	26.00
3	2552	100.00
4	2552	69.55

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV INV INPUT P (NO1+NO2) - ระหว่างวันที่ 01/07/2552 ถึง 31/10/2552

Figure 79 Rainy PV inverter input power (July - October 2009)

ระบบการนำข้อมูลเข้า



ข้อมูลจริงจากกราฟ

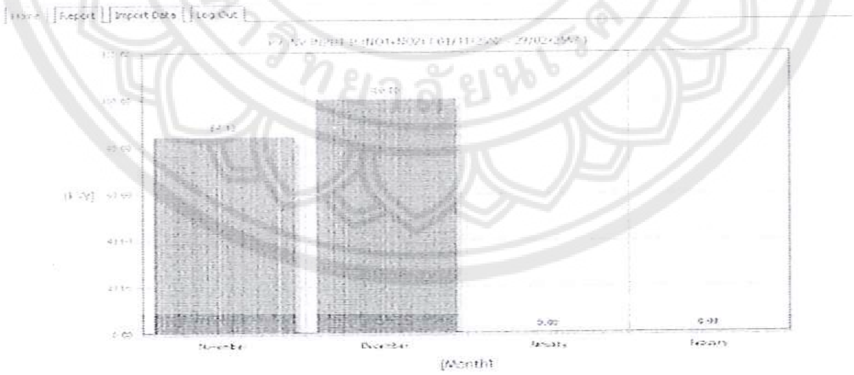
ลำดับ	วันที่ - เวลา	ค่าพลังงานที่ใช้ (หน่วย : kW)
1	2552	100.00
2	2552	83.35
3	2552	97.91
4	2552	83.08

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV INV INPUT P (NO1+NO2) - ระหว่างวันที่ 01/03/2552 ถึง 30/06/2552

Figure 80 Summer PV inverter input power (March - June 2009)

ระบบการนำข้อมูลเข้า



ข้อมูลจริงจากกราฟ

ลำดับ	วันที่ - เวลา	ค่าพลังงานที่ใช้ (หน่วย : kW)
1	2552	84.13
2	2552	100.00
3	2553	0.00
4	2553	0.00

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV INV INPUT P (NO1+NO2) - ระหว่างวันที่ 01/11/2552 ถึง 29/02/2553

Figure 81 Winter PV inverter input power (November 2008 - Febuary 2009)

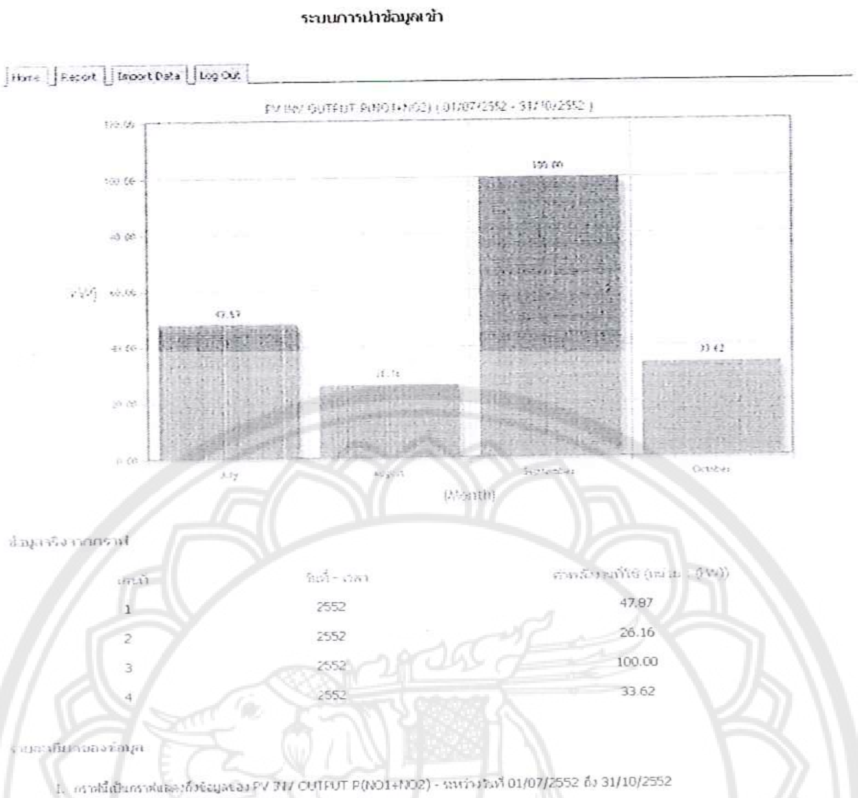


Figure 82 Rainy PV inverter output power (July - October 2009)

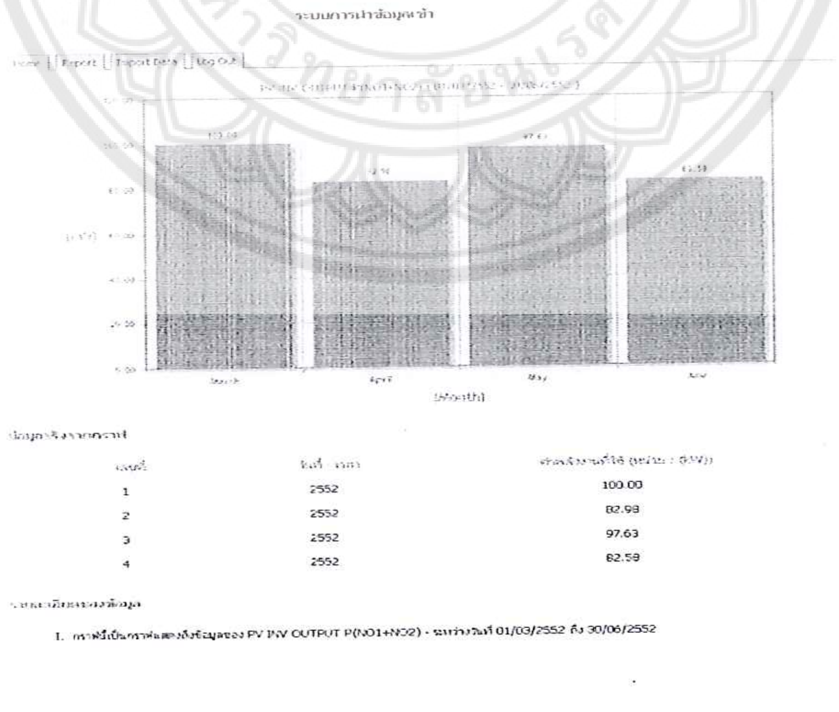


Figure 83 Summer PV inverter output power (March - June 2009)

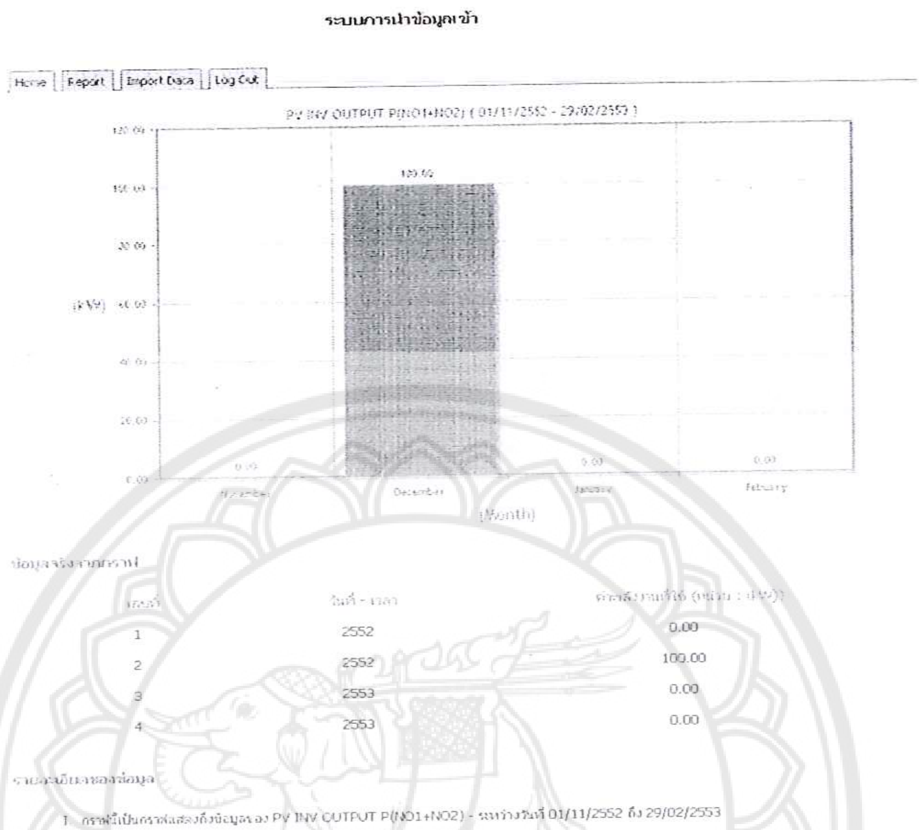


Figure 84 Winter PV inverter output power (November 2008 - Febuary 2009)

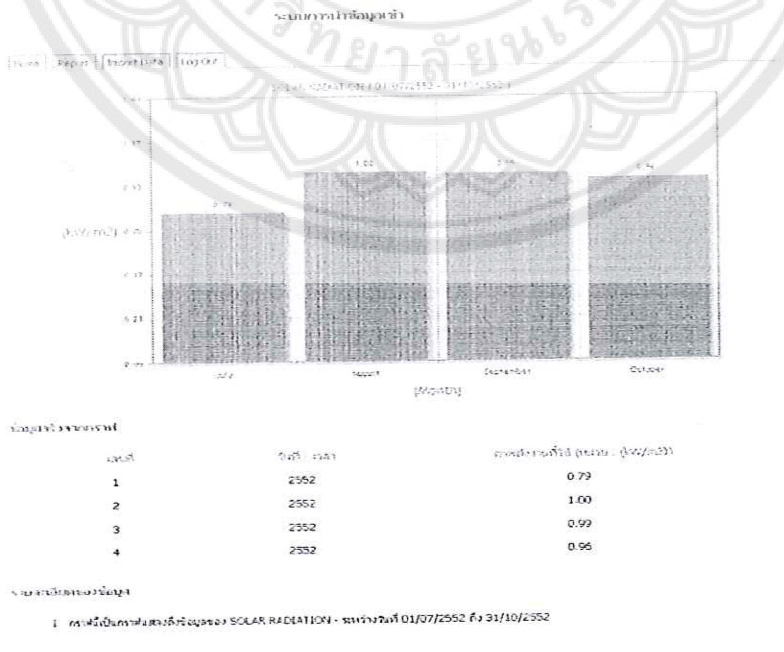
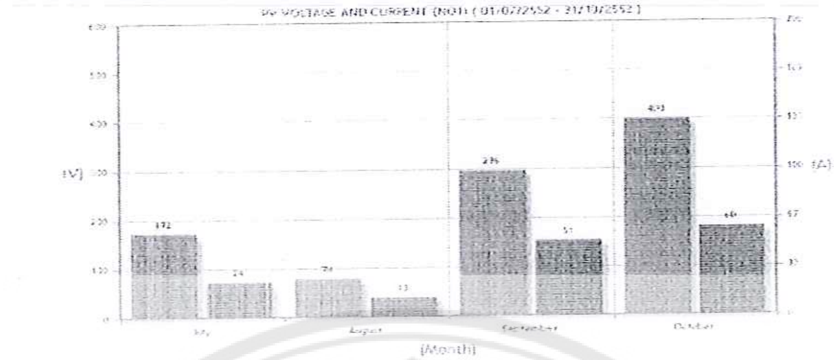


Figure 85 Rainy solar radiation (July - October 2009)

ระบบการนำข้อมูลเข้า

Home | Report | Import Data | Log Out



ข้อมูลจริงจากกราฟ

ลำดับ	วันที่ - เวลา	NO1 PV DC V แกน Y (หน่วย : (V))	NO1 PV DC I แกน Z (หน่วย : (A))
1	2552	172	24
2	2552	78	13
3	2552	296	51
4	2552	400	60

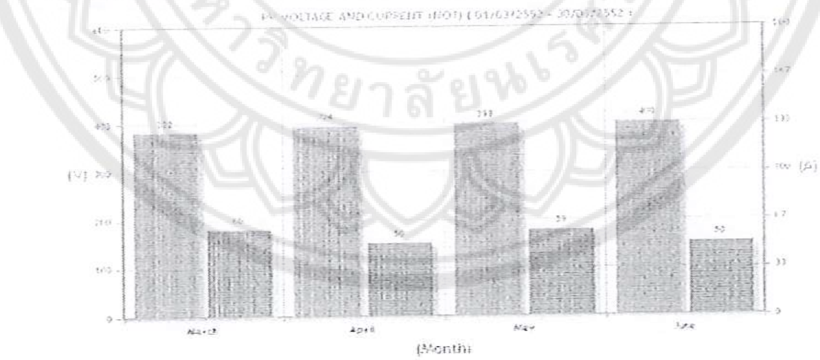
รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV VOLTAGE AND CURRENT (NO1) - ระหว่างวันที่ 01/07/2552 ถึง 31/10/2552

Figure 86 Rainy PV voltage and current (July - October 2009)

ระบบการนำข้อมูลเข้า

Home | Report | Import Data | Log Out



ข้อมูลจริงจากกราฟ

ลำดับ	วันที่ - เวลา	NO1 PV DC V แกน Y (หน่วย : (V))	NO1 PV DC I แกน Z (หน่วย : (A))
1	2552	382	60
2	2552	394	50
3	2552	398	59
4	2552	400	50

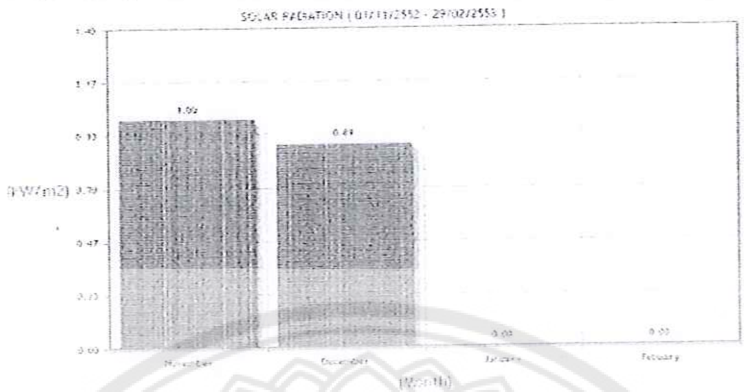
รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV VOLTAGE AND CURRENT (NO1) - ระหว่างวันที่ 01/03/2552 ถึง 30/06/2552

Figure 87 Summer PV voltage and current (March - June 2009)

ระบบการนำข้อมูลเข้า

Home | Report | Import Data | Log Out



ข้อมูลจริงจากกราฟ

ครั้งที่	วันที่ - เวลา	ค่าพลังงานที่ได้ (หน่วย : (kW/m2))
1	2552	1.00
2	2552	0.89
3	2553	0.00
4	2553	0.00

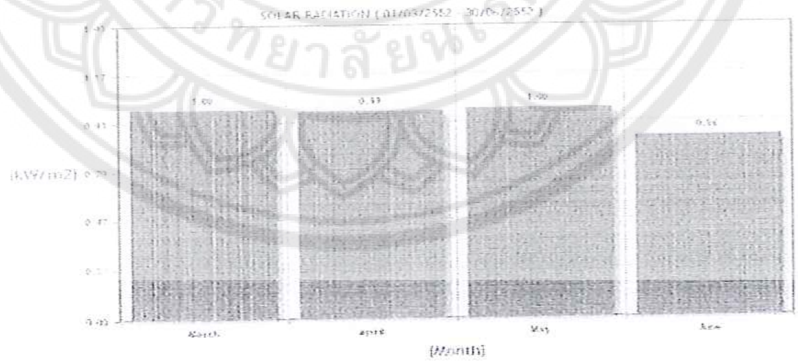
รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ SOLAR RADIATION - ระหว่างวันที่ 01/11/2552 ถึง 29/02/2553

Figure 88 Winter solar radiation (November 2009 - Febuary 2010)

ระบบการนำข้อมูลเข้า

Home | Report | Import Data | Log Out



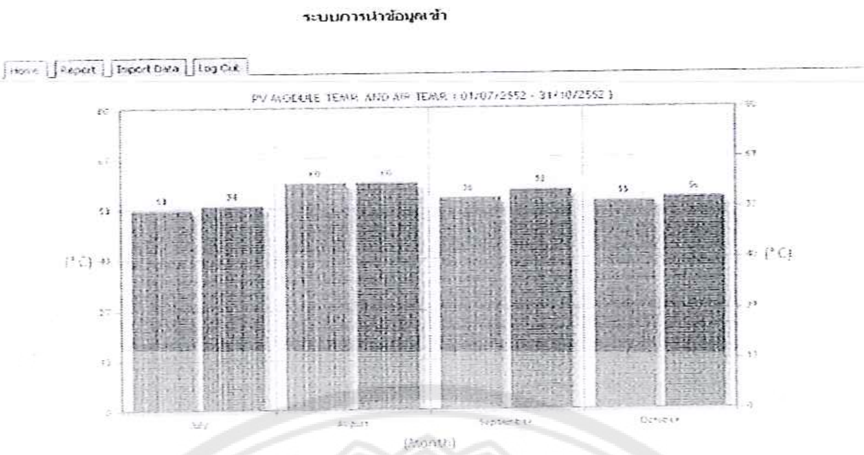
ข้อมูลจริงจากกราฟ

ครั้งที่	วันที่ - เวลา	ค่าพลังงานที่ได้ (หน่วย : (kW/m2))
1	2552	1.00
2	2552	0.99
3	2552	1.00
4	2552	0.86

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ SOLAR RADIATION - ระหว่างวันที่ 01/03/2552 ถึง 30/06/2552

Figure 89 Summer solar radiation (March - June 2009)



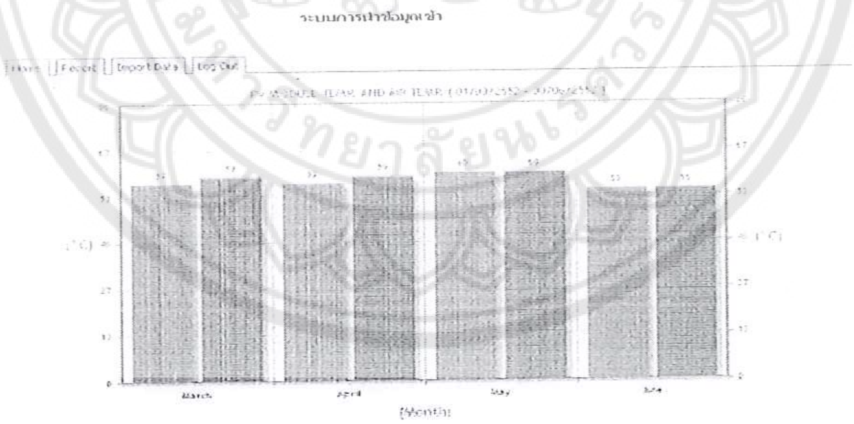
ข้อมูลจริงจากกราฟ

ลำดับ	วันที่ - เวลา	Module Temp.(Ave) แกน Y (หน่วย : (ºC))	Air Temp. แกน Z (หน่วย : (ºC))
1	2552	53	54
2	2552	60	60
3	2552	56	59
4	2552	55	56

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV MODULE TEMP. AND AIR TEMP. - ระหว่างวันที่ 01/07/2552 ถึง 31/10/2552

Figure 90 Rainy PV module temperature (July - October 2009)



ข้อมูลจริงจากกราฟ

ลำดับ	วันที่ - เวลา	Module Temp.(Ave) แกน Y (หน่วย : (ºC))	Air Temp. แกน Z (หน่วย : (ºC))
1	2552	57	59
2	2552	57	59
3	2552	60	60
4	2552	55	55

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PV MODULE TEMP. AND AIR TEMP. - ระหว่างวันที่ 01/03/2552 ถึง 30/06/2552

Figure 91 Summer PV module temperature (March - June 2009)

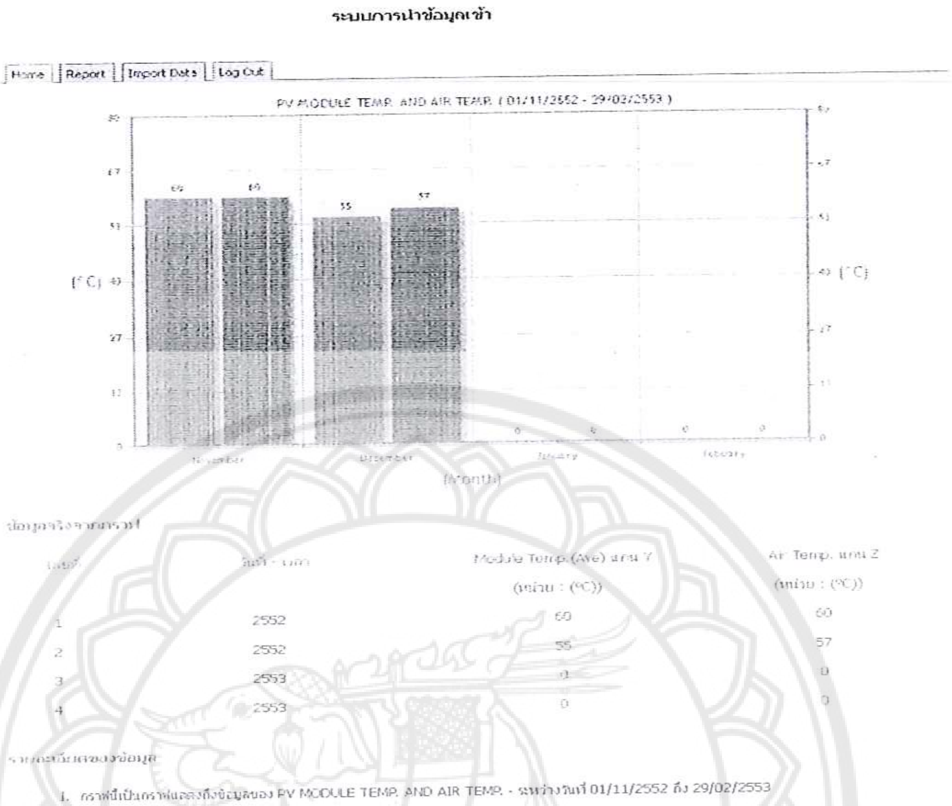


Figure 92 Winter PV module temperature (November 2009 - Febuary 2010)

Simulation method

Simulation value is calculated and notified before executed 30 minute by considering present PV generation energy ($P_{present}$), next 30 minute PV generation energy (P_{sim30}), next 60 minute PV generation energy (P_{sim60}), present load energy (E_{load}), next 30 minute load energy (L_{sim30}), next 60 minute load energy (L_{sim60}). From these parameters, P_{sim30}, P_{sim60}, L_{sim30}, and L_{sim60} are the future data that have to forecast. For P_{sim30} and P_{sim60} estimation, they are estimated by verifying with previous values and estimation based on the assumption that the value is changed follow the average different between present value and previous value. For the verifying with previous values, P_{sim30} and P_{sim60} are calculated from present PV generation energy ($P_{present}$) data during previous 30 minute to present, past week of present PV generation energy (P_{past}) data in the same period, and monthly average PV generation energy ($P_{average}$) data in the same period.

$$P_{select} = P_{past} \text{ or } P_{average} \text{ when } (|P_{sim} - P_{past}| \leq 3) \text{ or } (|P_{present} - P_{average}| \leq 3) \quad (16)$$

$$P_{sim30} = P_{select+30}\,((P_{present} + 1)/(P_{select} + 1)) \quad (17)$$

$$P_{sim60} = P_{select+60}\,((P_{present} + 1)/(P_{select} + 1)) \quad (18)$$

$P_{present}$ = Present Power generation energy (kWh)

P_{past} = Past 10 days of present Power generation energy (kWh)

P_{select} = Selected past week of present Power generation energy (kWh)

$P_{average}$ = Monthly average Power generation energy (kWh)

P_{sim30} = Next 30 minute Power generation energy (kWh)

$P_{select+30}$ = Next 30 minute selected past 10 days of present Power generation energy (kWh)

P_{sim60} = Next 60 minute Power generation energy (kWh)

$P_{select+60}$ = Next 60 minute selected past 10 days of present Power generation energy (kWh)

The calculation starts by comparing $P_{present}$ with P_{past} or P_{past} to identify P_{select} in the equation 16. Then, $P_{select+30}$ and $P_{select+60}$ are selected from selected past week of present PV generation energy in the next 30 minute and 60 minute respectively. After that, P_{sim30} is calculated from the equation 17. Finally, P_{sim60} is calculated from the equation 18. For the estimation based on the assumption that the value is changed follow the average different between present value and previous value, P_{sim30} and P_{sim60} are calculated from present PV generation energy ($P_{present}$) data during previous 30 minute to present, previous 30 minute PV generation energy ($P_{present-30}$) data during previous 30 minute to previous 60 minute, and previous 60 minute PV generation energy ($P_{present-60}$) data during previous 60 minute to previous 90 minute. The estimation based on the assumption that the value is changed follow the average different between present value and previous value for P_{sim30} and P_{sim60} is showed follows this:

$$P_{sim30} = P_{present} \quad \text{when} \quad |P_{present} - P_{present-30}| \geq 20 \tag{19}$$

$$P_{sim30} = P_{present} + ((P_{present} - P_{present-30}) + (P_{present-30} - P_{present-60}))/2 \tag{20}$$

$$P_{sim60} = P_{sim30} \text{when} \quad |P_{sim30} - P_{present-30}\ P_{present}| \geq 20 \tag{21}$$

$$P_{sim60} = P_{sim30} + ((P_{sim30} - P_{present}) + (P_{present} - P_{present-30}))/2 \tag{22}$$

$P_{present-30}$ = Previous 30 minute PV generation energy (kWh)

$P_{present-60}$ = Previous 60 minute PV generation energy (kWh)

The first step of estimation is checking the different value of $P_{present}$ and $P_{present-30}$. Second step, equation 19 is used to estimate P_{sim30} for the different value not lower than 20 while equation 20 is used to estimate $P_{sim30}$for the different value lower than 20. Third step, the different value of $P_{sim30}$and $P_{present}$ is checked. Finally, equation 21 is used to calculate P_{sim60} for the different value not lower than 20 while equation 22 is used to calculate P_{sim60} for the different value lower than 20. For L_{sim30} and L_{sim60} estimation, they are also estimated by verifying with previous values and estimation based on the assumption that the value is changed follow the average different between present value and previous value. For the verifying with previous values, L_{sim30} and L_{sim60} are calculated from present load energy ($L_{present}$) data during previous 30 minute to present, past 10 days of present load energy (L_{past}) data in the same period, and monthly average load energy ($L_{average}$) data in the same period. Figure 91 is presented the parameters and period that used in $L_{sim30}$and L_{sim60} estimation. The verifying with previous values calculation for L_{sim30} and L_{sim60} is presented follows this:

$$L_{select} = L_{past} \text{ or } L_{average} \text{ when } \ (|L_{sim} - L_{past}| \leq 3) \text{ or } (|L_{present} - L_{average}| \leq 3) \tag{23}$$

$$L_{sim30} = L_{select+30}\ ((L_{present} + 1)/(L_{select} + 1)) \tag{24}$$

$$L_{sim60} = L_{select+60}\ ((L_{present} + 1)/(L_{select} + 1)) \tag{25}$$

$L_{present}$ = Present Load energy (kWh)

L_{past} = Past 10 days of present Load energy (kWh)

L_{select} = Selected past week of present Load energy (kWh)

$L_{average}$ = Monthly average Load energy (kWh)

L_{sim30} = Next 30 minute Load energy (kWh)

$L_{select+30}$ = Next 30 minute selected past 10 days of present Load energy (kWh)

L_{sim60} = Next 60 minute Load energy (kWh)

$L_{select+60}$ = Next 60 minute selected past 10 days of present Load energy (kWh)

The calculation starts by comparing $L_{present}$ with L_{past} or $L_{average}$ to identify L_{select} in the equation 23. Then, $L_{select+30}$ and $L_{select+60}$ are selected from selected past 10 days of present load energy in the next 30 minute and 60 minute respectively. After that, L_{sim30} is calculated from the equation 24. Finally, L_{sim60} is calculated from the equation 25. For the estimation based on the assumption that the value is changed follow the average different between present value and previous value, L_{sim30} and L_{sim60} are calculated from present load energy ($L_{present}$) data during previous 30 minute to present, previous 30 minute load energy ($L_{select+30}$) data during previous 30 minute to previous 60 minute, and previous 60 minute load energy ($L_{select+60}$) data during previous 60 minute to previous 90 minute. The estimation based on the assumption that the value is changed follow the average different between present value and previous value for L_{sim30} and L_{sim60} is showed follows this:

$$L_{select+30} = L_{present} \text{ when } \left| L_{present} - L_{select+30} \right| \geq 10 \tag{26}$$

$$L_{sim30} = L_{present} + ((L_{present}) - L_{present\,-30}) + (L_{present\,-30} - L_{present\,-60}))/2 \tag{27}$$

$$L_{select+60} = L_{sim30} \quad \text{when} \quad \left| L_{sim30} - L_{present} \right| \geq 10 \tag{28}$$

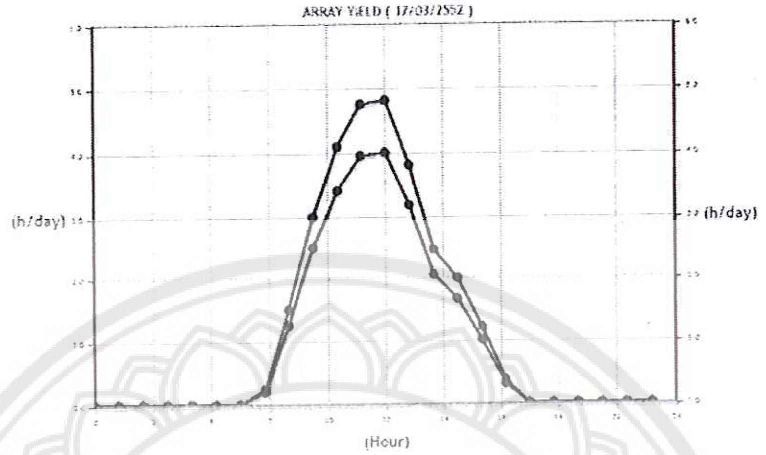
$$L_{select+60} = L_{sim30} + ((L_{sim30} - L_{present}) + (L_{present} - L_{present\,-30}))/2 \tag{29}$$

$L_{present\ -30}$ = Previous 30 minute load energy (kWh)

$L_{present\ -60}$ = Previous 60 minute load energy (kWh)

The first step of estimation is checking the different value of $L_{present}$ and $L_{present\ -30}$. Second step, equation 26 is used to estimate $L_{sim30}$for the different value not lower than 10 while equation 27 is used to estimate $L_{sim30}$for the different value lower than 10. Third step, the different value of L_{sim30} and $L_{present}$ is checked. Finally, equation 28 is used to calculate L_{sim60} for the different value not lower than 10 while equation 60 is used to calculate L_{sim60} for the different value lower than 10.

Simulation result



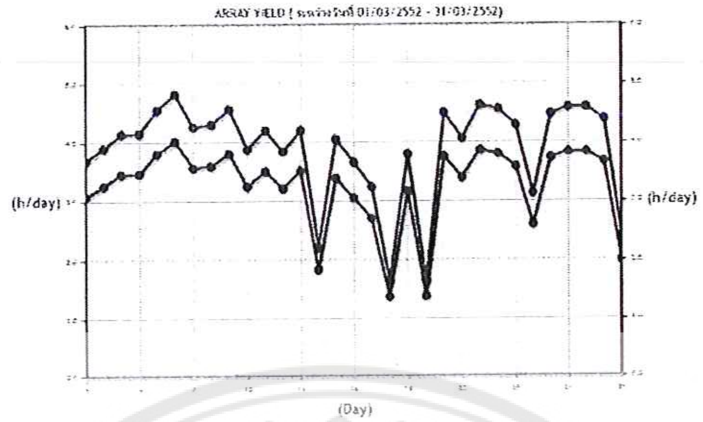
ข้อมูลจริงจากกราฟ

ลำดับที่	วันที่ - เวลา	Real. (หน่วย : (h/day))	Simulation. (หน่วย : (h/day))
1	17/03/2552 - 00:00 น.	0.00	0.00
2	17/03/2552 - 01:00 น.	0.00	0.00
3	17/03/2552 - 02:00 น.	0.00	0.00
4	17/03/2552 - 03:00 น.	0.00	0.00
5	17/03/2552 - 04:00 น.	0.00	0.00
6	17/03/2552 - 05:00 น.	0.00	0.00
7	17/03/2552 - 06:00 น.	0.00	0.00
8	17/03/2552 - 07:00 น.	0.20	0.24
9	17/03/2552 - 08:00 น.	1.25	1.50
10	17/03/2552 - 09:00 น.	2.50	3.00
11	17/03/2552 - 10:00 น.	3.41	4.09
12	17/03/2552 - 11:00 น.	3.95	4.74
13	17/03/2552 - 12:00 น.	4.00	4.80
14	17/03/2552 - 13:00 น.	3.18	3.81
15	17/03/2552 - 14:00 น.	2.05	2.46
16	17/03/2552 - 15:00 น.	1.66	1.99
17	17/03/2552 - 16:00 น.	1.01	1.21
18	17/03/2552 - 17:00 น.	0.31	0.38
19	17/03/2552 - 18:00 น.	0.00	0.00
20	17/03/2552 - 19:00 น.	0.00	0.00
21	17/03/2552 - 20:00 น.	0.00	0.00
22	17/03/2552 - 21:00 น.	0.00	0.00
23	17/03/2552 - 22:00 น.	0.00	0.00
24	17/03/2552 - 23:00 น.	0.00	0.00

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ ARRAY YIELD - ในวันที่ 17/03/2552

Figure 93 Simulation array yield show by daily



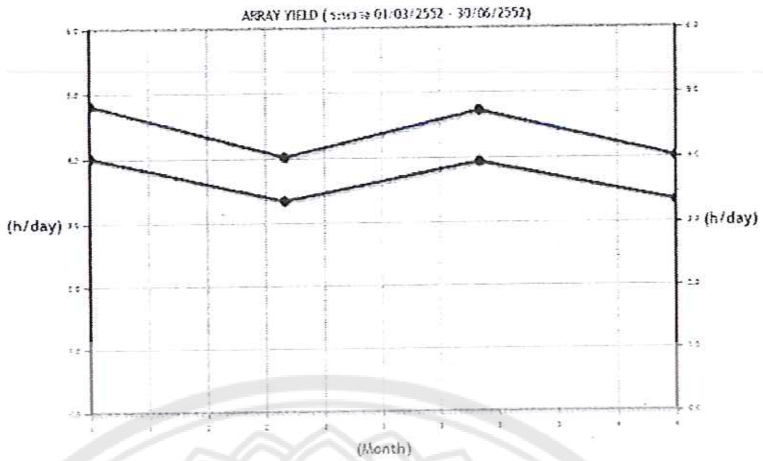
ข้อมูลจริงจากกราฟ

ลำดับที่	วันที่	Real (หน่วย : (h/day))	Simulation (หน่วย : (h/day))
1	01/03/2552	3.05	3.66
2	02/03/2552	3.23	3.88
3	03/03/2552	3.43	4.12
4	04/03/2552	3.44	4.13
5	05/03/2552	3.78	4.53
6	06/03/2552	4.00	4.80
7	07/03/2552	3.54	4.24
8	08/03/2552	3.57	4.28
9	09/03/2552	3.78	4.54
10	10/03/2552	3.72	3.86
11	11/03/2552	3.48	4.18
12	12/03/2552	3.19	3.82
13	13/03/2552	3.49	4.18
14	14/03/2552	1.82	2.19
15	15/03/2552	3.36	1.03
16	16/03/2552	3.02	3.63
17	17/03/2552	2.68	3.22
18	18/03/2552	1.36	1.63
19	19/03/2552	3.14	3.77
20	20/03/2552	1.37	1.64
21	21/03/2552	3.73	4.48
22	22/03/2552	3.37	4.05
23	23/03/2552	3.84	4.61
24	24/03/2552	3.78	4.54
25	25/03/2552	3.56	4.27
26	26/03/2552	2.58	3.10
27	27/03/2552	3.71	4.46
28	28/03/2552	3.81	4.57
29	29/03/2552	3.81	4.57
30	30/03/2552	3.64	4.37
31	31/03/2552	1.98	2.38

รายละเอียดของข้อมูล

I. กราฟนี้เป็นกราฟแสดงข้อมูลของ ARRAY YIELD - ระหว่างวันที่ 01/03/2552 ถึง 31/03/2552

Figure 94 Simulation array yield show by monthly



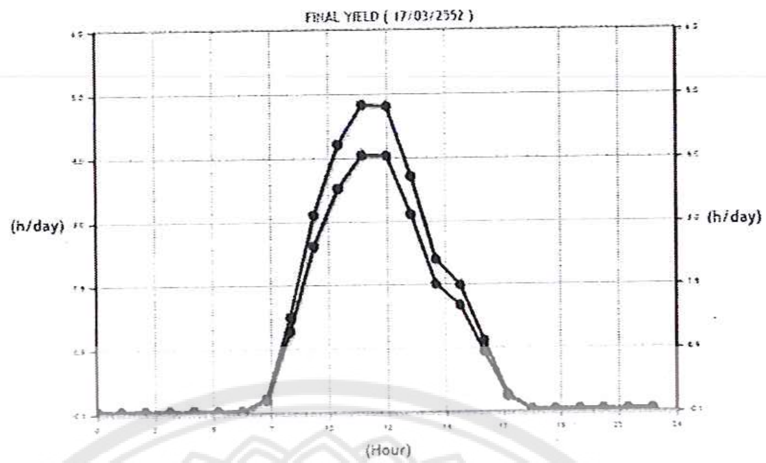
ข้อมูลจริงจากกราฟ

เลขที่	วันที่	Real. (หน่วย : (h/day))	Simulation. (หน่วย : (h/day))
1	2552	4.00	4.80
2	2552	3.33	4.00
3	2552	3.92	4.70
4	2552	3.32	3.99

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ ARRAY YIELD - ระหว่างวันที่ 01/03/2552 ถึง 30/06/2552

Figure 95 Simulation array yield show by season



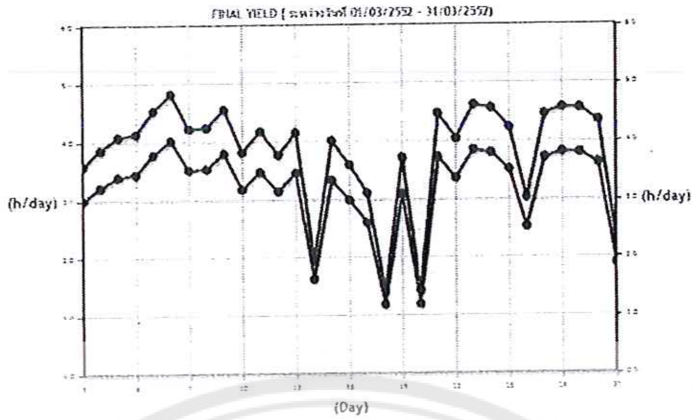
ข้อมูลจริงจากกราฟ

เลขที่	วันที่ - เวลา	Real. (หน่วย : (h/day))	Simulation. (หน่วย : (h/day))
1	17/03/2552 - 00:00 น.	-0.06	-0.07
2	17/03/2552 - 01:00 น.	-0.06	0.07
3	17/03/2552 - 02:00 น.	-0.06	-0.07
4	17/03/2552 - 03:00 น.	-0.06	-0.07
5	17/03/2552 - 04:00 น.	-0.06	-0.07
6	17/03/2552 - 05:00 น.	-0.06	-0.07
7	17/03/2552 - 06:00 น.	-0.06	-0.07
8	17/03/2552 - 07:00 น.	0.11	0.13
9	17/03/2552 - 08:00 น.	1.19	1.42
10	17/03/2552 - 09:00 น.	2.55	3.05
11	17/03/2552 - 10:00 น.	3.47	4.17
12	17/03/2552 - 11:00 น.	4.00	4.80
13	17/03/2552 - 12:00 น.	3.99	4.78
14	17/03/2552 - 13:00 น.	3.05	3.66
15	17/03/2552 - 14:00 น.	1.94	2.33
16	17/03/2552 - 15:00 น.	1.60	1.92
17	17/03/2552 - 16:00 น.	0.86	1.04
18	17/03/2552 - 17:00 น.	0.15	0.18
19	17/03/2552 - 18:00 น.	-0.06	-0.07
20	17/03/2552 - 19:00 น.	-0.06	-0.07
21	17/03/2552 - 20:00 น.	-0.06	-0.07
22	17/03/2552 - 21:00 น.	-0.06	-0.07
23	17/03/2552 - 22:00 น.	-0.06	-0.07
24	17/03/2552 - 23:00 น.	-0.06	-0.07

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ FINAL YIELD - ในวันที่ 17/03/2552

Figure 96 Simulation final yield show by daily



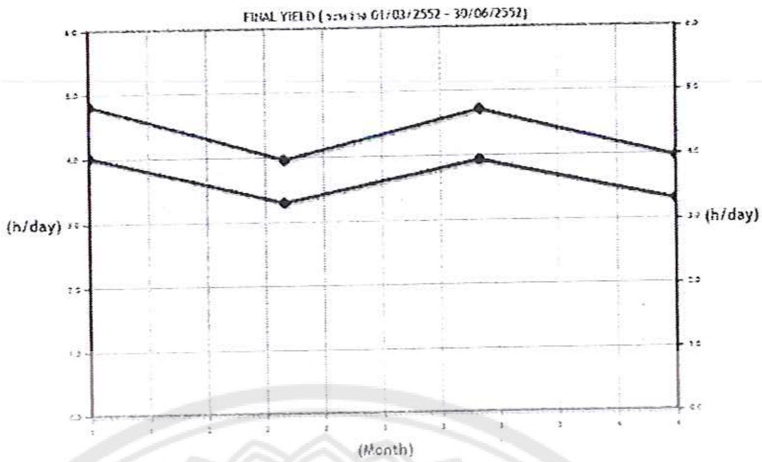
ข้อมูลจริงจากกราฟ

เลขที่	วันที่	Real (หน่วย : (h/day))	Simulation (หน่วย : (h/day))
1	01/03/2552	2.98	3.57
2	02/03/2552	3.20	3.84
3	03/03/2552	3.38	4.06
4	04/03/2552	3.43	4.11
5	05/03/2552	3.76	4.51
6	06/03/2552	4.00	4.80
7	07/03/2552	3.50	4.20
8	08/03/2552	3.52	4.22
9	09/03/2552	3.78	4.53
10	10/03/2552	3.17	3.80
11	11/03/2552	3.46	4.15
12	12/03/2552	3.13	3.75
13	13/03/2552	3.45	4.13
14	14/03/2552	1.61	1.94
15	15/03/2552	3.32	3.99
16	16/03/2552	2.98	3.58
17	17/03/2552	2.59	3.10
18	18/03/2552	1.17	1.40
19	19/03/2552	3.08	3.70
20	20/03/2552	1.18	1.42
21	21/03/2552	3.71	4.45
22	22/03/2552	3.35	4.02
23	23/03/2552	3.83	4.60
24	24/03/2552	3.78	4.54
25	25/03/2552	3.50	4.21
26	26/03/2552	2.51	3.01
27	27/03/2552	3.70	4.44
28	28/03/2552	3.79	4.55
29	29/03/2552	3.78	4.54
30	30/03/2552	3.61	4.33
31	31/03/2552	1.88	2.25

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ FINAL YIELD - ระหว่างวันที่ 01/03/2552 ถึง 31/03/2552

Figure 97 Simulation final yield show by monthly



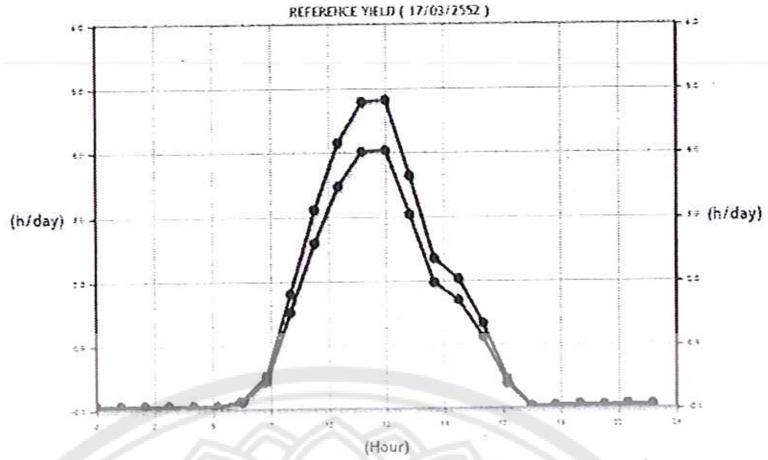
ข้อมูลจริงจากกราฟ

ครั้งที่	วันที่	Real. (หน่วย : (h/day))	Simulation. (หน่วย : (h/day))
1	2552	4.00	4.80
2	2552	3.28	3.94
3	2552	3.91	4.69
4	2552	3.28	3.94

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ FINAL YIELD - ระหว่างวันที่ 01/03/2552 ถึง 30/06/2552

Figure 98 Simulation final yield show by season



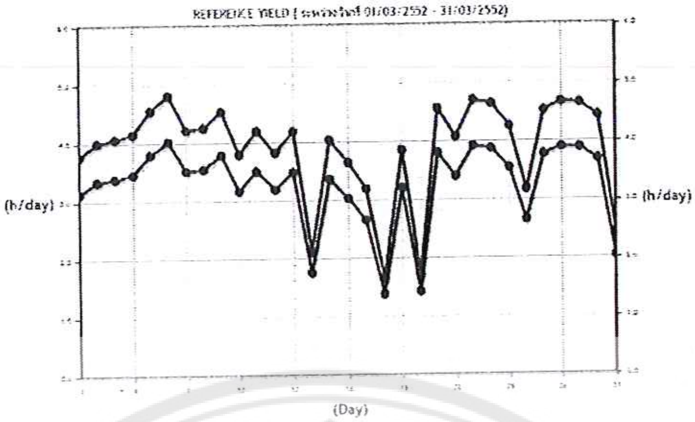
ข้อมูลจริงจากกราฟ

เลขที่	วันที่ - เวลา	Real. (หน่วย : (h/day))	Simulation. (หน่วย : (h/day))
1	17/03/2552 - 00:00 น.	-0.02	-0.02
2	17/03/2552 - 01:00 น.	0.02	-0.02
3	17/03/2552 - 02:00 น.	-0.02	-0.02
4	17/03/2552 - 03:00 น.	-0.02	-0.02
5	17/03/2552 - 04:00 น.	-0.02	-0.03
6	17/03/2552 - 05:00 น.	-0.02	-0.03
7	17/03/2552 - 06:00 น.	0.05	0.06
8	17/03/2552 - 07:00 น.	0.37	0.45
9	17/03/2552 - 08:00 น.	1.47	1.76
10	17/03/2552 - 09:00 น.	2.56	3.07
11	17/03/2552 - 10:00 น.	3.43	4.12
12	17/03/2552 - 11:00 น.	3.98	4.77
13	17/03/2552 - 12:00 น.	4.00	4.80
14	17/03/2552 - 13:00 น.	3.03	3.60
15	17/03/2552 - 14:00 น.	1.93	2.31
16	17/03/2552 - 15:00 น.	1.66	1.99
17	17/03/2552 - 16:00 น.	1.07	1.29
18	17/03/2552 - 17:00 น.	0.32	0.39
19	17/03/2552 - 18:00 น.	-0.04	-0.05
20	17/03/2552 - 19:00 น.	-0.03	-0.04
21	17/03/2552 - 20:00 น.	-0.02	-0.02
22	17/03/2552 - 21:00 น.	-0.03	-0.03
23	17/03/2552 - 22:00 น.	-0.01	-0.02
24	17/03/2552 - 23:00 น.	-0.02	-0.02

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ REFERENCE YIELD - ในวันที่ 17/03/2552

Figure 99 Simulation reference yield show by daily



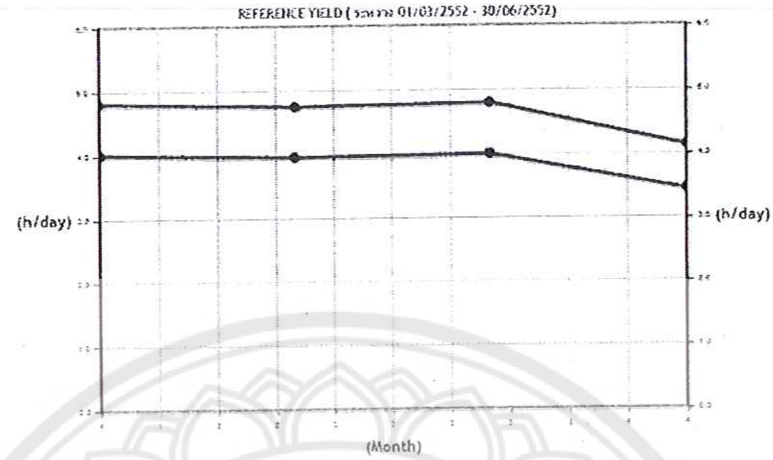
ข้อมูลจริงจากกราฟ

ลำดับ	วันที่	Real (หน่วย : (h/day))	Simulation (หน่วย : (h/day))
1	01/03/2552	3.12	3.75
2	02/03/2552	3.32	3.98
3	03/03/2552	3.37	4.05
4	04/03/2552	3.44	4.13
5	05/03/2552	3.78	4.54
6	06/03/2552	4.00	4.80
7	07/03/2552	3.50	4.20
8	08/03/2552	3.53	4.24
9	09/03/2552	3.77	4.52
10	10/03/2552	3.15	3.78
11	11/03/2552	3.49	4.18
12	12/03/2552	3.18	3.81
13	13/03/2552	3.47	4.17
14	14/03/2552	1.75	2.10
15	15/03/2552	3.35	4.02
16	16/03/2552	3.02	3.63
17	17/03/2552	2.65	3.18
18	18/03/2552	1.37	1.65
19	19/03/2552	3.20	3.84
20	20/03/2552	1.42	1.71
21	21/03/2552	3.79	4.55
22	22/03/2552	3.39	4.06
23	23/03/2552	3.91	4.69
24	24/03/2552	3.86	4.63
25	25/03/2552	3.53	4.24
26	26/03/2552	2.64	3.16
27	27/03/2552	3.76	4.51
28	28/03/2552	3.88	4.66
29	29/03/2552	3.87	4.64
30	30/03/2552	3.68	4.42
31	31/03/2552	2.02	2.42

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงข้อมูลของ REFERENCE YIELD - ระหว่างวันที่ 01/03/2552 ถึง 31/03/2552

Figure 100 Simulation reference yield show by monthly



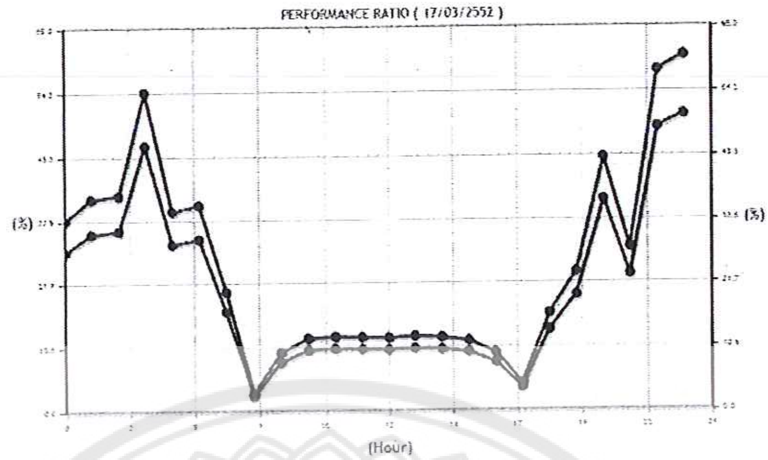
ข้อมูลจริงจากกราฟ

เลขที่	วันที่	Real. (หน่วย : (h/day))	Simulation. (หน่วย : (h/day))
1	2552	4.00	4.80
2	2552	3.95	4.74
3	2552	3.99	4.79
4	2552	3.43	4.12

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ REFERENCE YIELD - ระหว่างวันที่ 01/03/2552 ถึง 30/06/2552

Figure 101 Simulation reference yield show by season



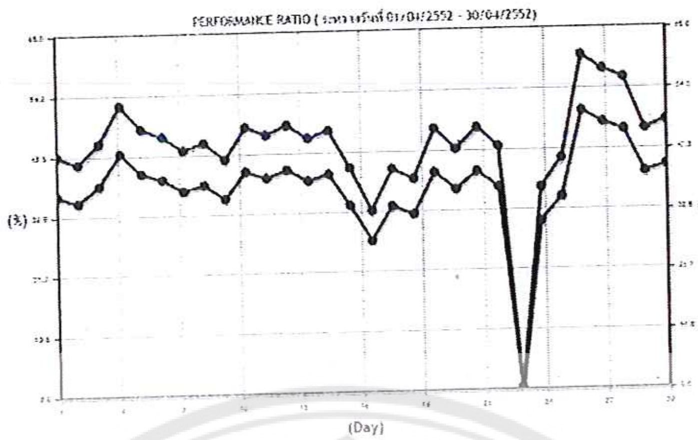
ข้อมูลจริงจากกราฟ

เลขที่	วันที่ - เวลา	Real. (หน่วย : (%))	Simulation. (หน่วย : (%))
1	17/03/2552 - 00:00 น.	26.92	32.31
2	17/03/2552 - 01:00 น.	30.04	36.04
3	17/03/2552 - 02:00 น.	30.53	36.63
4	17/03/2552 - 03:00 น.	45.05	54.07
5	17/03/2552 - 04:00 น.	28.23	33.87
6	17/03/2552 - 05:00 น.	29.09	34.91
7	17/03/2552 - 06:00 น.	16.79	20.15
8	17/03/2552 - 07:00 น.	2.36	2.84
9	17/03/2552 - 08:00 น.	8.10	9.72
10	17/03/2552 - 09:00 น.	10.18	12.21
11	17/03/2552 - 10:00 น.	10.38	12.45
12	17/03/2552 - 11:00 น.	10.31	12.37
13	17/03/2552 - 12:00 น.	10.22	12.26
14	17/03/2552 - 13:00 น.	10.44	12.53
15	17/03/2552 - 14:00 น.	10.29	12.35
16	17/03/2552 - 15:00 น.	9.83	11.79
17	17/03/2552 - 16:00 น.	8.06	9.68
18	17/03/2552 - 17:00 น.	3.70	4.44
19	17/03/2552 - 18:00 น.	13.62	16.35
20	17/03/2552 - 19:00 น.	19.41	23.29
21	17/03/2552 - 20:00 น.	35.65	42.78
22	17/03/2552 - 21:00 น.	22.89	27.47
23	17/03/2552 - 22:00 น.	47.92	57.51
24	17/03/2552 - 23:00 น.	50.00	60.00

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PERFORMANCE RATIO - ในวันที่ 17/03/2552

Figure 102 Simulation performance ratio show by daily



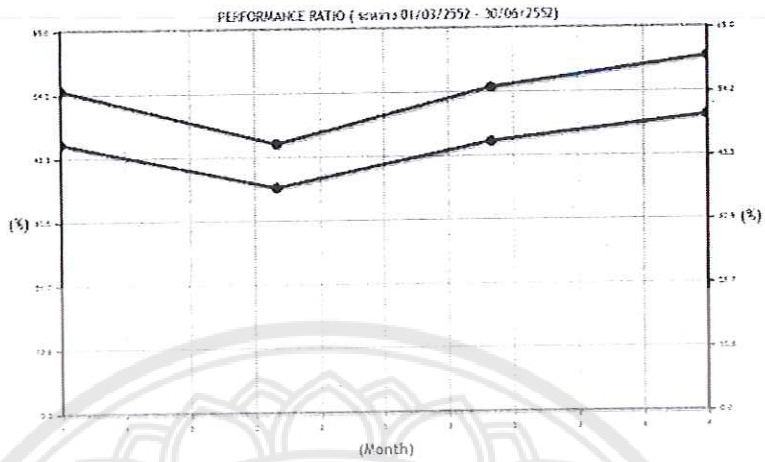
ข้อมูลจริงจากกราฟ

เลขที่	วันที่	Real. (หน่วย : (%))	Simulation. (หน่วย : (%))
1	01/04/2552	36.01	43.22
2	02/04/2552	34.77	41.73
3	03/04/2552	37.83	45.40
4	04/04/2552	43.55	52.26
5	05/04/2552	39.96	47.95
6	06/04/2552	38.79	46.55
7	07/04/2552	36.68	44.02
8	08/04/2552	37.74	45.29
9	09/04/2552	35.19	42.23
10	10/04/2552	40.00	48.00
11	11/04/2552	38.79	46.55
12	12/04/2552	40.17	48.21
13	13/04/2552	38.18	45.82
14	14/04/2552	39.29	47.15
15	15/04/2552	33.61	40.33
16	16/04/2552	27.15	32.58
17	17/04/2552	33.35	40.03
18	18/04/2552	31.86	38.24
19	19/04/2552	39.27	47.13
20	20/04/2552	36.21	43.45
21	21/04/2552	39.37	47.25
22	22/04/2552	36.54	43.85
23	23/04/2552	0.00	0.00
24	24/04/2552	30.34	36.40
25	25/04/2552	34.66	41.59
26	26/04/2552	50.00	60.00
27	27/04/2552	47.90	57.48
28	28/04/2552	46.58	55.90
29	29/04/2552	38.96	46.75
30	30/04/2552	40.15	48.18

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PERFORMANCE RATIO - ระหว่างวันที่ 01/04/2552 ถึง 30/04/2552

Figure 103 Simulation performance ratio show by monthly



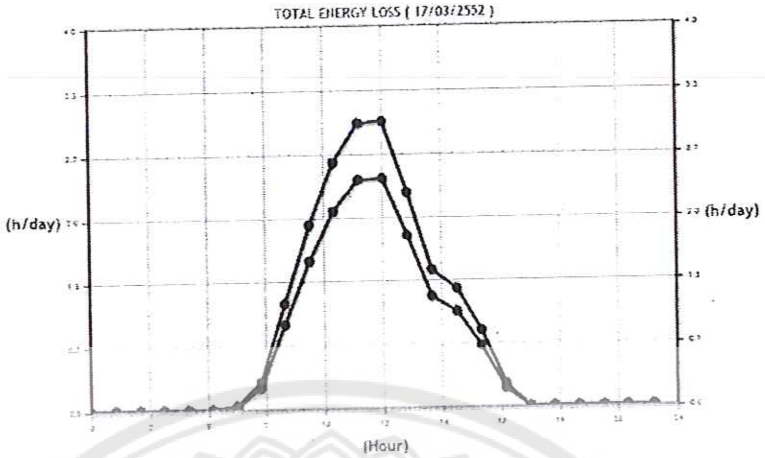
ข้อมูลจริงจากกราฟ

เลขที่	วันที่	Real. (หน่วย : (%))	Simulation. (หน่วย : (%))
1	2552	45.64	54.77
2	2552	37.89	45.47
3	2552	45.69	54.83
4	2552	50.00	60.00

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ PERFORMANCE RATIO - ระหว่างวันที่ 01/03/2552 ถึง 30/06/2552

Figure 104 Simulation performance ratio show by season



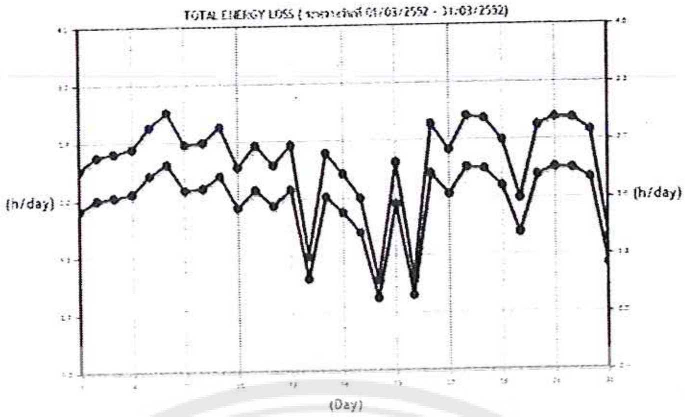
ข้อมูลจริงจากกราฟ

เลขที่	วันที่ - เวลา	Real. (หน่วย : (h/day))	Simulation. (หน่วย : (h/day))
1	17/03/2552 - 00:00 น.	0.00	0.00
2	17/03/2552 - 01:00 น.	0.00	0.00
3	17/03/2552 - 02:00 น.	0.00	0.00
4	17/03/2552 - 03:00 น.	0.00	0.00
5	17/03/2552 - 04:00 น.	0.00	0.00
6	17/03/2552 - 05:00 น.	0.00	0.00
7	17/03/2552 - 06:00 น.	0.04	0.03
8	17/03/2552 - 07:00 น.	0.28	0.22
9	17/03/2552 - 08:00 น.	1.10	0.88
10	17/03/2552 - 09:00 น.	1.92	1.54
11	17/03/2552 - 10:00 น.	2.57	2.06
12	17/03/2552 - 11:00 น.	2.98	2.39
13	17/03/2552 - 12:00 น.	3.00	2.40
14	17/03/2552 - 13:00 น.	2.25	1.80
15	17/03/2552 - 14:00 น.	1.44	1.16
16	17/03/2552 - 15:00 น.	1.24	1.00
17	17/03/2552 - 16:00 น.	0.80	0.64
18	17/03/2552 - 17:00 น.	0.24	0.19
19	17/03/2552 - 18:00 น.	0.00	0.00
20	17/03/2552 - 19:00 น.	0.00	0.00
21	17/03/2552 - 20:00 น.	0.00	0.00
22	17/03/2552 - 21:00 น.	0.00	0.00
23	17/03/2552 - 22:00 น.	0.00	0.00
24	17/03/2552 - 23:00 น.	0.00	0.00

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ TOTAL ENERGY LOSS - ในวันที่ 17/03/2552

Figure 105 Simulation total energy loss show by daily



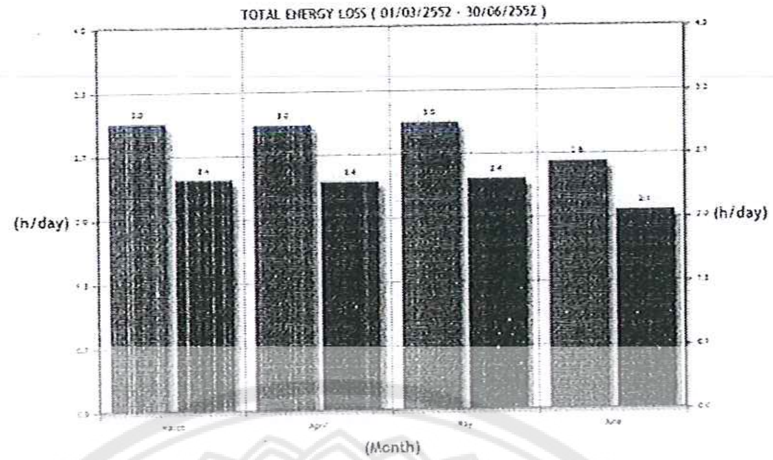
ข้อมูลจริงจากกราฟ

เลขที่	วันที่	Real (หน่วย : (h/day))	Simulation (หน่วย : (h/day))
1	01/03/2552	2.34	1.87
2	02/03/2552	2.49	1.99
3	03/03/2552	2.53	2.02
4	04/03/2552	2.58	2.06
5	05/03/2552	2.83	2.27
6	06/03/2552	3.00	2.40
7	07/03/2552	2.63	2.10
8	08/03/2552	2.65	2.12
9	09/03/2552	2.83	2.26
10	10/03/2552	2.36	1.89
11	11/03/2552	2.61	2.09
12	12/03/2552	2.39	1.91
13	13/03/2552	2.61	2.09
14	14/03/2552	1.32	1.06
15	15/03/2552	2.51	2.01
16	16/03/2552	2.27	1.82
17	17/03/2552	1.99	1.59
18	18/03/2552	1.04	0.83
19	19/03/2552	2.40	1.92
20	20/03/2552	1.07	0.86
21	21/03/2552	2.84	2.27
22	22/03/2552	2.54	2.03
23	23/03/2552	2.93	2.34
24	24/03/2552	2.90	2.32
25	25/03/2552	2.65	2.12
26	26/03/2552	1.98	1.58
27	27/03/2552	2.82	2.25
28	28/03/2552	2.91	2.33
29	29/03/2552	2.90	2.32
30	30/03/2552	2.76	2.21
31	31/03/2552	1.52	1.21

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ TOTAL ENERGY LOSS - ระหว่างวันที่ 01/03/2552 ถึง 31/03/2552

Figure 106 Simulation total energy loss show by monthly



ข้อมูลจริงจากกราฟ

เดือนที่	วันที่	Real (หน่วย : (h/day))	Simulation. (หน่วย : (h/day))
1	2552	3.00	2.40
2	2552	2.97	2.37
3	2552	2.99	2.39
4	2552	2.57	2.06

รายละเอียดของข้อมูล

1. กราฟนี้เป็นกราฟแสดงถึงข้อมูลของ TOTAL ENERGY LOSS - ระหว่างวันที่ 01/03/2552 ถึง 30/06/2552

Figure 107 Simulation total energy loss show by season

ข้อมูล Forcast Power Simulate

วันที่ - เวลา	ปัจจุบัน	30 นาทีจริง / Forcast
01/12/2551 - 12:00:00	87.00	87.00 / 84.97
30/11/2551 - 12:00:00	87.00	87.00
29/11/2551 - 12:00:00	87.00	85.00
28/11/2551 - 12:00:00	84.00	85.00
27/11/2551 - 12:00:00	83.00	84.00
26/11/2551 - 12:00:00	83.00	83.00
25/11/2551 - 12:00:00	85.00	85.00
24/11/2551 - 12:00:00	85.00	82.00
23/11/2551 - 12:00:00	85.00	85.00
22/11/2551 - 12:00:00	85.00	86.00
21/11/2551 - 12:00:00	-1.00	-1.00

Figure 108 Sample simulation result of next 30 minute

ข้อมูล Forcast LOAD Simulate

วันที่ - เวลา	ปัจจุบัน	30 นาทีจริง / Forcast	60 นาทีจริง / Forcast
01/12/2551 - 12:00:00	22.00	8.00 / 19.32	7.00 / 8.28
30/11/2551 - 12:00:00	30.00	10.00	6.00
29/11/2551 - 12:00:00	11.00	26.00	7.00
28/11/2551 - 12:00:00	25.00	31.00	10.00
27/11/2551 - 12:00:00	17.00	28.00	7.00
26/11/2551 - 12:00:00	33.00	31.00	6.00
25/11/2551 - 12:00:00	48.00	44.00	23.00
24/11/2551 - 12:00:00	46.00	42.00	6.00
23/11/2551 - 12:00:00	45.00	46.00	6.00
22/11/2551 - 12:00:00	88.00	94.00	14.00
21/11/2551 - 12:00:00	22.00	24.00	18.00
20/11/2551 - 12:00:00	11.00	21.00	11.00

Figure 109 Sample simulation result of next 30 minute and next 60 minute

Simulation module can generate forecast result of generation energy power and load demand of microgrid system. Next 30 minute and next 60 minute from present time can matching and balancing between generation energy powers with load demand. When the agent based get the right value, it will contribute to higher final yield value. As a result, performance ratio will be increase.

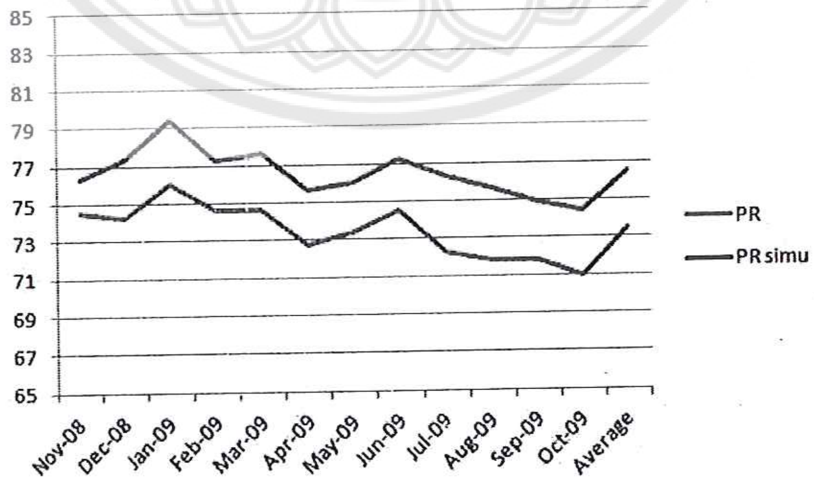


Figure 110 Comparison simulation result of performance ratio

Table 9 Comparison of PV microgrid system efficiency

System efficiency	Agent-Based	Original	Differences
Array yield	4.33	4.32	0.01
Final yield	3.99	3.84	0.15
Reference yield	5.21	5.21	0
Performance ratio	76.50 %.	73.45%	3.05%

From table 9 simulation result of array yield, final yield, reference yield and performance ratio are 4.33 h/day, 3.99 h/day, 5.21 h/day and 76.50% respectively while annual array yield, final yield, reference yield and performance ratio are 4.32 h/day, 3.84 h/day, 5.21 h/day and 73.45% respectively. Differances of simulated array yield, final yield, reference yield and performance ratio with annual array yield, final yield, reference yield and performance ratio are 0.01 h/day, 0.15 h/day, 0 h/day and 3.05% respectively.

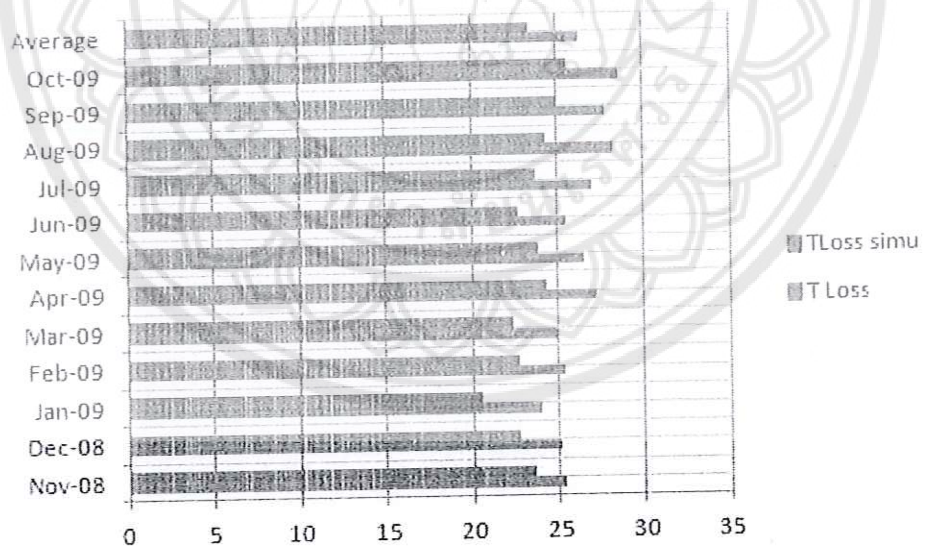


Figure 111 Comparison simulation result of energy loss

In table 10 show simulated system loss, array capture loss and total loss are 6.62%, 16.84% and 23.46% respectively while annual system loss, array capture loss and total loss are 9.06%, 17.21% and 26.27% respectively. Differances of simulated system loss, array capture loss, total loss with annual system loss, array capture loss, total loss are -2.44%, -0.37% and -3.21% respectively.

Table 10 Comparison of PV microgrid system energy loss

Energy loss	Agent-Based	Original	Differences
System loss	6.62%	9.06%	-2.44%
Capture loss	16.84%	17.21%	-0.37%
Total loss	23.46%	26.27%	-3.21%

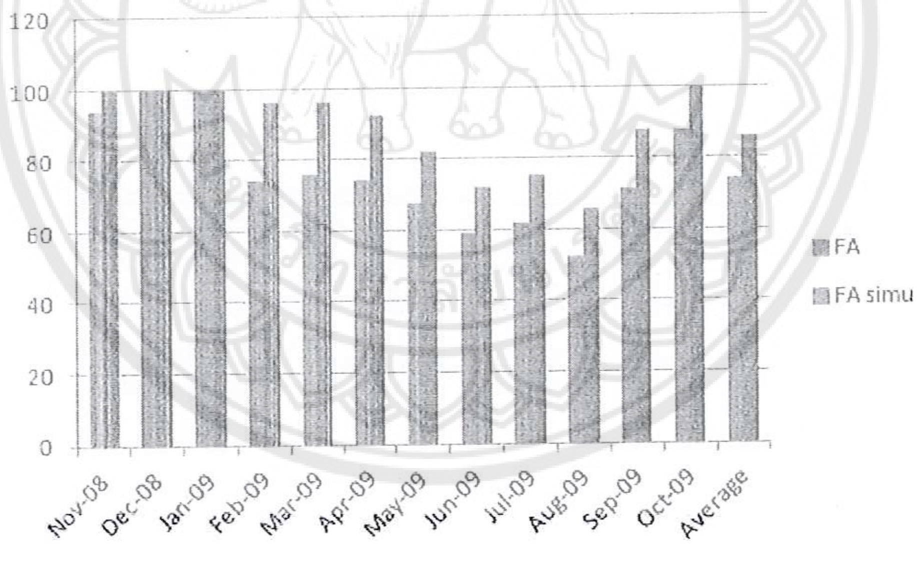


Figure 112 Comparison simulation result of solar fraction

Table 11 Comparison of PV microgrid system utilization factor

Utilization factor	Agent-Based	Original	Differences
Solar fraction	86.16%	74.30%	+11.86%

From table 11 show simulated solar fraction is 86.16% and annual solar fraction is 74.30%. difference is 11.86%.

CHAPTER V

CONCLUSION

Conclusion

This thesis have purpose to develop an energy management system by using agent based simulation function for microgrid system. In this thesis use data from 120 kW. PV micro grid system of School of Renewable Energy Technology (SERT), Naresuan University, Phitsanulok, Thailand.

The microgrid system have a lot of data in each day. For long term data management process the data from the microgrid system can become larger day by day and have too much information. Many data are inconvenience to utilize. To solve this problem, a proper database system manager needs to be developed. This system administrator can easily control and operate the microgrid system. The advantage of developing microgrid energy management system are easy to access the microgrid system from everywhere in every time.

The energy management system (EMS) was created by PHP language. Data stored in SQL (Structured Query Language) file format and database created by mySQL using RDBMS (Relational database management system) theory. All programs used to develop EMS program are freeware. The application used to connect EMS program and SQL database is ODBC (open database connectivity) and installed on Microsoft windows server 2003 enterprise operating system for using EMS program over the internet.

The advantage of data storage in SQL file format is, smaller file size than CSV excel file format. 12 months data used in this work was around 3.78 GB, when converted XLS file format to SQL file format decreased to 331 MB, around 11.42 times smaller in size.

EMS consists of three main modules namely Monitoring module, Report module and Simulation module. Monitoring module monitors necessary information from microgrid system such as solar radiation, module/array temperature, ambient temperature etc. Report module summarizes data from microgrid system such as load, PV voltage and current, PV + DG generated power etc. Simulation module will consider energy management concepts like System efficiency, Energy loss and Utilization factor (Solar fraction). Information used for improved microgrid system performance consists of, System efficiency indicators (performance ratio, array yield, final yield and reference yield), Utilization factor indicator (solar fraction) and energy loss indicators (capture loss and system loss). Relations used to calculate data were taken from International Energy Agency for Photovoltaic Power Systems (IEA-PVPS) task 2. Performance, reliability and analysis of photovoltaic systems was done in accordance with EU guidelines and IEC-61724 standard.

The microgrid energy management system is used to present all conditions in the system and to inform the system administrator in any status of the microgrid system. The system administrator can use data and simulation result from energy management system to estimate system performance and to set the production plan for matching the load demand with renewable energy resources. And in case of system error, the energy management system can show system alarm to system administrator by system result report.

The assumption is ineffective

1. The system performance will be increased. The results of simulation using EMS of array yield, final yield, reference yield and performance ratio as 4.33 h/day, 3.99 h/day, 5.21 h/day and 76.50% respectively while annual(without EMS) array yield, final yield, reference yield and performance ratio are 4.32 h/day, 3.84 h/day, 5.21 h/day and 73.45% respectively. Differences of simulated array yield, final yield, reference yield and performance ratio with annual array yield, final yield, reference yield and performance ratio are 0.01 h/day, 0.15 h/day, 0 h/day and 3.05% respectively. Reference performance ratio of the PV generator is 75.48 %.

2. To reduce energy lost in the system. The results of simulated system loss, array capture loss and total loss as 6.62%, 16.84% and 23.46% respectively while annual system loss, array capture loss and total loss are 9.06%, 17.21% and 26.27% respectively. Differences of simulated system loss, array capture loss, total loss with annual system loss, array capture loss, total loss are -2.44%, -0.37% and -3.21% respectively. Reference capture loss of PV generator is about 16 %, reference system loss of PV generator is about 8 % and Reference total loss is about 26%

3. Renewable energy fraction (Solar fraction) will be increased. The results of simulated solar fraction as 86.16% and annual solar fraction 74.30%, with a difference of 11.86% in both. Reference solar fraction is 50%

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