Ting Ye

Modelling of Load Management Systems

for Buildings using MATLAB/SIMULINK

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Supervising examiner : Prof. Dr.-Ing. Gustav Vaupel
Second examiner : Prof. Dr.-Ing. Franz Schubert

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Ting Ye

Title of the Master Thesis

Modelling of Load Management Systems for Buildings using MATLAB/SIMULINK

Keywords

Load Management, Load Profile, Optimization, Electrical Work Estimation, Modelling, Simulation, Matlab/Simulink, Load Extrapolation

Abstract

A load management system is used to save electrical energy by optimizing the load profile of a building (via reducing the peak loads). A model of a network of a higher number of independent load management systems is currently developed in the R&D project “E-Island”. The core of this model was formed by the individual work of three master theses. This is one of them. The aim of this thesis was to develop a submodel of a load prediction system as an integral part of a load management system of a building. The model was built in Matlab/Simulink. A two way, medium, linear load method was used to forecast the electric work of the end of each polling period (15 minute interval). This estimated work value is compared with a maximum allowed work value. If the estimated value is higher than the allowed limit, a matrix is calculated containing information about which devices in the respective building should be shut down in order not to overrun the set load limit. This matrix then serves as input in the part of the model of the load management system which models the behaviour of the building devices (not this thesis).

Thema der Masterarbeit

Modellbildung eines Lastmanagement Systems für Gebäude in MATLAB/SIMULINK

Stichworte

Lastmanagement, Strom, Lastprognose, Modellbildung, Simulation, Matlab, Simulink

Kurzzusammenfassung

Ein Lastmanagementsystem dient dazu, durch die Optimierung des Lastprofils (Absenkung der Lastspitzen) elektrische Energie zu sparen. Im Forschungsprojekt „Insel“ wird zur Zeit ein Model eines Netzwerks unabhängiger Lastmanagementsysteme entwickelt. Das Kernstück dieses Models entstand durch die Arbeit dreier Masterarbeiten. Dies ist eine davon. Ziel dieser Arbeit war es ein Teilmodel für die Prognose der Lastentwicklung in der aktuellen Abrechnungsperiode (Viertelstunde) zu erstellen. Der berechnete Lastwert wird mit einem vorgegebenen Limit verglichen. Bei Überschreiten des Limits wird eine Matrix berechnet mit Informationen welche Geräte der Gebäudetechnik abgeschaltet werden sollen, um das Lastlimit nicht zu überschreiten. Diese Matrix dient dann als Input für den Modelteil, der das Verhalten der Gebäudetechnik des jeweiligen Gebäudes simuliert (nicht in dieser Masterabeit).

Content

Glossary

IEA – Internal Energy Agency

INSEL – Internetbasiertes System eines erweiterbaren Lastmanagements

GSM –Global System for Mobile Communications

GPRS –General Packet Radio Service

DC – Direct Current

AC – Alternating Current

TCP/IP –Transmission Control Protocol / Internet Protocol

RTP – Real Time Transport Protocol

LCD – Liquid Crystal Display

DBMS – DataBase Management System

GUI – Graphical User Interface

CSV – Comma Separated Value

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1 Introduction

1.1 Motivation

Energy-saving is the main topic in the current industry. From thousands of reports in the website of the Internal Energy Agency (IEA) it can be seen that the usable energy becomes less and less. This leads energy to be a critical problem. Fig 1.1 shows that the price for energy increases tremendously during the passing years. Now the crude oil costs more than 100 dollars per barrel.

Fig1.1 Price of Crude oil in last year [1]

This means wasting energy reduces your profitability. For every 1$ saved on energy costs, most USA businesses would have to make 10$ worth of sales to make the same 1$ of profit. So, for example, wasting just 1,000$ a year on energy due to poor energy management would require 10,000$ worth of sales to make the equivalent 1,000$ of profit. Additionally wasting energy causes unnecessary high amounts of CO_2 emissions which contribute to global warming. For 1kWh electrical energy you need to burn about 0,25 Kg of coal. During this process about 0,956 kg of carbon dioxide are released into the atmosphere which contributes to the greenhouse effect. [2]

Electricity energy is a common energy in our daily life. Since electricity generator was invented by Michael Faraday, man can never live without it. We need lamp in the night; we need computer to achieve complex computation; we need larger machine to produce cars and so on. All of them need to consume the electricity energy. The consequences of energy wasting are described before, so some energy management should be done in order to save the energy. As the electricity energy is the main energy consumption in the world, it should be treated as the most emergent object.

Load management is widely used to save the electricity energy. It reduces the peak value of the system through switching off some devices automatically. On the other hand, the devices which have been switched off should have almost no effect to the whole system.

1.2 Objective

The goal of the thesis is to develop a load forecasting strategy and an integrated model for the simulation of a load management system. Historical load (MW) data and weather data would be used to issue a 15 minutes period load forecast. This means a day is divided into 96 periods and the predicted load value will be the load value at the end of each period. Additionally the load management controller could be used to test the effects of load control on the electric utility's peak demand. Three main blocks are used in this model.

1. Data base

   The data base contains the historical load data of the buildings with several different functions. Fig 1.2 shows three different load profiles of three buildings. On the left side is the load profile of the University of Hamburg. At day time (9:00~18:00) it has the peak value. This is because at that time most students take their courses. The middle is the load profile of the Central Market. It has a very high base load because of a high number of cooling facilities which operate 24h a day. The third is the sediment dredger of the harbor management company. It has no base load, but an unpredictable load form. Its peak values are very high and are randomly distributed.

   Before simulating the effect of a load management for one building, historical load profiles of that building should be stored in the data base to serve as an input for later simulations.

   Additionally, factors such weather, date, holidays and so on are also stored in this data base. These factors are also important for load forecasting. For example, the load profile of a University during the Semester and Holidays are quite different. Additionally a very hot summer will cause higher power consumption for air condition. So these factors also play an important role in load forecasting.

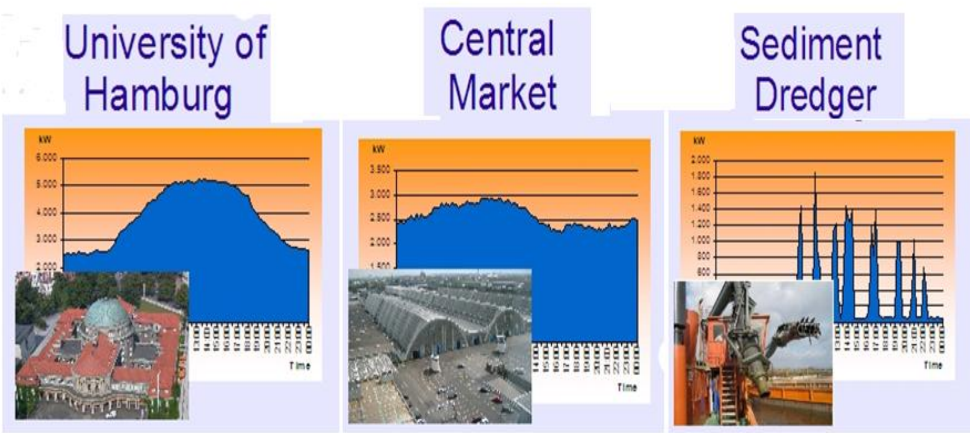


Fig 1.2 Different load profile [3]

2. Models for building
   This block will construct several models which represent the building on which the load management will be applied. One can turn on or switch off building devices such as ventilation systems or pumps in these buildings.

3. Controller

   A maximum load prediction is executed in this controller. If the predicted average load for a 15 minute interval is exceeds the maximum allowed load limit, the control will disconnect some devices in one building to reduce the expected peak value.

Three students have taken part into this project, each implement one of the blocks above. The main task of this thesis is to implement the “Controller” block. This block can do the work prediction and can give the command to change the status of the devices (switch on or switch off) according to the estimated work value. Note here it only gives the command, but does not actually execute. The execution is done by the second block described above.

1.3 INSEL Project

In this part a short description of a project named “INSEL” will be given. The project of the master thesis is actually a part of this INSEL project. It does the theoretical calculation of the INSEL project. This master thesis is based on the modeling and simulation. It is more or less the theoretical prove. After this section, one can have a clear idea how a real model can be built in the industry.

INSEL is the abbreviation for German words “Internetbasiertes System eines erweiterbaren Lastmanagements”. The translation of it is “an extended load management system based on internet”. The HAW (University of Hamburg for applied science) gets the project INSEL, which should be finished in period between September 2006 to August 2009. The main people concerned with this project are HAW Hamburg, BWA (Behörde für Wirtschaft und Arbeit), Evonik AG, engineer office SUmBi Hamburg and Envidatec GmbH Hamburg.

Fig 1.3 gives a view of how this system works. All the information about the load from the substation side is transmitted by the Vida 84 communication module. Then it is connected to the server via the route. For the wireless communication, the GSM/GPRS network is used. Internet is used to connect all equipments including the database and controller.

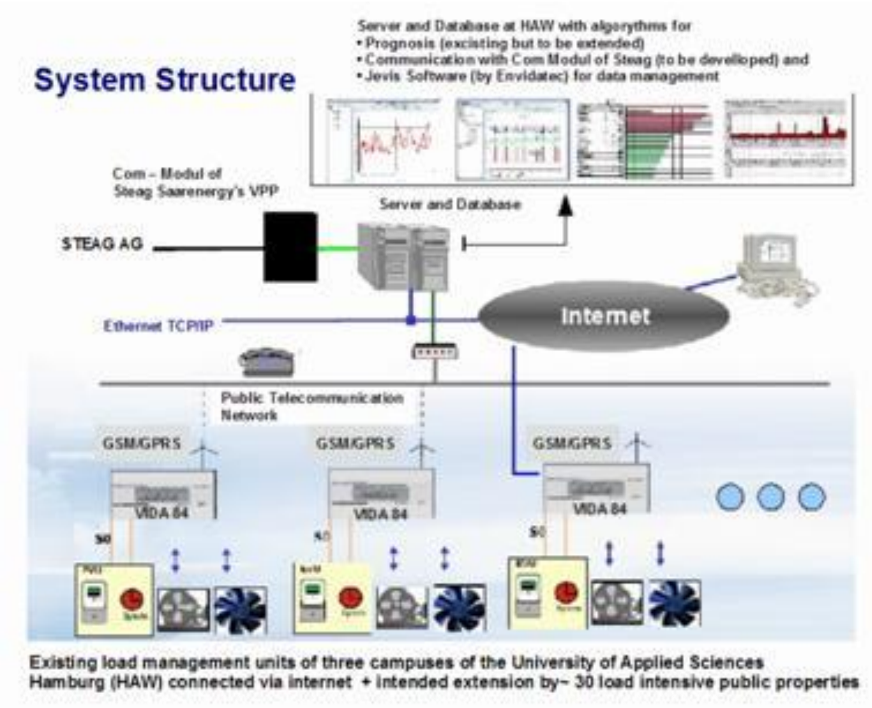


Fig 1.3 INSEL system outline [4]

During the development of this INSEL project, an electric network of around 40 public institutions which is based on internet will be built. The voltage of this transmission network will be in the middle level (10kV). More information about the electricity transmission network can be found in Chapter 2. This network will be the basic feedback of the research project for the following questions:

1. How these 40 independent load management systems are controlled, so that the summer load of these 40 institutions is optimized? Note here the performance of the total 40 institutions is the key point, not only for the single institution.
2. How much load, which is sold by the power supply company Evonik AG, can be taken out form the above network? This part of load is the saved part.

It is expected that the infrastructure which is built during this project can have the ability to reduce the electric energy from 3 to 5 Megawatt (MV). Of course, it also depends on the date (workday or holiday), the time in one day and the season in one year. These 3 to 5 Megawatt (MV) can be used as the backup load for these 40 institutions or as the free load for the selling of Evonik AG.

1.4 Scope of this thesis

In order to keep the contents logically associated, this thesis is organized as follows:

Chapter 1 is the introduction. It contains the motivation and objective of this thesis and its purpose, besides the concept of INSEL will also be given.

Chapter 2 introduces some common concepts related to load management. One will know how the electricity energy is produced and transmitted. Such concepts will be helpful for the reader to understand the following sections.

Chapter 3 explains the importance that the load management plays in the industry and how load management can be put into practice. The advantages and disadvantages of several methods used to do the load management will also be discussed.

Chapter 4 shows how to design such a system. A common project management approach is used here. Some diagram such as class diagram, state diagram will be used.

Chapter 5 implements the design into a real model by using Matlab. The approach of creating a model in Matlab /Simulink is described. The algorithm used to do the estimation will also be explained in this chapter. At the end of this chapter the code will be explained.

Chapter 6 gives the testing results of the designed system. As what has been discussed in the section 1.2, this project has been divided into three different parts and they are distributed to three students. My task is to build the model of controller. Hence the result of my part—controller will be demonstrated first. Then the simulation results of the whole system will be presented.

Chapter 7 draws the relevant conclusions.

2. State of Art

In this chapter, some basic concepts in the field electricity production and load management will be explained first. This is the background knowledge which will help the reader understand the rest part of the thesis.

2.1 Electricity Production

Michael Faraday, FRS (September 22, 1791 – August 25, 1867) was an English chemist and physicist (or natural philosopher, in the terminology of that time) who contributed to the fields of electromagnetism and electrochemistry.

His biggest contribution was the Faraday's law which proved that moving a permanent magnet near a conductor (such as a metal wire) produces a voltage in that conductor. The resulting voltage is proportional to the speed of movement: moving the magnet twice as fast produces twice the voltage. [5]

For the common but special case of a coil of wire, composed of N loops with the same area, Faraday's law of electromagnetic induction states that

$$\varepsilon = -\mathrm{N} \times \frac{\mathrm{d}\Phi\mathrm{B}}{\mathrm{dt}}$$

where

ε is the electromotive force (emf) in volts

N is the number of turns of wire
Φ_B is the magnetic flux in webers through a single loop. The direction of the electromotive force (the negative sign in the above formula) was first given by Lenz's law.

More generally, the relation between the rate of change of the magnetic flux through the surface *S* enclosed by a contour *C* and the electric field along the contour is defined as:

$$\oint_C \mathrm{E} \cdot \mathrm{dl} = -\frac{\mathrm{d}}{\mathrm{dt}} \int_S \mathrm{B} \cdot \mathrm{dA}$$

where

E is the electric field,
dl is an infinitesimal element of the contour *C*,
B is the magnetic field.

The directions of the contour *C* and of dA are assumed to be related by the right-hand rule. Equivalently, the differential form of Faraday's law is

$$\nabla * E = -\frac{\partial B}{\partial t}$$

which is one of the Maxwell equations.

According to this law, the Electrical generator was build. From the mathematical equation of the law it can be seen that once the energy is converted, it should be consumed. Otherwise it is wasted. This is one reason for why the load management should be applied to save the energy. This will be discussed later.

2.2 Power and work

Power is a common term used in physical range. Usually it goes hand in hand with the term "energy", but they are not the same thing. Energy is the property of matter that makes things happen. To make things happen, energy must change form or change locations. Power is a measure of how fast those energy changes are happening. Energy comes in a set of quantities called Joules (1 Joule = 1 Newton *meter). [6]

That's the mechanical definition. A Joule is not a lot of energy, unless you're a hummingbird. A hummingbird in flight converts 1 Joule of energy to heat, kinetic energy, and aerodynamic lift, every second. That means the little bird requires about 1 Watt (1 J/s) of power to fly. Energy units like Btu's (British thermal units) or calories are defined in terms of thermal energy. A Btu is approximately the amount of energy needed to increase the temperature of 1 pound of water by 1 degree Fahrenheit. A calorie is the amount of energy needed to raise the temperature of 1 gram of water by 1 degree Celsius.

Electrical power is the rate at which electrical energy is converted into another forms, such as motion, heat, or an electromagnetic field. The common symbol for power is the uppercase letter P. The standard unit is the watt, which is symbolized by W. In utility circuits, the kilowatt (kW) is often specified instead (1 kW = 1000 W).

One watt is the power resulting from an energy dissipation, conversion, or storage process equivalent to one joule per second. When expressed in watts, power is sometimes called wattage. The wattage in a direct current (DC) circuit is equal to the product of the voltage in volts and the current in amperes. This rule also holds for low-frequency alternating current (AC) circuits in which energy is neither stored nor released. At high AC frequencies, in which energy is stored and released (as well as dissipated or converted), the expression of power is more complex. [7]

In a DC circuit, a source of U volts, delivering I amperes, produces P watts according to the formula:

$$P = U*I$$

When a current of *I* amperes passes through a resistance (R) of Ohms, then the power in watts dissipated or converted by that component is given by:

$$P = I^{2*}R$$

When a potential difference of *U* volts appears across a component having a resistance of *R* ohms, then the power in watts dissipated or converted by that component is given by:

$$P = U^2/R \qquad (2.1)$$

In a DC circuit, power is a scalar (one-dimensional) quantity. In the general AC case, the determination of power requires two dimensions, because AC power is a vector quantity. Assuming there is no reactance (opposition to AC but not to DC) in an AC circuit, the power can be calculated according to the above formulas for DC, using root-mean-square values for the alternating current and voltage. If reactance exists, some power is alternately stored and released by the system. This is called apparent power or reactive power. The resistance dissipates power as heat or converts it to some other tangible form, which is called true power. The vector combination of reactance and resistance is known as impedance.

Work is amount of energy which has been transformed. Electrical work means how much electrical energy is transmitted to other energy. It can be calculated by the following equation:

$$W=P*t$$

In this equation P is the power of the system and t is a unit of time. Work is commonly defined as kWh which means the unit for power P is kW (1000 W) and the elapsed amount of time (t) during which the energy was applied is one hour.

The average power (often simply called "power" when the context makes it clear) is the average amount of work done or energy transferred during a fixed unit of time. The instantaneous power is then the limiting value of the average power as the time interval Δt approaches zero.

$$P = \lim_{\Delta t \to 0} \frac{\Delta W}{\Delta t} = \lim_{\Delta t \to 0} P_{avg}$$

When the rate of energy transfer or work is constant, all of this can be simplified to

$$P = \frac{W}{t} = \frac{E}{t}$$

where W and E are, respectively, the work done or energy transferred in time t (usually measured in seconds).

In this thesis the unit of power will be kW and the unit of work will be kWh. In the model the measured time steps are minutes (1/60 hour). So before calculating the work in kWh from the actual power, the elapsed time has to be changed to the appropriated fragment of an hour first. According to this the energy applied in the system each minute (work) can be calculated into as

$$W\ (kW/minute) = P(kW)*1/60$$

Later in this thesis, the transformation of unite is used very often.

2.3 Electrical Load

If an electric circuit has a well-defined output terminal, the circuit connected to this terminal (or its input impedance) is called the load. (The term 'load' may also refer to the power consumed by a circuit, that topic is not discussed here.)

Load affects the performance of circuits that output voltage or currents, such as sensors, voltage sources, and amplifiers. A household's power socket provides an easy example: it is a voltage source, outputting 220 V AC for example (as in China), with the household's appliances connected to it collectively making up the load. When a power-intensive appliance is switched on, it reduces the load impedance, causing the output voltage to drop. This drop can be observed; for instance, when turning on a vacuum cleaner dims the lights.

Now let's take a real family electric circuit as an example. Fig 2.1 shows a simple domestic electricity circuit. There are two lines (front line and zero line) which connect to the electric equipment. All the equipments are connected parallel to each other. When the switch is turned on, the electrical bulb will shine. Which means electrical energy is converted into light (just another form of energy). In this situation, the electric bulb is the load. When one or more devices are connected to the outlet, the load will increase. Different load will cause a different affection on the whole system. As is said before, all the appliances are connected parallel. Hence the more appliances there are, the smaller the total resistance will be. Because the voltage between the front line and the zero line is fixed (220V in China), the power of the system will increase (according to equation (2.1)). This will cause a lager current in the front line or zero line. Large currents cause high temperatures on these two lines and may melt them. Lots of fire accidents in family are caused by this reason. Two methods can be used to anti this problem.

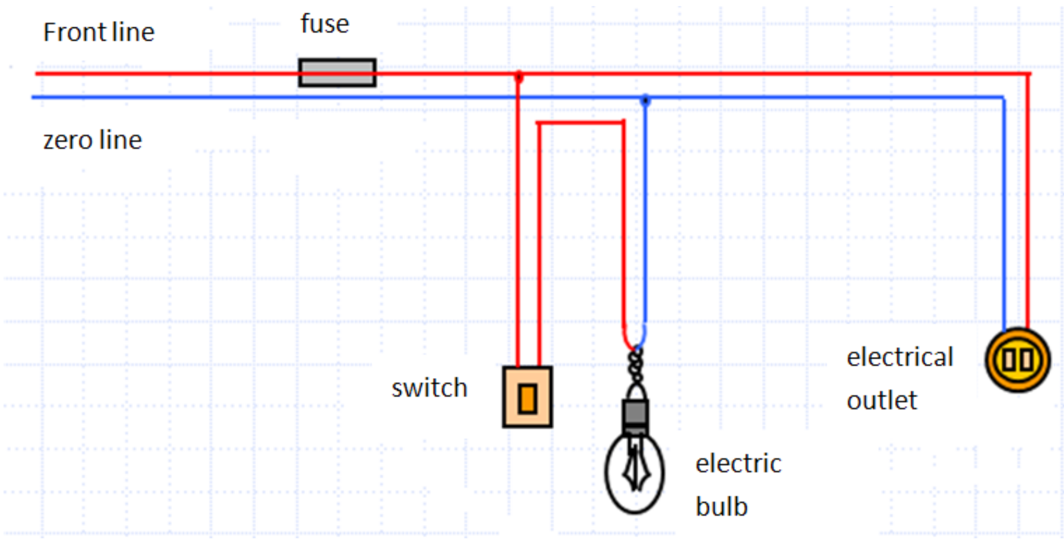


Fig 2.1 Simple exemplary domestic circuit

A common way is shown in Fig 2.1. A fuse is added at the front line side. This fuse has a lower melting point than the front line. As the temperature rises, it will melt first. So an open circuit will be formed. But this method has a lager drawback. Once the fuse melts, all the equipments will be shut down at the same time. Could you image this happening while you are writing a report on your PC? Such a situation is also disastrous for a workshop in a factory and usually is not allowed.

Another solution is use the load management system. This system will detect the load of the system. If there is an overload, some appliances will be shut down. So the total load of the system will be decreased. Of course some mechanism is needed to determine which appliance should be switched off first. This will be discussed in a later chapter. One advantage of load management system is that it can ensure the safety of a system. Of course, this is not the main purpose of why a load management system should be applied for this thesis. More benefits of a load management system will be discussed in chapter 3.

2.4 Power Generation, Transmission and Distribution System

A graphic illustration of equipments used in a typical electric power generation, transmission and distribution system is shown in Fig 2.2. [8]

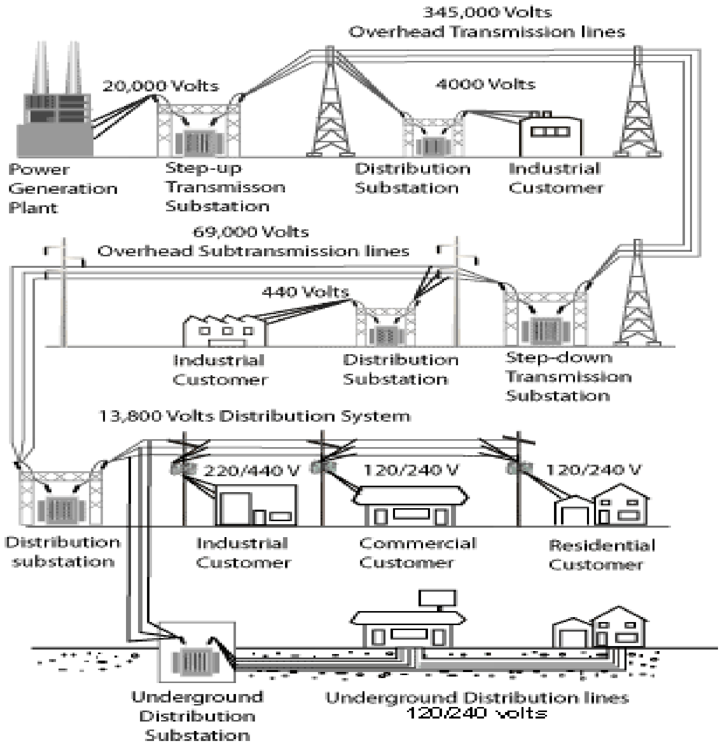


Fig 2.2 Power Generation, Transmission and Distribution System [8]

A typical power generation, transmission and distribution system has these components:

- Power Generation Plants
- Substations
- Transmission Lines
- Distribution Systems

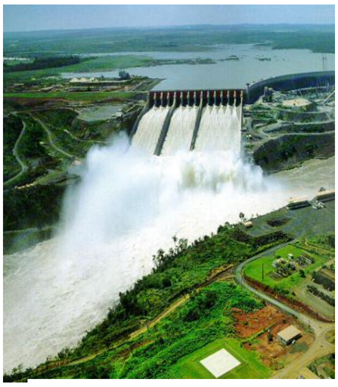
All these components determine the capacity of the power from the electrical power company to the end-user. In other word, the max load is limited by those hardware. If the load at the user side is larger than this capacity, the damage of the infrastructures may happen. Now the explanations of each component will be discussed.

2.4.1 Power generation plant

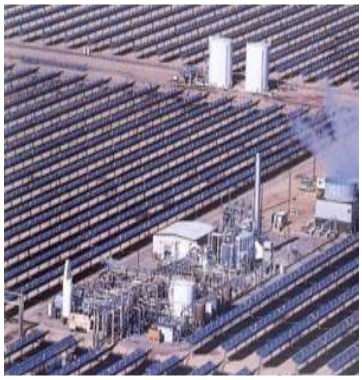
A power generation plant is a facility designed to produce electric energy from another form of energy. These forms of energy can be thermal energy, potential energy, wind energy and solar energy. Different power plants are shown in Fig 2.3.

The easiest way to get the thermal energy is the burning of fossil fuels such as coal, petroleum and natural gas. This is the most common way in the past century. But it has large drawbacks. The quantity of such resource is less and less which causes the cost of power generation raised rapidly. On the other hand it produces greenhouse gas which pollutes the atmosphere of the earth. Hence new methods such as geothermal energy and nuclear energy are immerged. Geothermal energy is the heat from the core of the earth. It is usually found in volcanoes, fumaroles (holes where volcanic gases are released) and hot springs**.** We can use the steam and hot water produced inside the earth to create the electrical power.

Fossil fuel power plant



Hydroelectric power plant



Solar thermal power

Nuclear power plant

Wind power plant

Fig 2.3 Different power plant

Nuclear energy is the new form of energy and has well developed in the past ten years. It is somewhat complicated and depends on the facts about nuclear physics and nuclear engineering. Presently, nuclear energy provides for approximately 16% of the world's electricity. Nuclear power can come from the fission of uranium, plutonium or thorium or the fusion of hydrogen into helium. Natural uranium is almost entirely a mixture of two isotopes, U-235 and U-238. Most nuclear power plants today use enriched uranium in which the concentration of U-235 is increased from 0.7 percent U-235 to (nowadays) around 4 to 5 percent U-235.

Potential energy is usually got from falling water. Hydroelectric facilities can be found above all the longest 15 rivers in the world. It is a renewable resource, which is generated by hydraulic turbines that rotate due to the force of moving water as it flows from a higher to a lower elevation. The water can be flowing in natural streams and rivers or contained in man-made facilities such as reservoirs, pipelines and canals. There are two main categories of hydroelectric power generation: conventional methods (produce electricity via water flow in one direction) and pumped storage methods, which are both producers and consumers of electricity as the water used to generate electricity can be recycled by pumping it back uphill.

Wind energy is also a renewable energy source because the wind will blow as long as the sun shines. Like old fashioned windmills, today wind machines use blades to collect the wind kinetic energy. Windmills work because they slow down the speed of the wind. The wind flows over the airfoil shaped blades causing lift, like the effect on airplane wings, causing them to turn. The blades are connected to a drive shaft that turns an electric generator to produce electricity. Holland is famous for his windmills.

Some people partition solar energy to the first thermal energy. Of course, it transforms the thermal energy to the electrical energy. But in the first energy sort, all the materials used to create energy are from the earth. But this is the energy from the sun and hence belongs to a new sort. It uses the heart of the sun to produce energy like the geothermal energy in the earth.

2.4.2 Substations

A substation shown in Fig 2.2 is a high-voltage electric system facility. It is used to switch generators, equipments, and circuits or lines in and out of a system. It is also used to change AC voltages from one level to another, and/or change alternating current to direct current or direct current to alternating current. Some substations are small with no more than a transformer and associated switches. Others are very large with several transformers and dozens of switches and other equipments. Substation can be divided into two types: Transmission substation and distribution substation.

Transmission substation is used to transmit the electrical power. The transmission station near the power plant is called the step-up transmission substation. It receives electric power from a nearby generating facility and uses a large power transformer to increase the voltage for transmission to distant locations. It has a very high voltages(more than 69kV). The reason is long distance will consume energy and a high voltage can reduce the consumption. Another transmission substation is called step-down transmission substation, which is located at switching points in an electrical grid. They connect different parts of a grid and are a source for subtransmission lines or distribution lines. As its name shows, it reduces the voltage of the transmission line. The reason for that is subtransmission lines are near the end user. The voltage after step-down transmission substations will no more than 69kV.

Distribution substations are located near to the end-users. Distribution substation transformers change the transmission or subtransmission voltage to lower levels for use by end-users. Because of the different usage purposes (industrial, commercial or residential) a typical distribution voltages vary from 34,500Y/19,920 volts to 4,160Y/2400 volts. 34,500Y/19,920 volts is interpreted as a three-phase circuit with a grounded neutral source. This would have three high-voltage conductors or wires and one grounded neutral conductor, a total of four wires. The voltage between the three phase conductors or wires would be 34,500 volts and the voltage between one phase conductor and the neutral ground would be 19,920 volts.

In some big cities, the space is so limited and it is almost impossible to allocate the distribution substations on the ground. Therefore underground distribution substations are immerged and also located near to the end-users. Another advantage of underground is such distribution substations are anti nature disaster. It is especially suitable for the location where hurricane often takes up. An underground system may consists of Conduits, Duct runs, Manholes, High-voltage underground Cables, transformer vault, Riser and Transformers. It is shown in Fig 2.4.

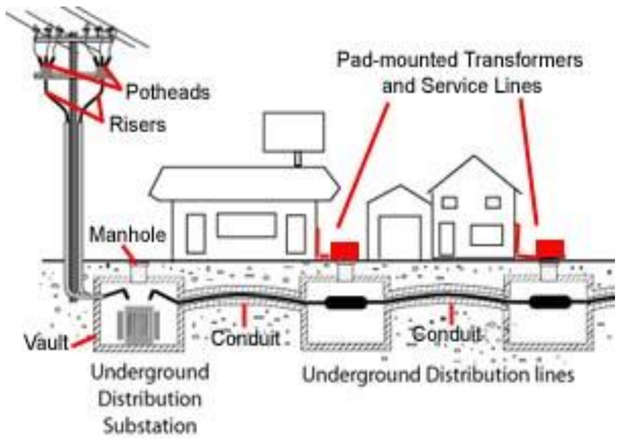


Fig 2.4 Underground Distribution Substation [8]

2.4.3 Transmission Line

Transmission lines carry electric energy from one point to another in an electric power system. They can carry alternating current or direct current or a system which is a combination of both. Also, electric current can be carried by either overhead or underground lines. The main characteristics that distinguish transmission lines from distribution lines are that they are operated at relatively high voltages, they transmit large quantities of power and they transmit the power over large distances. There are three types of transmission lines: overhead transmission line, subtransmission line and underground transmission line.

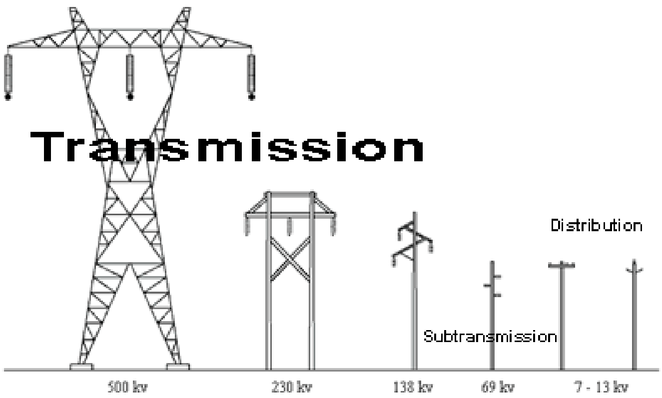


Fig 2.5 Over head transmission line [8]

Overhead AC transmission lines share one characteristic; they carry 3-phase current. The voltages vary according to the particular grid system they belong to. Transmission voltages vary from 69 kV up to 765 kV. Fig 2.5 shows different types of overhead AC transmission lines which are classified by the voltage range. Subtransmission lines carry voltages reduced from the major transmission line system. Typically, 34.5 kV to 69 kV, this power is sent to regional distribution substations. Underground transmission lines are more common in populated areas. They may be buried with no protection, or placed in conduit, trenches, or tunnels. More information can be found in [9].

2.4.4 Distribution Systems

Fig 2.6 Integrated distribution system [8]

A distribution system consists of all the facilities and equipments connecting a transmission system to the customer's equipment. For different end-user, the distribution system is not the same. Fig 2.6 shows an integrated distribution system. The incoming power is in the left side of the figure. It goes through a lightning arrester and sir-break switches. Then it comes through the step-down Transformer and the distribution bus. At last it goes to the outgoing distribution lines. Its voltage here is 4 times lower than the input.

The large amount of power is transmitted to the industry customer. Most industries use heavy machinery such as cranes or they have pipelining workshop. In order to run them they need 2,400 to 4,160 volts and usually have their own substations to reduce the voltage from the transmission line to the desired level for distribution throughout the plant area. They usually require 3-phase lines to power 3-phase motors.

Commercial customers are the companies without heavy machines. They may have several buildings which are powered by one interface from the power supply company. They usually served at distribution voltages, ranging from 14.4 kV to 7.2 kV through a service drop line which leads from a transformer on or near the distribution pole to the customer's end use structure. They may also require 3-phase lines to power 3-phase motors used for central air condition system.

The residential user voltage is 120 volte or 240 volte and is single phase. The distribution electricity is reduced to the end use voltage via a transformer. Two kind of distribution methods are shown in Fig 2.6. The left side is the overground distribution. The right is the underground distribution. For both overhead lines and underground line, power is delivered to the residential customer through a service drop line which leads from the distribution pole transformer to the customer's structure. This can be seen on the right figure. The second way is more common in big city due to the lack of space in the city.

Overground Residential distribution

Underground Residential distribution

Fig 2.7 Distribution system for residential customer [8]

3 Load Management

3.1 Introduction to load management

Electric load is the amount of electricity that flows into an electric circuit at any moment. Management of this load means managing the use of the major electric appliances of a circuit, in order to avoid short term high load peaks.

Load Management is important in the industry due to cost factor, deriving from situation of high demand which exceeds the utility company's supply capabilities. Cost factor means that the prices for power consumed by a costumer can vary. Several reasons can be used to explain this. For example, in some places electrical energy is limited. In order to fairly distribute limited recourses, each customer is allowed to use a certain amount of power. If the amount exceeds this quantity, the prices may be doubled. Another reason may be from the power plant itself. The working principles of different power plants are discussed in section 2.4. Once the power is produced, it should be consumed. Otherwise it is wasted. It can be also seen from the construction of the transmission network for the electricity that there is no way to store the energy. So the electric utilities will produce the electrical energy according to the historical load form. The relationship of load consumption and load producing can be seen in Fig 3.1.

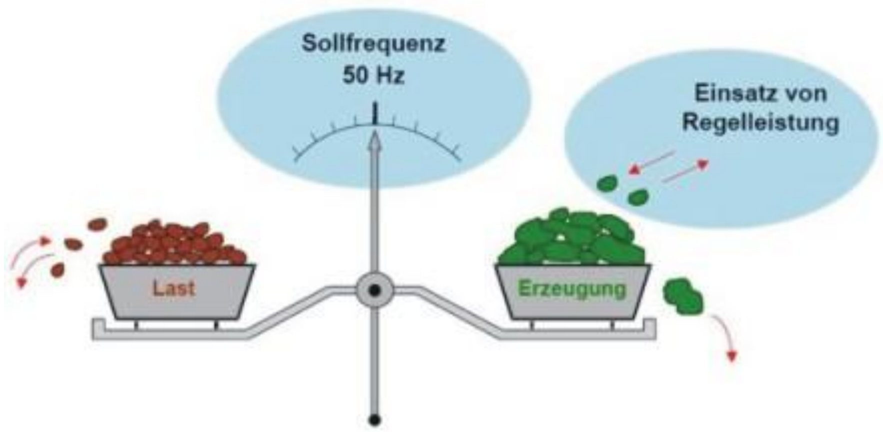


Fig 3.1 Electricity production and consumption [10]

In order to overcome the overload, they will have a backup dynamo. If the load consumption is larger than the production, the backup dynamo will be used. But starting a new dynamo only for a short time increases the cost for power producing. Of course the electric utilities will not pay this increased amount of money. They want the user to pay them. Hence the power supply company will have the following policy shown in Table 3.1 to get the money back. (All data is assumed, not real)

Load	Price(euro/KW)	Discount
<1000KW	100	No
1000~1200KW	140	20% 23:00~05:00
1200~1500KW	160	30% 23:00~05:00
>1500KW	200	40% 23:00~05:00

Table 3.1 Price List of power supply company

From the table it is clear that the price for the energy increases largely during the day. But at night, the overall power consumption is lower. Therefore in this example the power supply company grants a discount between 23:00 and 05:00 which makes the difference smaller. In order to save cost, a company will now try and limit its load to under 1000kW during the day. In some special case, it can be 1000~1200kW. The power which is larger than 1200kW is not allowed. At night, the maximum load can be extremely large. Demand exceeding a utility company's supply capabilities means that the real power consumption is larger than the supply capability. The supply capability is determined by the hardware which is discussed in section 2.3. For example the material of the transmitting line, the transformer in the company and so on. If the consumption is larger than the capacity, it will cause overload and the whole power supply system may face with emergency shut downs.

There are two possible ways to control the load. First, a slowly increasing power demand brings the load to a preset threshold, and second, load has to be brought down from some high value to a preset threshold as quickly as possible. After that, in both cases, all that is left to do is to maintain the load as near that threshold as possible for as long as possible (or necessary). The usual approach is to disconnect equipments in any predetermined the order and keep it disconnected as long as needed. In cases when disconnection times are long a company may opt for load rotation. Load rotation means reconnecting disconnected equipments after some time while disconnecting other devices. In most cases, load management will have to ensure for as long as possible that the normal production or the normal work process is not affected.

Now an example should be helpful to understand what has been explained above. Suppose a building has four systems. They are two air conditioning systems, one ventilation system and one workshop system. The air conditioning system 1 has the lowest priority and the workshop system has the highest priority. Table 3.2 shows how these four systems work. If the load exceeds the maximum allowed value, the air condition system 1 which has the lowest priority will be switched off first. After

15 minutes, we must turn on the air conditioning system 1. Otherwise it will exceed the maximum switch off time. Therefore the ventilation system should be turned off. 10 minutes later, the ventilation system should also be turned on again. But at this time the air condition system 1 can not be switched off. Its minimum running time is 15 minutes. So the air conditioning system 2 will be turned off. 5 minutes later, the air conditioning system 2 will be turned on and the air conditioning system 1, which has reached the minimum running time, can be switched off again. The essentiality of power management can be found from this example. During the above procedures, some equipments have been disconnected and reconnected, but the whole system has not been effected.

System name	Priority	Maximum switch off time	Minimum running time
Air conditioning 1	1	15	15
Ventilation	2	10	5
Air conditioning 2	3	5	5
Workshop	4	5	30

Table 3.2 Parameters of subsystems in one building

Of course the example shows an ideal situation, for a real system some factors may be changed. In summer with high temperature, the maximum switch off time of air conditioning will be reduced and the minimum running time will be increased. In summer the sunlight is equate. Therefore its priority may be reduced to 1. During the lunch time, the priority of the workshop can also be reduced. With so many factors taken into account, it is not possible to control the whole system manually.

The purpose of load management systems is to automate these procedures, and to run them as swiftly and efficiently as possible. While maintaining load below a set limit is not difficult to do, care must be taken that the threshold is straddled as closely as possible. As for the two cases mentioned above, the second one is harder to handle. It is critical in that if load can not be brought down fast it will exceed the maximum load allowance and the company pays penalties. On the other hand, if initial shed cycle overshoots the desired high limit by too large of an amount, the company loses revenue. Therefore it is important to keep the threshold in a flat line.

3.2 Methods of load management

What follows is a discussion of some issues which are used to make the load management. It must be understood that even though these issues are discussed separately as if they happen one at a time, they actually occur concurrently. Any observed demand curve is always the result of many competing factors, including actual demand at the time, current management cycle activity, previous management cycle activity, and states of the individual load points at the time. The source of these methods is [11]. The reason to describe these methods is that the later implementation will use one of them.

3.2.1 One-Way Load Management

One-way load management means the communication between the controller and the load is one way communication. The devices which are controlled by the load management system are not able to send the information about their status back to the controller. The reason for that is that most switches in today's market are one way. Such method will have some effects when the high load need to be quickly shed down to a preset limit.

In an ideal situation, if every switch is connected to a load which is active, the total load could be reduced by the desired amount in a single management cycle. This is shown in Fig 3.2. Vertical dashed lines are polling times and the orange line represents the threshold, and the blue line is the measured load. At the second vertical dashed line, the controller shut down some devices. In the next cycle, the total load has been reduced to the predefined value.

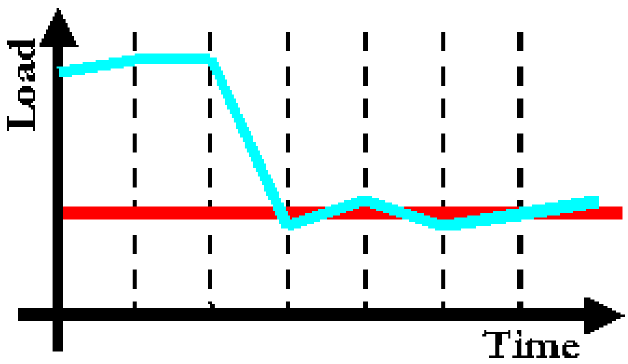


Fig3.2 Ideal response of one-way load management

What happens in reality is that some devices, which are not consuming any power at that time (switched off) are also connected to the load management system. Since the communication of one-way load management system is one way, the controller has no way to get that information while shedding load. This leads to a situation shown in Fig 3.3 which is similar to the one depicted before. The load management system switches off some devices at the second dashed line, but some of them devices have the off status. After the first polling cycles the total load has not been reduced to the desired limitation due to the factor that not enough loads were shed. Hence another shed cycle is executed. Sometimes it takes a few polling cycles until the total load value reached the desired limitation which leads to a very slow system response time. From the figure it can be seen that the load stays above the high threshold for a longer time, during which the company should pay penalty fees.

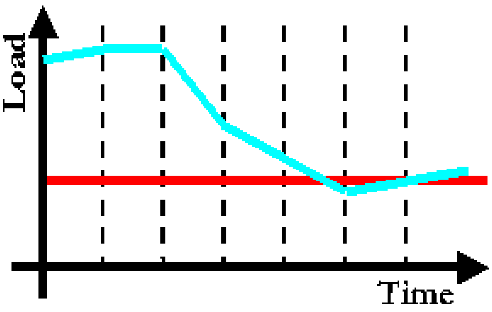


Fig 3.3 Real response of one-way load management

To reduce the error, a high intelligent controller will be used. This controller will connect to a data base through which it can find the percentages of connected equipments which have no power consumption at all. After that, it will rescale the loads which should be shed. Although this method reduces the response time, it is inaccurate. As a consequence more loads may get shed during the first cycle.

3.2.2 Two-Way Load Management

In contrast to the first method, a two-way load management has a bidirectional communication between the controller and the load side. Devices in the load management system are able to report back to the controller whether the respective loads are running during the time of management.

When a two-way load management system enters into a shed cycle, the amount of load it reduces is all active load. For example, the total current load is 99kW and the maximum allowed load value is 90kW. The controller will first turn off some devices which have a sum load equal to 9kW. But it will detect that one or two of them are switched off, which have a sum load equal to 3kW. It will immediately disconnect another device which has a load equal to 3kW. If this device is also not active, the same algorithm will be applied until the active load is disconnected. All these calculations are done in one polling time. The response time in this situation is identical to the ideal response of a one-way load management shown in Fig 3.2.

3.2.3 Active Cycle Demand Correction

This method is based on the two-way load management. When a system polls for demand data after an active management cycle, the observed demand reading is too high. This is because the reading is the average load between the current and the previous polling cycles. Two factors affect the observed demands:

a) Load was shed during that time,
b) The shed process is not an instantaneous event

Let's use the same example as what has been used in the last section. Assuming at time t1, the beginning of a shed cycle, the total current load is 99kW and the maximum allowed work value is 90kW. At time t2, 9kW load is reduced by the controller. But at the same time some devices which have load value 3kW may also be switched off actively. "Active" means the controller do not disconnect them. This leads to the total load at time t3 lower than the maximum allowed value. An unwanted system overreaction during the second management cycle is got, as shown in Fig 3.4.

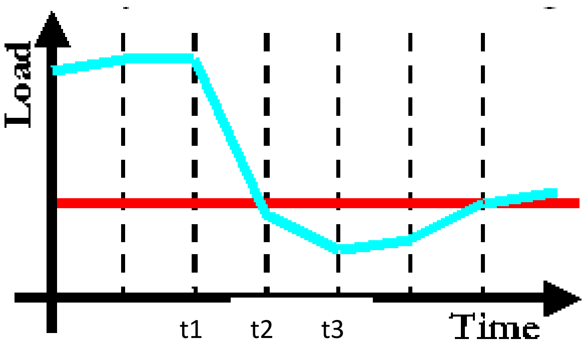


Fig 3.4 Error in two-way power management

To recover it, the system may attempt to release some load which may or may not work depending on whether total load fell below release threshold, and whether individual load points are self starting when power is restored.

The "Active Cycle Demand Correction" must be applied in order to compensate for this. Factors such as amount of load shed during previous cycle, amount of time it took to accomplish that, and the system polling period will be taken into account to calculate how much load should be reduced at the beginning of each polling cycle. This minimizes the overshoot depicted in Fig 3.4 and returning the situation to the one sketched in Fig 3.2.

3.2.4 Average Demand Extrapolation

As already mentioned, the purpose of a load management system is to maintain the peak of load values in a desired value. All the method discussed above is doing that when the peak exceeds the maximum allowed value, the exceeded amount of load will be switched off by the load management system. During periods of increasing demand, this method results in load profiles such as the one depicted in Fig 3.5 which is an unwanted result. At any time the total load is just above the maximum allowed value which means the load management system do not works.

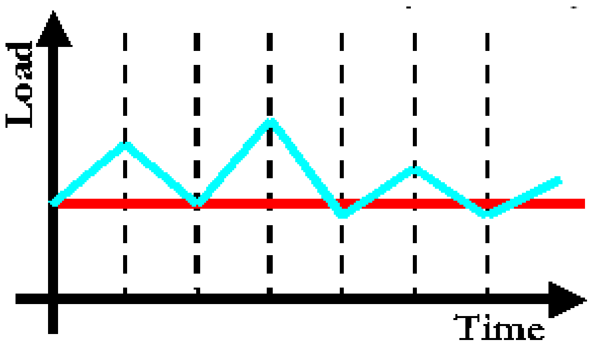


Fig 3.5 Problem caused by average demand extrapolation

This will cause the penalty of the company by the power supply company (see Table 3.1). For this reason, when demand is rising, the Average Demand Extrapolation algorithm should be employed. Still the same example is used here to explain this method. Assuming at time t1, the beginning of a shed cycle, the total current load is 99kW and the maximum allowed work value is 90kW. Normally 9 kW load should be reduced. But it will take the increasing trend of the load into account. At time t1, it estimates the load at time t2 will be 102kW. So it will reduce 12kW during the polling time instead of 9kW. This results in situations more like the one shown in Fig 3.6.

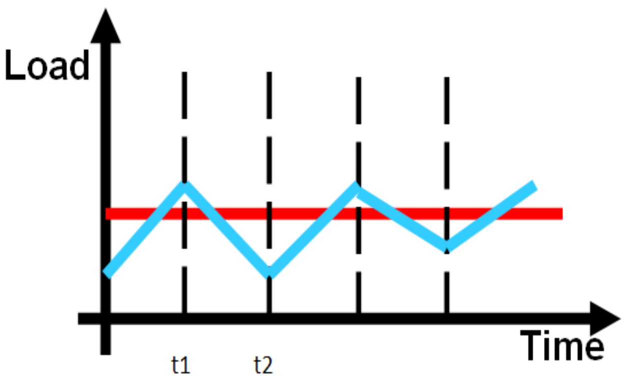


Fig 3.6 Response of Average Demand Extrapolation

In most cases, the load is under the allowed value. In the beginning of shed period, the load is larger than its maximum value. But the distance is not large. One can set the value of red line a little bit lower than the real maximum value.

The control depends on the extrapolated load value. Hence the quality of the controller is determined by the extrapolation method. The next section will introduces some method used to do the estimation.

3.3 Load Extrapolation Method

This section will explain the data extrapolation method introduced by [12]. The longer and shorter of each method will also be discussed.

1. Free load method

   This method reacts very quickly to changes in the flow of load. That means the response time is short. Once a change happens, it will do some controlling. Hence it should be used only for very constant load. Alterations are quickly optimized.

2. Medium load Method

   By contrast to the first method, this method is very suitable for quickly changing load fluxes. The load fluxes will be integrated and the expected load outcome after 15 minutes will be calculated from that integration. This method reacts slower compared to the Free Load method. If the polling time for the first method is 1 minute, then the polling time for this will be 15 minutes. The predicted load value may be enlarged if a larger continuous load rise appears at the end of a 15 minute period.

3. Short time Difference Free load method

   It is based on the Free load Method. In addition to the Free Load Method the difference of the last couple of intervals of calculated load forecasting values to the actual measured load values is taken into account. For example, the expected load at minute 13 for minute 15 is 1000KW. The Expected load at minute 14 for minute 15 is 1200KW. Then the final expected load at minute 14 will be 1200*a+1000*(1-a). "*a*" is called the weight coefficients. This method has the advantages that a continuous rise or reduction of the load can be better accounted for in the trend calculation. This method has the same short reaction time as the Free Load Method.

4. Short Time Difference Medium Load Method

   This method is based on the Medium Load Method. Like what has been done in the third method, the difference of the last couple of intervals of the calculated load forecasting values to the actual measured loads values will be first calculated. Then it will be taken account into calculation of the final estimation value. Obviously this method has the advantage that a continuous rise or reduction of the load can be better accounted for in the trend calculation. This method has a longer reaction time than the Free load Method.

5. Difference load Method

   In this method two dynamic parts contribute to the forecasting value. Both parts are repeatedly re-calculated and then added together to give the new forecasting value for the end of the 15 minute interval. The first part is the long-time difference of all the estimated values in the last 4(or less) period to the actual measured. If the period is 15 minutes, then all the estimated value in the past hour will be taken into account. The second part consists of the difference of the last interval to the actual measured value. The weighing factor of each part is constantly adjusted when a new period comes. Compare to the 4^{th} method, this method takes last 4 periods into account while the Short time Difference Medium load Method takes several minutes in one period into account.

   The reaction time of this method is the longest among of all methods. Hence it is most suitable for very fast changing load fluxes. Compared to other methods, the calculated forecasting profile is almost flat around the maximum allowed value. Therefore fewer switching operations are executed on the connected devices.

For all five methods above, the following parameters should be adjustable:

1. Interval of the calculated load forecasting. This is the interval between two load trends calculations in seconds. The newest software can do the new calculation every second. But real system, it probably don’t need that often. Once pre 10 seconds or even once per minute should be fine.
2. Short time difference interval. This is the number of intervals for which the short time difference between forecasted value and really reached value is taken into account. They are used in method 3,4 and 5.
3. Long time difference interval. This is the number of intervals for which the long time difference between forecasted value and really reached value is taken into account. It is used only for method 5.

3.4 Components of Load Management System

The methods used to control the load have been discussed in the previous section. This section will describe the components used in a load management system. The common components are main controller, sensor, transmission system, display system and data base.

1. Main controller

   The main controller is usually a powerful processor. It may be a PC, a microcomputer or a combination of them. It can get data from the load side. A prearranged program has been installed in this processor. Besides, it should have some human interfaces which allow people to change the parameter. It has larger memory spaces which allow it to control a large system. It should also process the data with a very fast speed.

2. Sensor

A sensor is a device which measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument. An electric meter or energy meter is a device that measures the amount of electrical energy supplied to a residence or business. The most common type is known as a kilowatt hour meter or a joule meter. Utilities record the values measured by these meters to generate an invoice for the electricity. They may also record other variables including the time when the electricity was used. But such kind of meter can not be used for load management. The first reason is the reaction time. As is know it detect Kilowatt per hour, the resolution is larger. It can not detect the load for every minute. The second reason is only human can read the value of this meter. But we need a processor to control it, which means the measured value should be a signal and can be transmitted. Now a modern sensor is an all-digital one. It will first detect the current and voltage. The detected values are transformed to a digital signal. It has a microcontroller on its side which calculates the product of the two. According to chapter 2, this product is the power value.

3. Transmission system

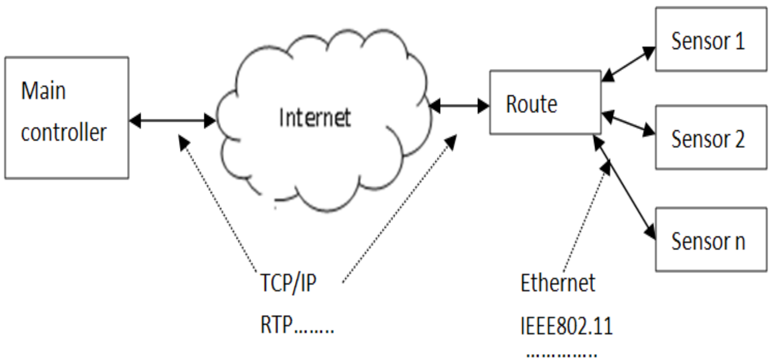


Fig 3.7 Remote Load management system

There are a lot of ways to transmit the signals. If the system is an isolated one, then the sensor is directly connected to the main controller. In most applications used in load management system, a remote control is needed. Internet has been well developed and is suitable to do the real-time transmitting. The delay between the two communication sides can be less than 1ms. Fig 3.7 shows how it works. A lot of sensors are connected with a route. If they are connected by lines, then the Ethernet protocol is used. Of course, one can also use the wireless connection. In this situation, IEEE 802.11 protocol will be used. The Route is connected with the internet and the main controller is also connected with the internet. They communicate with each other through different internet communication protocols such as TCP/IP or RTP.

4. Display system

   The purpose of display system is let the manipulator know how the whole system works. It will display the current load and the historical load in one or more days before according to the user demand. Nowadays Liquid Crystal Display(LCD) is well developed and is the most suitable for the load management system. It connects to the main controller via the RS232 interface.

5. Data base

   A computer database is a structured collection of records or data that is stored in a computer system. A database relies upon software to organize the storage of the data and to enable a person or a program to extract desired information. The term "database" refers to the collection of related records, and the software should be referred to as the database management system (DBMS); this has sometimes abbreviation database manager or database system. Data server can be used as the hardware. It has a larger storage which stores the historical load data of buildings with different functionality. It is also connected to the internet and the main controller can connect with it through web service.

4 Design

4.1 Project Management

This master thesis deals with a project which simulates a load management system. Any project can be developed through 5 steps.

1. Requirements analysis
2. Analysis
3. Design
4. Implementation
5. Testing

Requirements analysis means what aims the project wants to achieve. Analysis means break the whole project into several different parts. Each project can achieve a specified aim according to the requirements shown in the first step. How many steps does the project contain? No detailed solution developed in this step. The third step is design. In this step possible solutions of what has been discussed before are disussed and decided upon.. Interfaces are defined, the type of the data, the operation system and the software used to develop the project are determined. The fourth part is implementation. This part uses a specified programming language to achieve what has been decided in step 3. Compared to step 3, this step is easier. In the last step the performance of the model should be tested. All the requirements in step one should be fulfilled. The diagram of model construction is shown in Fig 4.1

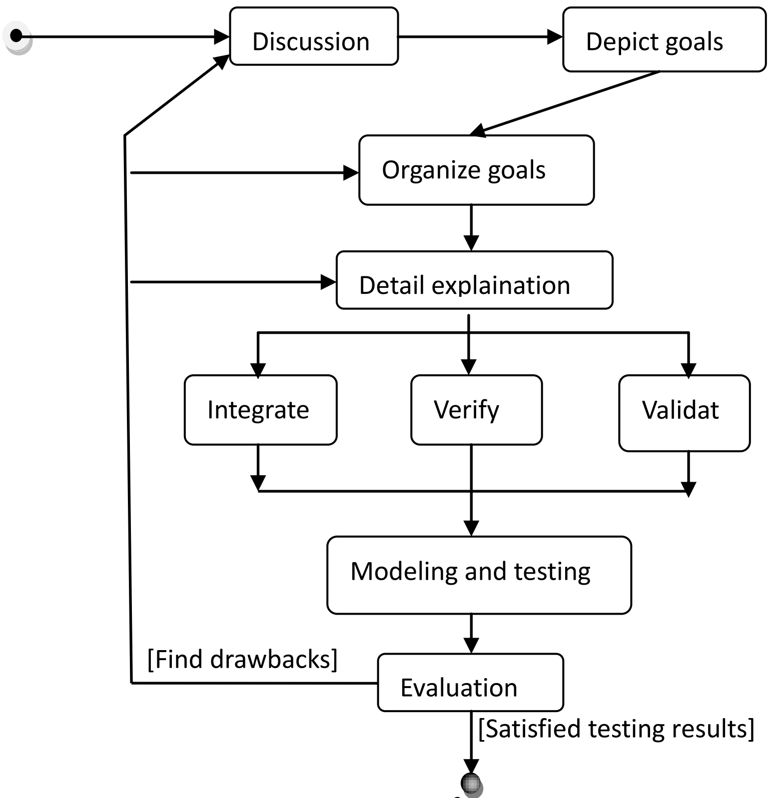


Fig 4.1 Diagram of project management

At first, people get together and discuss about the aims of the project. After this, people will describe the aims the project. These aims are not organized which means the order of them is not arranged. So the next step is to organize them. The aims are defined only roughly and are not explained in detail. Hence the next step should be making the clear explanations of them. After that three steps will be run simultaneously. They are integration, verification and validation. Once the above steps have been done, it is easy to construct the model and do the testing. The evaluation will be the last step. If the testing results are satisfying, the project is finished. If not, go back to the upper step and find out the reason. Reconstruct the model and do the testing again until a pleasant result is got.

4.2 System Analysis

The master project is developed using the approach shown in last section. Therefore the first step was the requirements analysis. The following requirements were taken into account while designing the load management system in this thesis:

1. Get the initial information from the data base.
2. Accept and refine real time load and use it as input to the load forecasting model;
3. Provide failure handler. When a software failure or dead lock takes place, the error message will be displayed. This message indicates that the work value exceeds the maximum allowed value. Note this message is only a warning and do not stop the program.
4. People are allowed to change the parameters (i. e. the maximum load allowance) during the run time.
5. The estimation error should be less than 10%

Above are the requirements of the project. According to these five requirements, several analyses can be done below:

1. The system has a data base.
2. System can get information from the data base.
3. The data types between each block may be different, the system should adjust it.
4. Some devices should be assumed in order to consume the power.
5. The controller should know the current state of power consumption.
6. The controller has some human interfaces, through which the user can change some parameters.
7. The controller can estimate the work value in the future.
8. The controller has an automatic error handling mechanism.

4.3 System Design

The system is supposed to have the following functionality:

1. There are altogether 28 buildings which are needed to be controlled.
2. Devices in each building are connected to a number of substations
3. Each substation has a number of priority classes.
4. Each building has one controller
5. One data base is connected to all the buildings

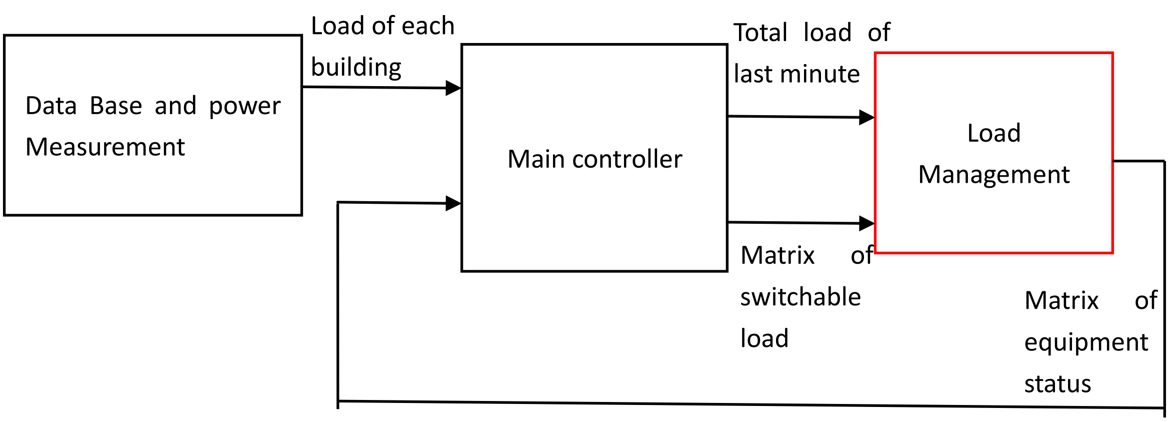


Fig 4.2 System Outline

The total system is shown in Fig 4.2. This project has been divided into three independent parts (shown as blocks). Altogether three people took part in this project. Each one is responsible for one block shown in Fig 4.2.

The function of the left block is collecting the information. This includes getting the initial values for the system (the measured load profiles of each building). As explained in the introduction, if the object is the university, a typical power consumption curve of this university will be first send to the controller. From Fig 1.2 it can be seen that buildings with different functions have totally different power shapes.

The middle block is called main controller which has two functions. The first is information procession. This means it will get the information through the interface provided by the first block. For example, suppose we have a university as the control-object. Then the main controller will send information “University, data, day, season” to the search engine. “Data” and “day” as well as “season” here are used to find historic load profiles that are typical for the university on a specific weekday in a specific season. These are then used to process a load profile of the university for that specific day and season. The second block simulates the behavior of the building devices which would be connected to a load management system. The right block

"Load management" will pass a matrix to the middle. This matrix indicates which equipments should be turned on and which equipments should be turned off. According to this matrix, the main controller should turn on or turn off the corresponding equipments.

The main task of this thesis is to implement the red block shown in Fig 4.2. The function of this block is the load management. It also has two tasks. The first task is to predict the work value of the whole system in the end of every period (15 minutes). Several load management and work predication methods are introduced in chapter 3. Our system can get the feedback of the load side which means the devices used to control loads are able to report back to the controller whether the respective loads are running at the time of management. Hence it is a two-way load management. It uses 15-minute time as the forecasting period, which shows it is a medium load method. This method has a longer response time and is suitable for the fast load change. If the expected value is larger than the maximum allowed work value, it will decide which equipments should be switched off according to the matrix sent by the middle block. If this value is smaller or equal to the maximum allowed work value, it will simply pass the matrix, which is got from the middle block, back to the middle block again.

An object oriented method is used to build each model. Object oriented means the attention is focused on the class instead of the individual procedures. This method is suitable for large projects and has a large reusable possibility. In our project, there are altogether 26 buildings which should be controlled. If a normal procedure method was used, there would be many repeated codes. This would result in long processing (simulation) times. A class concept is very important here to reduce redundant code. For example, a class named "building" can be constructed first. This building class has some attributes and functions. After the class is finished, each building can be implemented as each instance of the class "building". This relationship can be depicted in Fig 4.3.

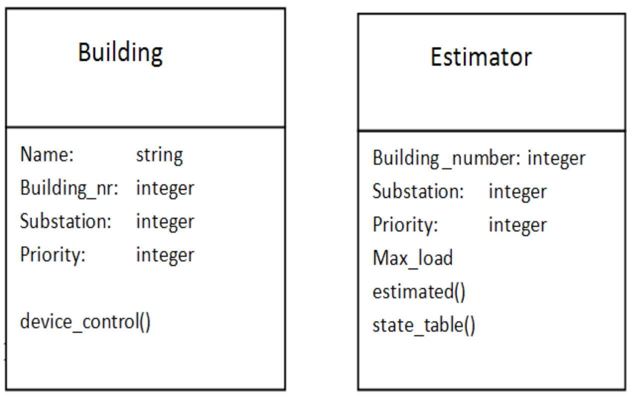


Fig 4.3 Class diagram

Fig 4.3 shows two classes. One class is called Building. It has four attributes. The Attribute Name is a string type. The other three are of integer type. Built_nr shows the serial number of the building in the whole system. Substation and Priority give the information of how many substations the building has and how many priorities each substation has. It has also a function device_control() which is used to control the device in the building. The other class is called Estimator. It has four attributes. Building_number tells which building the estimator belongs to. The other two have the same meaning as the first class. Max_load is the maximum allowed load value. Function estimate() is used to estimate the work value and state_table is used to change the state of the devices (switch on or switch off). A class is an abstract concept. In order to get the real object, an instance of each class has to be created. An example can be seen in Fig 4.4.

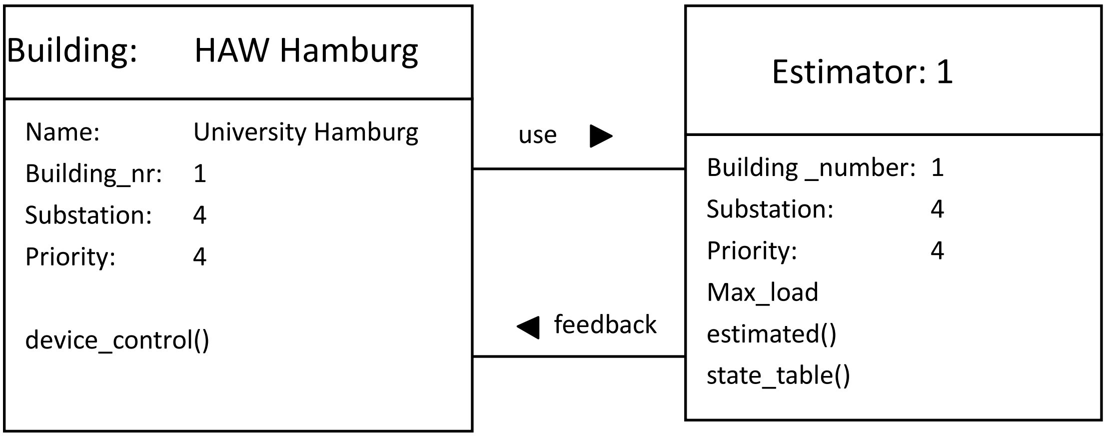


Fig 4.4 Object diagram

Fig 4.4 shows two instances of the two classes shown in Fig 4.3. The building is called “HAW Hamburg”. Its serial number in the whole system is 1. It has four substations and each substation has four priorities. The instance “Estimator: 1” has the building number 1, which means that this estimator belongs to building 1. So it will have the same substations and priorities as the building. It has three methods which can achieve the function of this estimator. Classes can have relationships with each other. The line in Fig 4.4 shows the relation between the object “HAW Hamburg ” and “Estimator: 1”. Building “HAW Hamburg” uses estimator “1” to do load estimation. Estimator “1” gives the feedback to the building. This feedback tells the building which devices should be turned on and which should be turned off.

A state diagram is used very often in project management. It is used to graphically represent finite states of a project. A state diagram consists of input symbols, output symbols, states and transition conditions.

Fig 4.5 shows the state diagram of the system. It has one input signal "current power" and two states (control and not control). Suppose the system starts at state "no control". According to the input value, an estimated value will be gotten. If this estimated value does not exceed the maximum allowed value, the state will not change. If the estimated value is larger than the maximum allowed value, it will jump to the second state. In this state, the control algorithm will be applied until the estimated value gets smaller than the allowed value. Then the system will jump to the first state again. There is no output value of this system.

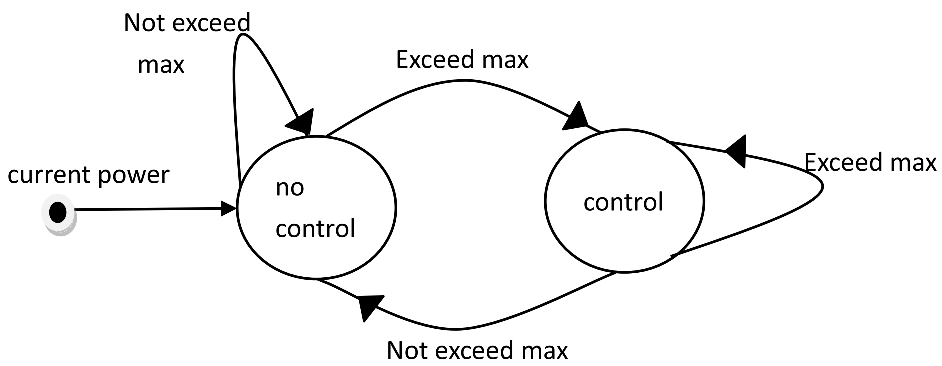


Fig 4.5 state diagram of the system

Finally we will discuss the hardware and software used to implement this project. The purpose of this project is to do simulations of the behavior of load management systems in a larger number of buildings. There is a lot of software which could be used to create the model and do the simulation. Matlab is such a powerful software for modeling and used in this project. Version 7.0 of Matlab offers more than enough functions to be able to finish this project. Hence it was chosen as the development tool. In order to run Matlab fluently on a PC a CPU quicker than 2GHz is preferred.

The three steps in project management for this thesis have accomplished. In the development of the project, the first three steps took most of the time. Once they had been done, the rest was just only to implement according to them. The next chapter will show how to implement what has been discussed in this chapter.

5 Implementation

This chapter shows the implementation of the model. The basic background knowledge of Matlab/Simulink will be given first. It is shown how a model can be constructed using Simulink, how to set the parameters for simulation runs and so on. Then the implementation of the control block will be shown. It contains two sub-blocks---"Power estimation" and "Equipment control". The detailed analysis of each will also be given. At last the real code will be explained.

5.1 Introduction to Matlab Simulink

Simulink is software which is used to build models. Such models can be used for the purpose of simulating and analyzing dynamic systems. Both linear system and nonlinear system are supported by the Simulink. The simulation time can be continuous time, sampled time, or a hybrid of the two. Systems can also be multi-rate, i.e. have different parts that are sampled or updated at different rates. If one have build a model and want to know whether it works or not, then Simulink enables you to get the answer. With Simulink, one can easily builds models from scratch, or take an existing model and add to it. At moment Simulink is used by thousands of engineers around the world to build the model and solve real problems in a variety of industries. The following topics highlight the key aspects of Simulink:[13]

- Tool for Model-Based Design
- Tool for Simulation
- Tool for Analysis

Model-based design means using a graphical user interface (GUI) for building models as block diagrams, using click-and-drag mouse operations. This interface simplifies the process of model drawing. Drawing the models is just like what painter would do with pencil and paper (or as most textbooks depict them). By contrast to simulation packages which require one to formulate differential equations in a language or program, this interactive graphical environment need no background knowledge. Simulink includes a comprehensive block library of sinks, sources, linear and nonlinear components, and connectors. User can also customize and create his own blocks. Models are hierarchical, so user can build models using both top-down and bottom-up approaches. The system can be first viewed at a high level, and then double-click block, which is in the high level, to go down through the levels to see the detail of the model. Through this approach one can easily get an insight into how a model is organized and how its parts interact with each other.

A lot of tools help the user to do the simulation. After one defines a model, one can simulate it. Matlab offers choices of mathematical integration methods, either directly start from the Simulink menus or by entering commands in the MATLAB Command Window. The menus are convenient for interactive work, while the command line is useful for running a batch of simulations (for example, if one is doing Monte Carlo simulations or wants to sweep a parameter across a range of values). The scopes and other display blocks enable the user to see the simulation results while the simulation runs. In addition, one can change many parameters used for simulation which may result to a totally different system behavior. Question like "what if" can be answered. The simulation results can be stored in the MATLAB workspace for post processing and visualization.

Model analysis tools include linearization and trimming tools, which can be accessed from the MATLAB command line, plus many tools in MATLAB and its application toolboxes. Because MATLAB and Simulink are integrated, one can simulate, analyze, and revise his models in either environment at any point.

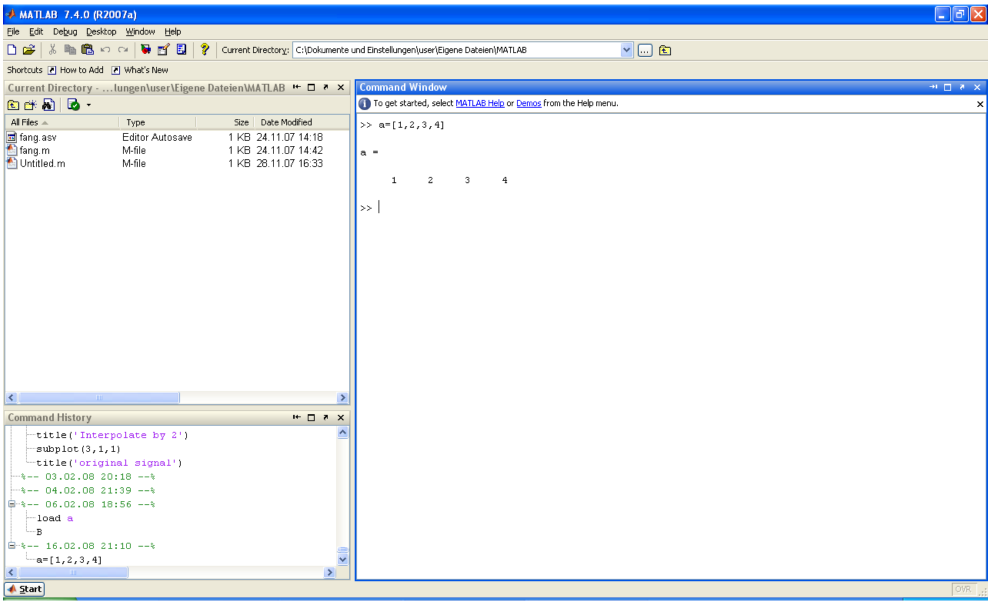


Fig 5.1 Matlab working Window

The Matlab command window is shown in Fig 5.1. One the upper left side is the directory window. All the files in this directory will be displayed in this window. Left lower part is the command history window. One can easily find the commands which were used last. At the upper side, one can choose the directory. One important point that must be mentioned here is that only the files in the current directory can be executed. If one wants to execute files outside the current directory, the directory needs to be changed. The right part is the command window. Users can type any valid Matlab command here. The result will also be displayed in this window. For example, the command a=[1,2,3,4] is typed in Fig 5.1. This command creates a one dimension array “a” which has 4 elements. Between two “>>” marks, the results is shown. The variable “a” is stored in the workspace which means one can use this variable later without having to recreate it again.

The work window to create a model is shown in Fig 5.2. Number “10.0” at upper side shows the simulation time. This value can be modified by the user. The simulation can be started or stopped by the icons which are on the left side of the time display window. The model can be constructed hierarchically. The three arrows let the user go through the models different hierarchical levels. The Library Browser displays a tree-structured view of the Simulink block libraries installed on operating system. It has 27 different classes which are sorted by different application ranges. The “Simulink” class is the most commonly used class which has 16 subclasses, with which one can build almost all models. The other classes are combinations of the basic elements shown in the “Simulink” class. One can simply choose elements from the “Simulink Library Browser” and drag them to the working window. Or one can copy the elements in the “Simulink Library Browser” and paste them in the model window. Many Simulink blocks can accept or output matrix signals. A matrix signal is a two-dimensional array of signal elements represented by a matrix. Each matrix element represents the value of the corresponding signal element at the current time step. This feature is important for the construction of the model in this thesis. Another important feature is that after creating a Simulink block called “Matlab function” one can make an m-file to specify the function of this block.

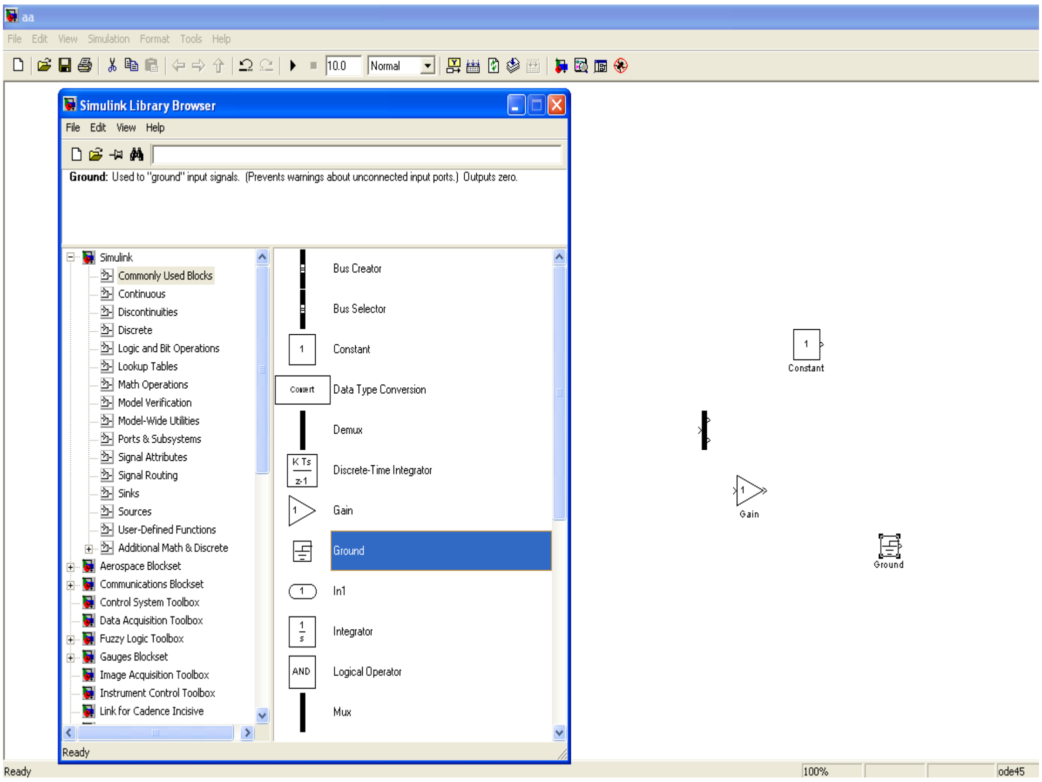


Fig 5.2 Working window for modeling

5.2 Modeling

The flow chat of the system is shown in Fig 5.3. It gets the power value and the switchable load matrix as input. Then it will do the estimation and get the estimated work value for the 15th minute. If this value is larger than the allowed value, it will turn off some equipment. As a last step it will output a matrix which shows which equipment should be turned off and which should be turned on.

The flow chart shown in Fig 5.3 can be constructed in a model by using Simulink. As said in section 5.1, the model can be a hierarchical one. This is good for reusing the model. So the first thing will be to create a user defined block. This has two input ports and one outputs port. Simulink offers the function for generating a user defined block.

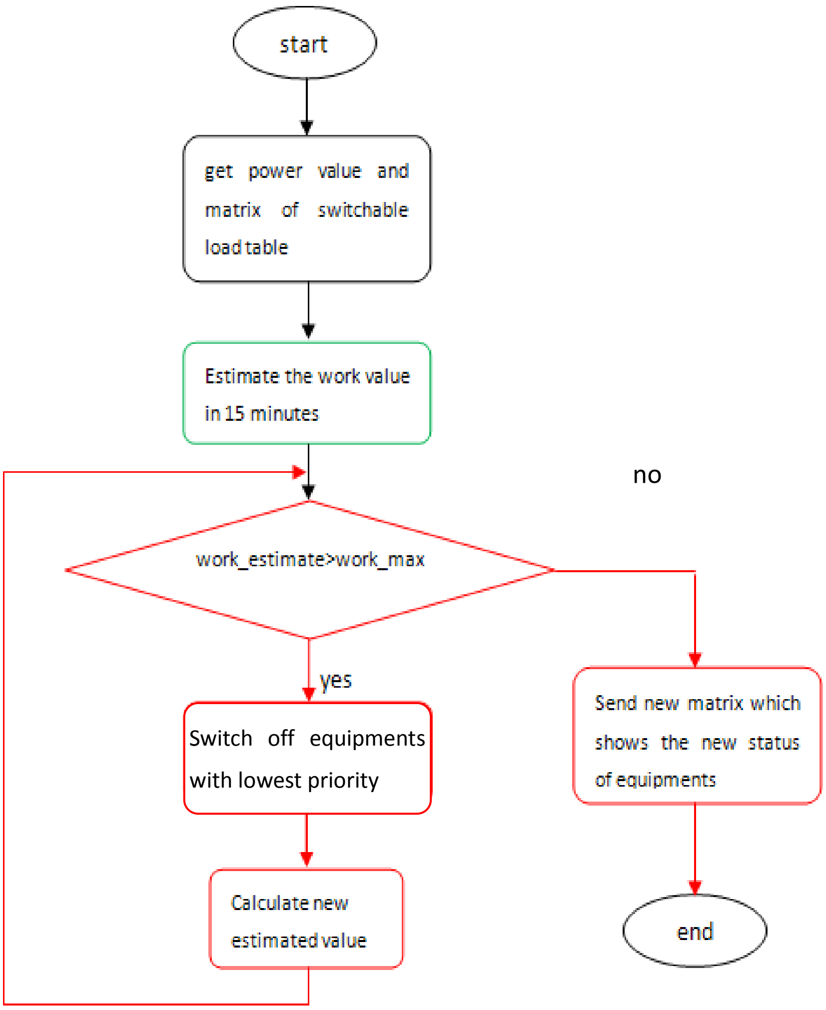


Fig 5.3 Flow chat of the system

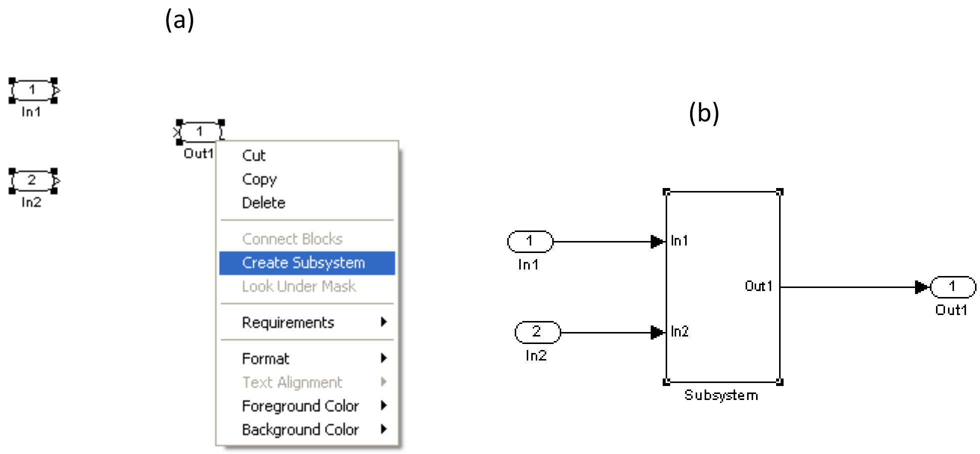


Fig 5.4 creating a user defined block in Simulink

Fig 5.4 shows how to generate a block with two inputs and one output. First take two input ports and one output port from Simulink library. Then choose these three ports and right click mouse. At last choose "create subsystem items". Now a user defined block has been created. It is shown in Fig 5.4(b).

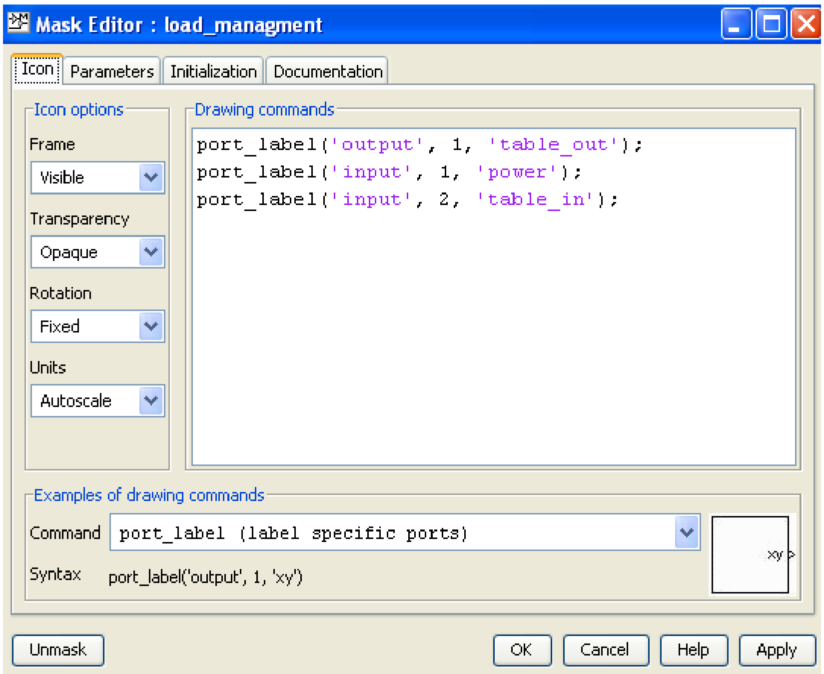


Fig 5.5 Edit Mask

Using the "Edit Mask" item, one can make the notation of each port and the whole block. Fig 5.5 shows the statements used to label three ports. The output port is called "table_out". The input ports are called "power" and "table_in". Four "Icon options" (Frame, Transparency, Rotation and Units) shown in Fig 5.5 are used to modify the visual effect of the block. The "Parameters" pane enables user to define and describe mask dialog box parameter prompts and name the variables associated with the parameters. The initialization pane is used to do the initialization. One can set the initial values of variables used in simulation. The documentation pane enables the user to define the mask type and specify the block description and the block help which tells people how to use this block.

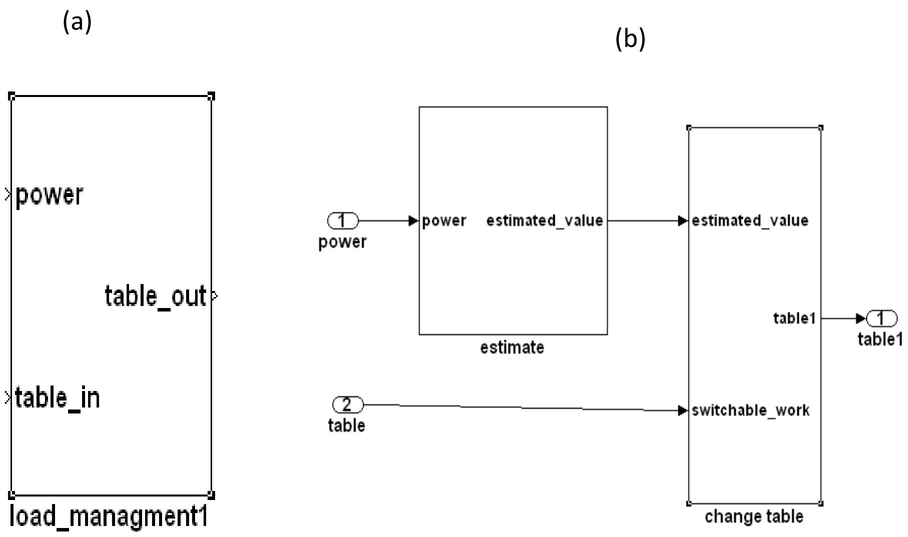


Fig 5.6 Model of load estimation block

Fig 5.6(a) shows how this model looks like after making the notation. Of course, it is the first level only. Choosing the "Look under Mask" item, one can modify the subsystem. The subsystem is shown in Fig 5.6 (b). There are altogether two blocks. The "estimate" block shown in Fig 5.6(b) corresponds to the green part shown in Fig 5.3. It is used to do the estimation. The "change table" block corresponds to the red part shown in Fig 5.3. It will determine which devices should be turned on or turned off. In order to achieve the function shown in Fig 5.3, these two blocks have also subsystem. The components of these two blocks will be explained later.

5.3 Function Block Realization

In this section, the realization of the two function blocks "estimate" and "change table" shown in Fig 5.6(b) will be explained. As said before, these two blocks also have subsystems which make it easy to understand how these blocks work.

5.3.1 Power Estimation

Power estimation is the key point of this thesis. Fig 5.7 shows how this block is implemented. In order to get the estimated value, three input signals are needed. Port "power" contains the current power value of the system. Port "clock" shows the current time. Port “load_old” is the load value of last time (t-1). A Matlab Function block is used here. The function of this block is specified by an m-file. The m-file defines how to deal with the inputs signals and what output signal should be passed out. It has two output signals. One is the value of the estimated work in the 15th minute. The work value of the last minute is needed to do the calculation of this estimation. Hence another output is the value of the current work value. This output is connected to a unite delay, which delays the value by one simulation period. After that it serves as input at the port “load_old’ of the block shown in Fig 5.7.

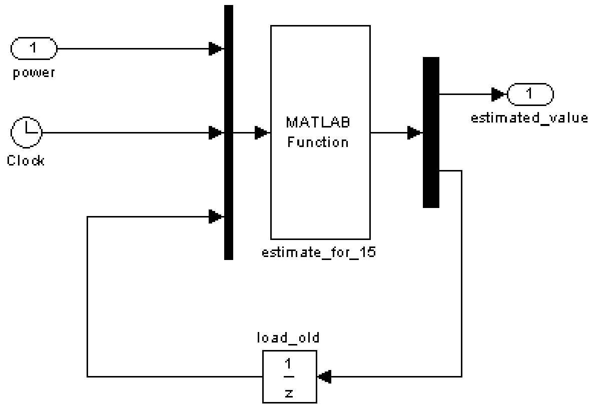
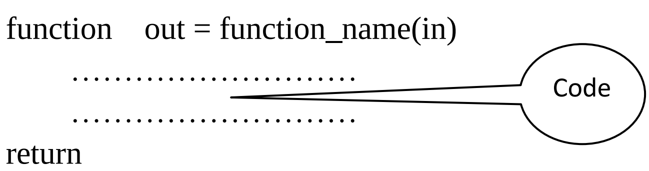


Fig 5.7 Implementation of estimation block

Any “m-file” which is used to specify a “Matlab Function” block has a fixed format. It is shown below:



The first line defines the name of the function, the input and output of the function. Note here the name of the function should be equal to the name of the “m-file”. If these two are not equal, the compiler will show the debug error. The last line should be “return”. Between them are the code lines.

The code of the m-file which controls the Matlab function block “estimate_for_15” displayed in Fig 5.7 is as follows (the red lines in the code are the notion for this file):

```
function out=estimate(in)
      %show that system begin to work
      disp(sprintf('\n************** start ********************** '));
      %pass the input value to three variable
```

```
power_minute=in(1);
time=in(2);
work_minute_old=in(3);
%time is limited from 0 to 14 (totally 15 minutes)
minute=mod(time,15);
disp(sprintf('current minute is %d',minute));
disp(sprintf('current power is %d',power_minute));
%change the power value to work value
work_minute=power_minute*(1/60);
work_minute=work_minute+work_minute_old;
if minute==0
    work_minute=work_minute-work_minute_old;
end
%display the work value of the current minute and the last minute
disp(sprintf('current work is %f',work_minute));
disp(sprintf('work for last minute is %f',work_minute_old));
%do estimation
if minute==0  %special case
    power_actual=work_minute;
else
    power_actual=work_minute-work_minute_old;
%because t=1min, power_actual is equal to the difference of work
end
out=zeros(2,1);
out(1)=(14-minute)*power_actual+work_minute;
%display the forecasting work value in the 15th minute
disp(sprintf(' the estimated work value for the 15th minute is %d ',out(1)));
% the second output value is current work value
out(2)=work_minute;
return;
```

It uses two known values to estimate an unknown value. So it is a linear estimation method. Fig 5.8 can be used to explain this method. The starting time is t_0. At this time the work value of the whole system is 0 by definition since a new polling period starts here. In this figure we have $t_1 = t_0 + 1$ and $t_2 = t_0 + 2$. The estimated value will be

$$\text{Work\_t}_{15} = \frac{(\text{Work\_t}_1 - \text{Work\_t}_0)}{t_1 - t_0} \times (15 - t_0) + \text{Work\_t}_0$$

Because $t_1 = t_0 + 1$ and $\text{Work\_t}_0 = 0$, the equation can be rewritten as follows:

$$\text{Work\_t}_{15} = (\text{Work\_t}_1 - 0) \times (15 - 0)$$

For time t_2, the estimated value will be

$$Work\_t_{15} = (Work\_t_2 - Work\_t_1) \times (15 - t_1) + Work\_t_1$$

For minute between 1 and 14, the estimated work value can be obtained by the same way shown above. For minute=0, the work value will be the real value at that time.

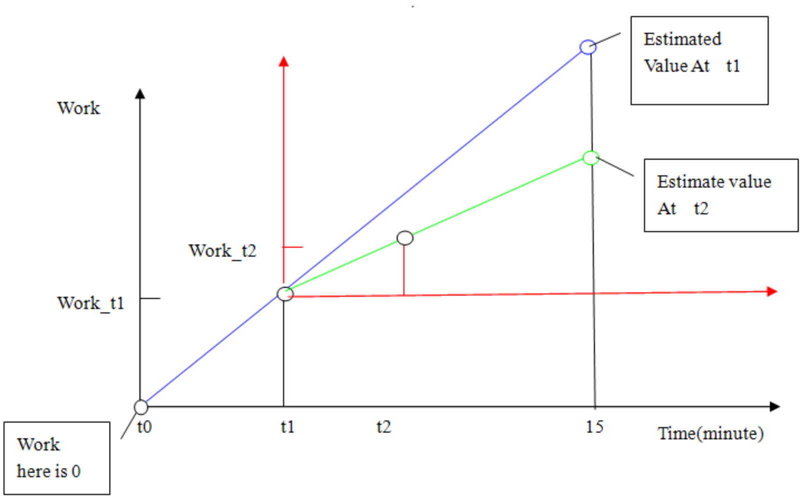


Fig 5.8 Method used to estimate the work

Of course, such a linear method can also be explained in a physical way. Electrical work can be calculated by the following equation,

$$W = \int_0^t Pdt \tag{5.1}$$

In this equation, P is the power value. Derivative both sides of equation 5.1, we get,

$$dW=Pdt \tag{5.2}$$

So the power $P = \frac{dW}{dt} \approx \frac{\Delta W}{\Delta t} = \frac{Work_{t_{i+1}} - Work_{t_i}}{1}$

where $Work_{t_i}$ is the work value in minute t_i

Now the power value has been got. Using equation 5.1 again, the estimated work value at time t_{i+1} will be

$$Work_{t_{15}} = \int_{t_{i+1}}^{15} Pdt = (15 - t_{i+1}) \times (Work_{t_{i+1}} - Work_{t_i}) + Work_{t_{i+1}}$$

$$=(15 - (t_i + 1)) \times (Work_{t_{i+1}} - Work_{t_i}) + Work_{t_{i+1}}$$

$$=(15 - t_i) \times (Work_{t_{i+1}} - Work_{t_i}) + Work_{t_i} \quad (5.3)$$

The same result has been got as before!

5.3.2 Device Rearrangement

This section describes how to control the equipment in the whole system according to the estimated work value.

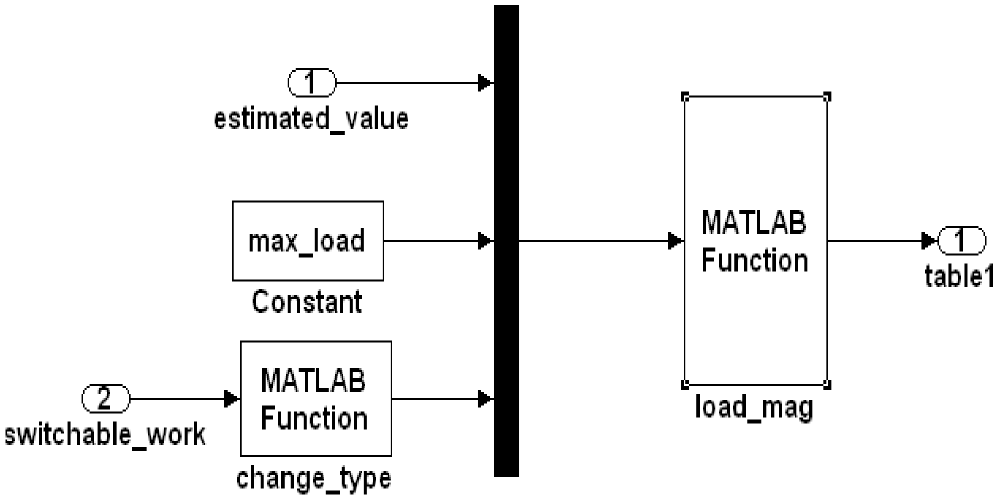


Fig 5.9 Subsystem of device control block

Fig 5.9 shows how the subsystem of the block "change table" shown in Fig 5.6 (b) looks like. It has three input ports. One port of them has a constant value. It is the maximum allowed value. This variable is created through the "Edit Mask" item shown in Fig 5.5. Double click the block shown in Fig 5.6(a). A dialog box like the one shown below will appear. One can easily set the value for this variable.

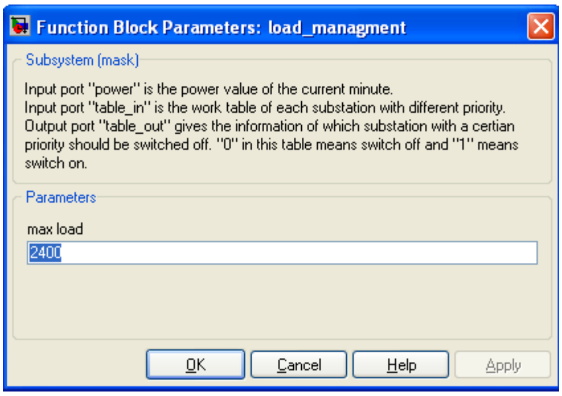


Fig 5.10 Parameter Setting

The m-file "change_type.m" corresponding to the block "change_type" is shown below. The red lines in this code are notations.

```
function out=change_type(table)
    % Get the size of matrix. Suppose this matrix is an m*n matrix. Then m
     represents
```

```
    % how many substations one building has and n means how many priorities
      each
    % substation uses.
    x=size(table);
    substation=x(1);
    priority=x(2);
    % output dimension is (nm+2)*1
    out=zeros((substation*priority+2),1);
    out(1)=substation;
    out(2)=priority;
    %change matrix with dimension m*n to matrix with dimension nm*1
    for i=1:substation*priority
        out(i+2)=table(i);
    end
return;
```

The purpose of this block is changing a two dimensional matrix to a one dimensional matrix. This is a practical approach. In reality the transmitting method are bus systems which can not transmit a two dimensional matrix. A solution to this problem is to first change the matrix format one dimension and then transmit it. In order to recover this matrix later, information about the original size of the matrix has to be sent.

The m-file “load_mag.m” corresponding to the Matlab Function block “load_mag” is shown below. The red lines in this code are notations.

```
function out = load_mag(in)
       work_15_estimate=in(1);
       work_max=in(2)/4;
       substation=in(3);
       priority=in(4);
       % out is the final output of the system, it is a matrix which has the
       %same dimension as the input matrix “switchable_work” shown in Fig 5.7.
       out=zeros(substation,priority);
      %recover matrix switch_work
      work_table=zeros(substation,priority);
      for j=1:substation*priority
          work_table(j)=in(j+4);
      end
      %display
      disp(sprintf('the new matrix of switchable work is '));
      disp(work_table);
      % if work_stimate larger than the maximum allowed work value, turn off
       % the equipments with lowest priority in substation one. After that,
```

```
% the estimated work value will be minus the work value caused by the
% equipment which has been turned off.
%Compare the new estimated value with
% the maximum value again. If the new value still larger than it, turn off
% the equipment with lowest priority in substation 2. Repeat the same thing
%until the new estimated value smaller than the maximum allowed value.
if work_15_estimate> work_max
  overload=1;
  row=1;
  column=1;
  while overload
      work_15_estimate=work_15_estimate-work_table(row,column);
      work_table(row,column)=0;
      if(work_15_estimate<=work_max)
         overload=0;
      end %if
      row=row+1;
      if row>substation
          row=1;
          column=column+1;
      end %if
      if  column>priority
          % case when turn off all the equipment, but the estimated value
          % still larger than the maximum allowed value
          disp(sprintf('system dead lock\n'));
          overload=0;
      end %if
   end %while
 end%if
 for j=1:substation*priority
     if work_table(j)>0
         out(j)=1;
     end
 end
%show which equipment is turned on and which is turned off
%For example if out(1,3)=0, turn off the equipments in substation one with
%priority three. If out(2,1)=1, turn on the equipments in substation two
%with priority one.
 disp(sprintf('the following devices should be switched off (0)\n'));
 disp(out);
  disp(sprintf('*********End*****************'));
 return
```

6 Testing

6.1 Testing the control system

The simulation of the load management block will be done first in this section. For testing a fixed number of load values are stored in array “B” as one input. The other input “switchable_table” would be a matrix of values corresponding to the switchable load in the different substations in this building. For testing purposes it was assumed to be a fixed matrix with the dimension 4*4 in order to be able to retrace the outcome of the calculations. The 4*4 size of the matrix means it’s a matrix coming from a hypothetical building that has 4 substations with each substation having 4 priorities. That is shown in Fig 6.1.

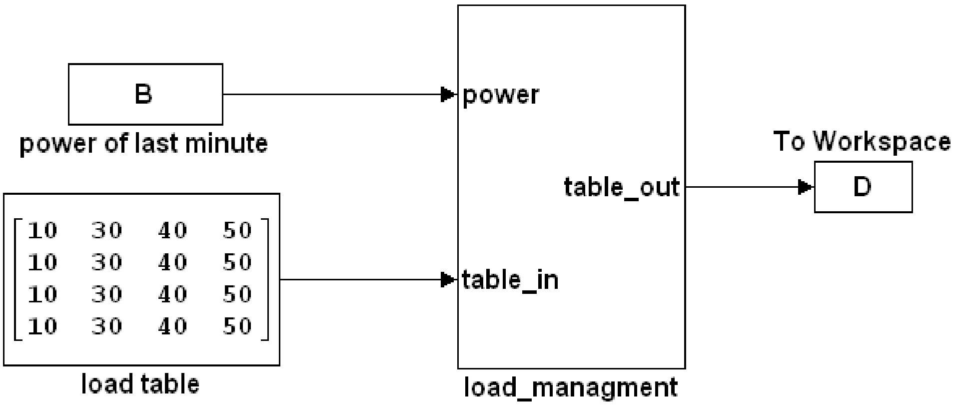


Fig 6.1 Simulation of Control block

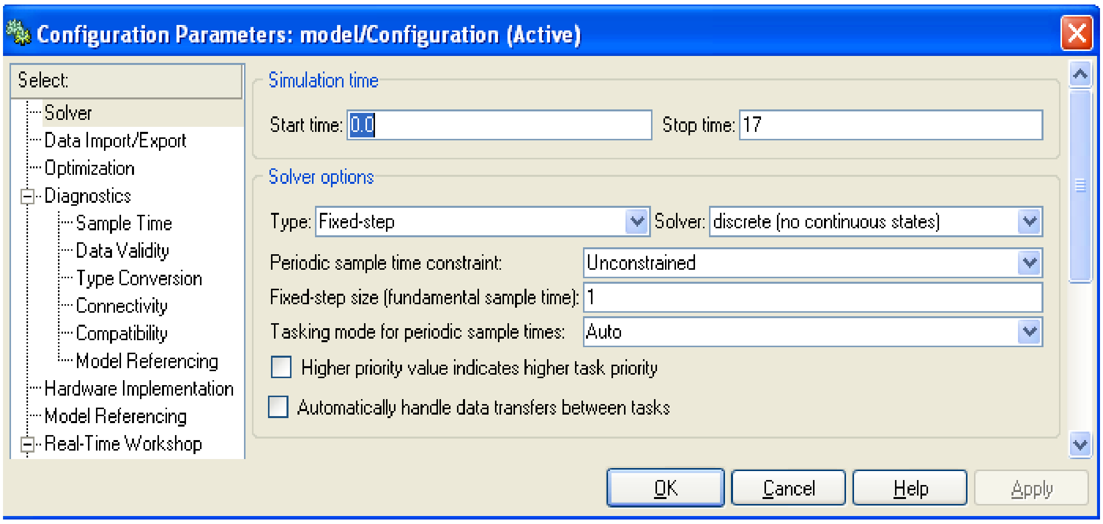


Fig 6.2 Configuration of the Simulation parameter

Before starting the simulation, it is important to configure the parameters used for the simulation. In order to test the integrality of the system, the simulation time should be larger than one period (15 minutes). Therefore the start time was set to be 0 and the stop time was set to 17. This means at least 17 assumed power values should be stored in array B. The system does the management step each step corresponding to one minute. So it is not a continuous system. The type should therefore be set to “fixed-step” and the solver should be set to “discrete”. The fix-step size should be set to 1. This is shown in fig 6.2.

At first set B=[2400		1800	2400	3600	1800
	2400	1800	3000	3000	3000
	1800	1800	3600	1200	1200
	2400	1800	3600]		

In order to make the further testing easily, one can store the value B in a “*.mat” file. This can be done through the following codes,

```
save data1;
load data1;
```

When the first line is typed in the Matlab command window, a file called data1.mat will be generated in the current directory. This file stores the value of array B. Next time if one wants to run the simulation again, it is possible to quickly reload the matrix by typing the second line in the command window. After that array B will be stored in the Matlab workspace. To ensure a “safe” environment for the testing the following three commands should be executed in the command window to clean the memory before starting the simulation,.

```
clear all;
close all;
clc;
```

The first line deletes all the variables that are currently stored in the Matlab workspace. The second line closes all the figures opened by Matlab. The last line clears the command window. After these three steps are executed, one can start the simulation. Only after this procedure it is ensured that the simulation results are correct. We can also visualise the values of the variables calculated during the simulation process.

Now let’s come back to the array B. Note that this is the power value with the unit kW. The corresponding work values for each minute are

B/60=[40	30	40	60	30	40
30	50	50	50	30	30

60 20 20 40 30
60]

The maximum allowed load value is set to 2400kW. So the maximum allowed work value will be 2400*15/60=600kWh.

At minute 3,7,8,9,12 and 17, the estimated work value will be higher than the maximum allowed work value.

As an example the simulation result at time 7 is shown below,

```
************** start **********************
current minute is 7
current power is 3000
current work is 320
work for last minute is 270
the estimated work value for the 15th minute is 670
the new matrix of switchable work is
    10    30    40    50
    10    30    40    50
    10    30    40    50
    10    30    40    50

the following devices should be switched off (0):

     0     0     1     1
     0     1     1     1
     0     1     1     1
     0     1     1     1

*********End*****************
```

The input power value at minute 7 is equal to B(8)=3000kW/h (B starts at minute 0 which corresponds to the last value of the 15 minutes before (!) the simulated interval). So the power value is correct. The total work value will be $\sum_{i=1}^{8} B(i)/60 = 320\ kWh$ and the work value for the last minute will be $\sum_{i=1}^{7} B(i)/60 = 270kWh.$ It is clear that the simulation result for the work value is correct. Applying equation 5.3, the estimated value for the 15th minute will be (15-8)*(320-270)+320=670kWh which is equal to the simulated value. Because the maximum allowed work value is 600kWh, some devices should be turned off. From the simulation results it can be seen that the devices with the lowest priority have been turned off. The total work caused by these equipments is 70kWh.
The result at the end of the simulation (minute 17) is shown below.

************** start **********************
current minuter is 2
current power is 3600
current work is 130
work for last minute is 70
the estimated work value for the 15th minute is 850
the new matrix of switchable work is

10	30	40	50
10	30	40	50
10	30	40	50
10	30	40	50

the following devices should be switched off (0)

0	0	0	1
0	0	0	1
0	0	0	1
0	0	1	1

*********End*****************

The modulation of 17 by 15 is 2. So the current minute is 2. Current power is 3600kW which is equal to B[17]. We know the current work value should be equal to (B[15]+B[16]+B[17])/60=130kWh. The result shows the current work is 130kWh. So the result is correct. The estimation is 850kWh which can also be proved to be true through the equation 5.3. Hence the superfluous work will be 850-600=250kWh. It can be proved that the summation of the removed work value in matrix "switchable_work" is equal to 280kWh. This value is a little bit larger than 250kWh. This is because the last group of devices (substation 4 priority 3) which have been switched off have a work value equal to 40kWh. At this time only 10kWh are needed to be turned off. So the deviation will be 30 kWh instead of 0.

6.2 Performance Analysis

The next step will be measuring the performance of this block. This means the examination of how large the deviation is between the real work value in the 15th minute for a sampled real load profile and the estimated work value of the developed algorithm is. This can be done by passing the real measured values to the system. The real measured load results of one building in two different days were used for this examination. The first problem for this test was the question of how to import the data from the Excel file it was saved in into Matlab. The answer is Excel Link. Excel Link is a software add-in that integrates Microsoft Excel and MATLAB in a Microsoft Windows-based computing environment. By connecting Excel and

MATLAB, one can access the numerical, computational, and graphical power of MATLAB from Excel worksheet and macro programming tools. Excel Link makes exchanging and synchronizing data between the two environments possible.

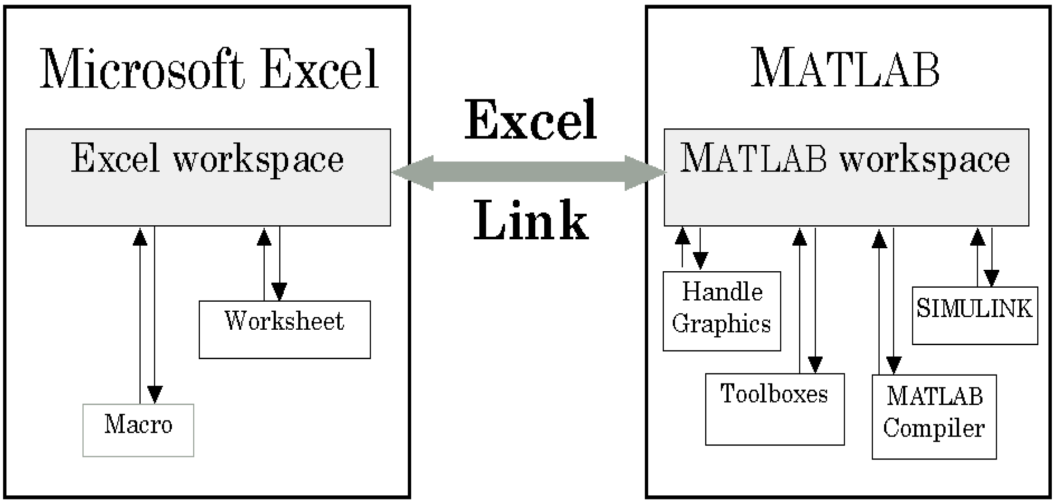


Fig 6.3 Excel Link
Source: Matlab Help File

Fig 6.3 shows how Excel Link works. It communicates between the Excel workspace and the MATLAB workspace. It positions Excel as a front end to MATLAB. With a small number of functions to manage the link and manipulate data, Excel Link is powerful in its simplicity. In order to use Excel Link three conditions should be met. [14]

- Approximately 202 kilobytes of disk space are required.
- Operating system requirements are: Windows 2000 or Window XP
- The version of Excel should be 2000 or 2003

The following codes are used to getting data form Excel file.

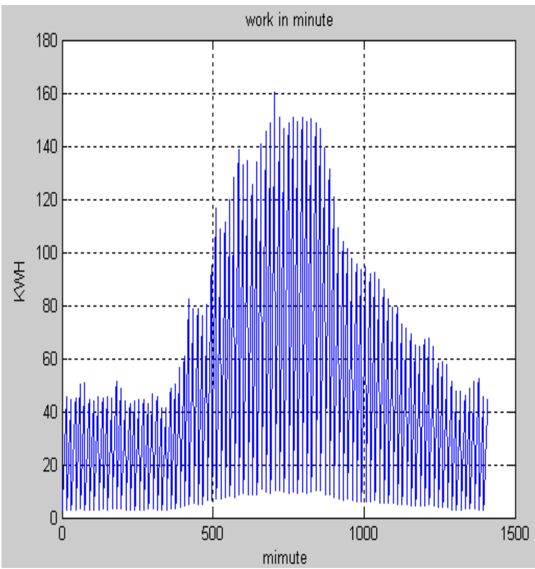
```
channel = ddeinit('excel','C:/ye/9mai.xls');
data = ddereq(channel,'r2c4:r1433c4');
plot (data);
save  data_mai
```

The first line initiates a conversation with Excel for the spreadsheet '9mai.xls'. The directory where this file stores is "C:/ye". The second line stores the data (from row 2 column 4 to row 1433 column 4 in Excel file 9mai.xls) to an array called "*data*" in Matlab workspace. The third line plots the data. It is used to prove whether the data have been successfully imported from Excle file. The fourth line stores the data in a mat-file. After that, if one wants to use these dates, there is no need to import it again.

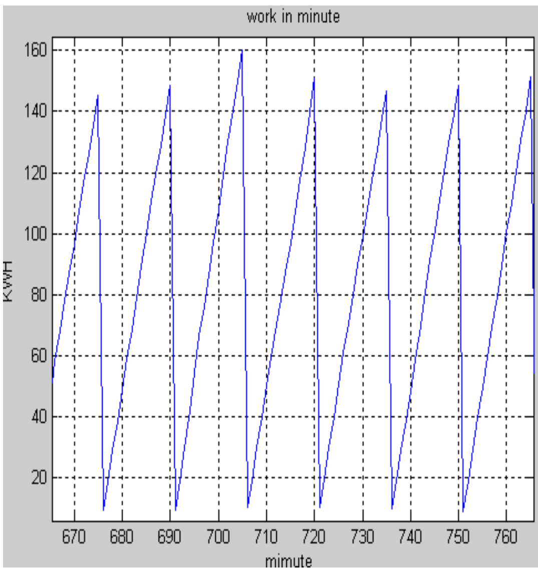
The m-file used to measure the estimation error is called **"measure_1.m"**. It is stored on the CD.

The simulation results are shown in Fig 6.4. Fig 6.4 (a) is the plot of the real work value. Fig 6.4(b) is the zoomed version of 6.4(a) (from minute 660 to 760). One period is 15 minutes. Every 15^{th} minutes the work falls near to zero. Fig 6.4(c) displays the measured work values of every 15 minute period. Fig 6.4(d) is the plot of the estimated work values. Compared to Fig 6.4 (c) it can be found that the values in each period are not the same. Fig 6.4 (e) and Fig 6.4 (f) show the error. This error is the deviation between the data shown in Fig 6.4 (c) and 6.4(d). Fig 6.4 (f) is the percentage of the deviation. In most cases, the error is smaller than 10%. The large value shown in Fig 6.4 (f) occurs at the beginning of a period. This is due to the limitation of the linear estimation method. If the estimated value is far away from the given values, a large deviation will be got. Fig 6.4 (g) gives the error distribution. The x-axis holds the error in percentage and the y-axis is the number occasions. It is nearly a standard normal distribution with mean value equal to zero. This verifies that in most cases the estimated values are correct. The number of points in range (-5,5) is larger than the number of points outside this range. This means that in most cases the error is smaller than 5%. Fig 6.4 (h) shows the relation between time and error. "*div-i*" means the percentage of deviation between the real value and the estimated value. For example, "div-5" means the deviation is 5%. At minute 1 of each period, there are altogether 16 times when error is equal to 5%. And at minute two, there are no more than 15 times when the error is equal to 5%. As times increases, the rate for the 5% error probability goes down fast. The same progression is found for other error probabilities. In minutes 1, 2 and 3 of each period, the probability for a large prediction error is high. After the 10^{th} minute the prediction becomes very accurate. This proves the that the linear estimation method which was selected for this thesis is suitable for the designed purpose.

(a)



(b)



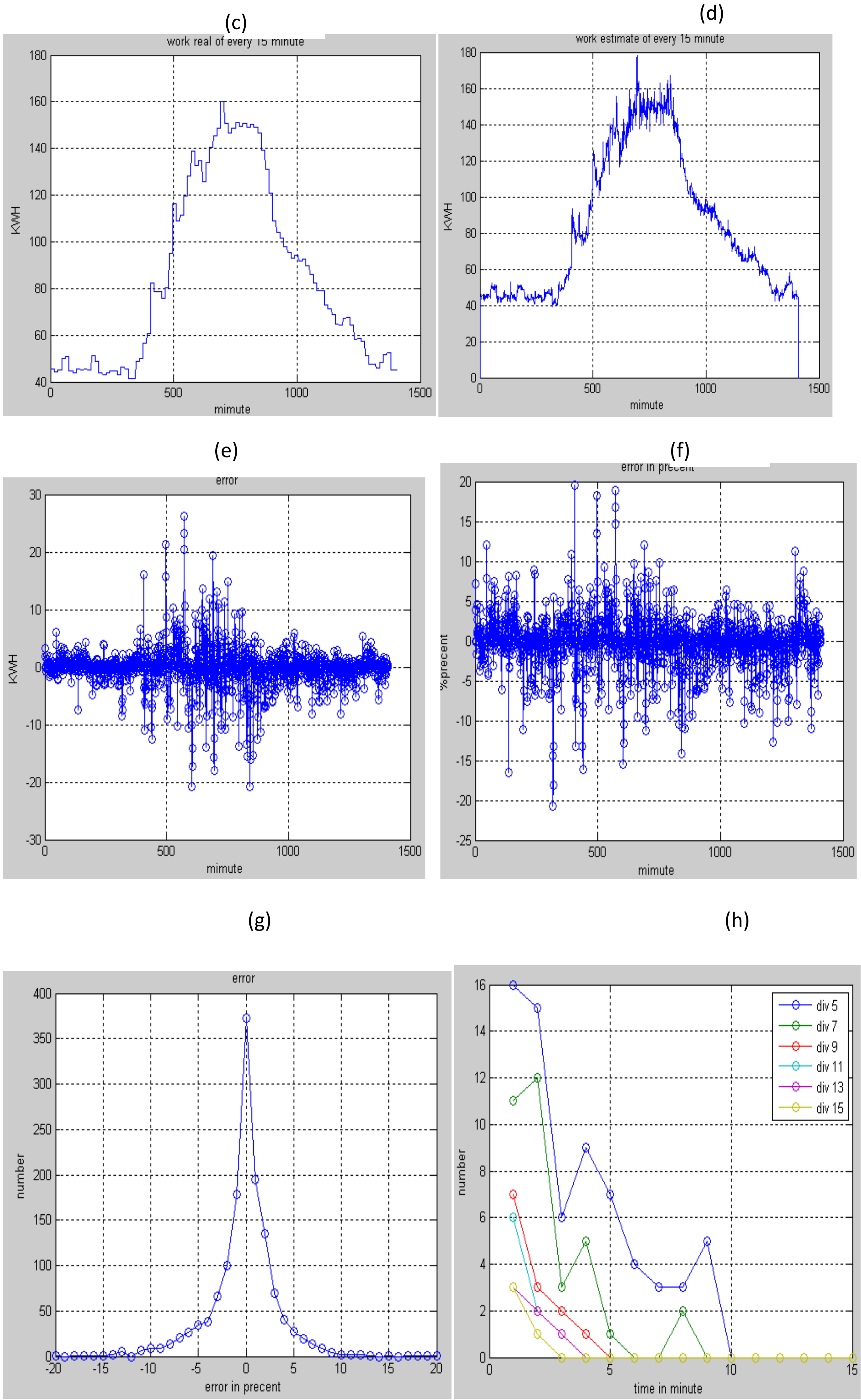


Fig 6.4 Measurement of system performance

The simulation results for another day are shown in Fig 6.5. Almost the same results have been got. The error distribution is again almost a normal distribution. Although at certain times the error percentage is larger than 10%, it can be concluded from figure Fig 6.5 that this always happens during the first 5 minutes of one period.

It can be concluded that the obtained error ranges are acceptable compared to the measurement results. In order to make the error range smaller (<5%), the control system should only be applied after the 5th minute. The results also proved that our system is a slow response system and hence it is suitable for continually changing load profile (cp chapter 3.3).

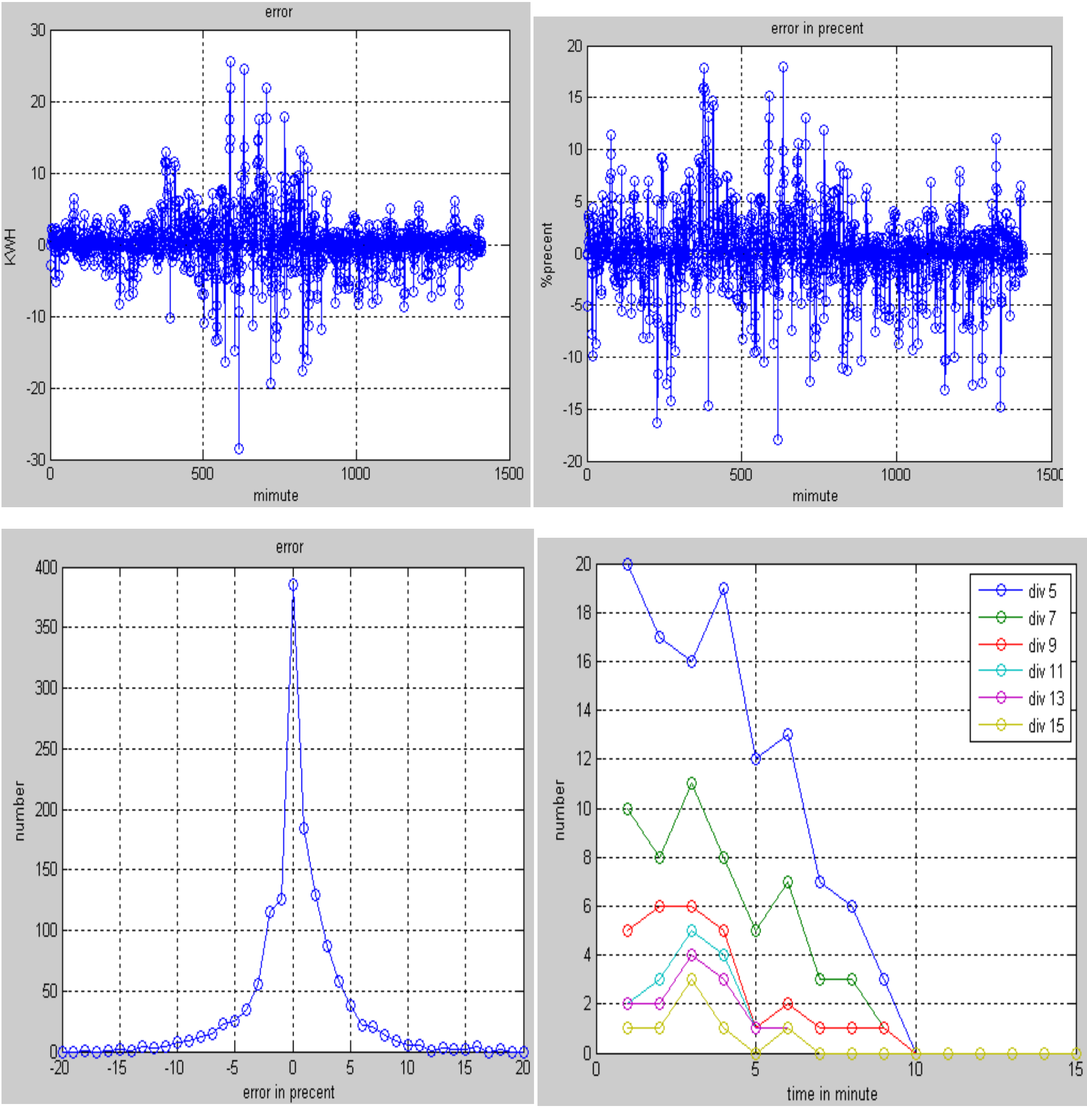


Fig 6.5 Error distribution and probability in one day

6.3 Testing of the whole system

In section 7.1 and 7.2, the function of the load management block has been proved to be good. In this section, the simulation results of the whole system will be examined The testing step is arranged in a proper sequence: first testing the control of one building and then testing the control of the whole 28 buildings. The reason is simple. If we direct test of 28 buildings, it will be impossible to know which part performed wrong when an unwanted result occurs.

The model for one building is shown in Fig 6.6. It has two input signals. One is from the data base. Before the system starts, it will first get the historical load data from the data base. After the system runs, this signal will be assumed as the current load value. Another signal is the time. In Simulink “Goto” and “From” are blocks which allow you to pass a signal from one block to another without actually connecting with them. The “Goto” block passes its input to its corresponding “From” block. A “Goto” block can pass its input signal to more than one “From” block, but a “From” block can receive a signal from only one “Goto” block. The input to that “Goto” block is passed to the “From” blocks associated with it as though the blocks were physically connected. “Goto” blocks and “From” blocks are matched by the use of “Goto” tags, defined in the tag parameter. A multiplexer combines the two signals together.

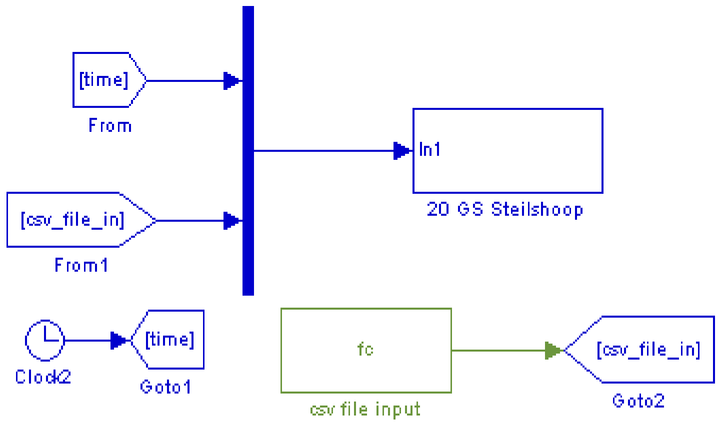


Fig 6.6 Model for testing one building

For simplicity, the output of the database is assumed to be a constant value in this test . The model should calculate a typical day load profile, i.e. to make correct load forecasting for the selected properties and create comma separated value file (CSV file) as output. To make the calculation of the typical day as accurate as possible, the following specifications have to be entered by the user using a graphical user interface (GUI):

- Public properties,
- Weekday,
- Season,

- Holiday restriction
- Temperature

Using these inputs, the program connects itself with the server placed at the Company Envidatec and gets the historical data from the database placed on that server.

The subsystem of block “20 GS Steilshoop” is shown in Fig 6.7. In Fig 6.7, the black part is the one developed in this thesis. Its performance has been proved in the previous section. The blue part is the main controller. The assumed appliances (load) are also in this part. The blue part transmits two signals to the black part. One is the power value of the last minute and the other is the load table. The black part transmits an array to the blue part which tells the main controller how to deal with the devices in the whole building. Here we can see both tables are transmitted in a form of array. In reality this is not possible. They would be transmitted using a serial signal. Therefore serial to parallel converter was installed at each input port and a parallel to serial converter was installed in the output part. Because Matlab allows matrix transmission, the converters are not shown in this model.

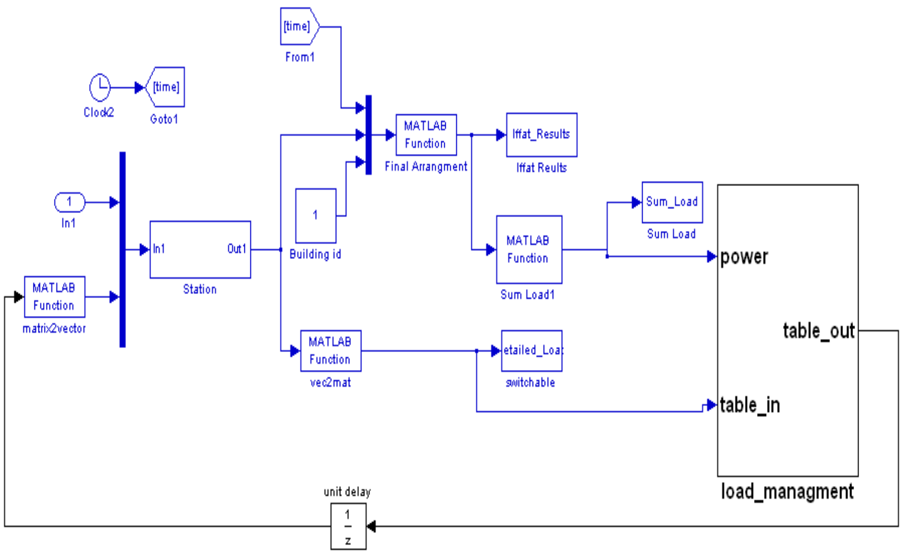


Fig 6.7 Subsystem of block “20 GS Steilshoop”

The subsystem of the block “station” shown in Fig 6.7 is displayed in Fig 6.8. It is a standard hierarchical model. From the upper figure (a) it can be seen that there are five substations in one building. The lower figure (b) displays one of the substation blocks “Lüftungszentrale Keller HS”. Altogether 4 devices are in this substation. Each substation may have eight priority classes. The devices in each group will have priority form 1 to 8. One or more devices can have the same priority. The “Matlab Function” block is used to detect the status of each device (on or off). As described before, this information is important for the load estimation.

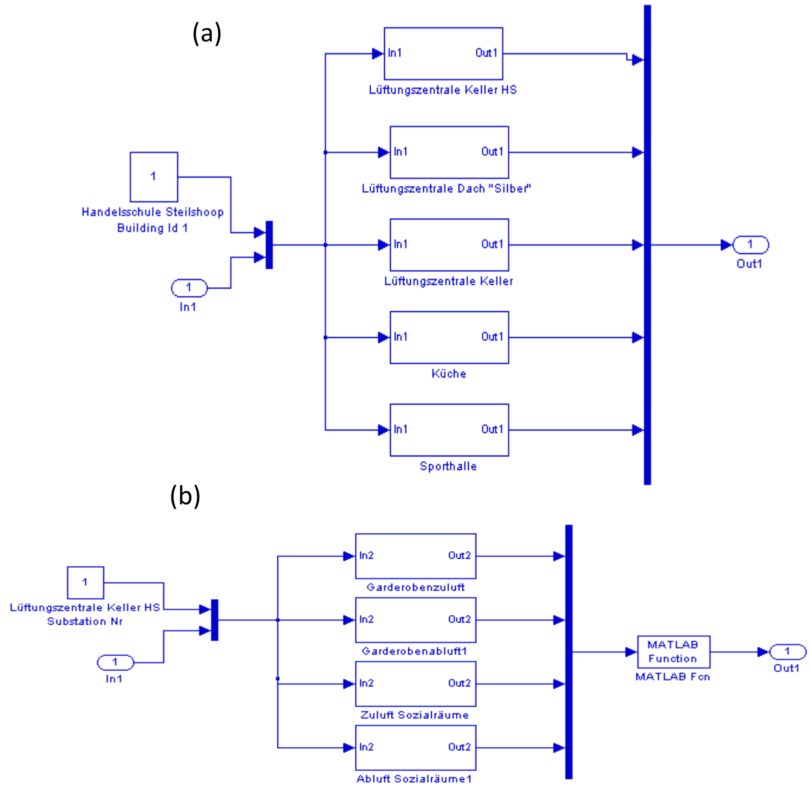


Fig 6.8 Substations and devices in one building

By double clicking the first device "Garderobenzuluft" block the following dialog box will be emerged. It is the parameters of that group.

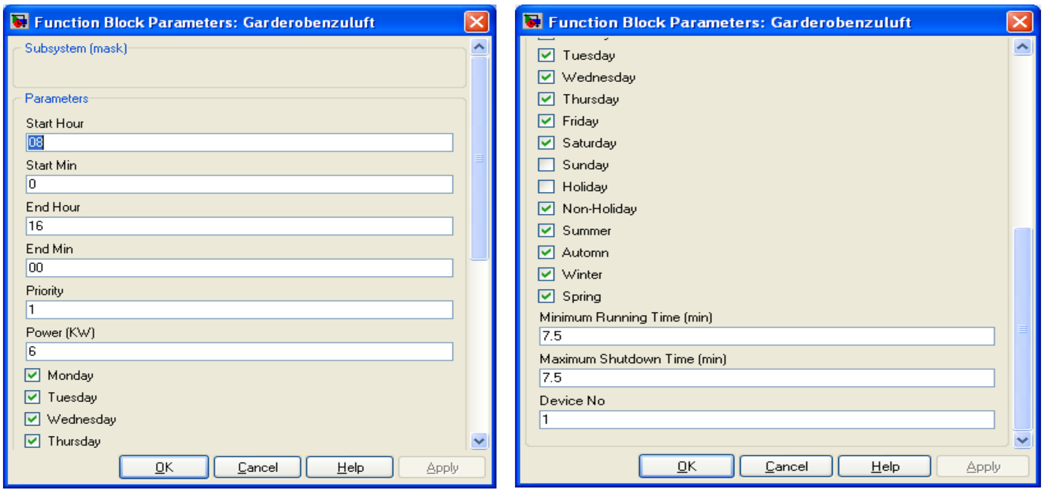


Fig 6.9 Parameters of device "Garderobenzuluft"

As said before, each device has its own traits. The "Start Hour" and the "Start Min" show when this device is working and the "End Hour" and "End Min" show when the device is not running. The example shown in Fig 6.9 tells that this device begins to work at 8 o'clock in the Moring and stops to work at 16:00 in the afternoon. It has the priority “1”.

The parameter “Power (kW)” is the power value of this equipment. The next 7 parameters “Monday” to “Sunday” give the information when this device works in a week. If the corresponding week day is being chosen, it means on this day the device will run. Otherwise, the device will not be run on that day. The example in Fig 6.9 shows this device will be run from Monday to Saturday. On Sunday, this device will not be run.

Next two parameters are “Holiday” and “Non-holiday”. It describes whether this device will be run on holidays or not. It is obviously that only one can be chosen from these two. Otherwise it is not logical.

The following four parameters are the four seasons in one year. It shows in which season this device will be used. This example shows that this device will be used in the whole year.

Parameter “Minimum running time” means the minimum running time after the device is turned on. If one turn on this device, it can be switched off only after 7.5 minutes. This limitation is normal in the real product. One can image that once an air condition is turned on, it need some time to warm up. If it is switched off during this warm-up time, some damage will be caused to this air condition. Parameter “Maximum shut-down time” means the maximum shut-down time when the device is turned off. If one turns off this device, it should be switch on after 7.5 minutes. The reason why such parameters are applied is simple. Supposing this device is an air condition system. The workshop needs a temperature under 25°C. At first the air condition is turned on and the temperature in the workshop is around 20°C. Now the air condition has been shut down because of the maximum allowed load value is reached. According to the measurement, after 8 minutes the, the temperature will raise to 25°C. For the safety reason, the air condition should be turned on at 7.5 minutes after it is switched off. Then people will not find that the air condition has already been switched off for a certain time but the energy has been saved. Therefore, a 7.5 minute maximum shut-down time is needed to let the controller get the information of how to control this device.

Now the simulation for the whole system can be started. The input signal is supposed to be a real power value in one day from building “20 GS Steilshoop”. The simulation results are shown in Fig 6.10. The maximum allowed power value is set to be 370kW. The left side is the plot of the power values for the all day. The axis unit is “minute” and the y axis is “kW”. When the power is lower than 370, no control at all. The peak values appear at minute 600 to 900. In other words the peak appears at 10am to 3pm. The right side is the zoomed version of the left figure. Most values are smaller than 370 kW. Only a few are between 370 kW and 380 kW which means the error percentage is 10/370=2.7%, which is in the acceptable range.

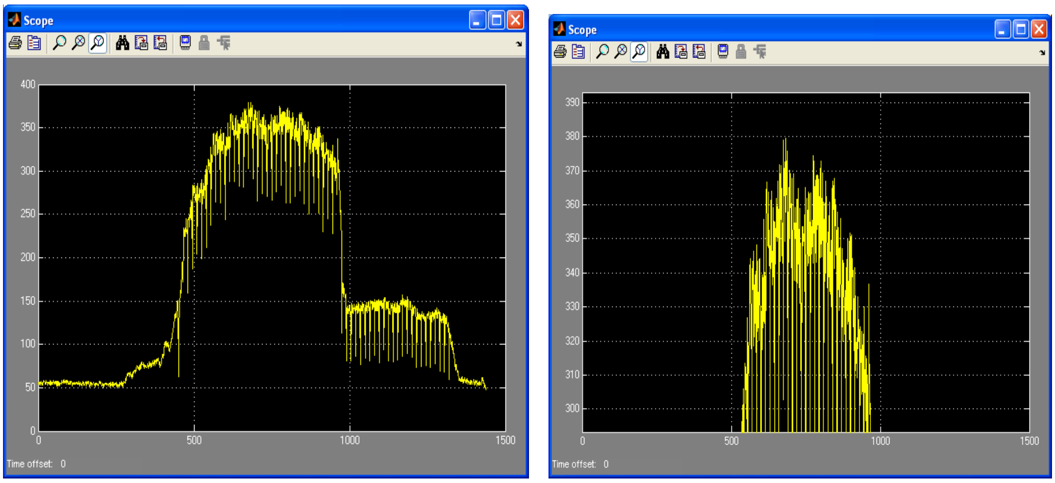


Fig 6.10 Simulation results for building “20 GS Steilshoop” with Max power 370kW

The second simulation will be started with condition that maximum power is 350kW. The results are shown in Fig 6.11. Compare with fig 6.10, it is clear that when the value is lower than 350kW, the two plots are the same. The right figure in Fig 6.11 is shown the zoomed version. We can see that the peaks value is smaller than those in Fig 6.10. This is due to the factor that the maximum allowed power value is 20kW smaller. But we can see, a lot of peaks are higher than 350kW. The reason is that although at that time the power value is large, the remaining time in one period is small. From chapter 2 it can be seen that work value is power multiply with the time. So the work value at the end of that period is not exceeds the allowed work value. So there will be no control at all.

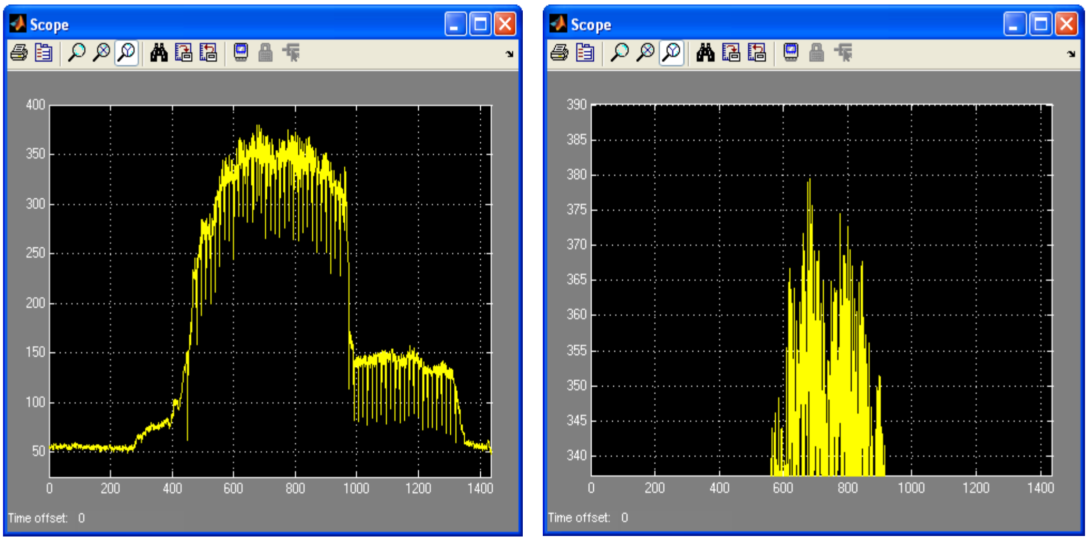


Fig 6.11 Simulation results for building “20 GS Steilshoop” with Max power 350kW

Here below is the result for minute 678.

************** start **********************

current minuter is 678

current power is 3.663100e+002

current work is 22.892500

work for last minute is 16.787333

the estimated work value for the 15th minute is 9.004933e+001

the new matrix of switchable work is

1.4500	0	2.9000	0	0	0	0	0
0	0	0	0.4437	0	0	0	0
1.3000	0	0	1.0000	0	0	0	0
0	0	0	0	0	0	0.2500	0
0	3.3500	0.3375	0.7500	0.7500	0.7500	0.7500	0.1875

the following devices should be switched off (0)

0	0	1	0	0	0	0	0
0	0	0	1	0	0	0	0
0	0	0	1	0	0	0	0
0	0	0	0	0	0	1	0
0	1	1	1	1	1	1	1

*********End****************

The maximum allowed work value is 350kW/60*15mimute=87.5 kWh. The estimated work value is 9.004933e+001. So 2.5KW should be subtracted. This can be seen from the status table. Substation 1 priority 1 and substation 3 priority 1 have been shut down. So the model works well.

The final model of the project is shown in Fig 6.12. It has 29 isolated buildings. Each building has a structure shown in Fig 6.7. It is clear that one database is connected to all the buildings. The main controller can connect to it and get the information used for the load prediction.

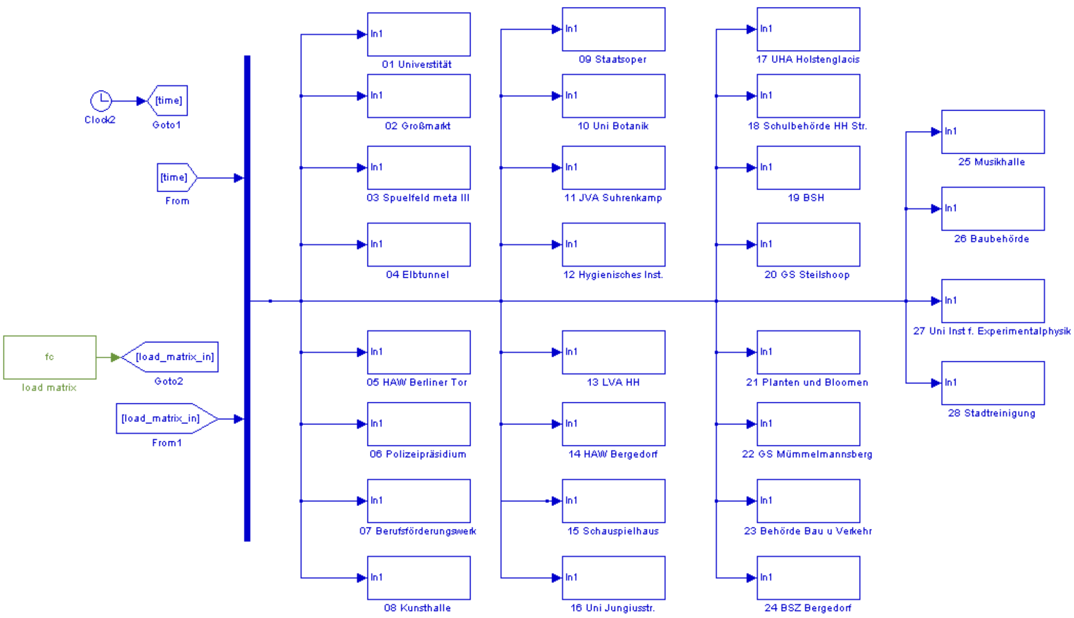


Fig 6.12 Model with 28 buildings

7 Conclusion

In this thesis one day is divided into 96 periods with each period equal to 15 minutes. The predication algorithm will be applied every minute in one period in order to estimate the work value of the system for the end of that period. A two way load management method is used which means the controller has sensor on the load side and can get the current status of the devices. The extrapolation method is the medium load method. It means the controller will have a long response time. [Chapter 3.3] A linear estimation method is implemented to predict the work value at the end of each period. If the estimated value is larger than the maximum allowed value, the system will give the command to turn off some equipments according to the switchable load table.

The testing results of the task implemented by this thesis are firstly shown in chapter 7. At first several assumed input signals is given to the system to test the system in 17 minutes which means 2 periods are involved. Then the performance of the prediction method is tested through inputting a series of real power values of a building in one day which is measured by a power supply company. The results prove the drawbacks of liner estimation algorithm. The estimated work value will get a large value at the beginning of each period (first 5 minute). After that the error is less than 8%. These testing results give the information that the control of the devices should be applied only after the 5^{th} minute in each period. At last the simulation results of the model which combines the three independent parts are given. The results prove the feasibility of the whole project.

Besides the implementation in this thesis, there are also some works that could be done in the future in order to improve the behaviour of the system. As is mentioned before, a high order extrapolation method should be used instead of linear extrapolation. Such extrapolation methods can be Polynomial extrapolation, Conic extrapolation and French curve extrapolation and so on.[15] Unlike the linear extrapolation, they use more than two known values to estimate the unknown value. The more known values they use to estimate the unknown values, the more precise the unknown value will be. But this increases the computation efforts. Therefore a high performance CPU is needed for the controller.

Another improvement could replace the normal medium method with the medium difference model. Difference model means the error for the pervious estimation will be taken account into the calculation for the current estimated value. For example, if the current minute is 13^{th} and the estimated work value is 10kW. At this time both the estimated work value and real work value for the 12^{th} minute are known. Suppose they are 9kW and 10kW. So the error of the 12^{th} minute is $\frac{9-10}{10} = -0.1$. Therefore the final estimated work value for minute 13^{th} will be 13*(1-0.1)=11.7kW. Because of time limitation, such approaches are not applied in this thesis.

Acknowledgement

I would like to thank all those who contributed to the success of this work.

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Furthermore, thanks to my second supervisor Prof. Dr.-Ing. Franz Schubert for reading this master thesis.

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Power Systems, IEEE Transactions onVolume 4, Issue 1, Feb 1989 Page(s):184 – 189

Appendix A

List of attachments In CD

1. thesis.pdf
   The PDF version of the thesis

2. Folder "test_1"
   The model used for the first testing shown in section 6.1

3. Folder "Performance_test"
   Two m-files used to test the performance of the estimation method.

4. Folder "test_one_building"
   The model used to test the building "20 GS Steilshoop".