Modeling the Load Pattern of a Network of Buildings with installed Load Management Devices using Matlab/Simulink

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Title of the Master Thesis

Modeling the Load Pattern of a Network of Buildings with Installed Load Manage-ment Devices using Matlab/Simulink.

Keywords

Load Management, Work Forecasting Algorithm, Energy Management, MatLab / Simulink, and other relevant words describing the Energy Management techniques

Abstract

This thesis focuses on the design, modeling and implementation of system that can simulate the resulting load profile for any required day, season etc; by using the de-tailed device parameters of building(s) in network(s) i.e. valid working time, minimum run & maximum shut down times etc, and compare the results with power consump-tion data, while being synchronized with the load management system at the same time. In this regard a work forecast algorithm was designed\developed which can cal-culate the possible reduction in power by turning off the devices in the remaining quarter of an hour during their valid working times; by keeping the track of device pa-rameters, hence providing the detailed information that which devices could be turned on or off and for how long. Implementation & Validation of work is done in Mat-lab/Simulink.

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Thema der Masterarbeit

Simulation des Lastverhaltens einer Anzahl von Gebäuden mit vernetzten Lastmanagement anlagen mot Matlab/Simulink.

Stichworte

Last Management, Energie Prognose Algorithmus, Energie Management, Matlab / Simulink and andere relevante Begriffe zur Beschreibung der Energie Management Technik

Kurzzusammenfassung

Diese Arbeit konzentriert sich auf die Planung, Modellierung und Implementierung von System, dass die daraus resultierende Belastung des Profils für irgend einen gewünschten Tag, Jahreszeit etc. simulieren kann. Dazu benutzt er den de-tailed Geräteparameter der Gebäuden in den Netzwerken, d.h. gültige Arbeitszeit, Minimum & Maximum Ausschaltzeit etc, und vergleicht die Ergebnisse mit Strom-Verbrauch-Daten und ist dabei synchron mit der Last-Management-System zur gleichen Zeit. In diesem Zusammenhang wurde ein Energie Prognose Algorithmus entworfen \ entwickelt, die die mögliche Reduzierung der Energie durch das Ausschalten der Geräte in der verbleibenden Viertelstunde während ihres gültigen Arbeitszeiten berechnen kann, indem sie den Geräteparameter verfolgt. Kurzgefaßt, der Algorithmus stellt detaillierten Informationen bereit, welche Geräte ein-oder ausgeschaltet werden können und für wie lange. Implementierung & Validierung der Arbeit erfolgt in Mat-Lab/Simulink.

Acknowledgment

- My deepest thanks to *GOD* Who is most beneficial and merciful, and Who provided me with the energy and capability to perform this task.
- I pay heartiest gratitude to my father *M.A. Syed Ghulam Hasnain Bokhari* whose personality has always been a guidance for me in all aspects of life. All my achievements are of him. I found no words to express myself for the prayers and good wishes that my mother *M.Sc. Syeda Munaza Khatoon Bokhari,* extended for me all the time.
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List of Abbreviation

CHP	Combined Heat and Power production
RES	Renewable Energy Sources
VPP	Virtual Power Plant
LEP	Load Estimation Project
JBFP	Java Based Forecasting Project
LMDP	Load Management Device Project
MVL	Medium Voltage Level
kW	KiloWatt
kWh	KiloWatt Hour
WFA	Work Forecasting Algorithm
mst	maximum shutdown time
mrt	minimum running time
GUI	Graphical User Interface

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Introduction & System Design

Chapter 1

INTRODUCTION

1.1 Introduction to Load Management

The electricity is a an essential part of life these days. It is impossible to produce certain necessary products without electricity. It is difficult without electricity for people to do things which they want to do. Our industrialized society requires the following important factors for its welfare i.e.

- To transmit and distribute the electric energy (kWh)
- To transmit and distribute the power (kW)

The supply of electricity is essential for development and progress in developing countries as well as in industrialized countries.The countries all over the world are using a variety of different primary energy sources e.g. Norway has the advantage of being able to mainly use hydro power while European counties like France more strongly depend on using a mix of nuclear, hydro and coal or gas-fired condensation plants.The countries like Great Britain and Germany are depending on fossil fuels too but showing an increasing fraction of electricity generation based on regenerative primary energy sources 21 % and 36 % respectively.[10]

''In the united states of America the mix of generation capacity, number of utilities etc varies strongly from state to state. There are usually several electric utilities which either have only generation facilities — selling power to other, local, utilities —or have a generation, transmission and distribution capacity. This implies that the cost for electricity energy and demand is not uniform across the USA '' [10]

1.2 Power system background

As the season and the time of day varies, the utilization of electric power and electric energy also varies. These variation depends on the different activities of residential commercial and industrial customers. The use of electricity is also dependent on the climattic situation. The following figure shows the load duration of power system of Sweden in 1984.

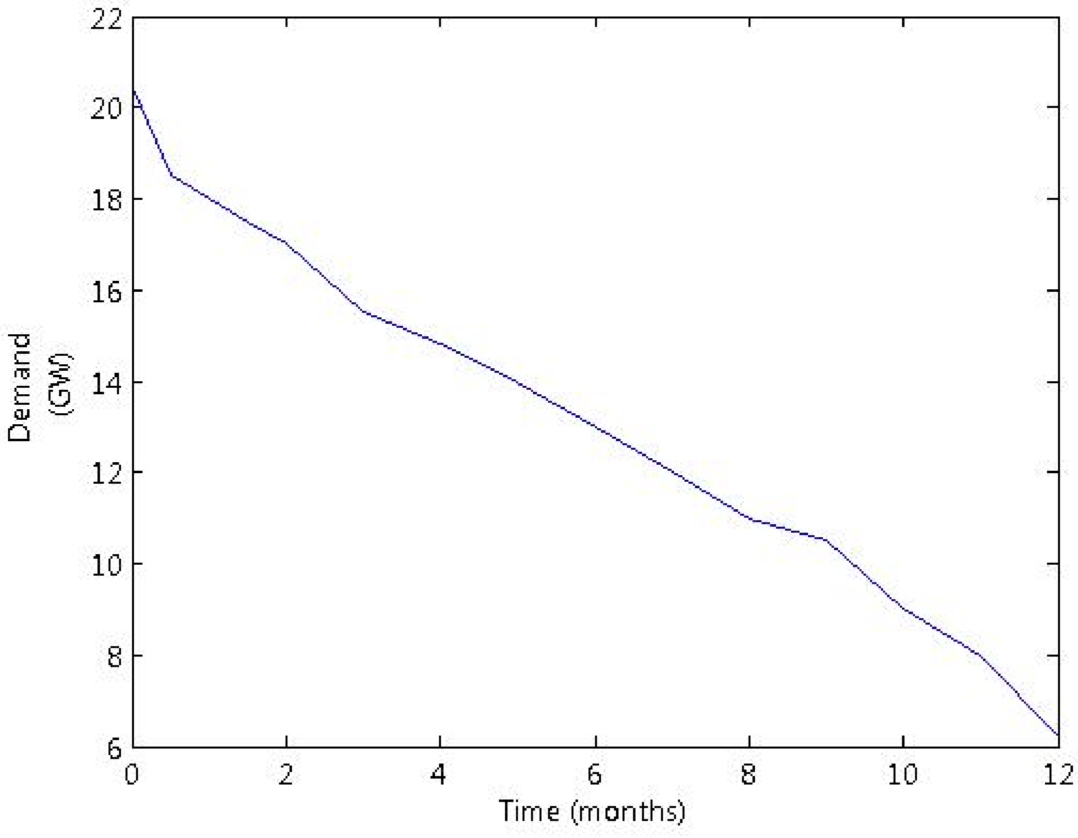


Figure 1.1: 1984 load duration curve,Sweden.Reconstructed from reference [10]

The electric energy use was 120.2 TWh with maximum 1 hour demand value of 20,666 MW and the annual load factor was 66.2 %. The weekly load curves of winter, spring, summer and autumn are shown in following figure

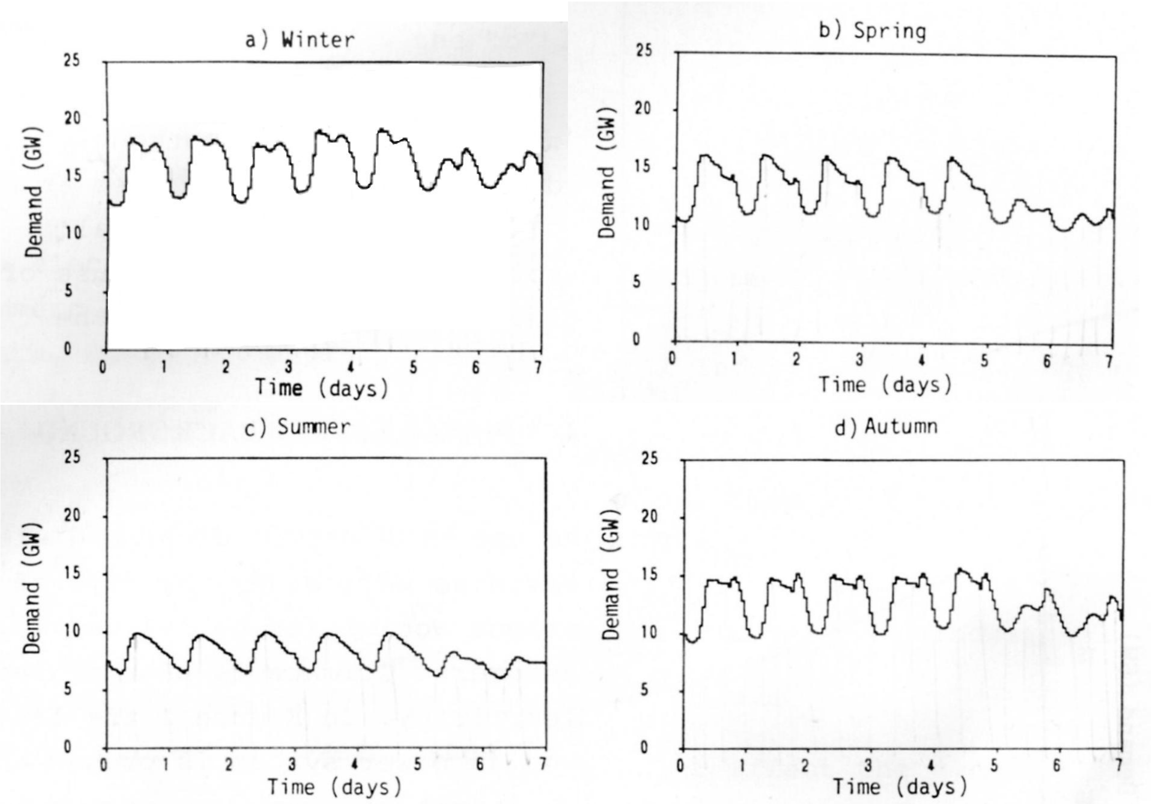


Figure 1.2: a) Winter , b) spring, c) summer and d) autumn, weekly load curves.Scanned from reference [10]

In 1985, the total use of electric energy was 130.8 Twh having 23,987 MW maximum 1 hour demand and annual load factor was 62.2 %.

In 1987 the maximum 1 hour demand increased to 26,000 MW due to the cold weather in January. The demand is changing due to the simultaneous variation in the utilization of generation capacity and as a consequence of customer habits and the nature of electricity as a product which is “ difficult to store ”. The mix of following kinds of power plants forms the generation capacity i.e.

- Hydro
- Nuclear
- Co-generation
- Oil or Coal condense plants
- Gas turbines

All power plants have different running costs and the policy which is made to meet the demand is to utilize the power plants with low running cost first and when the demand will increase then power plants with higher running cost will start working. So we can say that the costs of generating power depend on which power plant is on duty now[10].

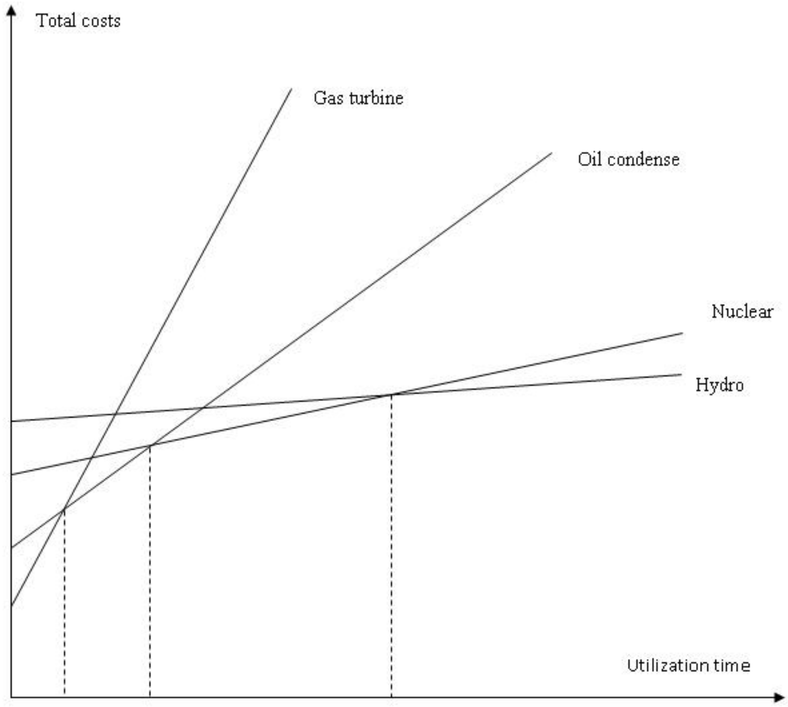


Figure 1.3: Power plant operation strategy .Reconstructed from the reference [10]

The following requirements are necessary to increase the efficiency and economics of power systems:

- System peak loads should be decreased
- The use of electric power during off-peak periods should be increased[10]

1.3 Background theory

The application of load management is conducted due to the following reasons

- The limited generation capacity of electricity & the mix of generation units
- The constraints on the transmission and distribution capacity.

''It is always possible to save money by peak load reduction since this can allow the capacity expansion to proceed more slowly than the increase in electricity consumption''.[10]

The consumption of electricity is rapidly increasing and the problem of capacity shortage is rising so it will be important to take step to get rid of this problem in near future[10]. There are two main actions which can be taken as a solution of above given problem:

1. Capacity Expansion
2. Load Management

Capacity Expansion requires high cost so Load Management is a better option.

''It is very interesting for the electric utilities to investigate the potential load changes that may result from widely implemented load management program''[10].

''Load management, which changes the shape of the electric load curve, so that generation by costly peaking units or capacity addition are avoided or deferred, is an effective technique to meet peak demand deficit''[13].

Capacity Expansion will be done on the production side and load management will be applied on the consumer side.

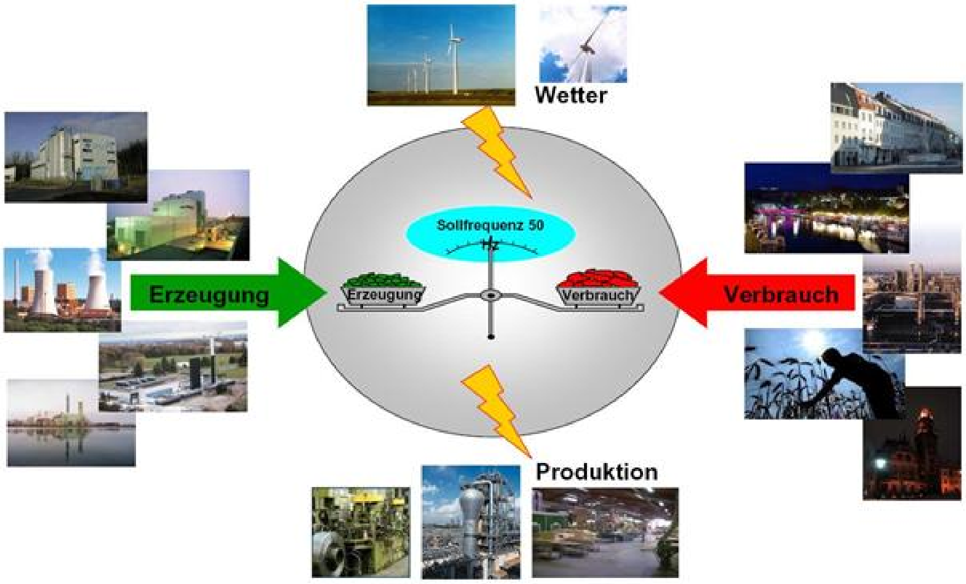


Figure 1.4: Flexibility of Energy[9]

An industrial Load Management programs can be used by electric utilities:

- To defer the plans of expansion of capacity.
- To optimize the utilization of existing resources like plants generation and transmission and distribution grids[10].

This Masters thesis will discuss the Load Management applied R &D project which is carried out by different organizations in Germany. This R & D project is called as E-island which is the abbreviation of EXPANDABLE INTERNET SUSTAINED LOAD AND DEMAND SIDE MANAGEMENT FOR THE INTEGRATION INTO VIRTUAL POWER PLANTS.

1.4 Thesis Objective

A central contribution for the simulations which will have to be carried out in the E-ISLAND project has been done in this masters thesis. The following Figure 1.5 shows the information flow between the three different contributions to the E-ISLAND modelling phase so far. This thesis is about the Load Estimation Project (LEP).

*In Figure 1.5 , the ''Sum Load'' (single value) is actually the Load that has been consumed by building on each minute.

Following are the few objectives of this thesis

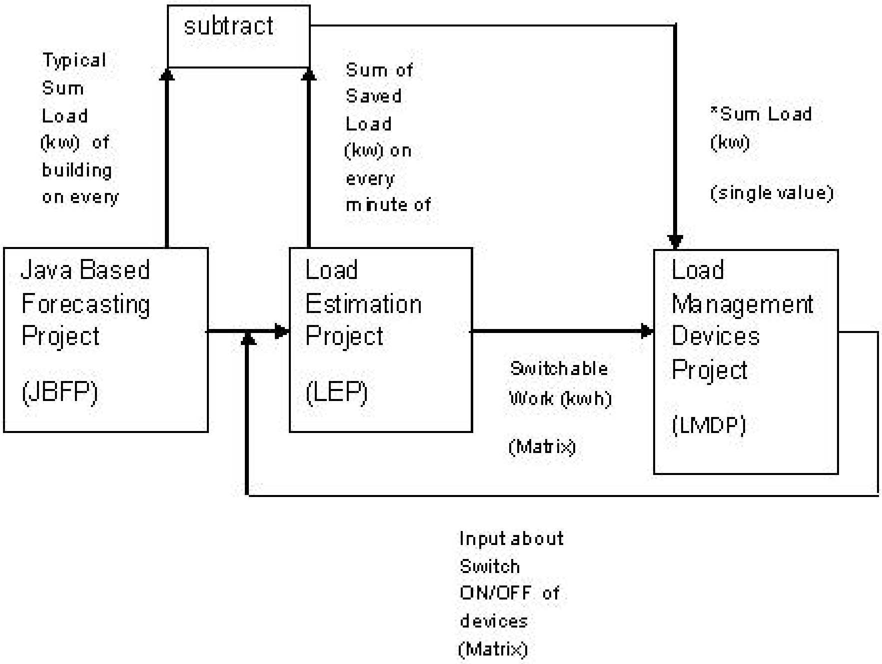


Figure 1.5: Block Diagram

- To build a model of larger number of buildings with installed Load Management System via a Matlab/Simulink.
  - The simulink Library Browser has been used to build a model of a larger number of buildings. Different load management substations and devices are configured in each building. A separate substation number has been assigned to each substation. The devices are configured using GUI (Graphical User Interface)
- To provide an interface between Java Based Forecasting Project (JBFP) and Load Management Device Project (LMDP).
  - Two CSV files are used for interfacing with the JBFP. For interfacing with the LMDP, Work Forecasting Algorithm plays an important role which is described in Chapter # 6
- To provide input to the LMDP for its own calculations.
  - The LMDP takes two inputs i.e. in matrix form and as a single value. The matrix form input is generated using a lot of data i.e. clock, JBFP's output, the GUI's data for all the connected devices, substation numbers, number of priorities, Work Forecasting Algorithm etc.This matrix input tells to LMDP about the switchable work of remaining quarter of an hour. The single value has been generated using the matrix form values and output of JBFP. This single values gives the information to LMDP about the consumed load of a building on each minute.See chapter # 5,6,7.

- To compare the peak values of load of a building having Load Management System with the peak values of load of the same building (at the same day) without the application of a Load Management System.
  - This results of this comparison have been demonstrated using graphs. The work space variables in Matlab are helpful in the construction of graphs. By observing the peaks of the graphs, one can see what changes occur in the load profile of a building after a load management system has been installed.

The all main tasks of this project have been mentioned in CHAPTER # 3

1.5 Applications:

- This Load Management System can be applied in industrial, commercial and residential buildings to provide the facility of load management to the customers of all these sectors.
- The load-management program is used to maintain, as nearly as possible, a constant level of load, thereby allowing the system load factor to approach 100%. The important benefits of load management are a reduction in the maximum demand, a reduction in power losses, better equipment utilization and savings through reduced maximum demand charges. *"Load shifting, one of the simplest methods of load management, is to reduce customer demand during the peak period by shifting the use of appliances and equipment to partial peak and off-peak periods. Here no loads are being switched off, but only shifted or rescheduled, and hence the total production is not affected*"[11].
- A load management system for hydrogen-oxygen fuel cells is provided, for powering vehicles.
  - The load management system operates such that under normal load conditions air is provided as the oxidizing agent for the hydrogen fuel. At high output conditions the air supply is enriched with additional oxygen. The system comprises means responsive to the amperage output from the fuel cell stack to activate valve means for the addition of pure oxygen into the air inlet line. There is also provided means for electrolyzing water to produce pure hydrogen and pure oxygen gas, which may be recyclable to the fuel cell. [12]

1.6 Thesis Outline

1. In **chapter1**, the introduction of Load Management and its background is described. Some load curves about power system have also been shown. You will also find Thesis objectives and Applications here in this chapter.
2. In **chapter 2**, an introduction of the R & D project E-island is given. Its purpose and the involved Methods are also discussed in this chapter.
3. In **chapter 3,** all thesis objectives (project tasks) have been mentioned in this chapter

4. In **chapter 4,** the system design requirements has been discussed .These requirements were decided before beginning of this thesis to fulfill its all objectives successfully

5. In **chapter 5**, the flow charts, block diagrams and working steps of this project has been described. This chapter tells that how the system design requirement has been fulfilled to achieve the project objectives.

6. In **chapter 6**, the Work Forecasting Algorithm is discussed using example.

7. In **chapter** 7, the Matlab code has been discussed in descriptive form as well as through block diagrams and flow charts.

8. In **chapter 8**, the results and conclusions of a project have been discussed .

9. In **chapter** 9, an oulook is given.

Chapter 2

The E-ISLAND Project

2.1 Background

The legal frameworks of a consistently increasing number of countries favor the power production from renewable energy sources (RES) and also encourage the combined heat and power production (CHP) in the times of global warming and increasing fossils fuel prices [8].

In Germany the total utilization of electricity coming from renewable resources has approached 11.6 % or a total 71,7 billion kWh in 2006 [1]. New targets have been developed for the function of distribution grid due to the fast increasing amount of electric energy deriving from decentralized generation. There can be following reasons for Load or frequency fluctuation:

- Wind and solar power are not helpful in plans of operation of grid but depend on weather conditions
- The combined heat Power Production does not depend on current situation of grid but on the heat demand.

That is why a lot of research work has been started in connectivity of higher number of decentralized generation units to Virtual Power Plant (VPP) through fast and reliable communication technologies (e.g. TCP/IP).This can develop bigger units and can submit them to the management regimes which display the need of the (distribution or transmission) grids [8].

The major part of most research work about Virtual Power Plant is suitable communication procedures and standardisation for the connection of small or medium generation capacities. The ten bigger research projects of virtual power plants with German participation are listed in [2] by Arndt et al. Some of them are just completed and some are still running. The possible benefits and fundamental problems of successfully operating a Virtual Power Plant are also explained in the research projects. According to Auer at el. In [3], there are presently two German Virtual Power Plants which are operating by utility companies :

1. The Virtual Power Plant ''Unna'' which has been operated by municipal utility of the city of unna.
2. The Virtual Power Plant of Steag Saar Energie AG [4, 5].

Both of the above Virtual Power Plants have different aims.

The earlier objective of the first is the optimization of the distribution grid of the city of Unna. This objective has been achieved by the management of the production of electric energy of the 5 (6 planned) connected Combined Heat and Power (CHP) sites. This is done to avoid the load peaks in the local distribution grid. The procedure of operation is also applicable to the gas grid (the CHP are gas powered) which causes a problem of multiparameter optimization. The operation of the Unna VPP has no Load Management presently though generally possible generally. In most of the research projects concerning Virtual Power Plants, load management is taken as a small issue. The integration of load management into VPP has rarely become a part of field studies or projects but its theoretical importance is often mentioned in studies [8].

The Load Management (Load Shedding) can play an important role in optimization of distribution grids. This is already contributing in more sensitive markets of electricity in USA as discussed in [6, 7].

Industrial load shedding at large scale is an important factor in the Virtual Power Plant of Steag Saar Energie. The emphasis of Steag Saar Energie AG is on selling reserve capacity on the liberalized German reserve capacity market. The Virtual Power Plant of Steag Saar Energie integrates the industrial and municipal generation reserves to large scale consumer load shedding from industrial processes. Load Shedding has become an established procedure for power distributors for the last 20 years [3]. The purpose of load shedding is to reduce the critical loads in the distribution or transmission system. High loads are caused by :

- Large and medium scale industries processing raw material such as iron ore or bauxite
- Using electric power for large scale engines (pumps etc)
- Heating or as process energy (e.g. large scale electrolysis in chemical engineering).

In 2006 the VPP of Steag Saar Energie was connected with more than 40 different generation or load management units which resulted in more than 1.000 MW qualified reserve capacity. This size of VPP provides 10 % market share to the Steag Saar Energie from the German tertiary reserve capacity market The VPP of Steag Saar Energie is only integrating units which are able to deliver 1MW over a period of at lease four hours.

Both VPP concepts are integrated by the “E-ISLAND” approach which performs the following functions:

- To get rid of load peaks on the distribution grid of Hamburg.
- Pool the sheddable loads $<$ 1MW of many public properties and placing into the reserve capacity market through the Virtual Power Plant of Steag Saar Energie AG[8].

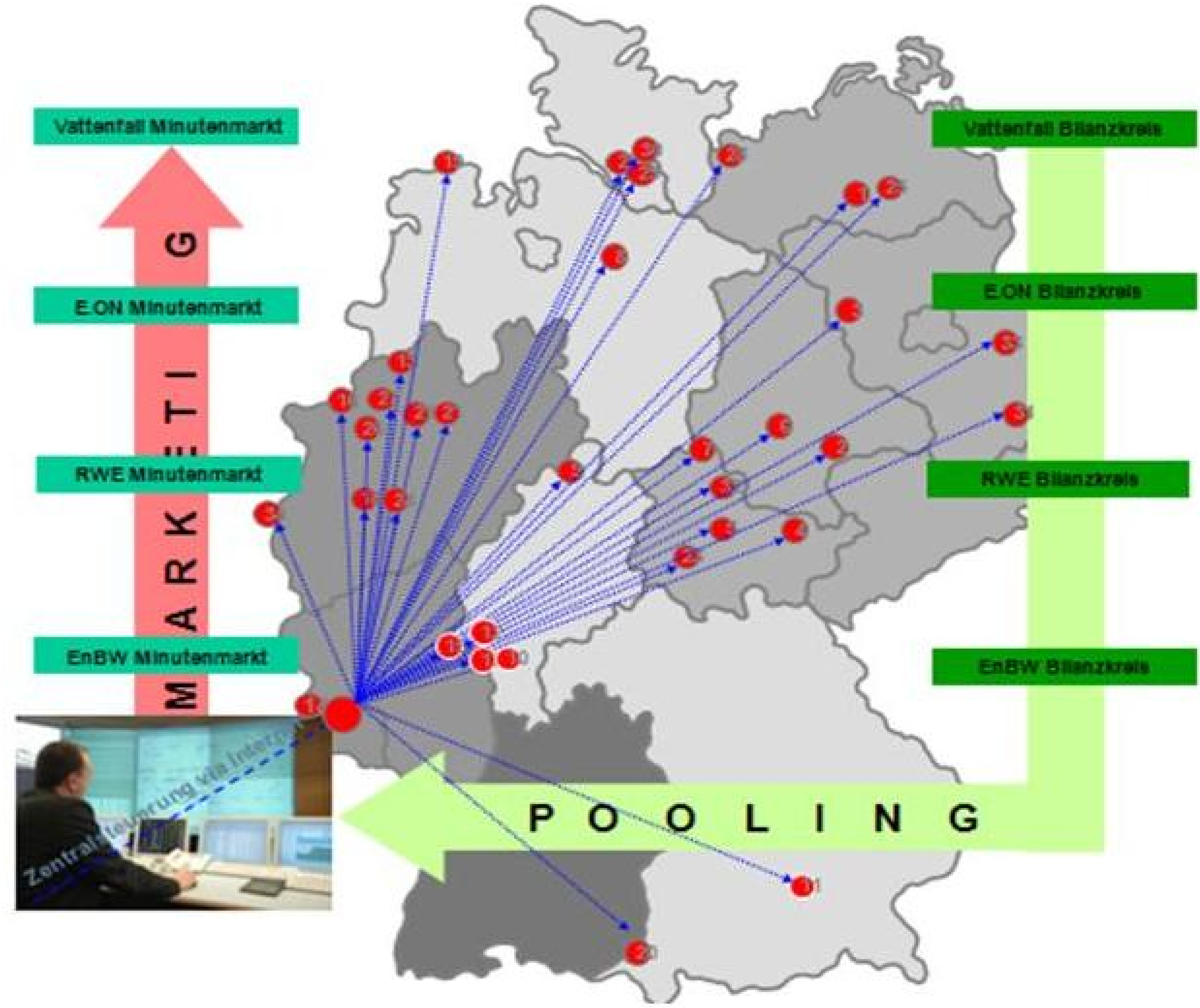


Figure 2.1: Virtual Reserve Power Plant of Steag Saar Energie AG[9].

2.2 The "E-ISLAND" Project

"E-ISLAND" stands for Expandable Internet Sustained Load And Demand Side Management For The Integration Into Virtual Power Plants.

E-Island is founded by the German ministry of education and research (BMBF).The project is carried out by public private partnership consortium.

Its members are following:

- University of Applied Sciences Hamburg
- The department of economics and employment of the city of Hamburg.
- Steag Saar Energie AG
- SUmBi and ENVIDAEC, two German engineering companies.

2.3 Objective of "E-ISLAND"

The major objective of "E-ISLAND" project is to build a simulink model of an internet based network of 40 public properties. The model's aim is to simulate the network of independent but centrally controlled load management systems.

The two research tasks given below will be examined using the results of the obtained simulations:

1. *"Find out how and to what degree 35 independent load management systems can be synchronized with the aim to harmonize the resulting load curve rather than the individual ones of the involved properties.*

2. *Find out how much load can be cut off for how long with the aim of selling it as reserve capacity to the Virtual Power Plant (VPP) of Steag Saar Energie AG"[8]* .

Figure 2.2: GSM/TCP IP network of MVL public properties of Hamburg includes all kinds of consumption patterns [9].

The expected amount of reserve capacity is 3-5 MW depending on different parameters like season, time of a day etc [8].

2.4 Methods

The modeling and simulation of the load profiles of all the buildings invloved for the next day (a day ahead) is used to check the potential of reserve capacity (and load curve smoothing). This modeling & simulation depends on the real time data of the involved properties. The data will be gathered by accurate meter readings with a high resolution (1 step/minute).The intended structure of the system is displayed in the figure below:

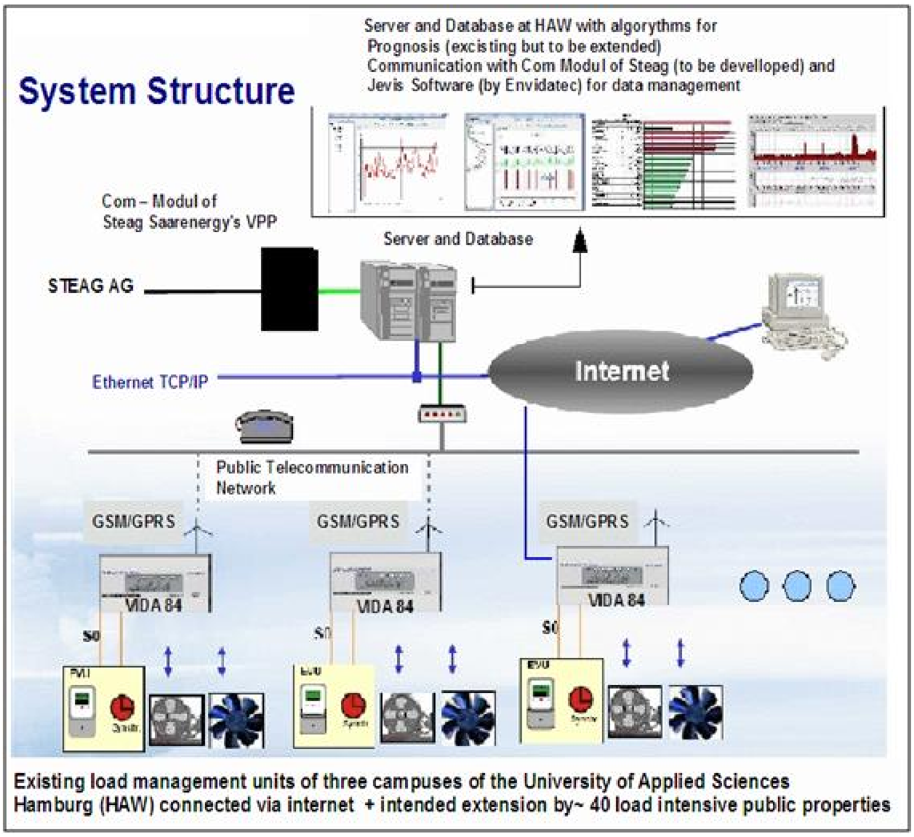


Figure 2.3: Intended system structure of „E-Island“[8].

The load profiles having a resolution of one step per minute are kept on the Vida 84 modules and are transmitted to server based database once per day. A prognosis tool uses the load profiles and weather data taken from university's weather station.

To determine and explain the possible sheddable loads (ventilation, air conditioning etc.),the technical infrastructure of all involved properties is analyzed.

The simulation runs will be used:

- To get a accurate idea of the best possible load profile for the following day.
- To analyse how much ”free” load capacity can be placed on the reserve capacity market through the VPP of Steag Saar Energie AG during each single hour of the following day.

After the simulation has proven that such a system would be useful the implemented communication network could be used to access the load management facilities of the properties. The maximum load allowances of each single load management device can then be adjusted automatically from any integrated PC serving as the control unit [8].

Chapter 3

Project's tasks

Following are the thesis objectives.

3.1 Work Forecasting Algorithm

To develop a Work Forecasting Algorithm which will forecast the switchable work of end of the quarter of an hour.

3.2 Load Shedding

To provide the facility of Load Shedding by switching ON and Off the devices. The calculations of following parameters are required to provide the facility of Load Shedding i.e.

- Stat and end working time of each device
- Maximum shutdown time of each device
- Minimum running time of each device

3.3 Load Estimation and Calculation

To calculate the Load values (Kilowatt) of those devices which have been switched OFF. This is actually a Saved Load (Kilowatt).The Used Load values are calculated using the Saved Load values.

3.4 Interfacing

To provide interfacing between other two projects i.e.

- Java Based Forecasting Project (JBFP)
- Load Management Devices Project (LMDP) These two projects are parts of E-Island project.

3.5 User Interaction

To provide the facility to user to interact with system .

3.6 Clock Generation

To provide the facility of clock to other project i.e. LMDP

- LMDP is taking clock from this under discussion project (Load Estimation Project, LEP).So the LEP is generating clock for its own calculation and to provide to other projects.

3.7 Simulation Time

To set Simulation time

- The simulation time will be set by this project (LEP) means that simulation results of how long time are required. The simulation results can be achieved of whole on day or the few hours of a day.

3.8 Device Data Storage

To store the configured data of each device i.e.

- Start and end working time of each device
- Load value of each device (Kilowatt)
- Working seasons of each device
- Working days of each device
- Minimum running time of each device
- Maximum shutdown time of each device

The data of each device, which is configured in Graphical User Interface, will be stored by using different files and variables. This stored data is helpful in achieving the above tasks.

3.9 Starting of Simulation

To start the simulation of particular day of particular season according to the user requirement.

3.10 Graph Generation

To generate the graphs of results of simulation

- The graphs of results of simulation will be generated to display the load curves so that the results can be analyzed properly and precisely.

This Load Estimation project (LEP) requires some extra information for the successful completion of above tasks. This information will be received from other two projects i.e. JBFP and LMDP. There are some system design requirements which should be pre-decided to achieve the above tasks # 3.2, 3.3, 3.4, 3.5, 3.9.These requirements has been discussed in Chapter # 4.

Chapter 4

System Design Requirements

E-ISLAND project has been divided into different parts i.e.

- Java Based Forecasting Project (JBFP)
- Load Estimation Project (LEP)
- Load Management Devices Project (LMDP) etc.

All these parts are done by different people of E-ISLNAD's team. So some requirements of system were pre decided between the team members to exchange the data with each other. As this has been told in chapter # 1 that this Masters Thesis is about the middle part of E-ISLAND i.e. Load Estimation Project so beside the tasks of Work Forecasting and Load Estimation, LEP is one which is also responsible for synchronization between other two projects simultaneously. It also has to provide interface between the other two projects. Therefore, there are some requirements for system design which LEP should meet to provide interfacing to other two projects.The system design requirements are given below.

How these requirements are fulfilled, will be discussed in part 2 of this masters thesis i.e. System Modeling & Implementation .

4.1 User Interaction

There are some following requirements to achieve the Objective of "User Interaction" (objective # 5 given in Chapter # 3) successfully.

4.1.1 User Interaction using Simulink library browser

There should be some user dependent data or we can say that user interaction should be a part of LEP. The user should be able to add as many buildings, substations and devices as he wants by taking different blocks from simulink library browser and placing into simulink model. The numbers of priorities should also be dependent on input of user.

4.1.2 User Interaction using Graphical user interface (GUI)

An user should be able to configure all devices using Graphical user interface (GUI).GUI should ask about pre decided data e.g.

- Start and end working time of each device
- Load value of each device (Kilowatt)
- Working seasons of each device
- Working days of each device
- Minimum running time of each device
- Maximum shutdown time of each device

4.2 Data Formats

There are some requirements to achieve the Objective of ‘‘Load estimation & calculation ‘’ and ‘‘Starting of simulation’’ (objective # 3 & 9 given in Chapter # 3) successfully.

4.2.1 Data formats between JBFP and LEP

JBFP should provide the data to LEP in form of files to achieve the objectives of ‘‘Load estimation & calculation’’ and ‘‘ starting of simulation’’. The ‘‘csv’’ or ‘‘dat’’ files should be used for exchanging data between JBFP and LEP. These csv files have been discussed in detail in Chapter # 5.The discussion is about that how these files will look like, where and how the data of these file be read. The data of whole day of all buildings should be provided to LEP at a same time but LEP should read this data minute wise. A csv file should contain the data of each building along with the building identification number (ID) which is mentioned in the beginning of csv file. There are some requirements to achieve the Objective of ‘‘Load estimation & calculation ’’ and ‘‘Starting of simulation’’ (objective # 3 & 9 given in Chapter # 3) successfully.

4.2.2 Data formats between LEP and LMDP

The data should be taken and provided from/to LMDP on every minute rather than taking data of whole day at a same time as in 4.2.1.We can say that data exchange between LEP and LMDP should be time dependent. The LEP is required to provide two inputs to LMDP i.e.

- A matrix of switchable work (the work which can be switchable in remaining quarter of an hour)
- A single value of SUM LOAD (the consumed load of a building)

A switchable work matrix should contain:

- No. of rows = no of substations
- No. of columns = no. of priorities

But only one input is required from LMDP to provide to LEP i.e. a matrix containing ‘1’ and/or ‘0’ where

- 1 means Switch On the device
- 0 means Switch Off the device

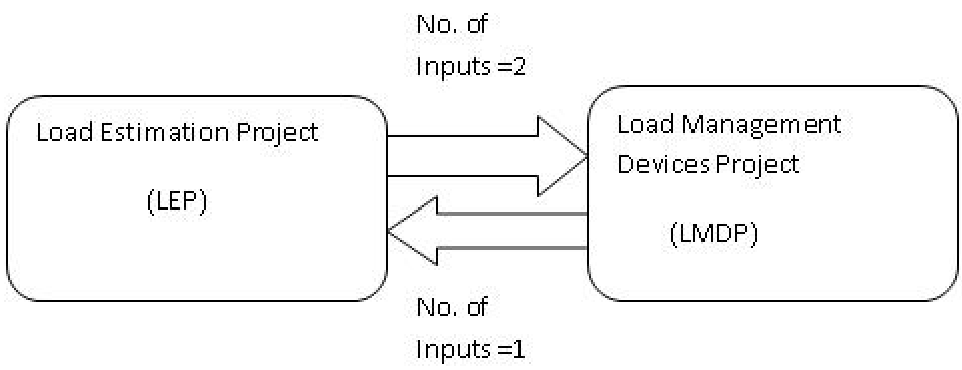


Figure 4.1: inputs exchange between LEP and LMDP

4.3 Clock Generation

The clock should be generated in LEP and provided to LMDP. The LMDP should not generate its own clock.

4.4 Unit delay

The LMDP should provide its output to LEP at time > 0 means a unit delay should be introduced between output of LMDP and input of LEP.

Part II

System Modeling & Implementation

Chapter 5

System Modeling

This chapter will tell us about the working Steps of project in descriptive form as well as through flow charts.In chapter # 4, the requirements for system design have been discussed. This chapter will tell that which steps are performed to fulfill these requirements.

5.1 Flow charts

5.1.1 Flow chart for building a model

The flow chart 1 (Fig 5.1) explains that how the simulink model of building is defined with its substations and devices using simulink libraray browser and Graphical user interface.

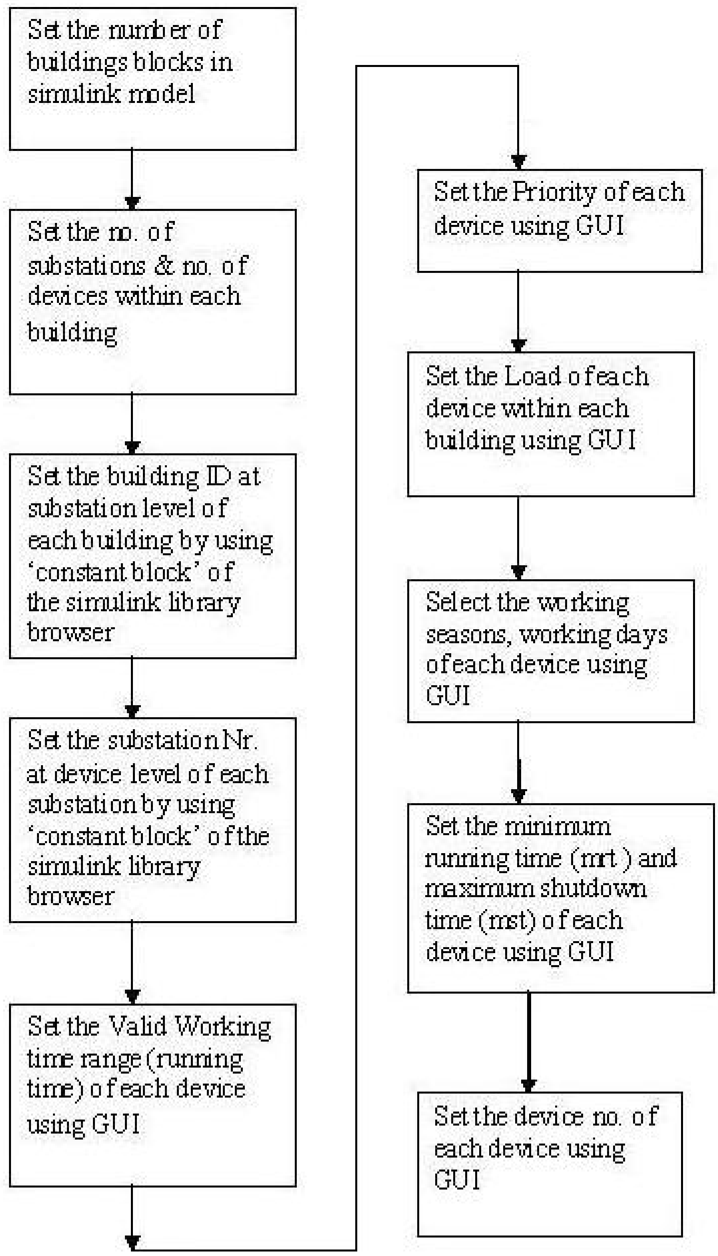


Figure 5.1: Flow Chart 1

5.1.2 Flow chart of Simulation Process

The model of a building has been designed in Flow chart 1(Fig 5.1) and now we move forward to Flow chart 2 (Fig 5.2 and Fig 5.3) . This step will explain that how this model of a building is working, how the data is being exchanged within this model and how this model is interacting with other projects i.e. the Java based forecasting project and the Load management devices project .

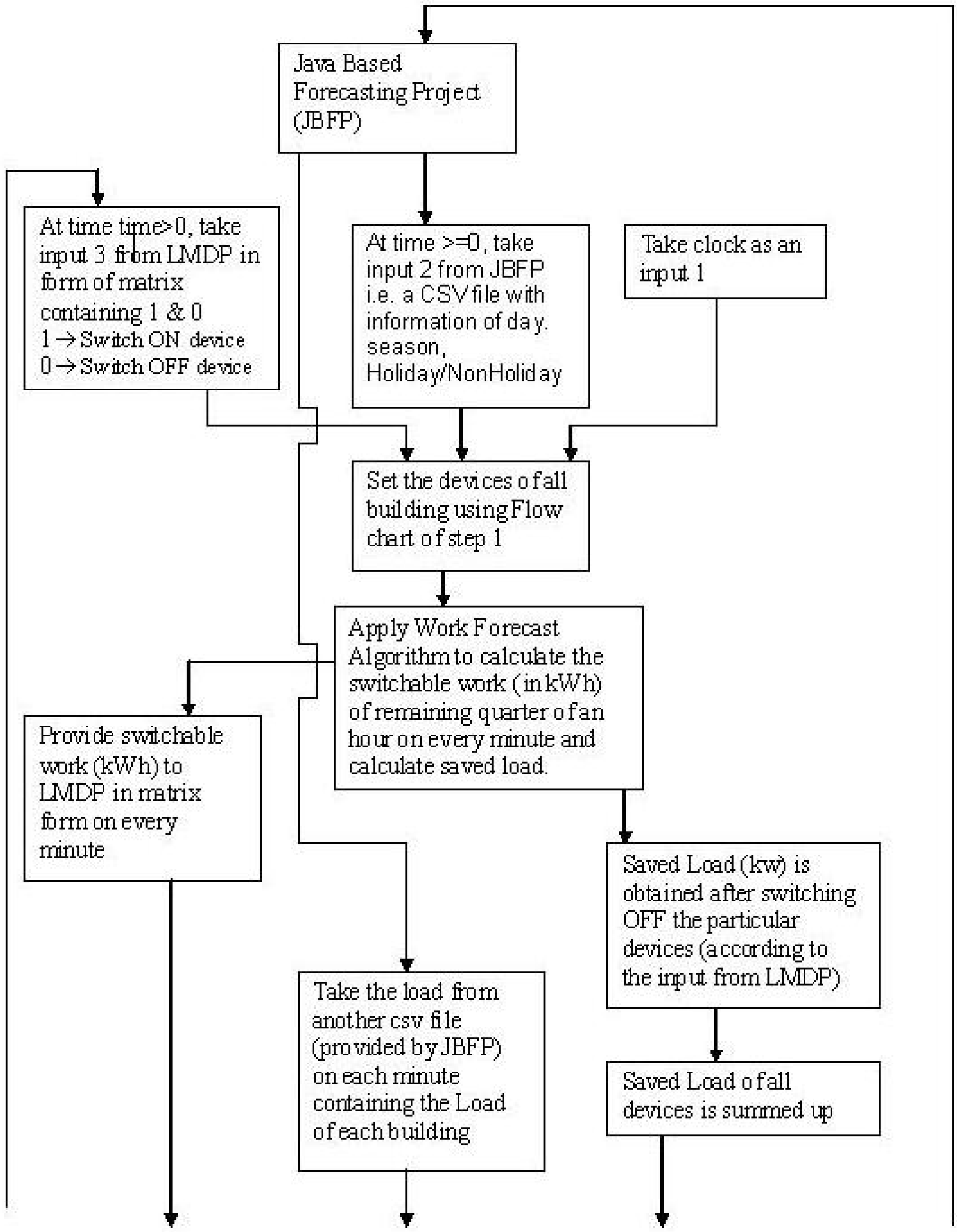


Figure 5.2: Flow Chart 2

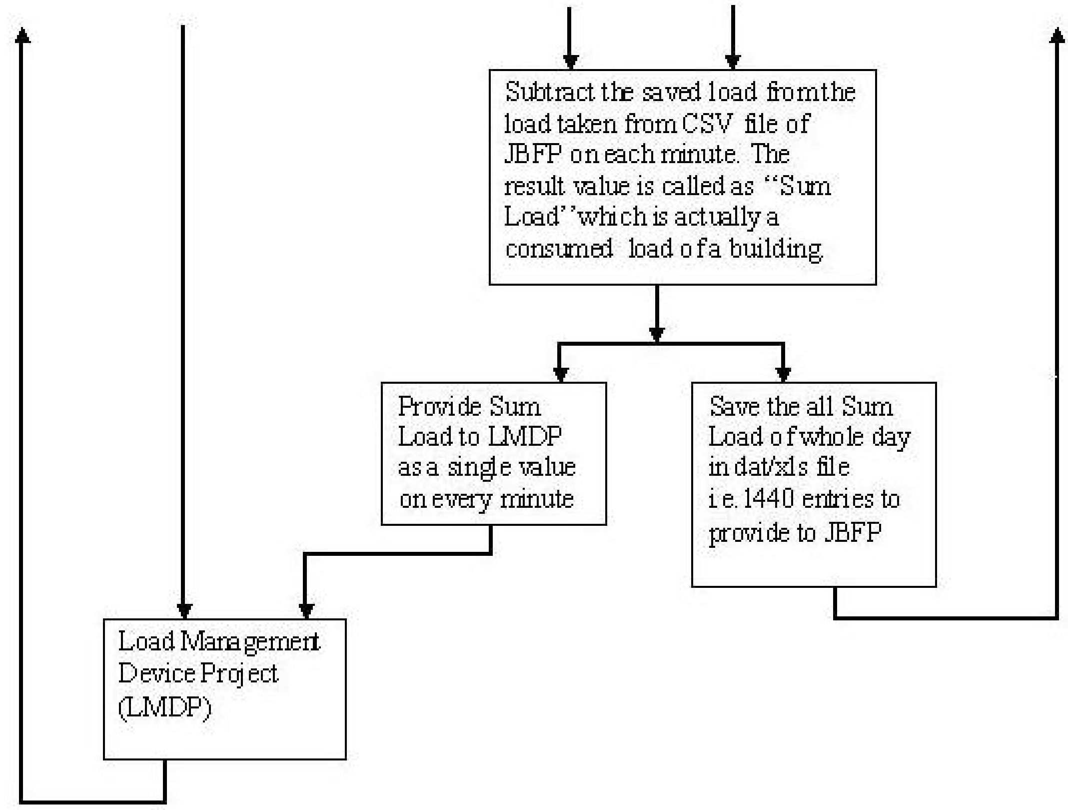


Figure 5.3: Flow Chart 2 (continued)

5.2 Basic block diagram

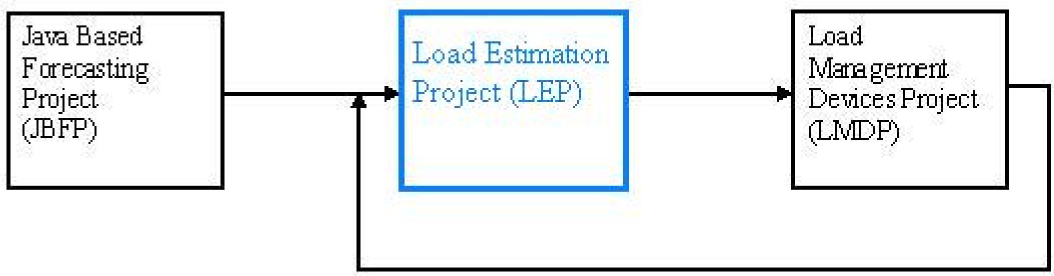


Figure 5.4: Basic block diagram

This project is about the central part of an above given block diagram (Fig 5.4) i.e. Load Estimation Project (LEP). The purpose of this project is the simulation of the load pattern of buildings which make use of a load management system.Furthermore it serves as the interface between two projects i.e. JBFP and LMDP

The JBFP will take data from the database and will generate two CSV files and provide them to the LEP.

The File1 (fig 5.5) provides information to LEP about the specific conditions of the simulation:which day of the week of which season do the load management data belong to and is that a holiday or a ”Non-Holiday”.

The File 2 (fig 5.7) contains load data of that particular day of the selected season of all the buildings in the databse. This file is generated by JBFP by taking historical data from the server of Envidatec company. It will tell us about typical day load consumption means that how load of particular day of particular season look like. An output of JBFP serves as an input for LEP.After the very first minute the LEP and the LMDP will work in loop until the load profiles of 1440 minutes (total minutes of a day) are simulated. In this loop the output of the LEP serves as input to the LMDP abd vice versa.

5.3 Data Format:

The data format to be exchanged between all three projects (JBFP,LEP and LMDP) was defined at the beginning of the projects.

5.3.1 Data format between JBFP and LEP:

The input which is taken from the Java Based Forecasting Project (JBFP) contains two CSV files.

5.3.1.1 First CSV file:

The first csv file (Fig 5.5) has three entries (3 columns and 1 row).These three entries/columns correspond to following parameters.

Column 1→Day
Column 2→Season
Column 3→Holiday/NonHoliday

More parameters (e.g. temperature, time...etc) could be added into this CSV file according to changing requirements of the simulation task. This would then require some addition of code into M-files of the LEP.

The digits of the first column correspond to seven days of a week starting with sunday:
Sunday → 1
Monday → 2
Tuesday→3
Wednesday→4
Thursday→5
Friday→6
Saturday→7

The digits of second column correspond to the four seasons of a year starting with spring:
Spring→1
Summer→2
Autumn→3
Winter→4

The digits of the third column differentiate Holiday from NonHoliday.
Holiday→1
Non Holiday→2

This first csv file will look like a Figure 5.5 :

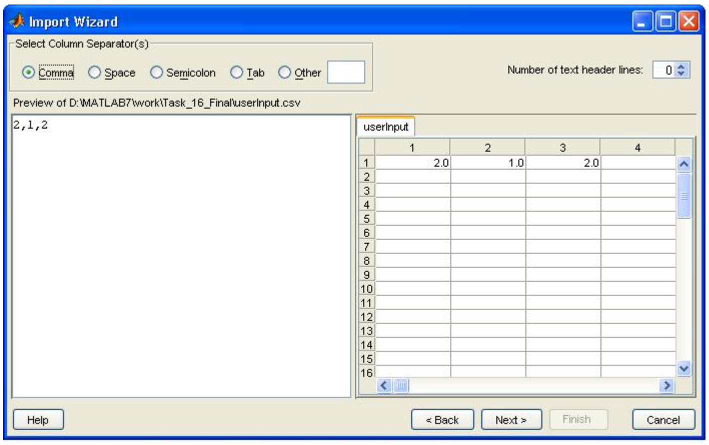


Figure 5.5: First CSV file provided to LEP by LMDP

(Fig 5.5) indicates to *Start Simulation Monday in spring which is a Non Holiday.*

The csv file is automatically placed in matlab's current directory so the simuilnk model will read the file from there. The matlab command ''csvread'' has been used to read this csv file.This command is written in Model Initialization function using the following path.

File→Model Properties→callbacks→Model initialization function

(see Fig 5.6)

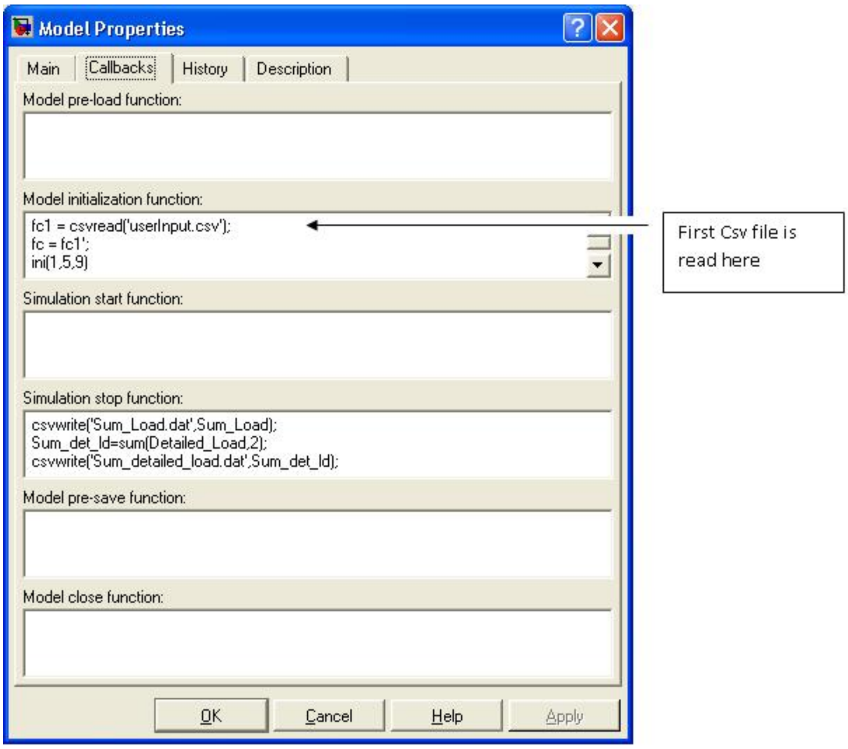


Figure 5.6: Initialization function in Model Properties

5.3.1.2 Second CSV file :

The second CSV file provides the information about the load profiles of the buildings in kiloWatt (kW). It contains the following:

1.Building ID of each building (1 to n).

- The first row of each column contains building ID of the building to which the specific load values of the following rows belong.

2. Following the first row, there are 1440 rows where each row contains the load data for one specific minute of the day.

- *(24 hours per day) * (60 minutes per hour) = 1440 minutes per day*

3. Sum Load (in kW) of individual building(building # 1 to building # n) in each minute.

- Each column corresponds to one building.

4. Sum Load of all buildings in each minute.The last column contains the sum load of all the buildings. This column has Building ID '0'.The buildind ID is placed at first row last column.

Similar to First CSV file, the second CSV file is also placed in current directory.

The second csv file looks like a following Figure 5.7.

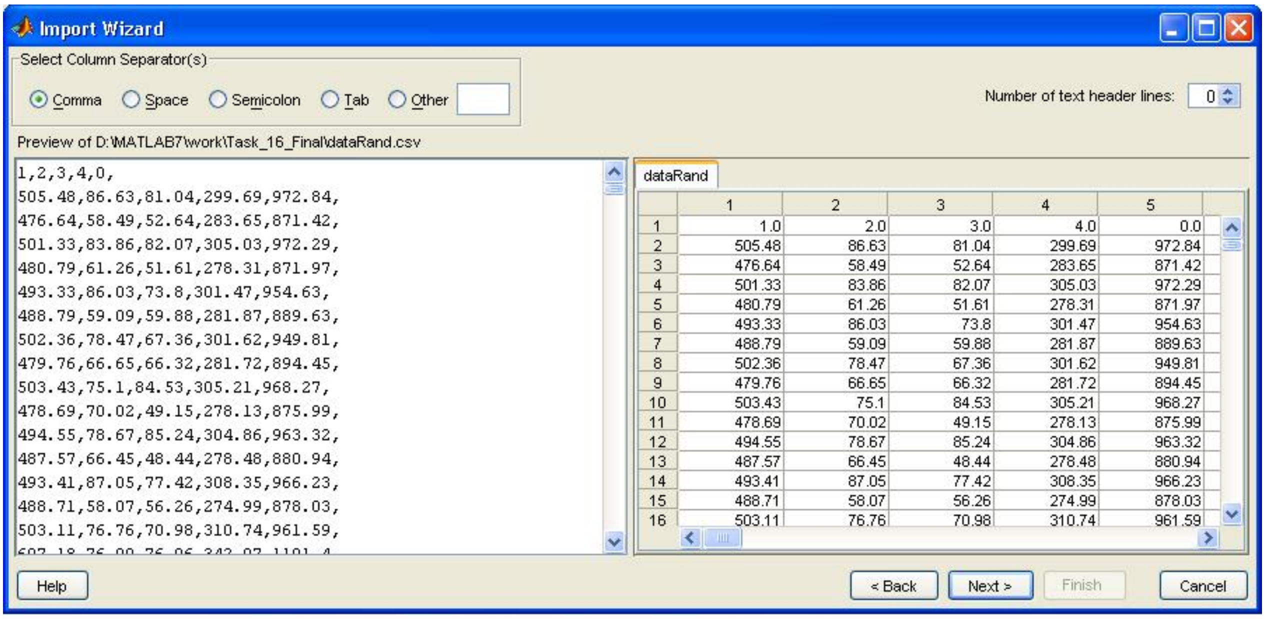


Figure 5.7: Second CSV file provided to LEP by LMDP

5.3.2 Data format from LEP to LMDP

The format of the data which is to be exchanged between the LEP and the LMDP has a matrix form. The number of columns of this matrix represents the number of priorities and the number of rows corresponds to the number of substations. The format of this data will be like the following example:

	Priority 1	Priority 2	Priority 3	....	....	Priority n
Substation 1	100 kwh	200 kwh	300 kwh			Any value
Substation 2	100 kwh	200kwh	300 kwh			
Substation 3	100 kwh	200 kwh	300 kwh			
....	....	......	....			....
....	....	......	....			....
Substation n	Any value	Any value	Any value			Any value

Figure 5.8: A data format used for data exchage from LEP to LMDP

The number of substations in each building can be the same or different from building to building. The same rule holds for the number of priorities in each substation. In example above, the value located at seconds row, second column is 100 Kilowatt Hour (kWh) which corresponds to the the sum of work (in kWh) that could be saved in the remaining time of the current 15 minutes by all the devices connected to substation 1 having priority 1. Similarly the value at second row and third column corresponds to the sum of switchable work (in kWh) of all the devices having priority 2 connected to the substation 1.In this example it is 200 Kilowatt Hour.

5.3.3 Data format from LMDP to LEP

The format of the data coming back from the LMDP to the LEP looks like the matrix displayed in the following Figure 5.9.It will just contain ones and/or zeros.

	Priority 1	Priority 2	Priority 3	....	....	Priority n
Substation 1	1	1	0			1
Substation 2	1	0	1			
Substation 3	0	1	0			
....	....	......	....			....
....	....	......	....			....
Substation n	1	0	1			0

Figure 5.9: A data format used for data exchange from LMDP to LEP

5.4 Working Steps

All the requirements of system design (given in chapter # 4) and objectives (given in chapter # 3) will be fulfilled by using the following working steps.

5.4.1 Building the model

- Set the buildings and their devices
  - The buildings,substations and their devices are set by placing simulink library blocks into simulink model.These blocks are placed in hierarchal structure (as shown in chapter # 7).
- Use the following simulink library blocks to make the simulink model executable.
  - Matlab function blocks
  - Constant blocks
  - Multiplexers
  - Demultiplexers
  - clock etc.

All these block are placed at different locations in simulink model according to their requirements.

- Set the devices of buildings using Graphical User Interface (GUI).The GUI will ask about the following information.
  - The range of the Valid Working time
  - The days of the week in which device works
  - The seasons of the year in which device works
  - Minimum running time of the device
  - Maximum shutdown time of the device
  - Device ID/Device No.
  - Load(kW) of device

All the devices may have different as well as the same configuration.The GUI will look like a Figure 5.10).

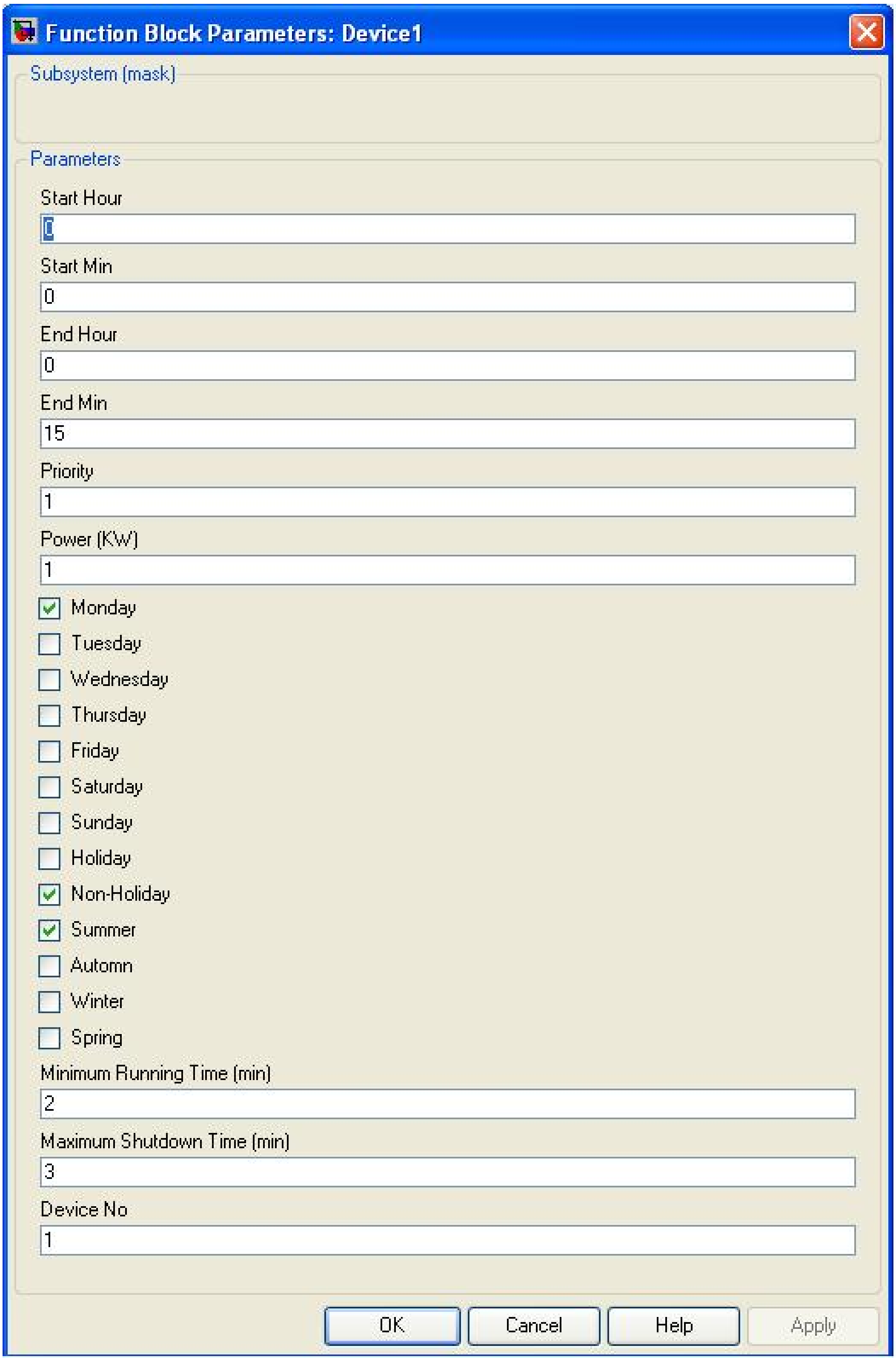


Figure 5.10: Graphical User Interface

The following devices are used in a simulink model.

Figure 5.11: Devices to be used

5.5 Simulation

- At very first minute input will be taken by LEP from first csv of JBFP (First CSV file shown in Fig 5.5)
- Now LEP will check that which devices have the same configuration (day, season, Holiday/Non Holiday) like given in CSV file (fig 5.5).The devices which have the same configuration will take part into that simulation. The Simulation for that particular day, season and Holiday/Non Holiday will be started. The data will be provided to next project LMDP.The format of data (to be exchanged in this step) has already been described in 5.3.2 .

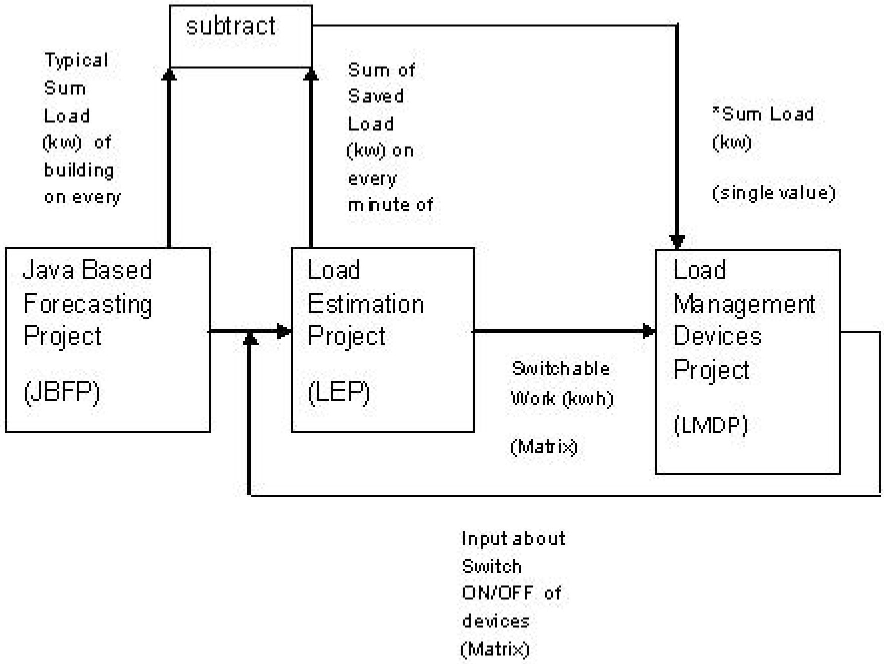


Figure 5.12: Block diagram explaing the working steps

-
- The LMDP will take two inputs from LEP at time ≥ 0 (as shown in above diagram) .
  - Matrix of Switchable Load (kWh)
    - ∗ Switchable load (matrix) is calculated using a WORK FORECASTING ALGORITHM (explained in Chapter # 6)
  - Scaler value of Sum Load (kW)
    - ∗ Sum Load (The load that has been consumed) is calculated by subtraction of sum of saved load value(taken from LEP) from the sum load value taken from second csv file which is generated by JBFP (Second csv file shown in fig 5.7).

The LMDP will apply its own algorithm and will check that whether the load (to be used) of a building at the end of the quarter of an hour is being exceeded than Max Allowed Limit of load (set by user in LMDP block) of that particular building or not. If the load of a building is being exceeded then LMDP will provide instructions to LEP to switch OFF particular devices.But if the load (to be used) is less than the Max allowed limit of load (set by in LMDP block) then LMDP will keep on providing the instruction of Switching On the devices.The instructions provided to LEP by LMDP about Switching ON/OFF the devices will be in matrix form. This matrix will just contains 1 and 0 where
1 means switch ON the device
0 means switch OFF the device

- The LEP will take the matrix from LMDP minute wise ,at time > 0 ,and will check the configured parameters e.g. valid working time, maximum shutdown time (mst) etc. (shown in GUI at last page) of all the devices. The LEP will apply this matrix (taken from LMDP) only if configured parameters allows. e.g. If LMDP provides 1 means switch ON the device then LEP will check that
  - whether device is in its valid working time range or not
  - Whether Maximum shutdown time has been elapsed or not etc

  Similarly If LMDP provides 0 means switch OFF the device then LEP will check that
  - Whether Minimum running time has been elapsed or not etc
- The LEP and LMDP will continuously work in loop till simulation time is elapsed.

Chapter 6

Work Forecasting Algorithm (WFA)

The Work Forecasting Algorithm (WFA) has been developed to forecast the work to be saved or switchable work in remaining quarter of an hour by shutting down the different devices e.g.

- at time =10 minutes, the Work Forecasting Algorithm (WFA) will calculate the work (to be saved) of remaining 5 minutes.

The basic purpose of this whole project(E-ISLAND) is to apply the load shedding of devices of building when the total consumed load of building is exceeded by the maximum allowed limit(Load value in kW).

Each building will have a maximum allowed limit of load (in kW) which is predefined in LMDP (Load Management Devices Project).When the total sum of load of all the devices of a building will be exceeded by the maximum allowed limit then the principles of load shedding will be applied i.e. switching ON /OFF the devices.

Work Forecasting Algorithm (WFA) is applied within LEP (Load Estimation Project). The LEP will apply the "switch ON/OFF" principle on the building by taking input from LMDP in form of 0 (switch OFF) or 1 (switch ON). But this principle is based on that information which is provided to LMDP by Work Forecasting Algorithm (WFA) in LEP.The WFA will provide the information (in form of matrix) to LMDP that how much work is switchable , which means how much work can be shutdown in remaining quarter of an hour. The shutdown work or switchable work is actually a work which can be saved in remaining quarter of an hour.

The "switch ON/OFF" principle is also based on the priorities. The devices having highest priority (e.g. 1) will be switched ON first as compared to lower priority devices (e.g. 3). This is how WFA helps the LMDP to provide Load Management facility to each building.

6.1 Monitoring Policies of Work Forecasting Algorithm

1. If mst has been elapsed then device will be switched ON even if LMDP is providing instruction (input) to make the device switch OFF.

2. If during mst, LMDP provide input to make the device ON then device will have to switch ON because mst is maximum duration of shutdown not a minimum duration of shutdown.

3. If once device has been started then it will run at least till mrt (minimum running time) in any case even if LMDP is providing instruction (input) to make the device switch OFF.We can say that mst (maximum shutdown time) and mrt (minimum running time) have higher priorty than instruction (input) from LMDP

4. At time = 0 (beginning of simulation), LMDP is not providing any input so nothing will happen on the devices means devices will remain OFF except if they have their valid working time at time = 0 (beginning of simulation).

5. If the valid working time of any device is started at $time > 0$ then it will immediately implement the input from LMDP e.g. If valid working time is started at $time > 0$ and at the same time LMDP provides '0' the device will have to be switched OFF.

6. The input from LMDP will be implemented on any device only when the device will be in its valid working time range otherwise not applicable.

6.2 Graphical Explanation of Work Forecasting Algorithm

The basic work forcast algorithm can be explained by considering the philosophy as per fig 6.1.

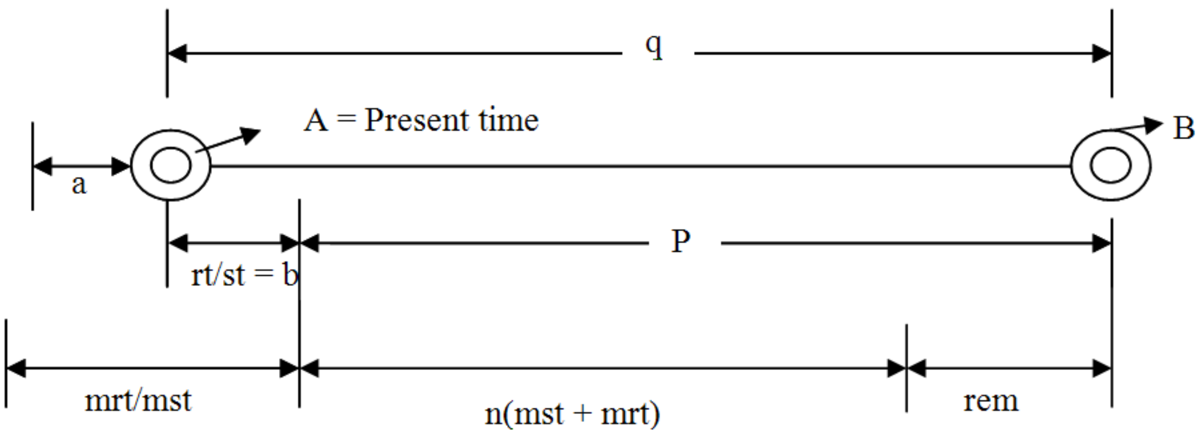


Figure 6.1: Work flow algorithm

Where

$q =$ time for which the calculation of reduction of load can be done.

$a =$ state of device before reference point A i.e. running or shut off, "a" will correspond for time of that state.

$b = mrt/mst - a$ will correspond to the remaining part for which the device will atleast run or shut off more. If previous state is "on", then $b = mrt - a = rt$, similarly if previous state is "off" then $b = mst - a = st$.

$P = n(mst + mrt) + rem$

$= rt + [mst + mrt + \cdots + mst + mrt] + rem$

$= st + [mrt + mst + \cdots + mrt + mst] + rem$

$rem =$ total remaining shut off time if $b = rt$

$rem =$ total remaining on time if $b = st$

$P = q - b$

The working principle for work forecast is as follows:

1. $kwb =$ kilowatt hour saved in "b" region
   (a) $kwb = kw \times b$, if $b = st$ otherwise $kwb = 0$
2. $kwp =$ kilowatt hour saved in "P" region
   (a) $kwp = kw \times n$
   (b) $P = n(mst + mrt) + rem$
3. $kwr =$ kilowatt hour saved in "r" region
   (a) $kwr = kw \times rem$ if $rem = st$ otherwise equal to zero

6.2.1 Example:

Let input matrix taken from LMDP is

$$= \begin{bmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

Where

- number of rows = number of substation
- number of columns = number of priorities

We assume for this example that input taken from LMDP is constant throughout the quarter of an hour. The purpose of this supposition of constant input is just to make this example understandable. More details can be seen in chapter # 8 section 8.2. Some more supposed data is given in a following table:

	Substation 1	Substation 2	Substation 3
Device 1:			
Valid working time (min)	0 → 15	0 → 15	0 → 15
Minimum running time(min)	2	2	2
Maximum shutdown time(min)	3	3	3
Load (in KW)	1	1	1
Priority	1	1	1
Device 2:			
Valid working time(min)	5 → 10	5 → 10	5 → 10
Minimum running time(min)	2	2	2
Maximum shutdown time(min)	3	3	3
Load (in KW)	2	2	2
Priority	2	2	2
Device 3:			
Valid working time(min)	10 → 15	10 → 15	10 → 15
Minimum running time(min)	2	2	2
Maximum shutdown time(min)	3	3	3
Load (in KW)	3	3	3
Priority	3	3	3

Figure 6.2: Supposed data used in example 6.2.1

The very small values has been assumed to just to make the example understandable.

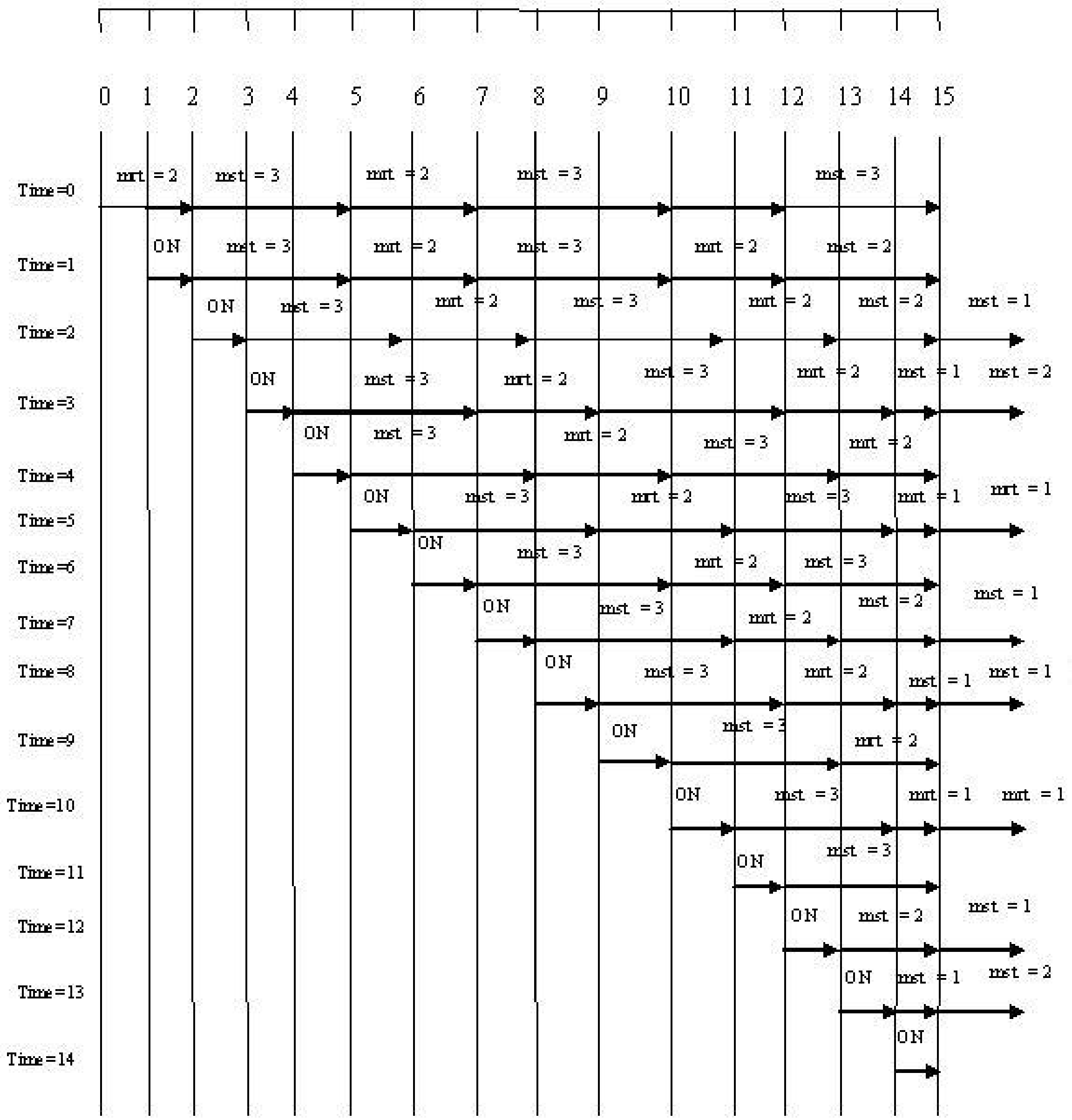


Figure 6.3: Graphical explaination of Work Forecasting algorithm

6.2.2 Explanation of Figure 6.3:

The devices which are connected with substation 1 and with priority 1 have a beginning of their valid working time at time = 0. So according to the Monitoring Policy # 3, if once the device has been started then it will run at least till *mrt* in any case, After the mrt is elapsed, the device will implement the off instruction (input) from LMDP, if any. As in this given example, the LMDP is providing '1' which means switch ON the device so after *mrt* is elapsed at time = 2, the device will be in "ON" state. As we are assuming constant input from LMDP so this device will remain ‘‘ON’’ throughout the quarter.WFA will be applied on every minute and forecasting of work of remaining quarter will be done. Please also see section 8.2 for further explaination.

6.2.3 How Work Forecasting Algorithm do Forecasting:

At time = 2, the device will be ON so according to WFA, the device should remain *on* for at least time = 3 but after time = 3 the device can be shutdown for maximum of *mst* after which it will be on (if device is in valid working time) for at least *mrt* and so on. So WFA will take sum of all *off times* of remaining quarter of an hour and will multiply it with Load (kW) of a device (given in GUI) and divide by 60 (minutes in one hour) to calculate the Forecasted Work in Kilo Watt Hour (kWh).

At time = 2
Sum of off time in remaining time of quarter=3+3+2 = 8 minutes
Load of device of substation 1 with priority 1 = 1 kW
Minutes per hour = 60
*Work to be shutdown/saved in remain time of quarter = (8 *1)/60 = 0.133 kWh*

The device connected with substation 3 has the same priority and valid working time as the device od substation 1 and same input is coming from LMDP for both devices of substation 1 and 3. So the graphical representation and work value(kWh) will be same for both devices of substation 1 & 3. The same principle will be applied for all devices connected with all substations. The matrix provided to LMDP at time = 2, using the same principle (as applied above in Fig 6.3), is

$$\begin{bmatrix} 0.133 & 0.3 & 0.15 \\ 0.133 & 0.3 & 0.15 \\ 0.133 & 0.3 & 0.15 \end{bmatrix}$$

The further explaination about the working of WFA is given in section 8.2 of Chapter # 8

Chapter 7

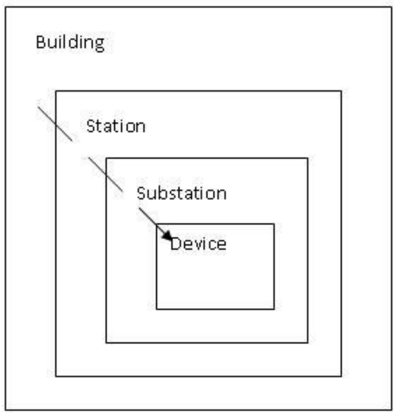
System Implementation

7.1 Hierarchal Structure of a Simulink Model

The hierarchal structure for system implementation requires that,

1. Device(s) must be set in a substation.
2. Substation(s) must be set in a station
3. Station(s) must be set in a Building.
4. Building(s) must be set in the main simulink environment.

The Fig 7.1 gives a phiosophical idea about the basic structure that how the model of a building is built up using Matlab simulink.



(a) Philosophical hirarchy

Figure 7.1: Philosophical structure of hierarchy

That means, that if there more than one devices, i.e. 2 grouped in more than one, i.e. 2, substations for 1 station and 1 building then we will set two substations in one station which is set in one building. Fig 7.2 can explain this generalization. (see Appendix B to get an idea about Hierarchal structure of buildings)

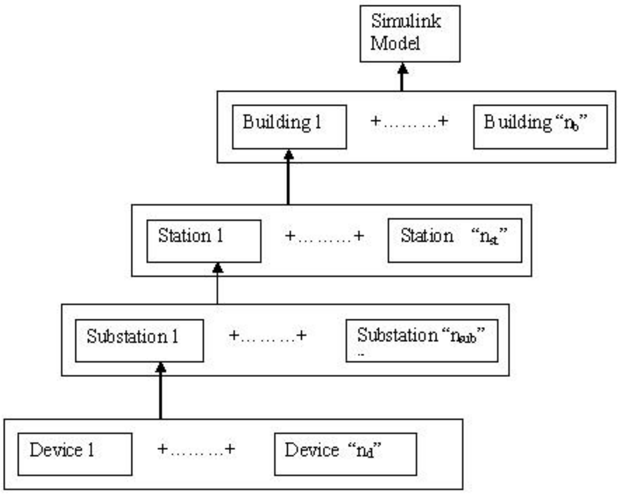


Figure 7.2: Implemented structure of hierarchy

7.2 Block diagram for system implementation

The Fig7.3gives a breif idea that how M-files are arranged to exchange data with each other, by considering 1 device, 1 substation, 1 station and 1 building as an example. It also tells that where the Load Management Device project is placed and which m-file is used to take data from csv file of Java based forecasting project i.e.the matlab file device.m is used to take data from csv file of Java based fore casting project (JBFP). We can also see that a matlab file frarr.m is providing input to Load management device project (LMDP) via two interface m-files i.e. ting_interface3.m and ting_interface.m

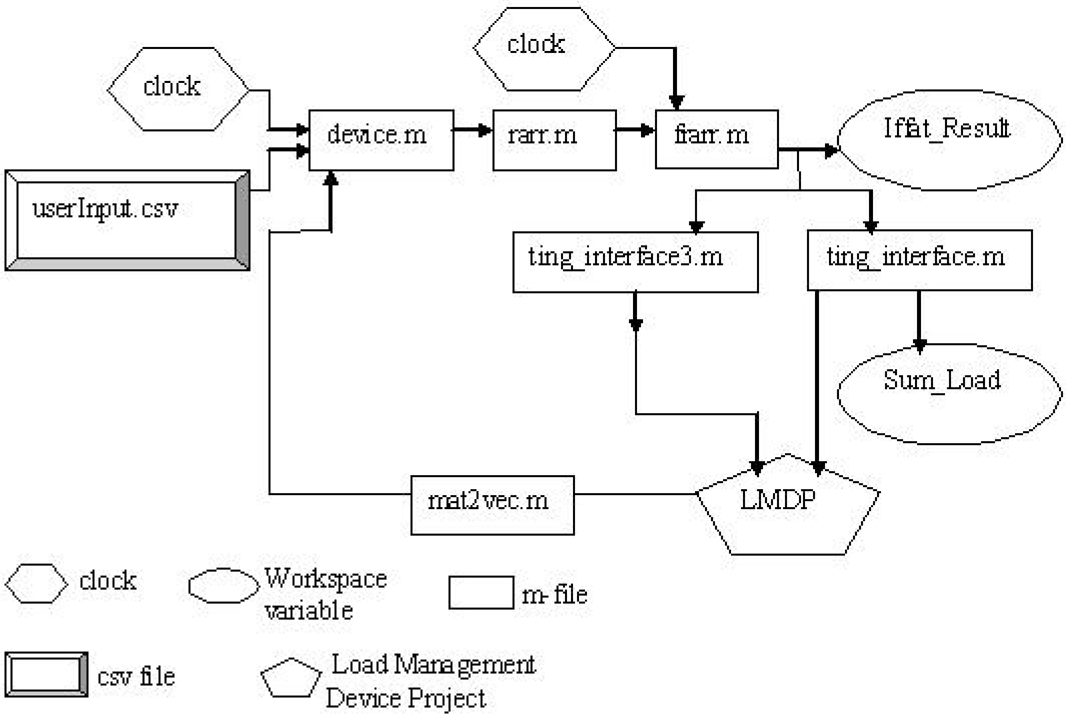


Figure 7.3: Block diagram

7.3 Flow diagram of Matlab code

The Figure 7.4,7.5 are explaining the steps which are performed to exchange data between matlab files (m-files). Each file is taking data from one file and providing to other. It gives an idea about the input and output of each file.(see the Matlab code of this project in CD)

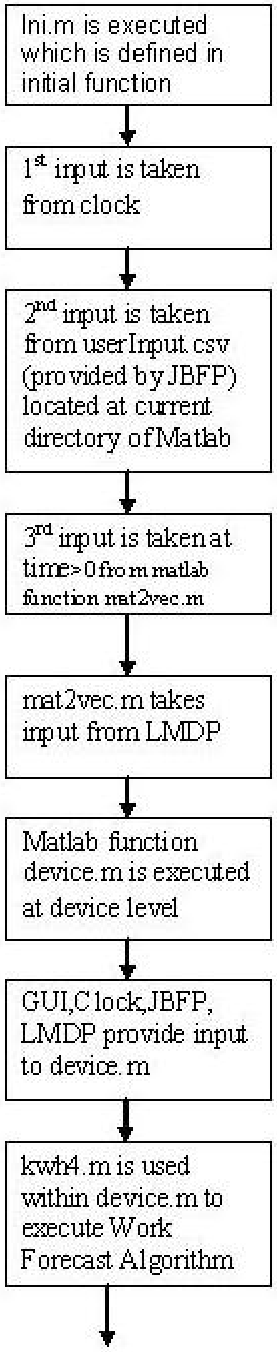


Figure 7.4: Flow Chart 1

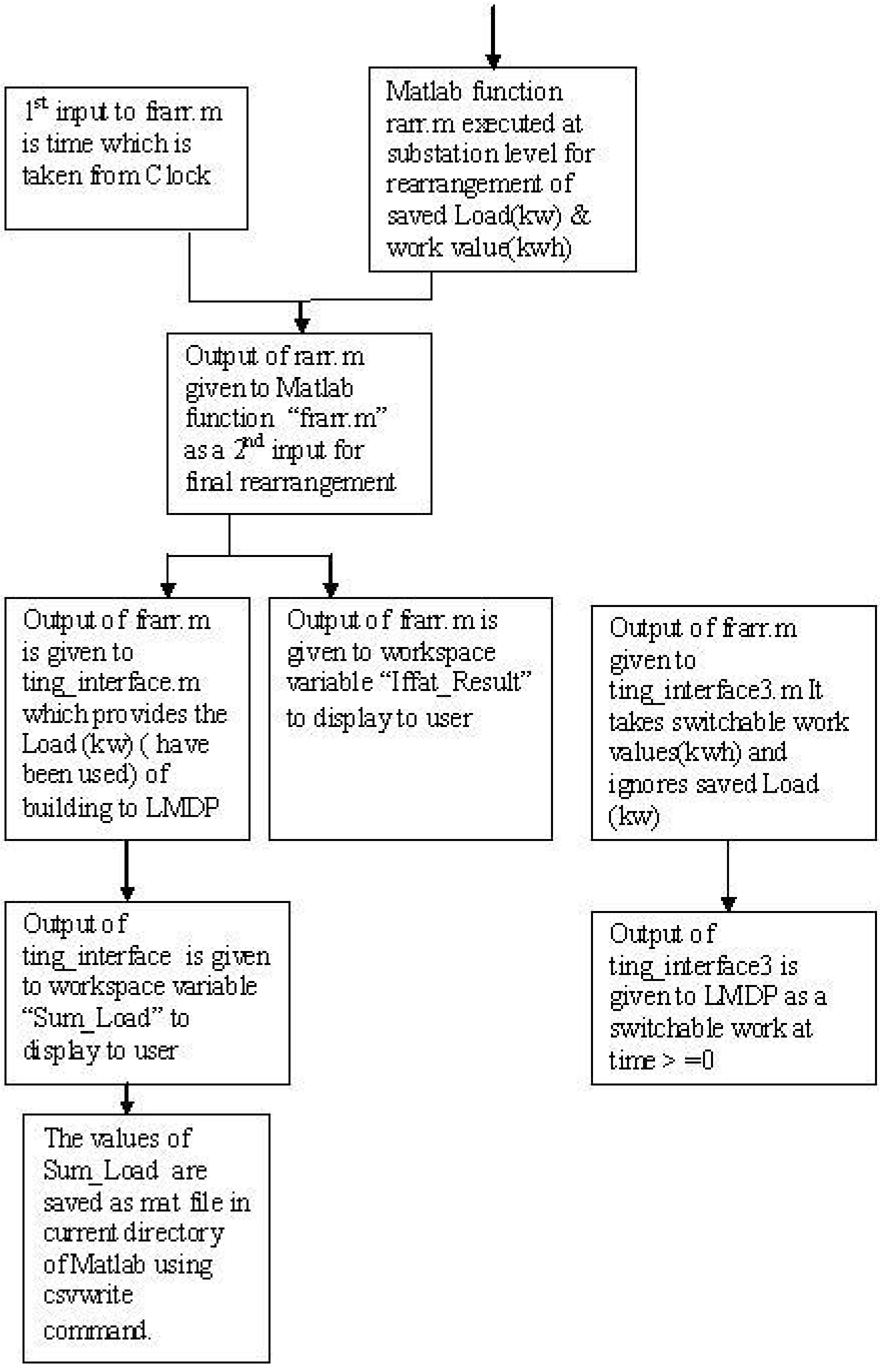


Figure 7.5: Flow Chart 1 continued

7.4 Functions of M-files

7.4.1 ini.m

This file requires some parameters i.e.

- *nob* (number of building)
- *sub_max* (maximum number of substation)

- *d_max* (maximum number of devices)

ini(nob, sub_max, d_max) is defined in initial function of model properties using the path:

- *File → Model properties →initial function*

7.4.1.1 nob

User has to write the total number of buildings in that simulink model e.g. If there are 4 buildings then
$nob = 4$

7.4.1.2 sub_max

User has to write the maximum number of substations of that specific building which has highest number of substation. e.g. If simulink model has 4 buildings and if

- Building 1 has 2 substations
- Building 2 has 1 substations
- Building 3 has 4 substations
- Building 4 has 3 substations

Then in above example that Building # 3 has highest number of substation i.e. 4 substation so
sub_max= 4

7.4.1.3 d_max

User has to write the number of devices of that specific substation which has highest number of devices e.g. if

- Each substation of Building 1 has 3 devices
- Each substation of Building 2 has 2 devices
- Each substation of Building 3 has 1 devices
- Two Substation of Building 4 has 2 devices and
- One Substation of Building 4 has 4 devices *then*

Then in above example maximum number of devices in one substaion of building 4 has number of dveices i.e. 4 devices so
d_max = 4
So in above example, we will provide the above parameters to"ini.m" in an initial function as ***ini(4,4,4)*** *.*

If a user makes changes in simulink model then he has to change these parameters. For example, if number of substations or/and number of devices or/and number of buildings are changed then these above parameters should be modified according to new simulink model.

ini.m generates a matrix of zeros where $rows = sub\_max$ and $column = d\_max$. This matrix is saved in two mat files for multiple purposes i.e. *lout.mat* and *tini.mat* . It is 3-dimensional matrix and nob (number of buildings) corresponds to third dimension.

The two mat files *''lout.mat''* and *''tini.mat''* are generated when ini.m is executed for different purposes.

7.4.1.4 lout.mat

This is used for counting maximum shutdown time (mst) and minimum running time (mrt).When any device is 'ON' then the value of matrix at the position of specific device of specific substation of particular building starts increasing from zero till its *shut off*. When device is 'OFF' then specific value (located at the position of that specific device of particular substation) starts decreasing from zero till it is *on*. We can say that if value of matrix is increasing in positive integers then means device is in *on region* its absolute value will correspond to the *on duration*. And if value of matrix is increasing in negative integers then means device is in *off region* and its will correspond to the *off duration* .

lout.mat can also be used to take information about *mst* and *mrt*. It tells the current situation of *mst* and *mrt*. It can be used to provide the information that how much *mst* and/or *mrt* has been passed and how much time is left in elapsing the *mst* and/or *mrt*.

7.4.1.5 tini.mat

This is used for counting the quarters of an hour. When any quarter of an hour is started, the value of matrix of that device starts increasing from 1 to 15. At 15 the counter is rest to to zero at the end of a quarter. This process is repeated for all quarters.

7.4.2 userInput.csv

This file is taken from Java based forecasting project. It provides the information that simulation of which specific day, season, Holiday/NonHoliday has to be started.

- Each 'day' has specific number i.e.

Sunday	1
Monday	2
Tuesday	3
Wednesday	4
Thursday	5
Friday	6
Saturday	7

Table 7.1: Day Numbering

- Each 'season' has specific number i.e.

- Similarly *Holiday and NonHoliday* corresponds to specific numbers i.e. *1, 2*

Spring	1
Summer	2
Autmn	3
Winter	4

Table 7.2: Season Numbering

7.4.2.1 Example

- Let us suppose that csv file contains the following parameters

$$\begin{bmatrix} 2 & 1 & 2 \end{bmatrix}$$

It indicates to start a simulation of *Monday* of *Spring* which is *NonHoliday* i.e.

$$\begin{bmatrix} \underbrace{2}_{Monday} & \underbrace{1}_{Spring} & \underbrace{2}_{Non-Holiday} \end{bmatrix}$$

- If csv file contains

$$\begin{bmatrix} 3 & 2 & 1 \end{bmatrix}$$

It means that start a simulation of *Tuesday* of *summer* which is *Holiday*, i.e.

$$\begin{bmatrix} \underbrace{3}_{Tuesday} & \underbrace{2}_{Summer} & \underbrace{1}_{Holiday} \end{bmatrix}$$

7.4.3 mat2vec

This Matlab function converts the matrix (taken from LMDP) to vector for being used in device.m because device.m needs the input in vector form for internal use. The input matrix taken from LMDP contains only 1 and 0.

1 means switch ON device

0 means switch OFF device

This Matlab function takes input from LMDP (Load Management Devices Project) in from of matrix at $time > 0$. The number of rows of matrix corresponds to number of substation of that building and number of columns corresponds to the total number of priorities. As the same m-files are being used for all the buildings so whenever the total number of priorities will be changed in m-file then the all buildings will generate 'switchable work' matrix according to new total number of priorities. The size of this newly generated matrix will be same for all the buildings because all buildings are using same m-files.

7.4.3.1 Example

- If
  - Total number of priorities = 3
  - Number of substation = 2

Then matrix exchanged between LEP (Load Estimation project) and LMDP (Load Management Device project) will have

- number of rows are 2 and
- number of columns are 3

for all the buildings.

- And if
  - total number of priorities = 4
  - Number of substation = 2

  Then the matrix exchanged between LEP (Load estimation project) and LMDP (Load Management Device Project) have

  - number of rows = 2
  - number of columns = 4

  for all the buildings.

7.4.4 device.m

This Matlab function is defined within device block. It takes input from following locations:

- clock
- Java Based Forecasting project (JBFP)
- Load Management Devices Project (LMDP)
- Graphical User Interface (GUI)

It compares the following parameters of each device with the parameters of csv file (userInput.csv)

- day
- season
- Holiday/NonHoliday

Only those devices take part into simulation which parameters are matched with the parameters of csv file (userInput.csv). It also load two mat files i.e. *lout.mat* and *inti.mat* to take into consideration the current status of maximum shutdown time (mst),minimum running time (mrt),start and end of quarters of an hour. Each hour contains 4 quarters.

The functions of lout.mat and tini.mat have already been described in previous page. The device.m performs mainly two functions

1. *To provide the saved Load (Kilowatt) values of devices which are switched OFF.*

   At time = 0 there will be no input from LMDP so only those devices will be ON which are in the range of their valid working time but at $time > 0$,the devices will be ON and/or OFF according to the input taken from LMDP.The ON-OFF process will also consider the mst and mrt.

   The device.m provides the saved load (kW) values of devices. It tells that how much load (kW) has been saved when any device is switched OFF. The device.m provides the load values (kW) of devices with their priorities.

2. *To forecast the work values(Kilowatt Hour) of devices for remaining quarter of an hour called as 'switchable work'*

   The Matlab function kWh4.m has been used within device.m. It describes an algorithm which calculates the work value (kilowatt Hour) of each device of remaining quarter of an hour. We can say that kWh4.m used for forecasting of work for remaining quarter of an hour. Work forecast algorithm has been described in chapter # 6.

An output of device.m contains the following parameters

- Priority of devices
- Work value (kWh) of devices
- Saved Load value (kW)

An output of *device.m* is an input of *rarr.m* in form of column vector i.e.

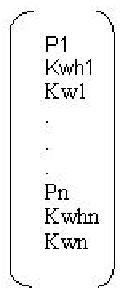


Figure 7.6: output of device.m

7.4.5 rarr.m

This Matlab function is used for rearrangement of saved Load (kW) and switchable work (kWh) values of devices according to their priorities. The switchable work values (kWh) of those devices which have same priorities will be summed up together for each substation.

7.4.5.1 Example

	Priority 1	Priority 2	Priority 3	Saved Load
Substation 1	8 (kwh)	4 (kwh)	0 (kwh)	300 (kw)

Figure 7.7: Table for example 7.4.5.1

It tells us that the sum of switchable work (kWh) of all the devices (connected to substation 1) having priority 1 is 8 kWh.

Similarly, the sum of the switchable work (the work which can be switchable in remaining quarter of an hour) of all devices (connected to substation 1) having priority 2 is 4 kWh.

An output of rarr.m is a column vector which contains switchable work (kWh) and sum of saved load (kW) of all devices of same substation. The saved Load (kW) will be placed at the last row of the column vector within each substation.

For above example, an output of rarr.m looks like following

$$\begin{bmatrix} 8 \\ 4 \\ 0 \\ 300 \end{bmatrix}$$

Figure 7.8: output of rarr.m

All the substation will produce column vector in same form. An output of all rarr.m , coming from different substations, will be multiplexed at substation level and provided to Matlab function frarr as an input.

7.4.5.2 Example

If there are two substations having configuration as per fig 7.4.5.2

	Priority 1	Priority 2	Priority 3	Saved Load
Substation 1	8 (kwh)	4 (kwh)	0 (kwh)	300 (kw)
Substation 2	5 (kwh)	2 (kwh)	0 (kwh)	400 (kw)

Figure 7.9: Table for Example7.4.5.2

then after multiplexing the output of all *rarr.m* will look like the fig 7.10

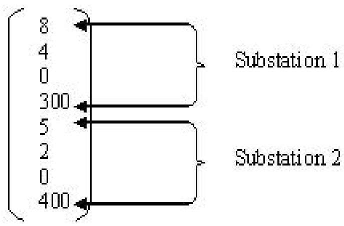


Figure 7.10: output of rarr.m after multiplexing

7.4.6 frarr.m

It is used for final rearrangement of saved Load (kW) values and work values(kWh). It performs two steps:

Step 1 It takes input from *rarr.m* in form of vector. The Matlab function frarr transforms vector into matrix. The last column of this newly generated matrix corresponds to the saved Load value(kW).The *frarr.m* will sum up all values (saved load values) of last column.

Step 2 *frarr.m* read csv file 'data.csv' which is generated by JBFP (Java Based Forecasting Project). This csv file contains Load values (kW) of each building on every minute. Each column corresponds to each building. The last column contains the sum of load of all the buildings on every minute. The 1st row of this csv file gives the information about building ID. The frarr.m reads csv file according to the building ID.

It takes Load value (kW) from this csv file and subtract the sum of saved load values (taken in step 1) from this load value (taken in step 2) on every minute and provides to LMDP via a *ting_interface.m*. Let us suppose that this newly generated value of load is called as ''SUM LOAD''. This value is actually the load that has been consumed by the building on each minute.

If we have total number of priorities = 3 then last column will be 4th where saved Load values (kW) are placed. If total number of priorities are changed then we will have to do some modifications in *frarr.m* i.e.

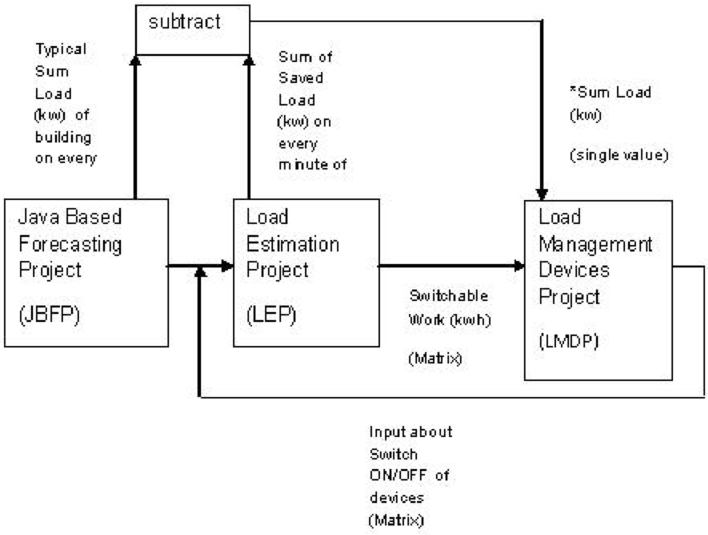


Figure 7.11: Block diagram

7.4.7 ting_interface.m

It takes matrix as an input from frarr.m and just picks the “SUM LOAD” value (kW) from the 1st row and last column and provides to the LMDP as an input.

7.4.8 ting_interface3.m

It just picks up the matrix of switchable work values (kWh) , ignores the Load values (kW) (present in last column 1st row) and provides this switchable work matrix (having no Load value) to LMDP as an input.

We can see in above figure that LMDP is taking two inputs from LEP. One input is taken from the output of ting_interface.m and other input is taken from the output of ting_interface3.m

7.5 What have to be done if

1. An user want to add/delete any building/station/substation/device then following steps should be remembered.

- Parameters of ini.m should be modified (read the description of ini.m in section 7.4.1) according to the new changes by using the path as follows:

  File→Model properties→callbacks→Model Initialization function

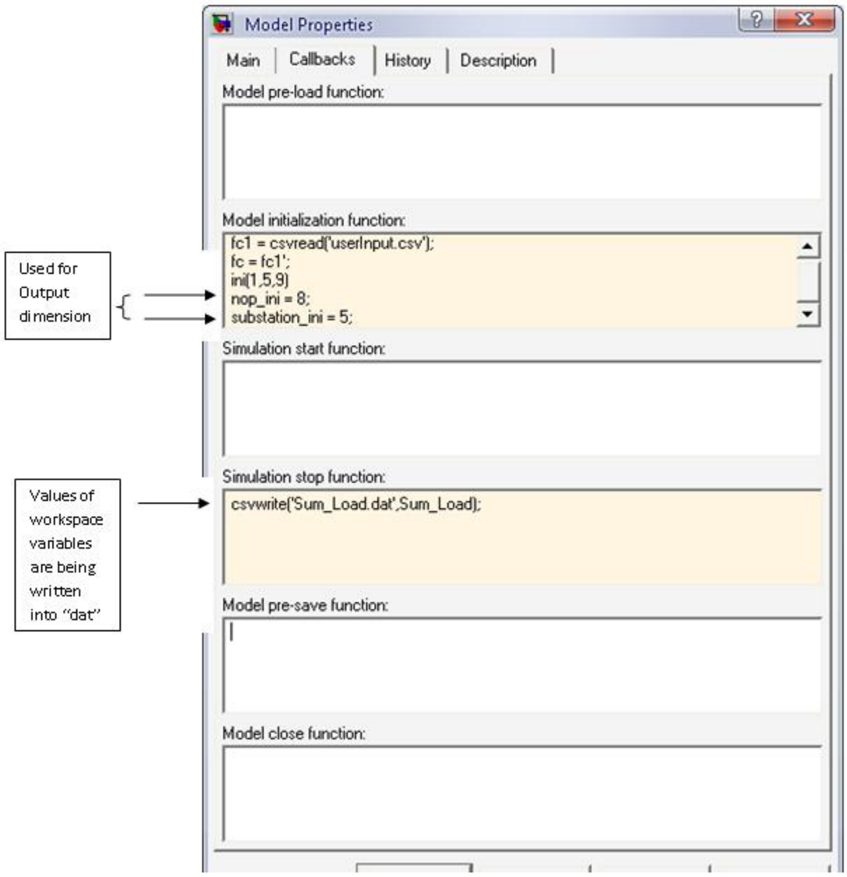


Figure 7.12: Model Properties

- In the above screenshot7.12 ini (1, 5, 9) is telling that there are
  - Max. no.of building =1
  - No.of substations of that building which have highest no.of substations= 5
  - No. of devices of that substation which have highest no. of devices = 9
- Input/output of multiplexer/demultiplexer should be modified according to new changes.
- Constant value block of substation Nr. and building Nr. should be modified according to new changes.
- The names of workspace variables should be modified according to new changes.
- GUI (Graphical User Interface) should be modified according to new changes.
- The output dimensions of following Matlab functions are required to modify according to new changes in Simulink model:

  mat2vec

  device

  rarr

frarr

vec2mat

The output dimensions (discussed later in next pages) of all above Matlab functions depend on different parameters. The parameters have been generalized for the convenience of the user. The above screenshot 7.12 is showing two parameters i.e.

nop_ini Total no. of priorities.

substation_ini No. of substations of that building which have highest no. of substations.

So now instead of typing different values in window of output dimension, user just have to modify the values of above parameters in "Model Initialization function" window.

- The parameters which are shown in the following screenshot should remain constant except the Simulation time which can vary according to requirement.

  Simulation →configuration parameters

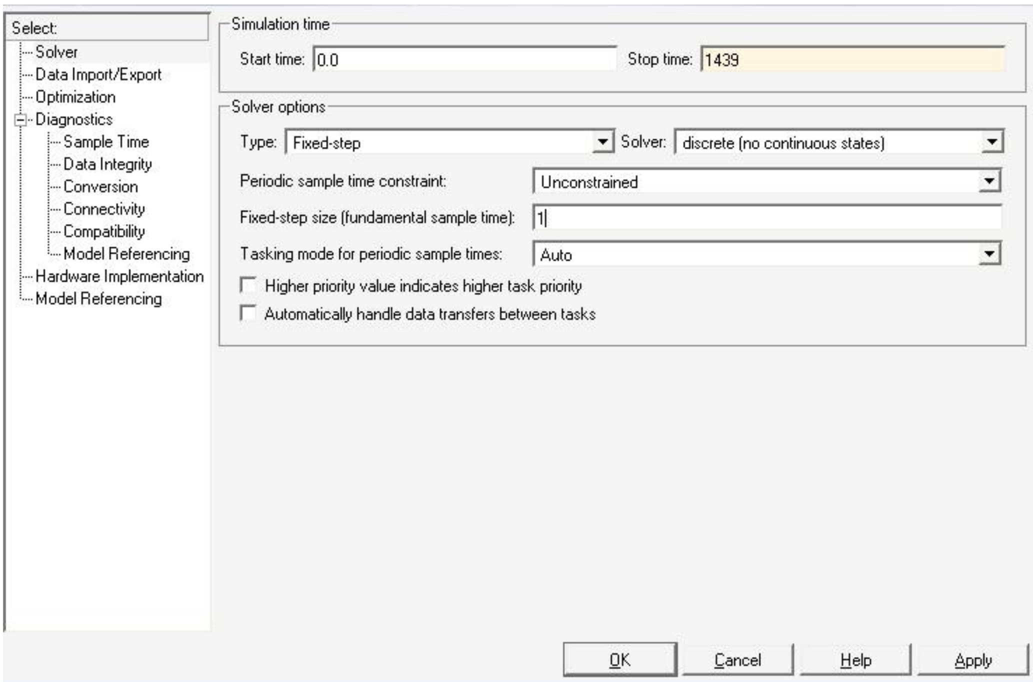


Figure 7.13: Configuration parameters

1. The total number of priorities are changed then the value of variable

   tot_no_pr

   in rarr.m, device.m,vect2mat.m and value of variable

   tot_no_pr_s

   in *frarr.m* will be modified according to new changes. The following line of frarr.m will also be modified according to new changes.

   If *total no. of priorities* = 3 then *frarr.m* will contain a line *kW_saved = sum (result(:,4))*

But when total no. of priorities = 4 then above line will be replaced by

kW_saved = sum (result(:,5))

7.6 Output dimensions

As this is mentioned before that output dimension of each Matlab Function depends on different parameters i.e. total no. of priorities, highest no. of substations etc. So now I would like to tell you that each Matlab function depends on which parameters and how the output dimension of each Matlab Function is calculated

7.6.1 Matlab Function "mat2vec"

Its output dimension is calculated by multiplying the no. of rows of switchable matrix by the no. of columns of switchable matrix where

- No. of rows of switchable matrix = No.of substations of that building which have highest no.of substations
- No. of columns of switchable matrix = Total no. of priorities
- According to values to Model Properties fig 7.12
- No.of rows = 5
- No. of columns = 8
- So the output dimension should be *5*8 =40*

7.6.2 Matlab Function "device"

Its output dimension is constant i.e. 3 ,because device.m has 3 output values i.e.

1. Priority
2. Kilowatt Hour
3. KiloWatt (read device.m in section 7.4.4)

7.6.3 Matlab Function "rarr"

Its output dimension = no. of priorities + 1

7.6.4 Matlab Function "frarr"

If a = No. of substations of that building which have highest no. of substations

Its output dimension = [a, total no. of priorities +1], which means

- Number of rows = a
- Number of columns = total no. of priorities +1

7.6.5 Matlab Function "vec2mat"

If a = No.of substations of that building which have highest no. of substations
Its output dimension = [a, total no. of priorities] which means

- Number of rows = a
- Number of columns = total no. of priorities

Chapter 8

Results and Conclusions

8.1 Validation of Switching ON/OFF principle

The simulink model of steilshoop school has been built to take the results.This *steilshoop school* model has 5 substations and each have different no. of devices.

This section will present the results which are obtained to check the function of switch ON/OFF (Load shedding) in the simulink model of this thesis project.The Fig8.1 is showing the load values (Kilo watt) when no load management device project is connected and the input provided to LEP is assumed all "ones" means that it is assumed that all devices are ON and no load management is being done.We can also say that no load is being saved. So this figure should be similar to the figure which is plotted by using "data.csv" file(Fig8.2).

The data.csv is a file which is providing the load values (kW) of a building having no load management system

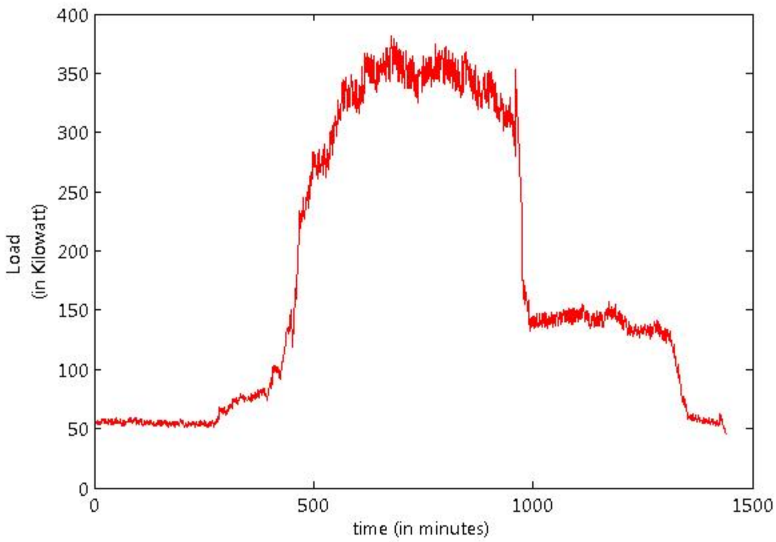


Figure 8.1: Results when all devices are assumed to be ON

- Fig 8.1→plotted using the Load values of LEP when no load management is applied and no load is being saved i.e. all devices are ON.

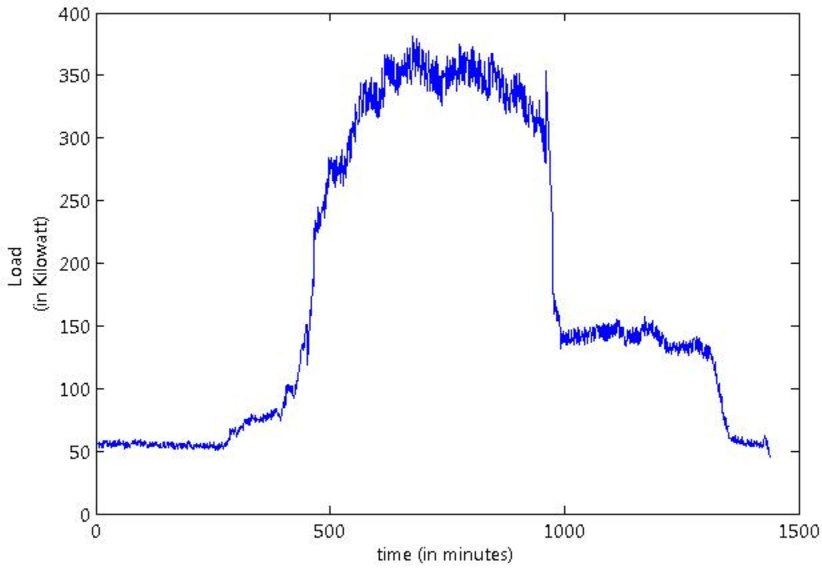


Figure 8.2: Results of plot of data.csv file taken from JBFP

- Fig 8.2→plotted using the load values of data.csv

We can see that both figures are showing the same load curves and if we plot them into one figure(Fig8.3) then we can see that there is a complete overlapping and no delay between both load curves has been observed.

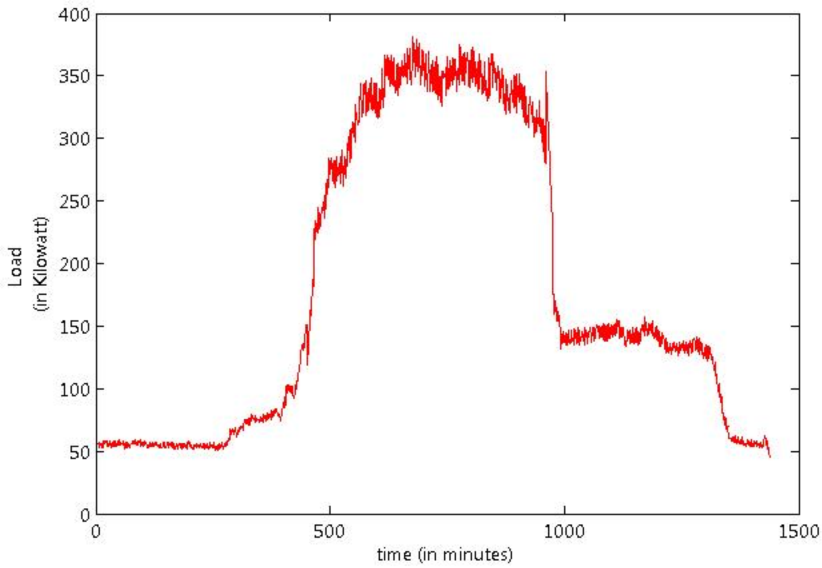


Figure 8.3: Combined Results of Fig8.1 and Fig8.2

Now it is assumed that all devices are OFF means ”zeros” are being provided to LEP. The Fig8.4 has been drawn using this assumption.One thing should be kept in mind that although zeros are being provied to LEP but the devices will run for minimum running time(mrt) and shutdown for maximum shutdown time(mst).

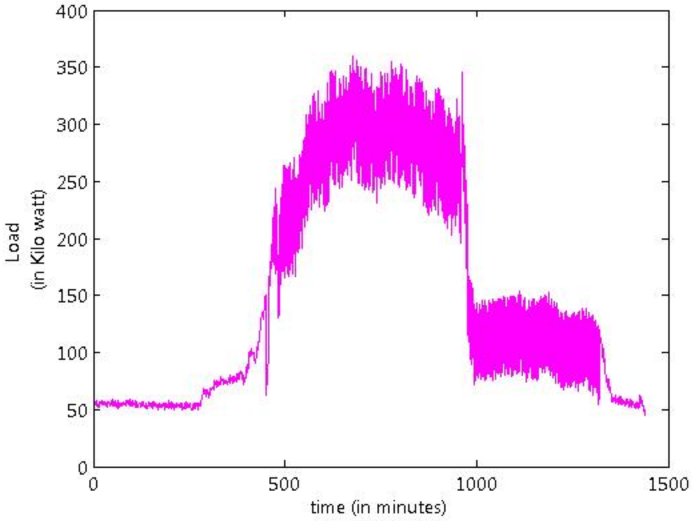


Figure 8.4: Results when all devices are assumed to be OFF or zeros are provided

If we compare the load curve of Fig 8.4 and Fig 8.1 by plotting them into one figure (Fig8.5) then we can see that load values have been reduced when all "zeros" are provided.In Fig 8.1, all devices are ON so there are high peak values but in Fig 8.4, as all devices are assumed to be OFF so peak load values are less. The comparison can bee seen in the following figure (Fig 8.5)

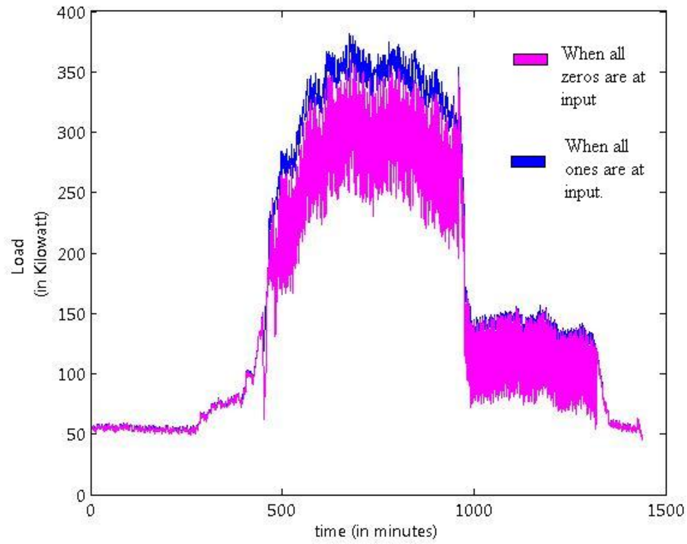


Figure 8.5: Combined Results of Fig8.1 and Fig8.4

So we can conclude from above discussion that the simulink model uesd in this thesis is switching the devices ON and/or OFF according to the provided input. The high peak load values are proving that the devices are being switched ON and low peak load values are proving that the devices are being switched OFF.So we can say that the function of switching ON/OFF of devices is performing successfully in a simulink model of this thesis.

If we calculate the area under the curve in Fig8.5 then it is about 3.9992e+004 kWh. This is a maximum amount of work which can be saved in one day in building of steilshoop school by applying Load Management System.

8.2 Validation of Work Forecasting Algorithm (WFA)

The simulink model of *steilshoop* school has been taken which have about 5 substations and each substation has different no. of devices. All are working on different timings and producing different load values. The results are complexed to explain due to many substations, devices,different timings of each devices and different load values of each device. Let us suppose that only one device is working. This assumption is made just for better and convenient understanding of results. The one more purpose of this assumption is to explain properly the results of Work Forecasting Algorithm.The name of device is Abluft Regionalsporthalle.

The valid working time of this device starts at 7:30 and ends at 22:00. It has a priority 2 and load value is 12 kW.Its minimum running (mrt) is 5 minutes and maximum shutdown time (mst) is 10 minutes.

Now we will discuss the results of a quarter which starts at 10:00 and ends at 10:14. As we are taking results in minutes so we can say that 10:00 corresponds to 600 and 10:14 corresponds to 614 where

- *600 is 1st minute of a quarter*
- *614 is a 15th minute of a quarter*

As LEP have to calculate the switchable work which can be switched OFF by LMDP in remaining quarter of an hour and output of LMDP will be implemented after a unit delay so that is why the WFA will also calculate the switchable work after one delay.At t = x, the Work Forecasting Algorithm (WFA) will start calculating the switchable work from t = x+1 till end of the quarter.

The minimum running time (mrt) of device has been elapsed before this quarter starts.So this device may be shutdown any time and may keep on running throughout the quarter depending on the input from LMDP.

At t = 600 , the WFA will calculate that how many minutes of this remaining quarter the device may be shutdown. As we are at 600 (1st minute of a quarter) so the remaining minutes of quarter starts from 601 and ends at 614 (15th minute of quarter). The switchable work in this quarter is started calculating from 601 minute..

At t = 600, the total time in which device can be shutdown is 10 minute (mst) and total load value of this device is 12 kW. so

- Switchable work at $t = 600 = 10 \times 12/60 = 2$

The device is still On beacuse LMDP is providing '1' so at next minute, the switchable work is calculated again

- Switchable work at $t = 601 = 10 \times 12/60 = 2$
- Switchable work at $t = 602 = 10 \times 12/60 = 2$
- Switchable work at $t = 603 = 10 \times 12/60 = 2$
- Switchable work at $t = 604 = 10 \times 12/60 = 2$

Now at t = 605, if we calculate that how long device may remain shutdown in remaining quarter of an hour then it will be about 9 minutes so

- Switchable work at $t = 605 = 9 \times 12/60 = 1.8$

As LMDP is providing '1' constantly so device will remain ON until it gets zero from LMDP.

The mst (maximum shutdown time) is keep on reducing as the time is passing. (see Fig6.3 for better understaning)

- Switchable work at $t = 606 = 8 \times 12/60 = 1.6$
- Switchable work at $t = 607 = 7 \times 12/60 = 1.4$
- Switchable work at $t = 608 = 6 \times 12/60 = 1.2$
- Switchable work at $t = 609 = 5 \times 12/60 = 1$
- Switchable work at $t = 610 = 4 \times 12/60 = 0.8$
- Switchable work at $t = 611 = 3 \times 12/60 = 0.6$
- Switchable work at $t = 612 = 2 \times 12/60 = 0.4$
- Switchable work at $t = 613 = 1 \times 12/60 = 0.2$
- Switchable work at $t = 614 = 10 \times 12/60 = 0$

As it is mentioned before that the calculation of switchable work at $t = x$ is done starting from $t = x + 1$but at $t = 14$ no remaining minute is left in this quarter so switchable work will be zero.The $t = 15$ is equal to $t = 0$ means beginning of next quarter.These results are attached in appendix A

Chapter 9

Future works

- Presently the JBFP and LEP exchange the data when they are on same compter. But it can be extended in a future in a way that they can exchange data even when they are not running on a same computer. JBFP can keep its data on a server and LEP can take data from that server using networking.

- There is only one Load Management system used for each building currently. In future, one central load management system for all buildings can be built up.There will be same max. allowed load limit for all buildings in that case.

- There is no option of minimum shutdown time yet. But in future, this option can be introduced.The minimum shutdown time means that the device will have to shutdown for atleast this minimum durartion of time.The device will not be able to switch ON until the minimum shutdown time is elapsed.

- Practically some devices take time in switching ON/OFF. But this extra time is not taken into this project but it can be taken into consideration in future.

- The status of Switch ON & switch OFF the devices is not visible yet in a present project but it can be visible in form of their kilowatt values and by using graphical representation in future.

- The interfacing between LEP (Load Estimation Project) and LMDP (Load Management Device Project) is not producing the exactly required results.Some tasks are being achieved e.g.

1. The data format between both projects is working fine.

2. Both projects are taking the values from each other and responding on them etc.

but still some unwanted peaks are visible.The reason of this problem has not been found out yet beacuse of shortage of time but it can be rectified in future

- The simulation time can be reduced by using different techniques (simulation can be faster) in future.

- Practically devices do not run with their full capacity but in this project, it is assumed that devices are ruuning with their full capacity.In future, a efficiency factor can be used which will tell the model to run the device with a specific efficiency in a particular time of a day. The efficiency will vary according to the time of a day. In the peak hours, devices will have higher efficiency but after that efficiency will be reduced.

Appendix A

Results of section 8.2 (WFA)

************** start **********************
current minuter is 600
current power is 3.106900e+002
current work is 5.178167
work for last minute is 83.069667
work estimate for the 15 minute is 7.767250e+001
the new matrix of switchable work is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 2 0 0 0 0 0 0
The table is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 1 0 0 0 0 0 0
*********End*****************
************** start **********************
current minuter is 601
current power is 3.288300e+002
current work is 10.658667
work for last minute is 5.178167
work estimate for the 15 minute is 8.190517e+001
the new matrix of switchable work is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 2 0 0 0 0 0 0
The table is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0
0 1 0 0 0 0 0 0
*********End*****************
************** start **********************
current minuter is 602
current power is 3.163000e+002
current work is 15.930333
work for last minute is 10.658667
work estimate for the 15 minute is 7.919033e+001
the new matrix of switchable work is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 2 0 0 0 0 0 0
The table is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 1 0 0 0 0 0 0
*********End*****************
************** start **********************
current minuter is 603
current power is 3.184000e+002
current work is 21.237000
work for last minute is 15.930333
work estimate for the 15 minute is 7.961033e+001
the new matrix of switchable work is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 2 0 0 0 0 0 0
The table is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 1 0 0 0 0 0 0
*********End*****************
************** start **********************
current minuter is 604
current power is 3.393200e+002
current work is 26.892333
work for last minute is 21.237000
work estimate for the 15 minute is 8.344567e+001
the new matrix of switchable work is

0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 2 0 0 0 0 0 0 0
The table is
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 1 0 0 0 0 0 0 0
*********End*****************
************** start **********************
current minuter is 605
current power is 3.384300e+002
current work is 32.532833
work for last minute is 26.892333
work estimate for the 15 minute is 8.329733e+001
the new matrix of switchable work is
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 1.8 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
The table is
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 1 0 0 0 0 0 0 0
*********End*****************
************** start **********************
current minuter is 606
current power is 3.386600e+002
current work is 38.177167
work for last minute is 32.532833
work estimate for the 15 minute is 8.333183e+001
the new matrix of switchable work is
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 1.6 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
The table is
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0

0 1 0 0 0 0 0 0
*********End*****************
************** start *********************
current minuter is 607
current power is 3.239600e+002
current work is 43.576500
work for last minute is 38.177167
work estimate for the 15 minute is 8.137183e+001
the new matrix of switchable work is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 1.4 0 0 0 0 0 0
0 0 0 0 0 0 0 0
The table is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 1 0 0 0 0 0 0
*********End*****************
************** start *********************
current minuter is 608
current power is 3.275100e+002
current work is 49.035000
work for last minute is 43.576500
work estimate for the 15 minute is 8.178600e+001
the new matrix of switchable work is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 1.2 0 0 0 0 0 0
0 0 0 0 0 0 0 0
The table is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 1 0 0 0 0 0 0
*********End*****************
************** start *********************
current minuter is 609
current power is 3.343900e+002
current work is 54.608167
work for last minute is 49.035000
work estimate for the 15 minute is 8.247400e+001
the new matrix of switchable work is
0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 1 0 0 0 0 0 0 0
The table is
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 1 0 0 0 0 0 0 0
*********End*****************
************** start **********************
current minuter is 610
current power is 3.556100e+002
current work is 60.535000
work for last minute is 54.608167
work estimate for the 15 minute is 8.424233e+001
the new matrix of switchable work is
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0.8 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
The table is
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 1 0 0 0 0 0 0 0
*********End*****************
************** start **********************
current minuter is 611
current power is 3.252300e+002
current work is 65.955500
work for last minute is 60.535000
work estimate for the 15 minute is 8.221700e+001
the new matrix of switchable work is
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0.6 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
The table is
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0
0 1 0 0 0 0 0 0 0

*********End*****************
************** start **********************
current minuter is 612
current power is 3.390200e+002
current work is 71.605833
work for last minute is 65.955500
work estimate for the 15 minute is 8.290650e+001
the new matrix of switchable work is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0.4 0 0 0 0 0 0
0 0 0 0 0 0 0 0
The table is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 1 0 0 0 0 0 0
*********End*****************
************** start **********************
current minuter is 613
current power is 3.268400e+002
current work is 77.053167
work for last minute is 71.605833
work estimate for the 15 minute is 8.250050e+001
the new matrix of switchable work is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0.2 0 0 0 0 0 0
0 0 0 0 0 0 0 0
The table is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 1 0 0 0 0 0 0
*********End*****************
************** start **********************
current minuter is 614
current power is 3.390300e+002
current work is 82.703667
work for last minute is 77.053167
work estimate for the 15 minute is 8.270367e+001
the new matrix of switchable work is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0

0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
The table is
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0
*********End*****************

Appendix B

Simulink models of project

The Fig B.1 is showing the simulink model of 28 buildings of Hamburg , out of which the building # 20 is (steilshoop school) is configured for this project to get the results.

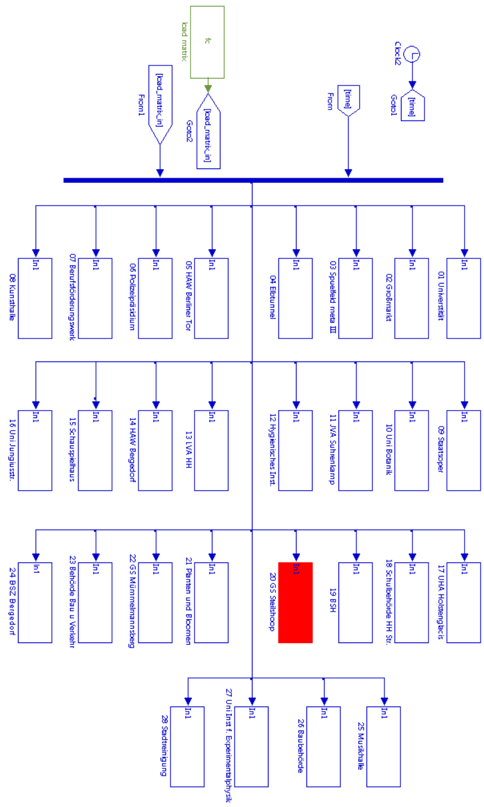


Figure B.1: A simulink model of 28 Buildings

The Fig B.2 is showing the Station level of building # 20 i.e. steilshoop school.The LMDP is conneted with LEP in this Fig B.2.

The Fig B.3 is displaying that how substations are connected with each other in a building. This is substation level of building # 20.i.e. steilshoop school.The Fig B.4 is displaying that how devices are arranged in substation of a building.The Fig B.5 is showing the arrangement of parameters of devices. These parameters are used to provide input to the Graphical user interface (GUI).

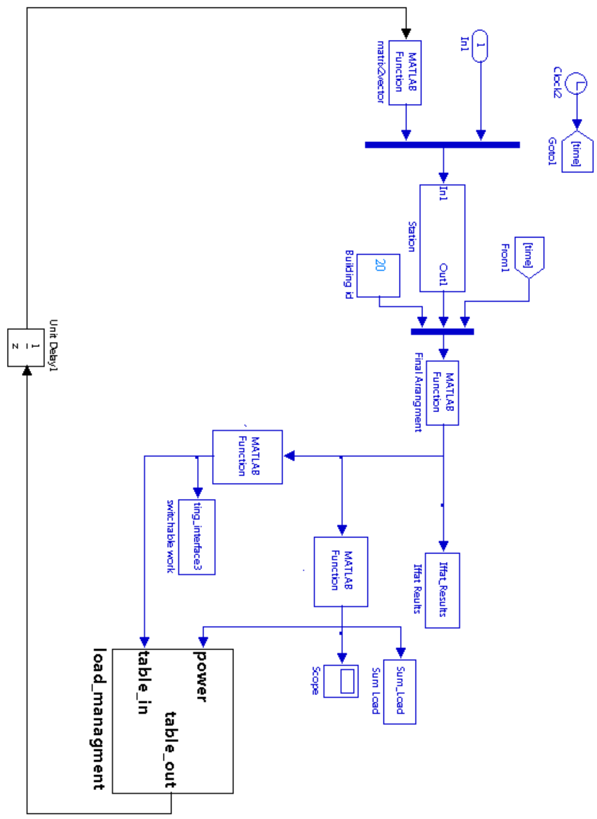


Figure B.2: Station Level of a building

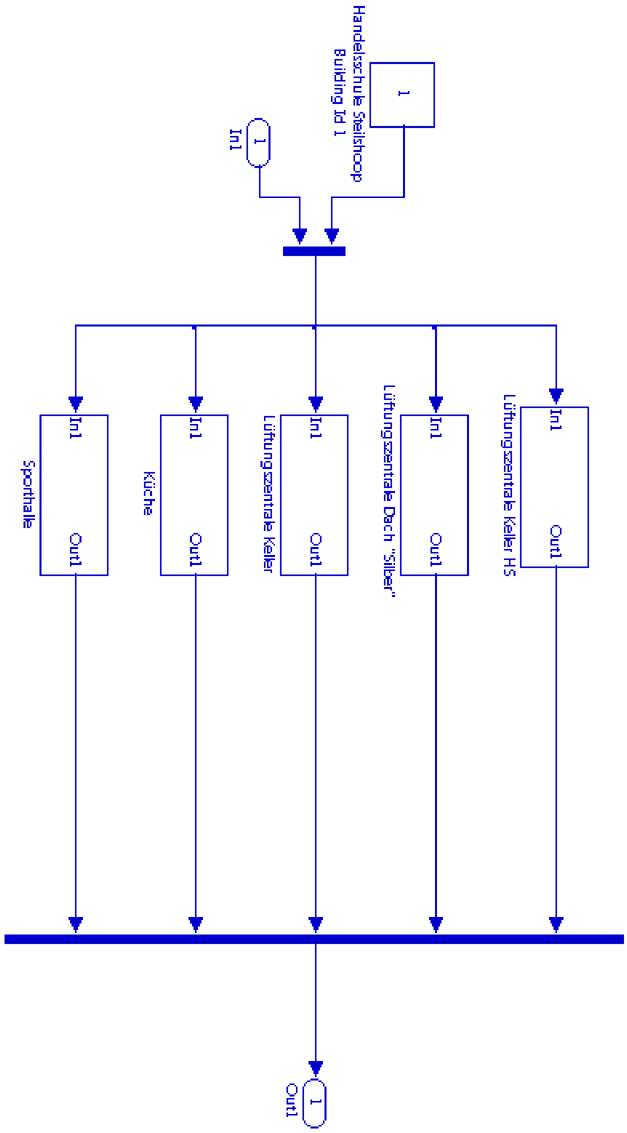


Figure B.3: Substations Level of a building

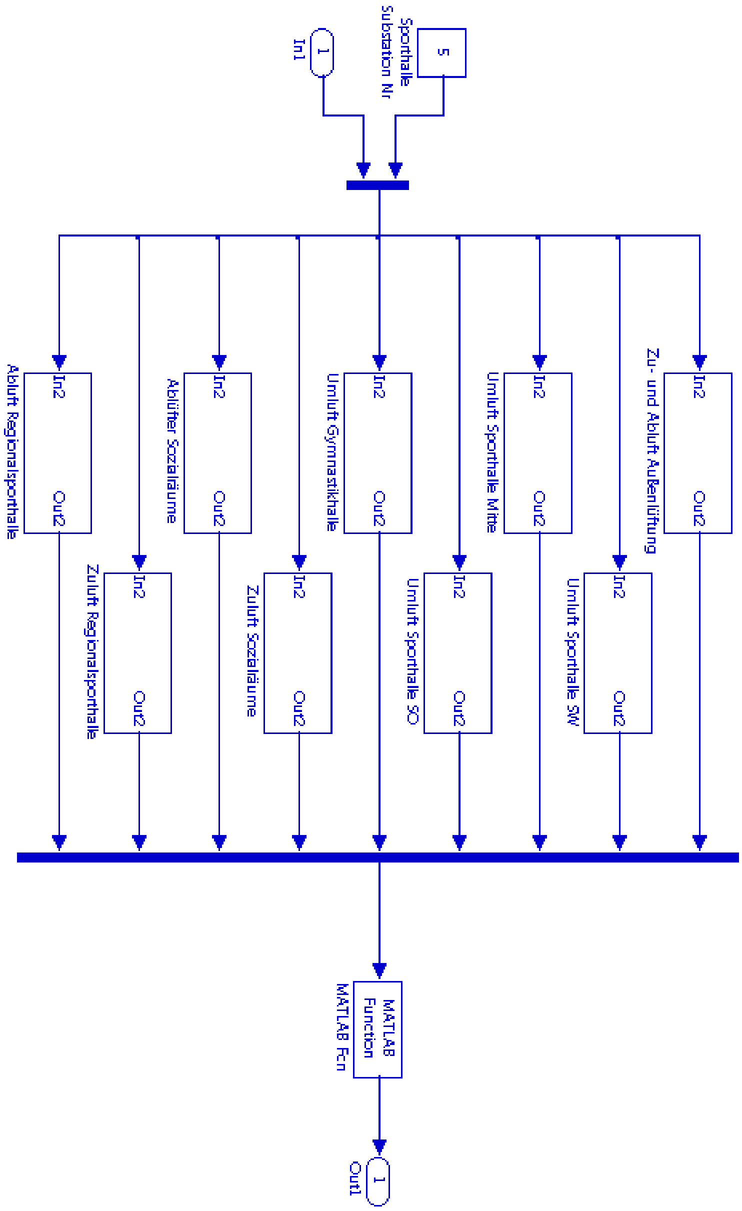


Figure B.4: Device Level of a building

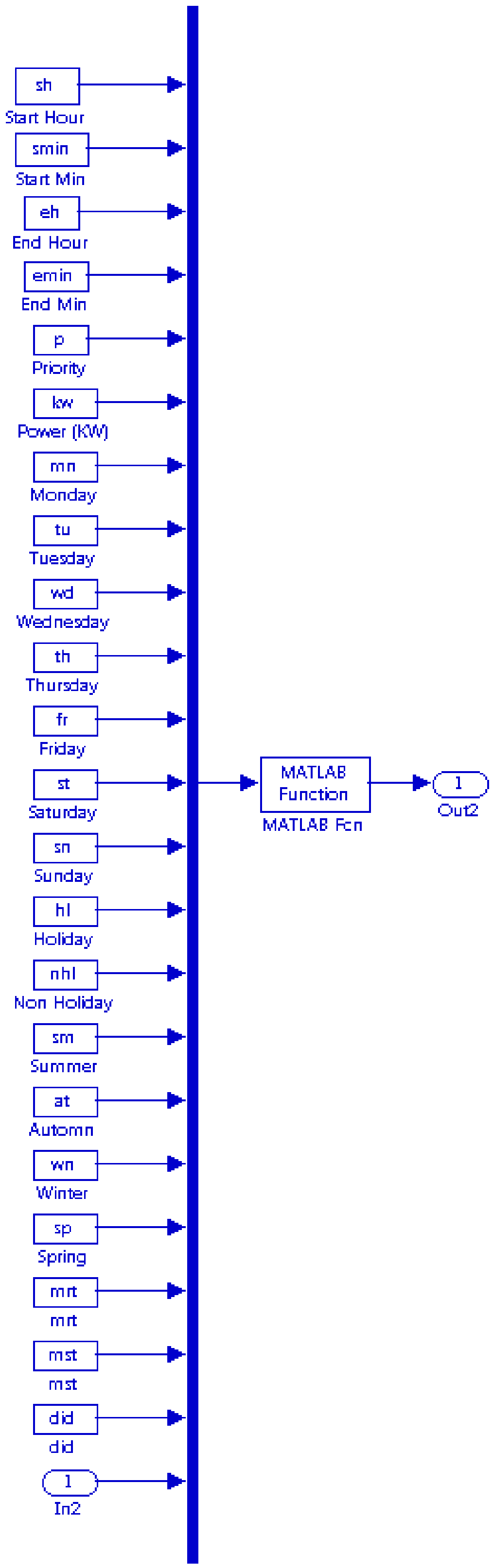


Figure B.5: Device parameters used for Graphical User Interface

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