TECHNO - ECONOMIC ANALYSIS OF BUILDING ENERGY SYSTEM WITH NET METER SOLAR PV IN SRI LANKA

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Dissertation submitted in partial fulfillment of the requirements for the Degree of Master of Science in Electrical Installations.

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DECLARATION

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Signature of the supervisor Date:

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ABSTRACT

In Sri Lanka net meter PV energy is popular in building sector and also it is promoted by the government. Every building owner would be like to have optimum energy design while minimizing the cost of energy when new buildings are at design stage. According to the 2014 Sri Lana energy balance, the energy consumption of commercial buildings accounts for about 25% of energy. So it is important to optimize consumption of fossil fuels in the building sector in order to reduce greenhouse gas emissions.

Optimum net meter solar PV capacity to be installed is depend on various factor such as tariff category, solar irradiation, building load profile, maximum demand of the building etc. Thus it is essential do analysis to decide the PV system capacity. But this analysis is tedious to do without data and expertise knowledge on high end analysis software.

In this research, a methodology is proposed to develop an optimum energy solution tool using techno- economic analysis for building energy system with net metered solar PV in Sri Lanka which are differ from load profile, tariff Scheme and the maximum demand.

The software HOMER was used to model the energy system and the simulation is validated using two actual situations.

From this research intelligent tool is developed which is very easy to use by anyone without expertise knowledge or practice to select optimum solar PV capacity to be installed and get details on investment cost, cost of energy, payback period etc. If the user cannot go for the optimum PV capacity due to the limitations on cost or area, then this tool can be used select whatever the possible feasible capacity using this tool. This developed tool have been verified considering two actual situations.

Key words: PV capacity, load profile, tariff Scheme, maximum demand, investment cost, cost of energy, payback period

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Contents

List of figures

List of tables

LIST OF ABBREVIATIONS

Abbreviation	Description
PUCSL	Public Utilities Commission of Sri Lanka
CEB	Ceylon Electricity Board
LECO	Lanka Electricity Private Limited
SLSEA	Sri Lanka Sustainable Energy Authority
kVA	kilo-Volt-Ampere
kWh	kilo Watt hour
kW	kilo Watt
PV	Photovoltaic
CoE	Cost of Energy
NPC	Net Present Cost
NREL	National Renewable Energy Laboratory
GSMB	Geological Survey and Mines Bureau

LIST OF ANNEXURES

CHAPTER 1

1 INTRODUCTION

According to 2014 Sri Lanka energy balance, the energy consumption of commercial buildings accounts for about 25% of energy use, so it is important to optimize consumption of fossil fuels in the building sector in order to reduce greenhouse gas emissions. Various types of renewable energy technologies can be considered to meet such energy demands, and net meter solar Photovoltaic is very popular in Sri Lanka.

However solar PV installation should be a feasible solution both economically and technically. Before the installation feasibility analysis should be carried out to obtain maximum outcome of it. Solar PV optimum capacity to be installed is depend on various parameters such as tariff category, solar irradiation, building load profile, maximum demand of the building etc. Thus it is essential do proper analysis to decide the PV system capacity and also good to know about the investment, cost of energy, payback period etc.

1.1 Net meter PV system

Net Metering is a policy that enables electricity customers to connect their own on-site generation system to the utility grid and receive credits on their electricity bills for their own renewable energy generation in excess of their electricity consumption that is exported to the electricity distribution network. Figure 1-1 shows an arrangement of net meter solar system.

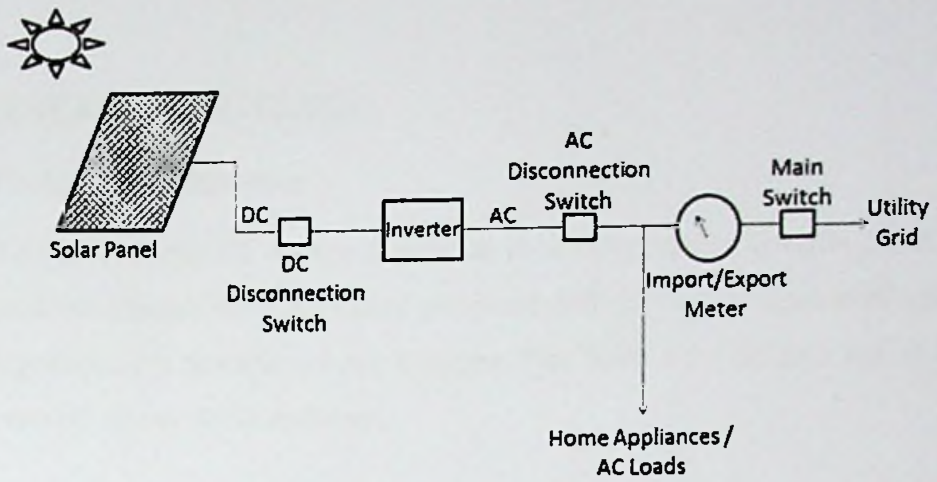


Figure 1-1 : Solar PV net metering arrangement

In the net metering, utility meter will be replaces with an import/export meter. The electrical energy is consumed from the grid is considered as import energy and electrical energy generated and supplied to the grid is considered as export energy. At the end of each monthly billing period, the electricity bill is prepared giving credit to the export and charging the consumer for the difference between the import and the export. If the export is more than the import in any billing period, the excess electricity can carry forward to use for their consumption requirements in the future. For a multi-tier tariff consumer, the energy balancing is carried out within each tariff-tier and credit in one tier is not transferable to another tier.

1.2 Electricity load profile in buildings

Load profile is a graph of the variation in the electrical load versus time. A load profile will vary according to customer type such as residential, commercial and industrial. Load profile represents the loading pattern of various electrical loads belong to an electrical installation. When consider the Sri Lankan buildings there are several load profile based on the purpose of that building usage such as office buildings, super markets, fashion outlets, banks, hospitals, hotels, prisons etc. Those variation details are obtained from a previous research [12].

CHAPTER 2

2 RESEARCH OUTLINE

2.1 Problem Identification

In Sri Lanka net meter PV energy is popular in building sector towards green energy concept. Even though there are many computer software tools capable of analyzing the integration of renewable energy systems, they need a lot of data and should be expert enough to use those software.

There are many computer software tools capable of analyzing the integration of renewable energy systems. For all those software need various parameters as inputs such as tariff data, solar irradiation levels, PV system cost, load variation pattern and etc. In general, design process can be divided into two parts: conceptual design and detailed design. At the conceptual design stage of a building it is tedious to do such analysis using those high end software. Instead if we can have a user friendly method which gives optimum combination of net meter PV system with important factors such as cost of energy, installation cost, payback period & etc, it will be really helpful at the conceptual design stage. Results of analyses from the conceptual design can be used as input information for the detailed design.

There are few simple tools developed to find out feasible net meter solar system only for the domestic sector. One tool is developed by Sri Lanka sustainable energy authority (SLSEA) which make an intelligent choice to go for the most economical net meter solar panel system based on investment and average electricity bill. But this is only for residential building and has no optimization. Some other simple online calculations are offered by solar installation companies in Sri Lanka such as St Anthony's Solar, J Lanka technologies, BAM green etc. All most all those consider only the domestic sector.

When consider the commercial buildings and others, optimum solar PV capacity to be installed is depend on tariff category, solar irradiation, building load profile, maximum demand of the building etc. But there is no simple tool to analyze the feasibility of PV installation and its outcomes for commercial buildings without high-end software and expertise practice.

2.2 Objective

Objective is to develop an optimum energy solution tool using techno- economic analysis for building energy system with net meter solar PV in Sri Lanka which differ from load profile (Cluster), tariff Scheme and the maximum demand.

2.3 Research Boundaries

The outcome of this research is only applicable for bulk installations. This is not applicable for domestic sector electrical installations. Also this is not applicable for multi category electrical installations which are consisted as retail type domestic, commercial and hotel electrical installations (electrical installations where its contract demand is above 42 kVA). Also, this is not applicable the transformers which are used for distribution purposes.

Sri Lankan government recently introduced a concept called "Battle for solar energy" which has three options; net metering, net accounting and net plus.

- Net metering: To continue the existing net metering system. No payment will be made for the excess electricity produced. But the excess electricity can carry forward to use for their consumption requirements in the future
- Net accounting: To make a payment for excess electricity at a rate of Rs.22/- per unit during the first 07 years and Rs.15.50 for the period of 8-15 year
- Net plus: Electricity producers using rooftop solar panels will be paid Rs.22/- per unit during the first 07 years and Rs.15.50 per unit for the period 08-20 years. Unlike in the net metering system, the electricity production and the consumption are independent. Accordingly customers have to pay for their consumption according to the tariff of that time and the electricity board will pay for the units of electricity produced under the above tariff

But in this research only the first concept is considered.

For the development of this tool power factor is assumed as 0.8

2.4 Literature Review

Numbers of research papers, journals, magazines, e books were referred to find out related similar work done on this topic and find out an approach to carry out this research.

Researches are done to provide methods to analyze reliable electricity and identify optimal systems with renewable energy [1]. But considered only a single case like a village or a city and not consumer based.

Even though most researches are done to optimize renewable energy capacities in standalone systems, there are many researches done to find out optimal renewable energy system parameters including solar PV also for grid connected systems [2], [3], [4]. But in many of researches only single load variation and tariff scheme is considered. They are like case studies and no tool was developed to have general idea for different cases. [7], [9], [10].

There are few tools developed nationally and internationally to find out energy system parameters such as capital cost, payback period. But they have limitations such as considered only a single category (Ex: Residential), no load variation pattern is considered etc. SLSEA has developed a tool which make an intelligent choice and go for the most economical net metered solar panel system based on investment and average electricity bill. This tool has no capability to decide the optimum system capacities. And also it considered residential buildings only and also not considered load variation pattern.

2.5 Methodology

For the timely completion of the research, the work flow was arranged in the manner given below.

2.5.1 Literature Survey

Under the literature survey, literatures in relation to hybrid energy systems, net meter PV systems, existing optimum energy solution tool in Sri Lanka were referred. Some of the papers contained hybrid energy system analysis where the software package

HOMER was used. The findings of the literature survey and other related information were discussed in section 2.4.

2.5.2 Model proposal

Figure 2-1 shows the proposed model which contains three selectable inputs, a database and an output. The first input; Type of building (cluster) is based on the load variation pattern of the building as Commercial, Office, Hotel etc (12 clusters with load curve are considered), the second input; tariff category is based on applicable tariff scheme on Commercial, Office, Hotel tariff schemes (GV2, GP2 & H2 are considered; details are annexed in annexure 2) and the third input is the maximum load demand range of the building. Optimization model contains a database which contain optimized net meter solar PV system parameters which are analyzed using a micro power system optimization software.

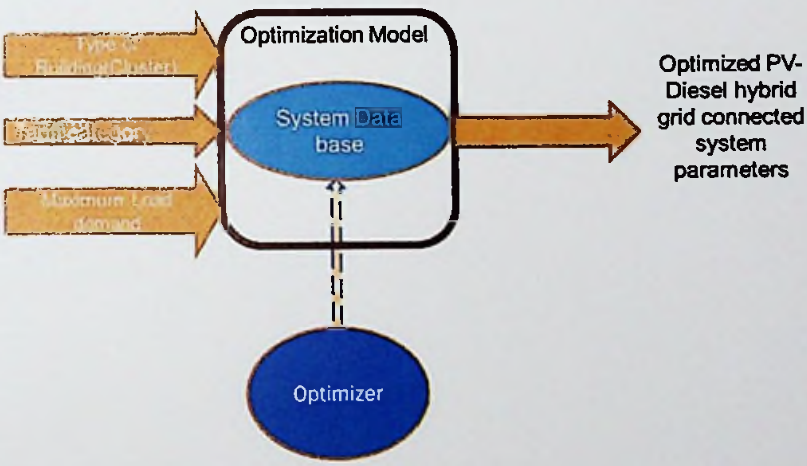


Figure 2-1: Proposed model

2.5.3 Identifying and collecting necessary data for modeling in HOMER

In preparation of the model, HOMER needs a large number of input data. The required input data relates to technical, financial and economic parameters of fuels, technologies and new investment options. Some of the input data for the model was extracted (and some were adjusted so that they are in line with the software package HOMER) from published documents by responsible government institutions of Sri Lanka including Ceylon Electricity Board , Public Utilities Commission of Sri Lanka and SLSEA. Some of the information was directly requested from respective institutions. (e.g.: information related to solar PV was directly requested from companies involving with solar PV installation). Table 2-1 summarize data collected from respective companies.

Component	Size (kW)	Capital cost ($)	Replacement cost ($)	O & M cost ($)	Lifetime
Generator	40	10345	6207	9	6000 hrs
	80	16552	9931	17	
	200	32414	19448	36	
	320	46897	28138	53	
	400	56552	33931	71	
	512	79310	47586	95	
	600	95172	57103	103	
	656	103448	62069	110	
	800	124138	74483	137	
PV	1	2500	2500	0	20 years
	10	10300	10300	0	
	30	27300	27300	0	
Converter	1	550	550	0	15 years
	10	3500	3500	0	
	15	4200	4200	0	
	30	8275	8275	0	

Table 2-1 : System component considered for simulation

2.5.4 Modeling and simulation

A base case was developed and was run. Grid connected net meter system for various buildings were modeled using the software package HOMER. Chapter 3 gives a comprehensive description in this regard.

2.5.5 Simulation validation

The simulation in this research were validated by comparing simulation results with two actual situations. Chapter 6 gives a comprehensive description in this regard.

2.5.6 Various system analysis

A base case was developed and run. Then another 114 cases were modeled by changing the parameters of base model such as tariff category, load curve (cluster type) and maximum load demand. Figure 2-3 shows all analyzed cases. Table 2-2 describes all the clusters with sample installations.

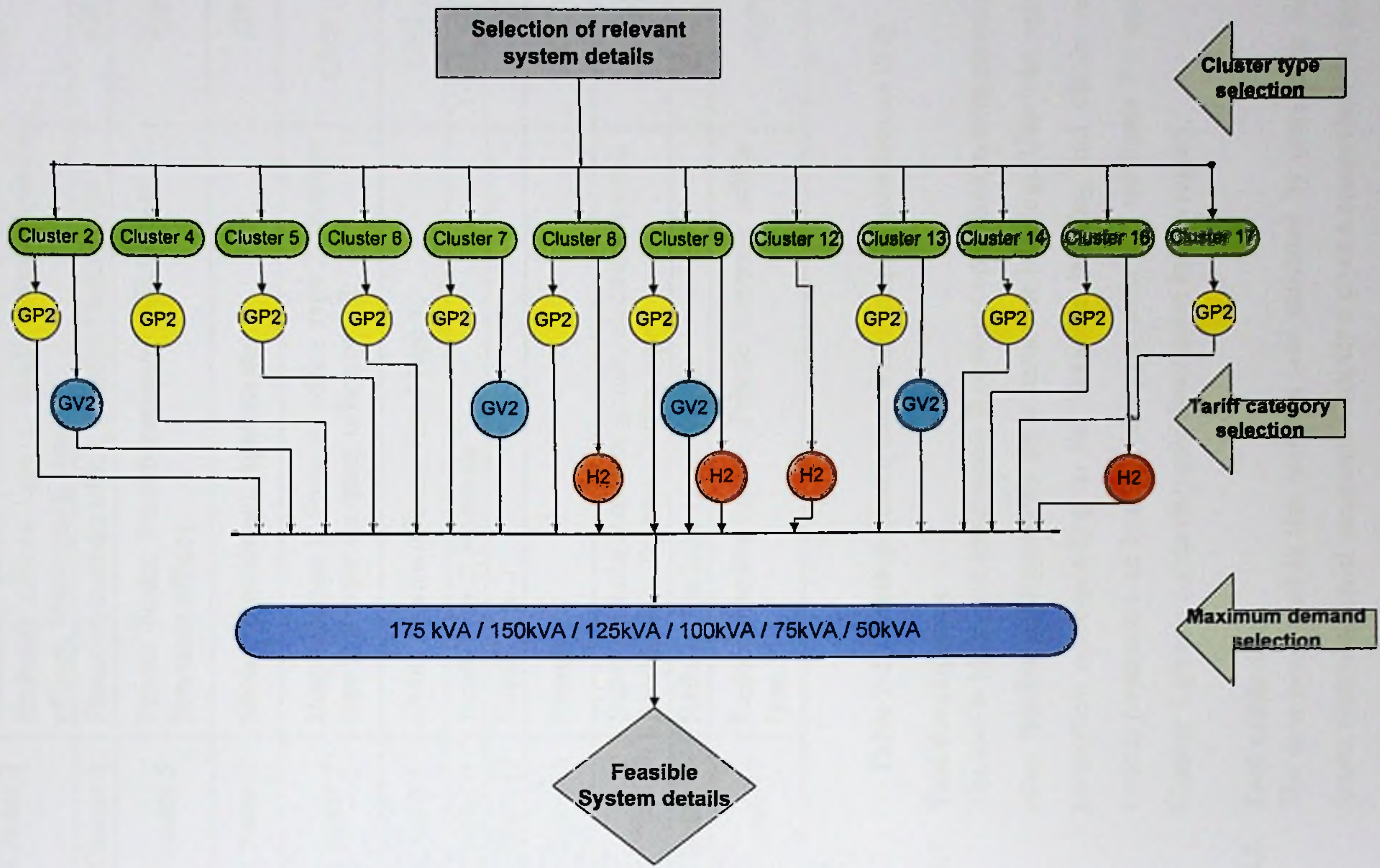


Figure 2-2 : Analyzed cases for database development

Cluster	Example installations	Possible tariff categories
Cluster 2	Government banks, Government offices, University faculty , Educational Institute type 1 , Embassy offices type 1, High commissioner's offices, Municipal Councils	GV2 , GP2
Cluster 4	Financial institute office, Fashion Outlets type 1	GP2
Cluster 5	Private banks, Private company offices type 1, Insurance offices	GP2
Cluster 6	Show rooms(shoes), Apartments	GP2
Cluster 7	Hospitals type 1, Embassy office type 2, Institute type 2, Private company office type 2	GV2 , GP2
Cluster 8	Utility service officers, Hotel type 1	GP2 , H2
Cluster 9	Hotels type 2, Hospitals	GV2, GP2 , H2
Cluster 12	Hotels type 3	H2
Cluster 13	Prisons	GV2 , GP2
Cluster 14	Super markets(consumer goods, electrical items), Food outlets, Fashion Outlets type 2	GP2
Cluster 16	Railway Stations, Hotel type 4	GP2 , H2
Cluster 17	Fashion Outlets type 3, Private company office type 3	GP2

Table 2-2 : Cluster description with sample installations [12]

2.5.7 Tool development

The tool is Microsoft excel based. It contains optimized system parameters and other feasible configurations for a particular building. User can select input parameters corresponding to the available building and obtain intelligent system parameters on building energy system and net meter PV installation. Chapter 5 gives a comprehensive description in this regard.

2.5.8 Tool validation

The developed tool in this research was validated by comparing simulation results with two actual situations. Chapter 6 gives a comprehensive description in this regard.

CHAPTER 3

3 HOMER SIMULATION

3.1 Software introduction

The HOMER Micro-power Optimization Model is a computer model developed by the U.S. National Renewable Energy Laboratory to assist in the design of micro-power systems and to facilitate the comparison of power generation technologies across a wide range of applications.

HOMER simulation process serves two purposes. First, it determines whether the system is feasible considering the system to be feasible if it can adequately serve the loads and satisfy any other constraints imposed by the user. Second, it estimates the life-cycle cost of the system, which is the total cost of installing and operating the system over its lifetime. HOMER models a particular system configuration by performing an hourly time series simulation of its operation over one year. It allows the modeler to compare many different design options based on their technical and economic merits. Figure 3-1 shows the schematic diagram of HOMER simulation software.

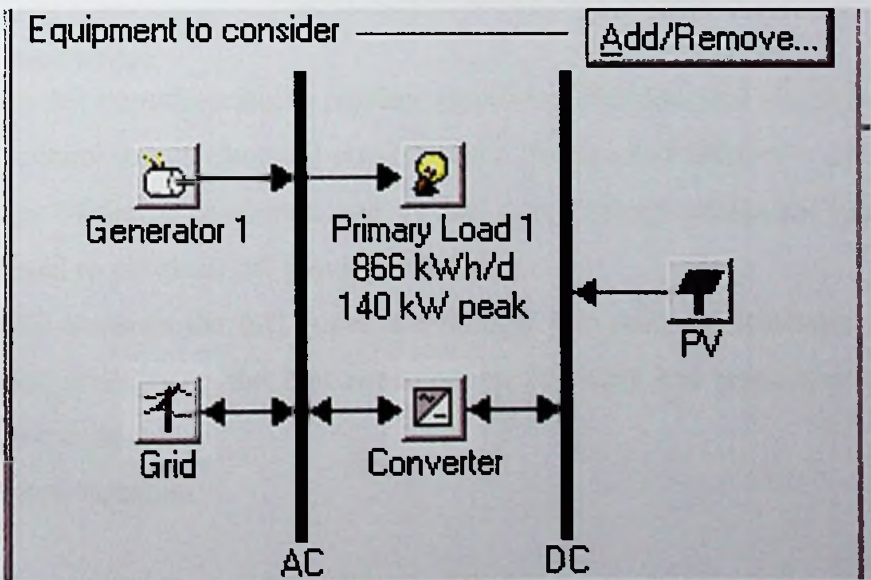


Figure 3-1 : Schematic diagram in HOMER simulation

3.2 Primary load

Primary Load is electrical demand that the power system must meet at a specific time. A single 24-hour profile of primary load in kilowatts as shown in the figure 3-2, can be specified that applies throughout the year. HOMER adds a user-specified amount of randomness to synthesized load data so that every day's load pattern is unique.

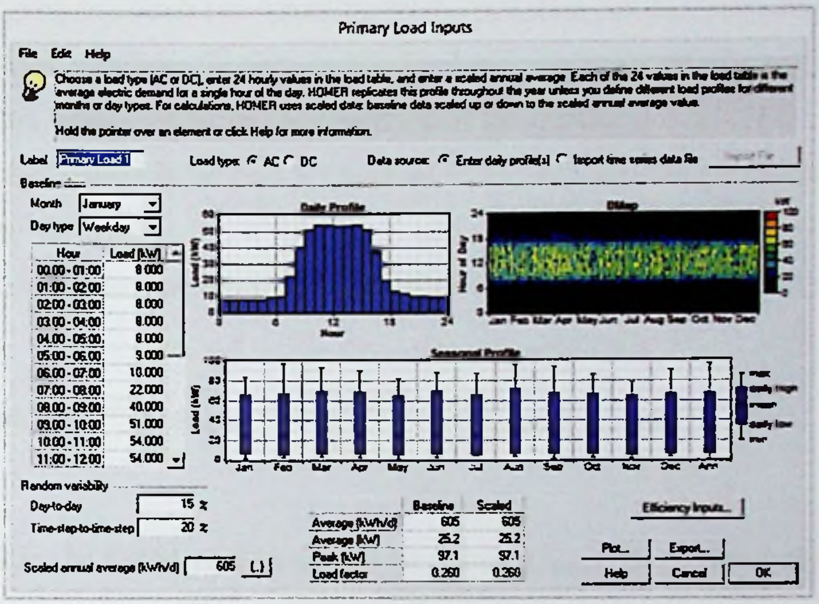


Figure 3-2: Primary load inputs

3.3 Generator

A generator consumes fuel to produce electricity. The principal physical properties of the generator are its electrical power output, its expected lifetime in operating hours, the type of fuel it consumes, and its fuel curve, which relates the quantity of fuel consumed to the electrical power produced.

HOMER assumes the fuel curve is a straight line with a y-intercept. Fuel curve is obtained considering the fuel consumption per hour and respective output power generation capability.

Fuel curve equation,

$$F = F_0 Y_{gen} + F_1 P_{gen}$$

Where F_0 is the fuel curve intercept coefficient, F_1 is the fuel curve slope, Y_{gen} the rated capacity of the generator (kW), and P_{gen} the electrical output of the generator (kW). If the fuel is denominated in liters, the units of F are L/h.

Figure 3-3 shows the input window for generator in HOMER. The user specifies the generator's initial capital cost in dollars, replacement cost in dollars, and annual O&M cost (without fuel) in dollars per operating hour. As it does for all dispatchable power sources, HOMER calculates the generator's fixed and marginal cost of energy and uses that information when simulating the operation of the system.

The fixed cost of energy is the cost per hour of simply running the generator, without producing any electricity.

HOMER uses the following equation to calculate the generator's fixed cost of energy

$$c_{\text{gen,fixed}} = c_{\text{om,gen}} + \frac{C_{\text{rep,gen}}}{R_{\text{gen}}} + F_0 Y_{\text{gen}} c_{\text{fuel,eff}}$$

where $C_{om;gen}$ is the O&M cost in dollars per hour, $C_{rep;gen}$ the replacement cost in dollars, R_{gen} the generator lifetime in hours, F_0 the fuel curve intercept coefficient in quantity of fuel per hour per kilowatt, Y_{gen} the capacity of the generator (kW), and $C_{fuel;eff}$ the effective price of fuel in dollars per quantity of fuel.

The marginal cost of energy is the additional cost per kilowatt-hour of producing electricity from that generator.

HOMER calculates the marginal cost of energy of the generator using the following equation:

$$c_{\text{gen,mar}} = F_1 c_{\text{fuel,eff}}$$

where F1 is the fuel curve slope in quantity of fuel per hour per kWh and $C_{fuel;eff}$ is the effective price of fuel in dollars per quantity of fuel.

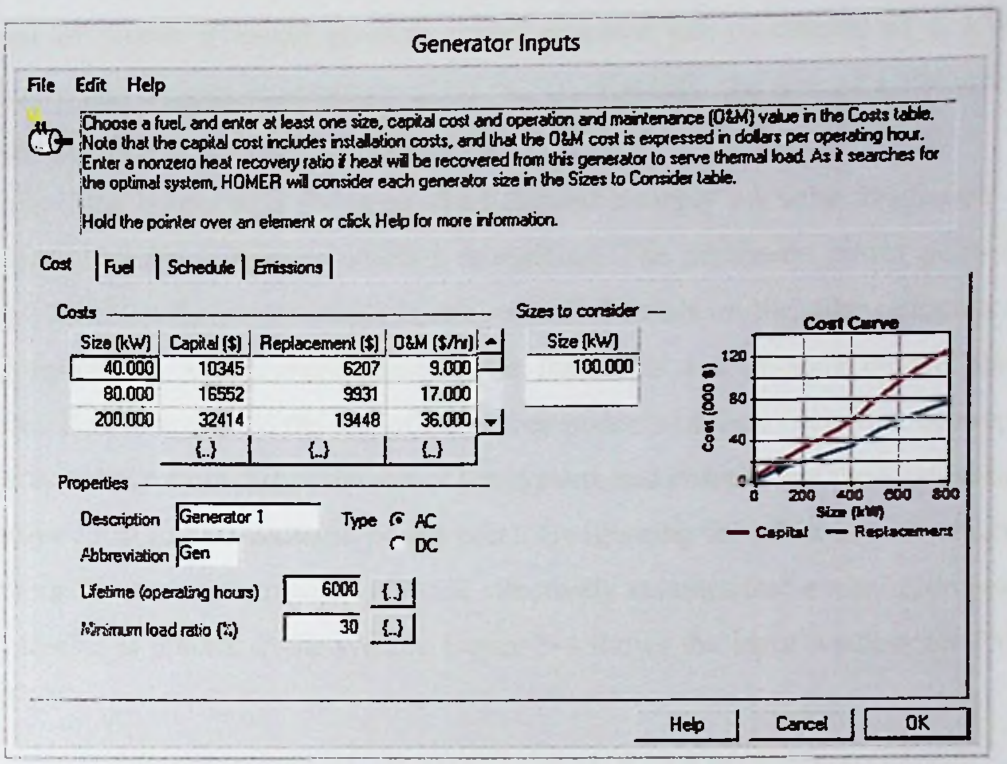


Figure 3-3 : Generator inputs

3.4 PV

HOMER models the PV array as a device that produces dc electricity in direct proportion to the global solar radiation incident upon it, independent of its temperature and the voltage to which it is exposed.

HOMER calculates the power output of the PV array using the equation,

$$P_{PV} = f_{PV} Y_{PV} \frac{I_T}{I_S}$$

Where, f_{PV} is the PV derating factor, Y_{PV} the rated capacity of the PV array (kW), I_T the global solar radiation incident on the surface of the PV array (kW/m^2), and I_S is 1 kW/m2, which is the standard amount of radiation used to rate the capacity of the PV array.

The rated capacity (sometimes called the peak capacity) of a PV array is the amount of power it would produce under standard test conditions of 1 kW/m^2 irradiance and a panel temperature of 25 ^{0}C. In HOMER, the size of a PV array is always specified in terms of rated capacity.

In reality, the output of a PV array does depend strongly on solar irradiation and nonlinearly on the voltage to which it is exposed. The maximum power point (the voltage at which the power output is maximized) depends on the solar radiation and the temperature. A maximum power point tracker is a solid-state device placed between the PV array and the rest of the dc components of the system that decouples the array voltage from that of the rest of the system, and ensures that the array voltage is always equal to the maximum power point. By ignoring the effect of the voltage to which the PV array is exposed, HOMER effectively assumes that a maximum power point tracker is present in the system. Figure 3-4 shows the input window for PV in HOMER.

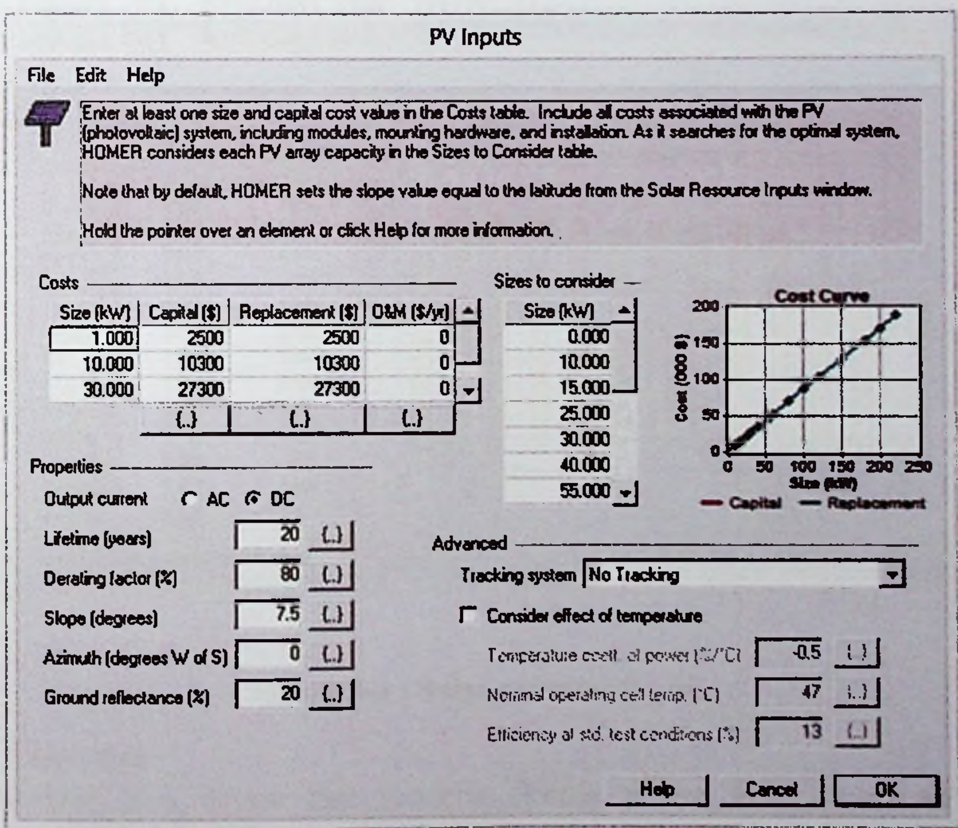


Figure 3-4 : PV inputs

3.4.1 Solar resource

To model a system containing a PV array, the HOMER user must provide solar resource data for the location of interest. Solar resource data indicate the amount of global solar radiation (beam radiation coming directly from the sun, plus diffuse radiation coming from all parts of the sky) that strikes Earth's surface in a typical year. HOMER generates synthetic hourly global solar radiation data using an algorithm developed by Graham and Hollands [15]. The inputs to this algorithm are the monthly average solar radiation values and the latitude. Figure 3-5 shows the input window for solar resource inputs.

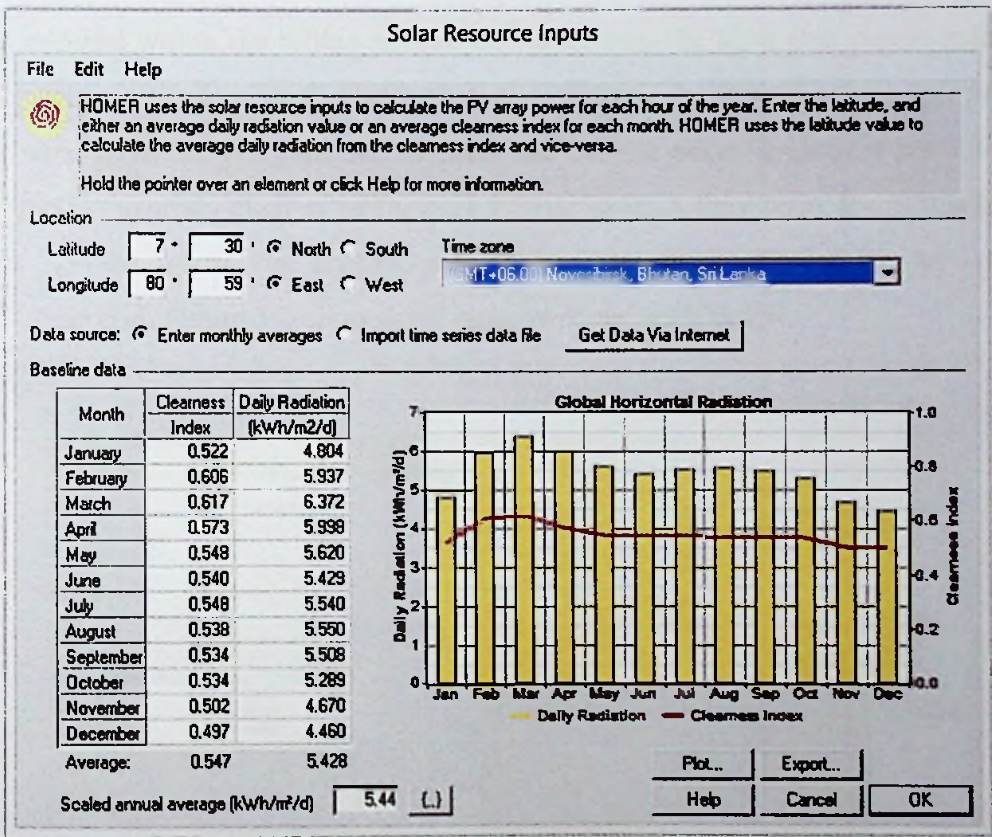


Figure 3-5 : Solar resource inputs

3.5 Converter

A converter is a device that converts electric power from dc to ac in a process called inversion, and/or from ac to dc in a process called rectification. The user specifies the inverter capacity, which is the maximum amount of

AC power that the device can produce by rectifying DC power, as a percentage of the inverter capacity. The inverter capacity is therefore not a separate decision variable. HOMER assumes that the inverter and rectifier capacities are not surge capacities that the device can withstand for only short periods of time, but rather, continuous capacities that the device can withstand for as long as necessary.

3.6 Grid

HOMER models the grid as a component from which the micro-power system can purchase ac electricity and to which the system can sell ac electricity. The cost of purchasing power from the grid can comprise an energy charge based on the amount of energy purchased in a billing period and a demand charge based on the peak demand within the billing period. HOMER uses the term grid power price for the price (in dollars per kWh) that the electric utility charges for energy purchased from the grid, and the demand rate for the price (in dollars per kilowatt per month) the utility charges for the peak grid demand. A third term, the sellback rate, refers to the price (in dollars per kWh) that the utility pays for power sold to the grid. Figure 3-6 shows grid input window in HOMER.

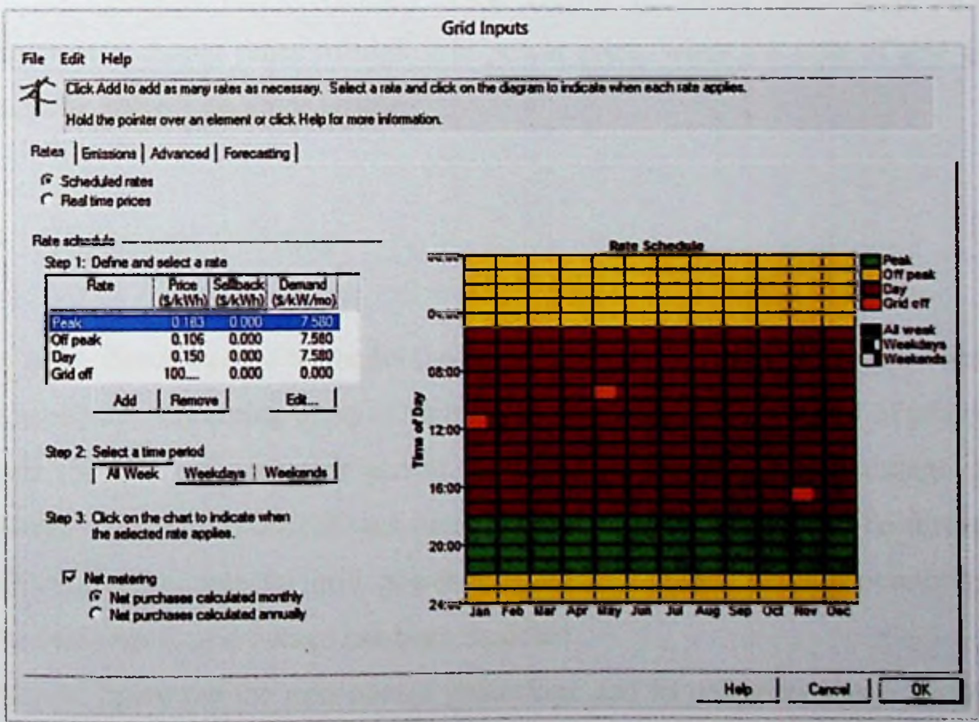


Figure 3-6 : Grid inputs

HOMER can also model net metering, a billing arrangement whereby the utility charges the customer based on the net grid purchases (purchases minus sales) over the billing period. Under net metering, if purchases exceed sales over the billing period, the consumer pays the utility an amount equal to the net grid purchases times the grid power cost. If sales exceed purchases over the billing period, the utility pays the consumer an amount equal to the net grid sales (sales minus purchases) times the sellback rate, which is often zero. The billing period is one month.

The maximum grid demand is the maximum amount of power that can be drawn from the grid. It is a decision variable because of the effect of demand charges. HOMER does not explicitly consider the demand rate in its hour-by-hour decisions as to how to control the power system; it simply calculates the demand charge at the end of each simulation. As a result, when modeling a grid-connected generator, HOMER will not turn on the generator simply to save demand charges. But it will turn on a generator whenever the load exceeds the maximum grid demand. The maximum grid demand therefore acts as a control parameter that affects the operation and economics of the system. HOMER may choose to run a generator only during times of high grid power price, when the cost of grid power exceeds the cost of generator power.

3.6.1 Grid outage modeling

There is no direct method to model the grid outage in HOMER. HOMER choose to run a generator only during times of high grid power price, when the cost of grid power exceeds the cost of generator power. In order to model the grid outage above mentioned feature in HOMER was used. By making the generator to be forced and introducing higher rate for grid power as compared with cost of generator power during that period, grid outage has been modeled.

In order to figure out the grid outage percentage and its occurrence two studies are done for real situations.

The first study is on grid outages considering the data on standby generator operation (2015) at Geological survey & mines bureau – Pitakotte. Figure 3-7 shows total grid outage hours in Pitakotte during weekdays and weekends in 2015.

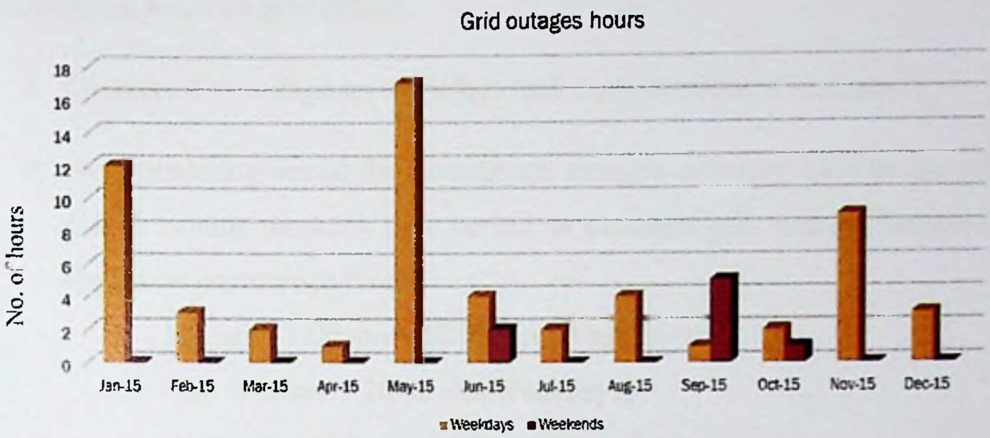


Figure 3-7 : Grid outage in year 2015

- Total rounded down time in 2015 weekdays = 60 hours
- Down time as a percentage in weekdays = 60/ (263*24) = 1%
- Total rounded down time in 2015 weekends = 8 hours
- Down time as a percentage in weekends = 8/ (102*24) = 0.3%

The second study is on grid outages considering the data on standby generator operation (2016) at "Suhurupaya", Baththaramulla. Figure 3-8 shows total grid outage hours at Baththaramulla during weekdays and weekends in the first quarter of 2016.

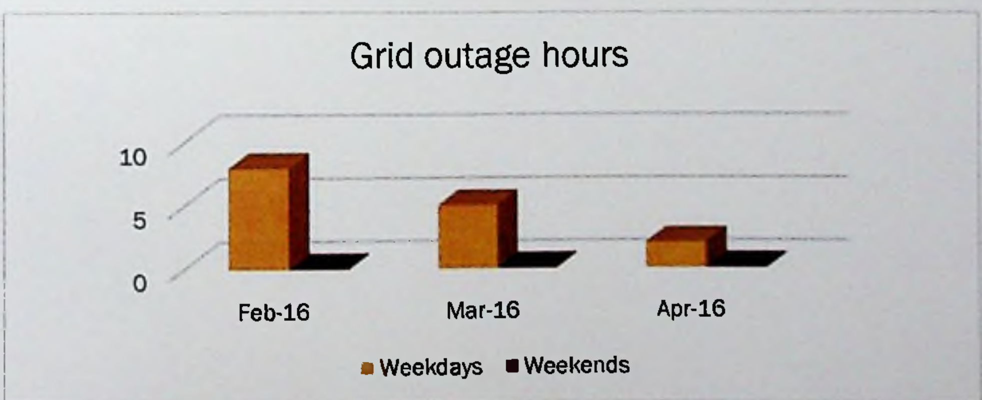


Figure 3-8 : Grid outage in 2016

- ➢ Total rounded down time in 2016 weekdays = 15 hours (February- April)
- ➢ Down time as a percentage in weekdays = 15/ (65*24) = 1%
- ➢ Total rounded down time in 2016 weekdays = 0 hours (February- April)
- ➢ Down time as a percentage in weekends = 0 %

Assumptions made on grid outage,

- ✖ Consider 1 % outage on weekdays and neglect weekend outages.
- ✖ By considering actual data maximum outages occurred months are selected. Use 3 months weekday time period to simulate grid outage. Selected hours (based on occurrence time):
    - o January 11.00 am – 12.00 pm (Weekdays)
    - o May 9.00 am – 10.00 am(Weekdays)
    - o November 4.00 pm- 5.00 pm(Weekdays)

Based on these assumptions generator and grid inputs are adjusted as shown in the figure 3-9. Tariff category is introduced as grid off with high and generator is forced ON during that that period.

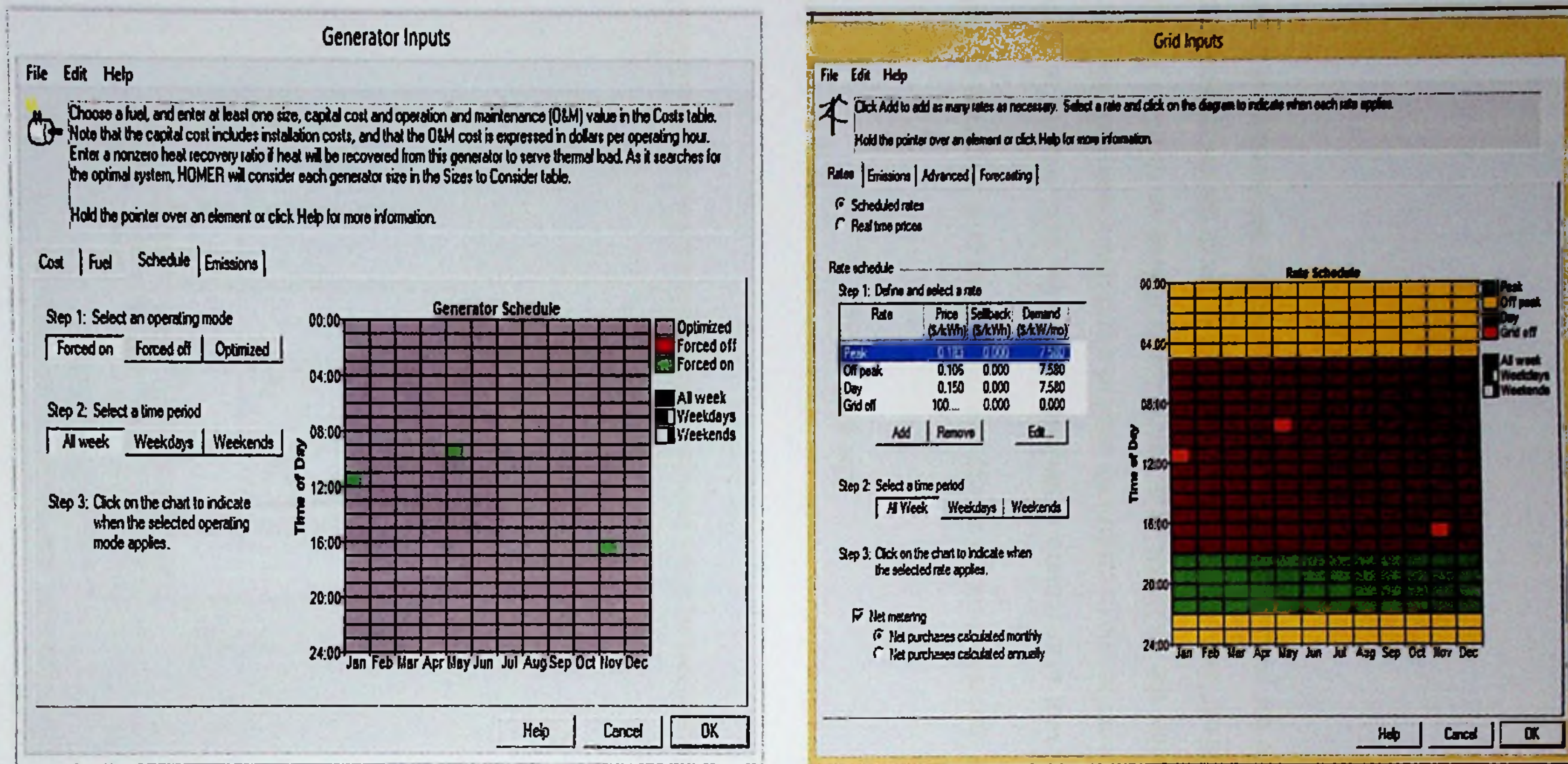
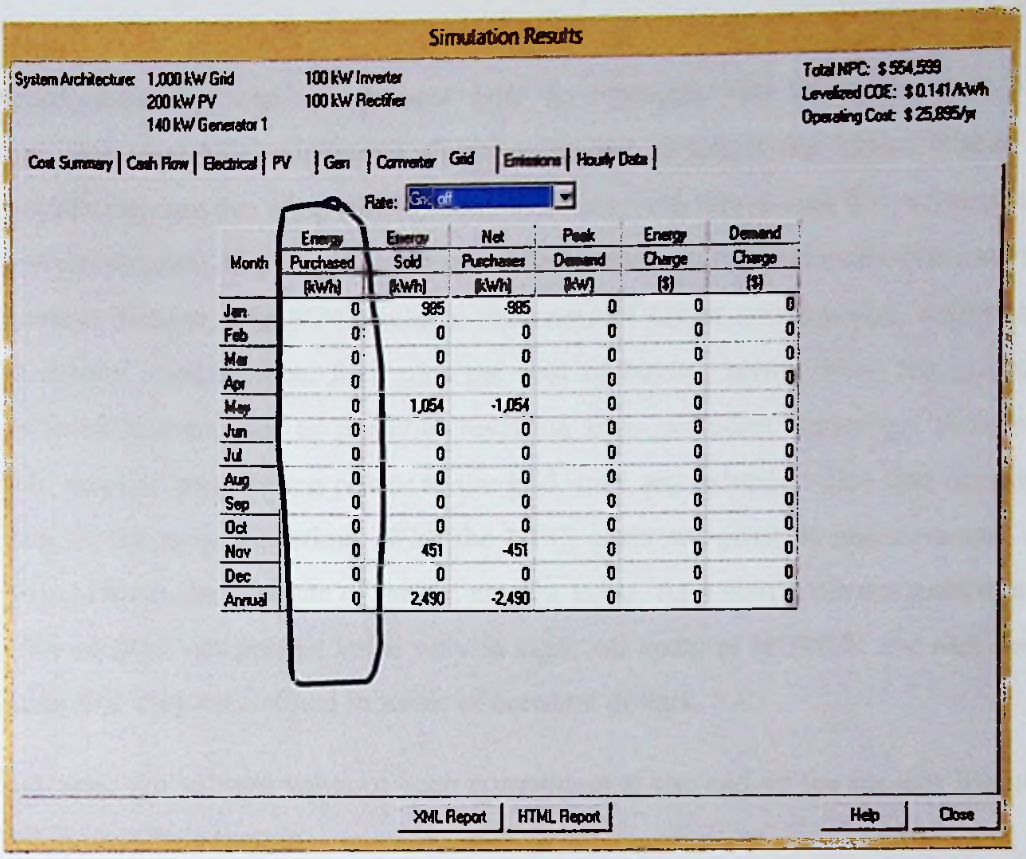


Figure 3-9 : Grid outage modeling in HOMER



Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)	Peak Demand (kW)	Energy Charge ($)	Demand Charge ($)
Jan	0	985	-985	0	0	0
Feb	0	0	0	0	0	0
Mar	0	0	0	0	0	0
Apr	0	0	0	0	0	0
May	0	1,054	-1,054	0	0	0
Jun	0	0	0	0	0	0
Jul	0	0	0	0	0	0
Aug	0	0	0	0	0	0
Sep	0	0	0	0	0	0
Oct	0	0	0	0	0	0
Nov	0	451	-451	0	0	0
Dec	0	0	0	0	0	0
Annual	0	2,490	-2,490	0	0	0

Figure 3-10 : Simulation results which shows zero energy purchase from when the grid outage

Figure 3-10 shows that the no energy purchased from grid under the grid off tariff.

- ✖ This will also require a modification of the grid feed-in tariff schedule to prevent the sale of electricity back to a grid that is not available. We do this by altering the HOMER grid inputs for grid feed in tariff to be $0 when the "Grid off" is scheduled. So this will not effect to the net present cost. It affects to the net purchases figure. This parameter has not considered in this research.

3.7 Economic modeling

HOMER uses the total net present cost to represent the life-cycle cost of a system. The total NPC condenses all the costs and revenues that occur within the project lifetime into one lump sum in today's dollars, with future cash flows discounted back to the present using the discount rate. The modeler specifies the discount rate and the project lifetime. The NPC includes the costs of initial construction, component replacements, maintenance, fuel, plus the cost of buying power from the grid and miscellaneous costs such as penalties resulting from pollutant emissions. Revenues include income from selling power to the grid, plus any salvage value that occurs at the end of the project lifetime. With the NPC, costs are positive and revenues are negative. This is the opposite of the net present value. As a result, the net present cost is different from net present value only in sign. All costs in HOMER are real costs, meaning that they are defined in terms of constant dollars.

To calculate the salvage value of each component at the end of the project lifetime, HOMER uses the equation

$$S = C_{rep} \frac{R_{rem}}{R_{comp}}$$

where S is the salvage value, C_{rep} the replacement cost of the component, R_{rem} the remaining life of the component, and R_{comp} the lifetime of the component.

For each component, HOMER combines the capital, replacement, maintenance, and fuel costs, along with the salvage value and any other costs or revenues, to find the component's annualized cost.

HOMER uses the total NPC as its primary economic figure of merit.

HOMER uses the following equation to calculate the total net present cost:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i, R_{proj})}$$

Where $C_{ann;tot}$ is the total annualized cost, i the annual real interest rate (the discount rate), R_{proj} the project lifetime, and CRF() is the capital recovery factor, given by the equation

$$\mathrm{CRF}(i,N) = \frac{i(1+i)^N}{(1+i)^N - 1}$$

where i is the annual real interest rate and N is the number of years. HOMER uses the following equation to calculate the levelized cost of energy:

$$\mathrm{COE} = \frac{C_{\mathrm{ann,tot}}}{E_{\mathrm{prim}} + E_{\mathrm{def}} + E_{\mathrm{grid,sales}}}$$

where $C_{ann;tot}$ is the total annualized cost, E_{prim} and E_{def} are the total amounts of primary and deferrable load, respectively, that the system serves per year, and $E_{grid;sales}$ is the amount of energy sold to the grid per year. The levelized cost of energy is the average cost per kilowatt-hour of useful electrical energy produced by the system.

3.8 HOMER simulation results

Simulation results are clearly shown that Type of building (Cluster type), Tariff category and Maximum Load demand has great influence to the energy system of the building. The optimum net meter solar PV capacity to be installed is changing with these three parameters. Chapter 4 gives a comprehensive description in this regard.

CHAPTER 4

4 SIMULATION RESULTS COMPARISON

For the simulation some parameters such as solar irradiance level, economic parameters, PV cost, Inverter cost, Generator cost are constant for all analysis. But the tariff category, maximum load demand and load curve is changing accordingly. Simulation results shows how the energy system parameters are changing with above three parameter.

Figure 4-1 shows, the optimum PV system capacity varies with maximum load demand and cluster type in same tariff category (GP2). It clearly shows that the optimum PV capacity is highly consumer based. Thus every building should be analyzed separately and decided the optimum PV capacity. Considering three cases building energy system is analyzed with the comparison and verified the influence of three parameters; Type of building (Cluster type), Tariff category and Maximum Load demand.

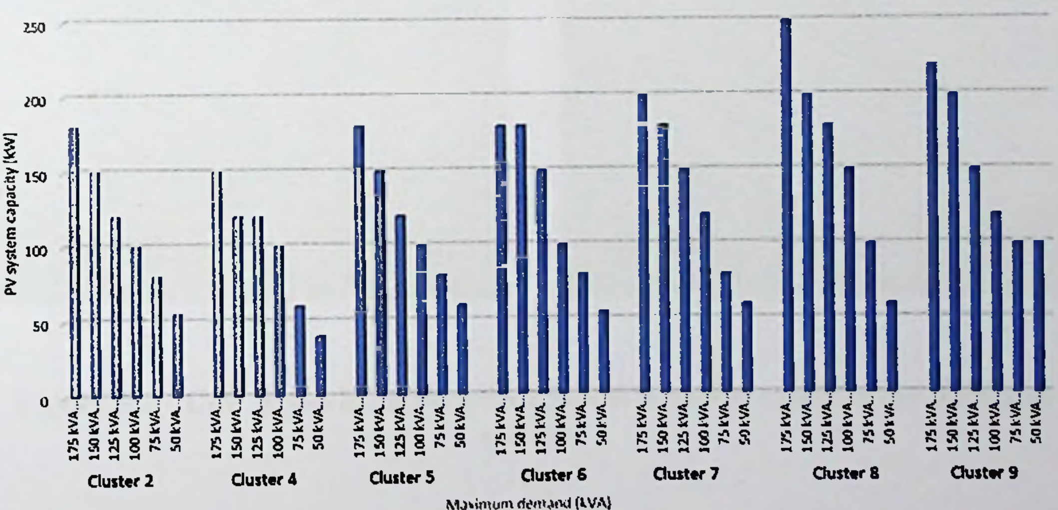


Figure 4-1 : Optimum PV capacity for different clusters with varying maximum demand

4.1 Influence of the load curve (Cluster type)

Cost of energy and payback period variation for different clusters with same maximum demand and same tariff category is shown in figure 4-2. The minimum point of the graph shows the optimum net meter solar PV capacity which minimize the cost of energy. For cluster 2 pattern load variation (Government banks, Government offices, University faculty, Educational Institute type 1, Embassy offices type 1, High commissioner's offices, Municipal Councils) with tariff category GP2 and 175 kVA maximum demand optimum solar PV system capacity is 180 kW whereas for the cluster 4 (Financial institute office, Fashion Outlets type 1) load variation with same tariff category and maximum demand the optimum solar PV system capacity is 150 kW. Payback period variation clearly shown that the payback period is increasing rapidly beyond the optimum PV capacity point.

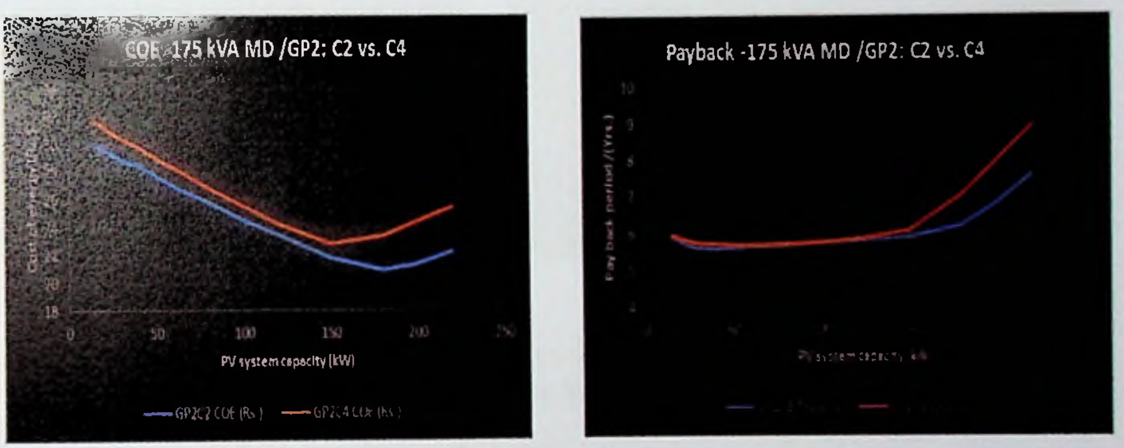


Figure 4-2 : CoE & payback period variation with PV capacity for different clusters

4.2 Influence of the tariff category

Cost of energy and payback period variation according to the tariff category with same maximum demand and same cluster is shown in figure 4-3.

For cluster 2 pattern load variation (Government banks, Government offices, University faculty, Educational Institute type 1, Embassy offices type 1, High commissioner's offices, Municipal Councils) and 175 kVA maximum demand with tariff category GP2, optimum solar PV system capacity is 180 kW and CoE energy is around Rs.21. For cluster 2 pattern load and 175 kVA maximum demand with tariff category GV2, optimum solar PV system capacity is same but CoE energy is around Rs.17. Since the grid energy cost is low in GV2 tariff category as compared to GP2, the payback period is high. User can compare their system considering both category and decide whether to install net metered solar PV.

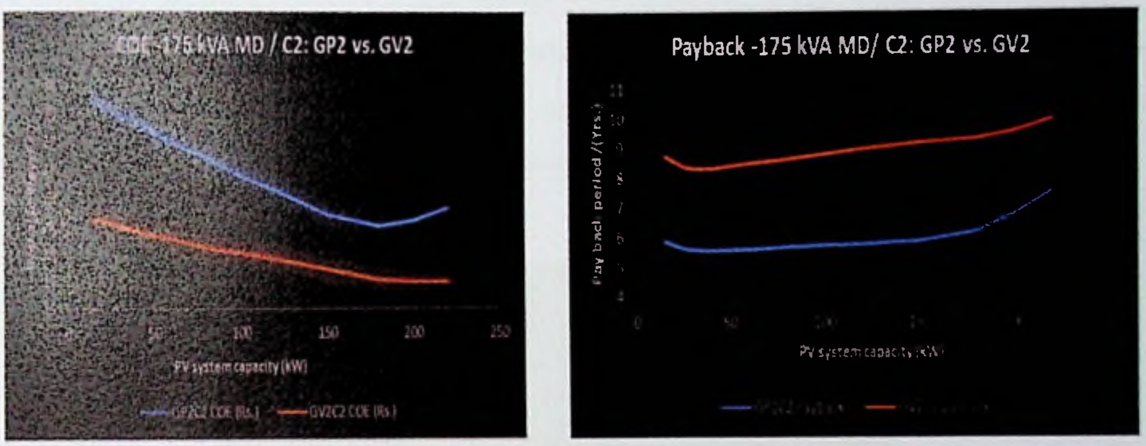


Figure 4-3 : COE & payback period variation with PV capacity for different tariff schemes

4.3 Influence of the maximum demand

Cost of energy and payback period variation according to the maximum demand with same tariff category and same cluster is shown in figure 4-4. For cluster 2 pattern load variation with tariff category GP2, two systems are considered with 175 kVA maximum demand and 150 kVA maximum demand. Optimum solar PV system capacity is 150 kW for 150 kVA system and 180 kW for 175 kVA system. This shows optimum PV capacity is increasing with maximum demand of the building.

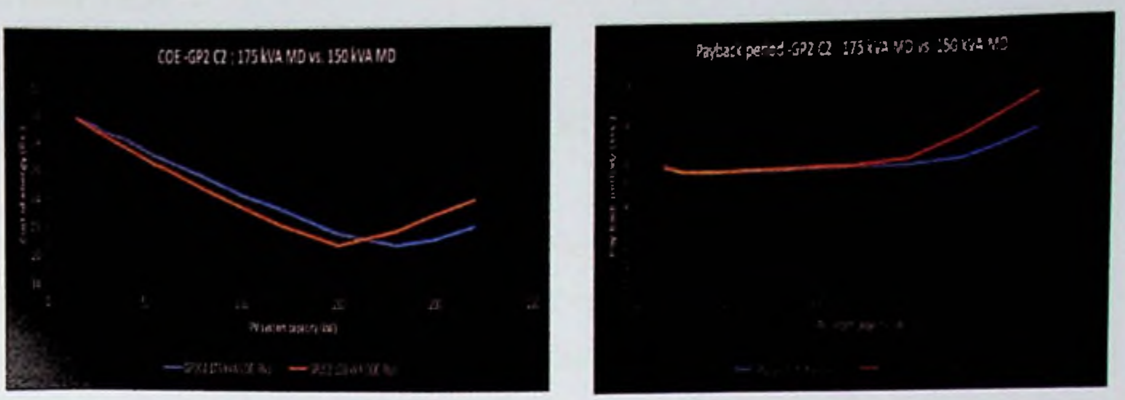


Figure 4-4 : COE & payback period variation with PV capacity for different maximum demand

Optimum PV capacity is increasing with maximum demand of a building. Figure 4-5 shows the optimum system capacity variation with maximum demand for a selected cluster (cluster 2) with same tariff category.

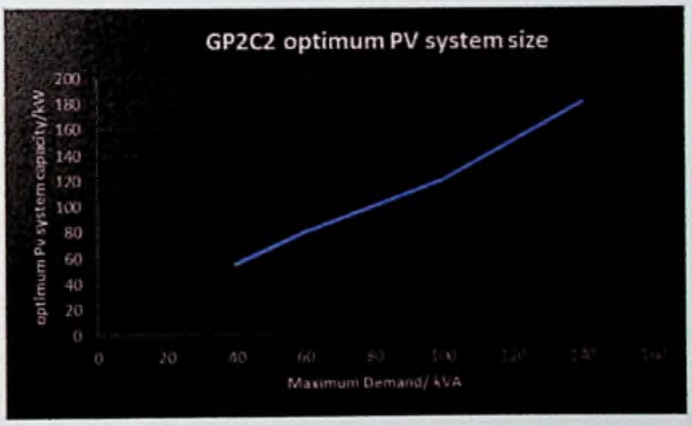


Figure 4-5 : Optimum PV capacity variation with maximum demand

CHAPTER 5

5 ANALYSIS TOOL DEVELOMENT

As described in the Chapter 4, HOMER simulation has done for 114 cases by changing the parameters of base model such as tariff category, load curve (cluster type) and maximum load demand. For a single case there is an optimum energy combination. But this optimum point may not be achievable due to the practical limitations such as area limitation, investment cost etc. Therefore other feasible combinations are also considered to develop this database tool. This tool gives the optimum net meter solar PV capacity which minimize the cost of energy and other feasible combinations with payback period. The output graphically shows how the system parameters such as CoE, payback period, area requirement, solar PV system cost and renewable energy percentage varies with feasible PV combinations. And also this can be used to compare other feasible system with optimum PV capacity.

Always the best energy combination is the one which gives minimum CoE. User can select other feasible solar PV systems as well but they should be always less than the optimum one in order to minimum payback period. With the net metering concept, solar PV installation than the optimum capacity is not economically viable.

5.1 Tool development

Figure 5-1 illustrates the algorithm used for tool development. Selected results from HOMER simulation such as PV system cost, capital cost, replacement cost, O &M cost, cost of energy, renewable fraction, simple payback period, discounted payback period etc, are extracted and stored in an Excel based database .

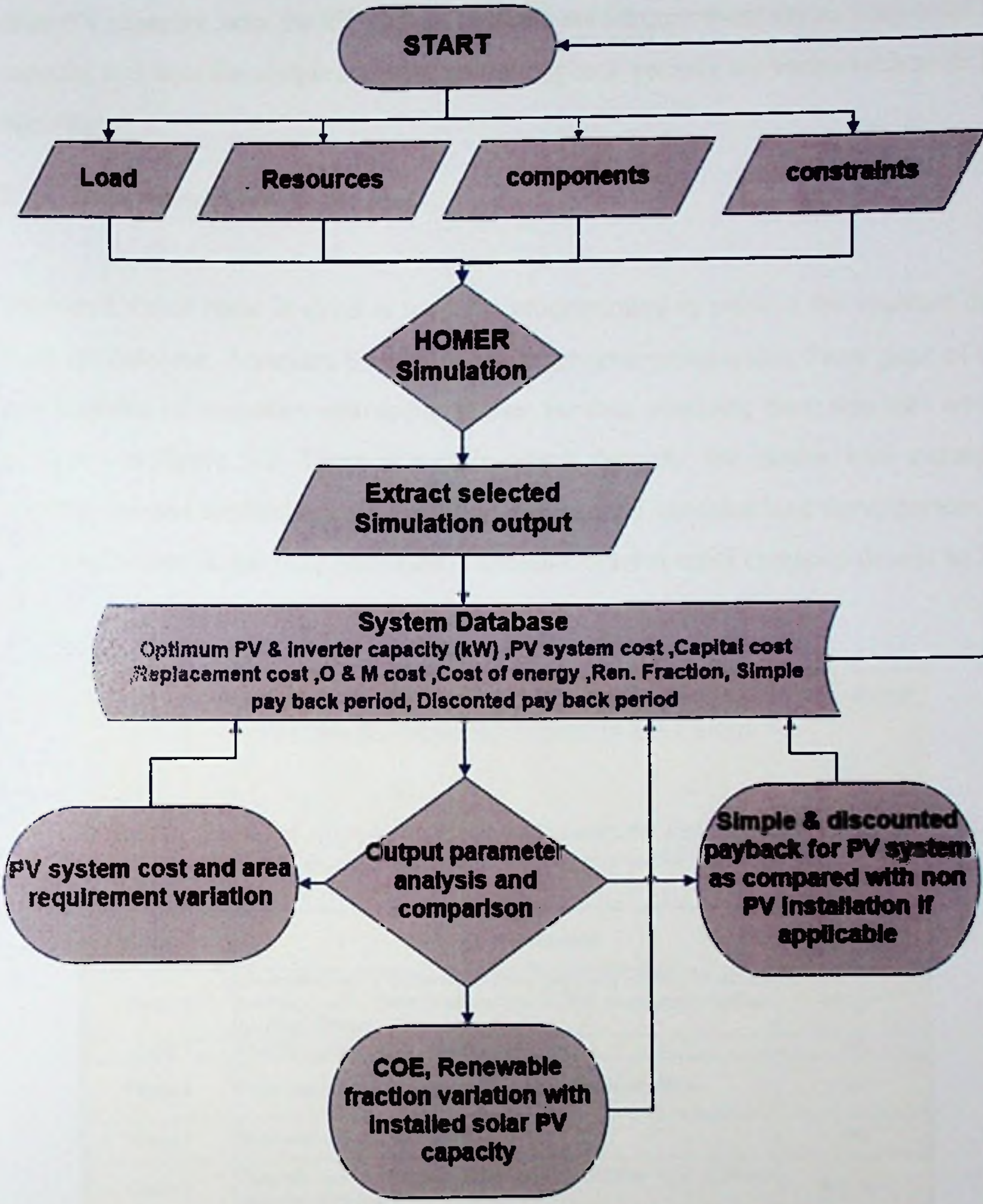


Figure 5-1 : Tool development algorithm

Microsoft visual basic in excel is used for programming to plot the selected parameters to see the variation with PV installed capacity. Homer results are compared to select best suitable energy combination based on system cost and area limitations. Those comparison shows how the cost of energy and renewable energy fraction varies with solar PV capacity, how the PV system cost and area requirement varies with solar PV capacity and how the simple and discounted payback periods are varies with solar PV capacity.

5.2 Data retrieval from the tool

Microsoft visual basic in excel is used for programming to retrieve the relevant data from the database. Annexure 6 contains all the programming codes. Front page of the tool contains all necessary instruction to user for data obtaining from this tool which is shown in figure 5-2. There is a table which describe the cluster with example installations and applicable tariff category. Annexure 1 contains load curve pattern of all clusters considered [12].Annexure 2 contains current tariff category details in Sri Lanka.

Techno- economic analysis of grid connected PV-diesel hybrid system for building sector in Sri Lanka

Press Ctrl+D to select your system parameters. Select the applicable tariff catergory, maximum demand and the relavant cluster as the below table

Cluster	Example installations	Possible tariff catregories
Cluster 2	Government banks, Government offices, University faculty , Educational Institute type 1 , Embassy offices type 1, High commissioner's offices, Municipal Councils	GV2, GP2
Cluster 4	Financial institute office, Fashion Outlets type 1	GP2
Cluster 5	Private banks, Private company offices type 1, Insurance offices	GP2
Cluster 6	Show rooms(shoes), Apartments	GP2
Cluster 7	Hospitals type 1, Embassy office type 2, Institute type 2, Private company office type 2	GV2, GP2
Cluster 8	Utility service officers, Hotel type 1	GP2, H2
Cluster 9	Hotels type 2, Hospitals	GV2, GP2, H2
Cluster 12	Hotels type 3	H2
Cluster 13	Prisons	GV2, GP2
Cluster 14	Super markets(consumer goods, electrical items), Food outlets, Fashion Outlets type 2	GP2
Cluster 16	Railway Stations, Hotel type 4	GP2, H2
Cluster 17	Fashion Outlets type 3, Private company office type 3	GP2

Figure 5-2 : Front page of the analysis tool

By pressing (Ctrl+D), a window will popup which contains 3 selectable inputs. User can select these inputs; tariff category, average maximum demand and load profile (cluster type) based on their building with the details in front page. By pressing the "Build" button, the tool will give the relevant details to the user required building. By pressing the "Clear" button, user can delete his requirement and select parameters again and By pressing the "Exit" button, user can exit from the window. Figure 5-3 shows the input window with selectable inputs and the error message if the selected combination is not existing.

If the selectable inputs are possible then the tool will display all possible feasible PV systems and its techno economical details with comparison graphs otherwise it give an error message which says "NOT REAL. Check your input parameters as the given table in front page".

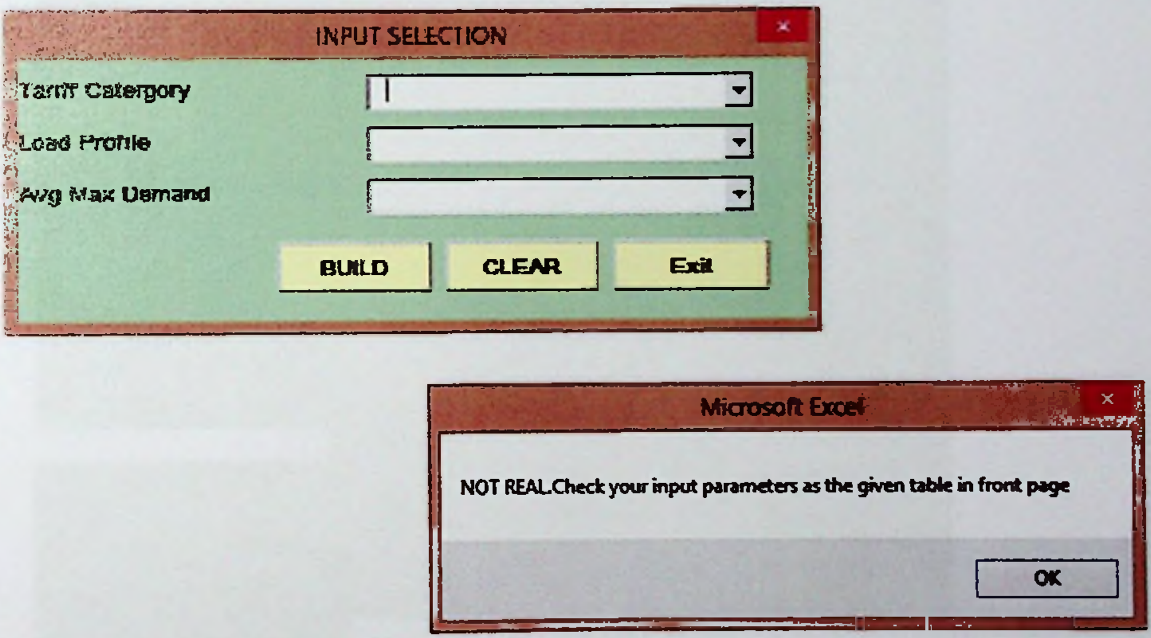
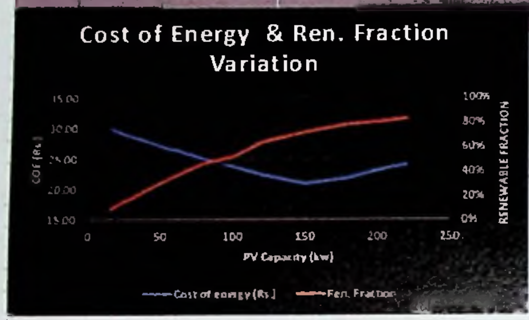
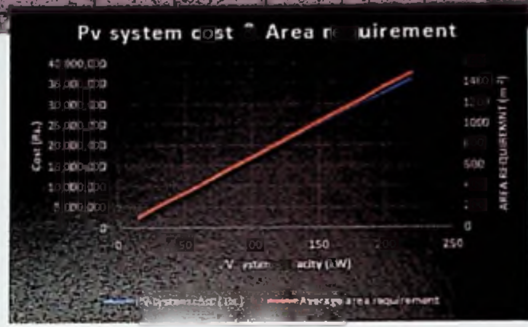


Figure 5-3 : Input window & error message

PV & inverter capacity (kW)	PV system cost ($)	PV system cost (Rs)	Capital cost ($)	Capital cost (Rs)	Replacement cost ($)	Replacement cost (Rs)	O & M cost ($)	O & M cost (Rs)	Cost of energy ($)	Cost of energy (Rs)	Ren. Fraction	Simple pay back period	Discounted pay back period	Average area requirement
220	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	32,360,665	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
200	[illegible]	32,807,410	[illegible]	35,974,210	76,292	[illegible]	[illegible]	32,623,260	[illegible]	[illegible]	80%	6.4	8.32	[illegible]
180	[illegible]	29,554,625	225,664	32,721,280	[illegible]	[illegible]	[illegible]	[illegible]	0.151	21.90	78%	5.79	7.33	1224
150	170,175	24,675,375	192,014	27,842,030	57,372	[illegible]	244,505	35,453,225	0.144	20.88	72%	5.03	6.17	1020
120	136,525	19,796,125	158,364	22,962,780	46,020	6,672,900	315,347	[illegible]	0.154	22.33	64%	4.83	5.98	816
100	114,092	16,543,340	135,893	19,709,995	38,453	5,575,685	372,094	[illegible]	0.165	23.64	52%	4.79	5.82	680
80	91,658	13,290,410	113,498	16,457,210	30,885	4,478,325	429,142	62,225,590	0.172	24.94	40%	4.74	5.75	544
60	69,225	10,037,625	91,004	13,204,280	23,317	3,380,965	487,618	70,704,610	0.182	26.39	30%	4.7	5.69	408
55	63,617	9,224,465	85,456	12,391,120	21,425	3,106,625	502,447	72,854,815	0.184	26.68	33%	4.69	5.67	374
40	46,792	6,784,840	68,633	9,951,495	15,749	2,283,605	547,221	79,347,045	0.192	27.84	24%	4.66	5.64	272
30	35,575	[illegible]	57,414	8,325,030	11,965	1,734,925	577,502	83,737,790	0.197	28.57	18%	[illegible]	[illegible]	[illegible]
25	29,967	4,345,215	51,806	7,511,870	10,073	1,460,585	593,164	86,008,780	0.2	29.00	15%	4.69	5.68	170
15	18,750	2,718,750	40,589	5,885,405	6,289	911,905	624,878	90,607,310	0.206	29.87	9%	4.84	5.9	102





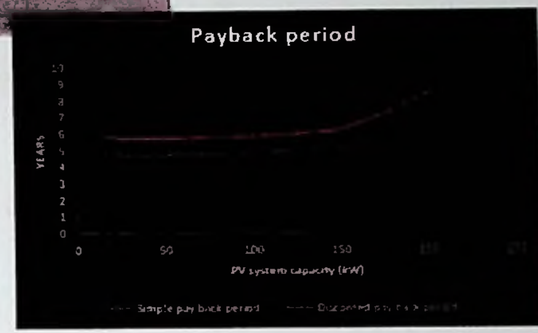


Figure 5-4 : Output window of the tool

If the input combinations are existing then the output window as shown in the figure 5-4 will pop-up. Figure 5-5 illustrates the algorithm of data retrieval from the tool.

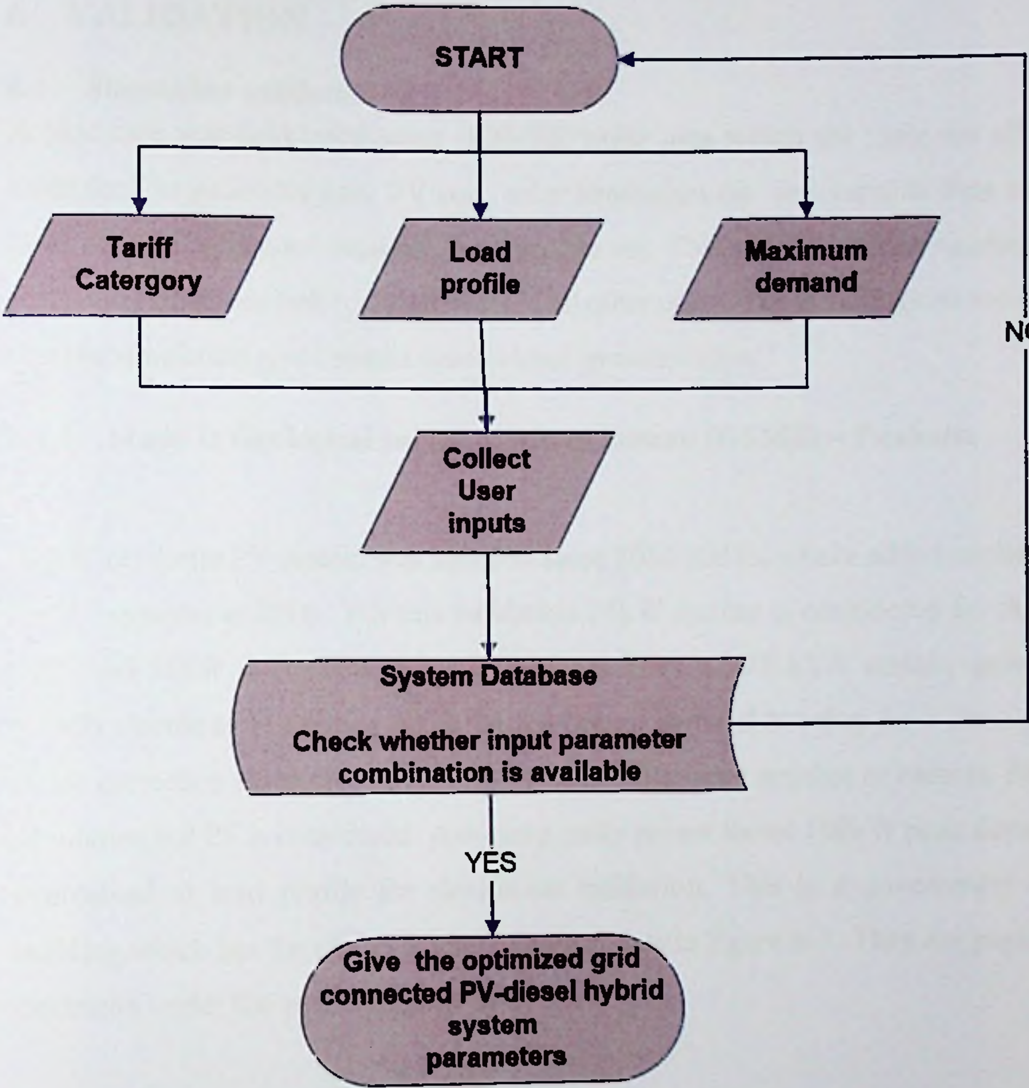


Figure 5-5 : Data retrieve algorithm from analysis tool

CHAPTER 6

6 VALIDATION

6.1 Simulation validation

A base case was developed using HOMER using data which are same for all other cases such as generator cost, PV cost, solar irradiation etc. and variable data such as tariff scheme, generator capacity, load profile etc. This simulation has validated for two actual situations before the analysis of all other cases. These validations are shown that the simulation gives results much closer to actual case.

6.1.1 Study 1: Geological survey & Mines bureau (GSMB) – Pitakotte

25 kW net meter PV system was installed since 2014 and they have added another two 15 kW systems in 2016 . For this validation 25kW system is considered for the year 2015 and 55kW is considered for 2016. They have a 175 kVA standby generator. GSMB electricity bill shows 100 kVA maximum demand but they have done power factor correction since they have laboratories with a large number of motors. For this simulation 0.8 PF is considered. Assuming unity power factor 100kW peak demand is maintained at load profile for simulation validation. This is a government office building which has the cluster 2 load pattern shows in figure 6-1. They are paying for electricity under the tariff category GP2.

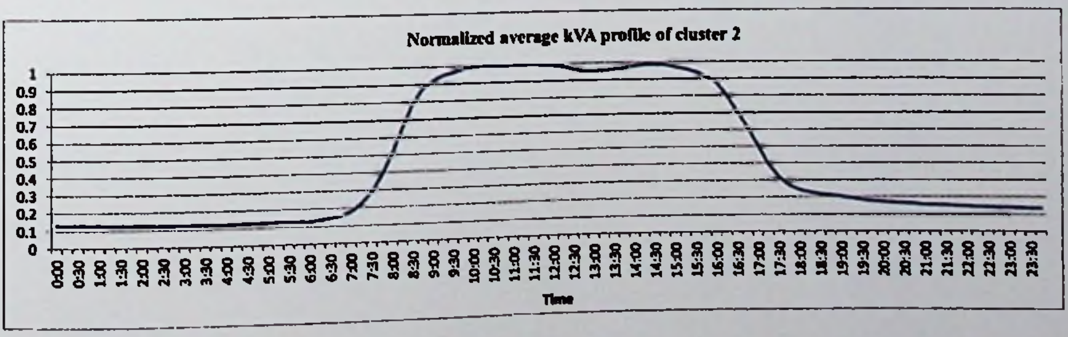


Figure 6-1 : Load variation pattern related to study 1 for simulation validation

6.1.1.1 Actual data- Study 1

Table 6-1 shows actual data solar PV generation and electricity consumption for the year 2015 and till April 2016. Considering their consumption average renewable fraction is tabulated in last column.

Year	Month	Solar PV units (kWh)				Grid consumption (kWh)				Total consumption (kWh)	Ren. Fraction (%)	Average ren. Fraction (%)
		25 kW system	15 kW at main building	15 kW at lab building	Total Solar units	Peak	Off Peak	Day	Total grid units			
2016	January	3056	1645	1221	5922	1992	2985	11025	16002	21924	27.0	28
	February	3160	1906	1716	6782	2186	3203	10347	15736	22518	30.1	
	March	3700	2245	1865	7810	2783	4006	13557	20346	28156	27.7	
	April	3666	2137	1612	7415	2378	3633	12104	18115	25530	29.0	
2015	January	-	-	-	-	-	-	-	20125	20125		
	February	-	-	-	-	-	-	-	18713	18713		
	March	-	-	-	-	-	-	-	22267	22267		
	April	-	-	-	-	-	-	-	19563	19563		
	May	-	-	-	-	-	-	-	19892	19892		
	June	2763	-	-	-	-	-	-	20509	23272	11.9	14
	July	3083	-	-	-	-	-	-	21743	24826	12.4	
	August	3215	-	-	-	-	-	-	19154	22369	14.4	
	September	2707	-	-	-	-	-	-	17068	19775	13.7	
	October	3079	-	-	-	-	-	-	17064	20143	15.3	
	November	2586	-	-	-	-	-	-	15994	18580	13.9	
	December	2635	-	-	-	1704	2644	12540	16888	19523	13.5	
Average									19082			

Table 6-1 : Actual data for study 1 for simulation validation

Actual average renewable fraction before 2016 is 14%, in 2016 28 %. Total average grid consumption is 19082 kWh units. Electricity bill and solar generation details at Geological survey & Mines bureau (GSMB) – Pitakotte are attached as annexure 3.

6.1.1.2 Simulation results- Study 1

Table 6-2 summaries the simulation results for GSMB building which shows the COE, renewable fraction and simple payback period. Figure 6-2 shows simulation results on electricity production and figure 6-3 shows simulation results on power consumption.

PV capacity (kW)	COE ($)	Ren. Fraction	Simple payback period
180	0.144	72%	5.04
200	0.147	76%	5.45
150	0.15	66%	4.83
220	0.153	78%	5.96
100	0.169	48%	4.73
80	0.178	40%	4.69
60	0.186	30%	4.65
55	0.188	28%	4.65
40	0.196	20%	4.62
30	0.199	15%	4.64
25	0.202	13%	4.68
15	0.206	8%	4.83

Table 6-2 : Simulation results for study 1 for simulation validation

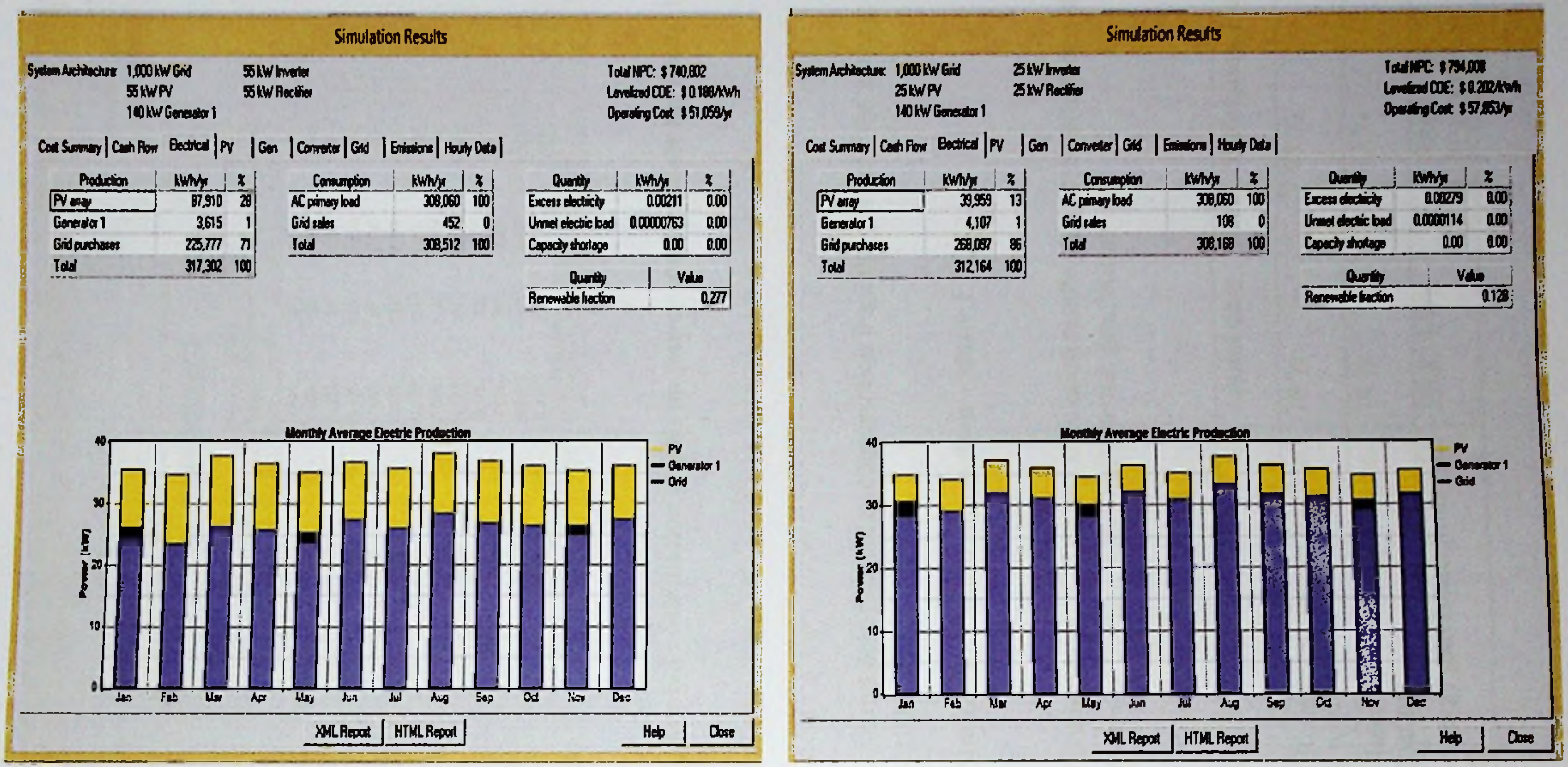
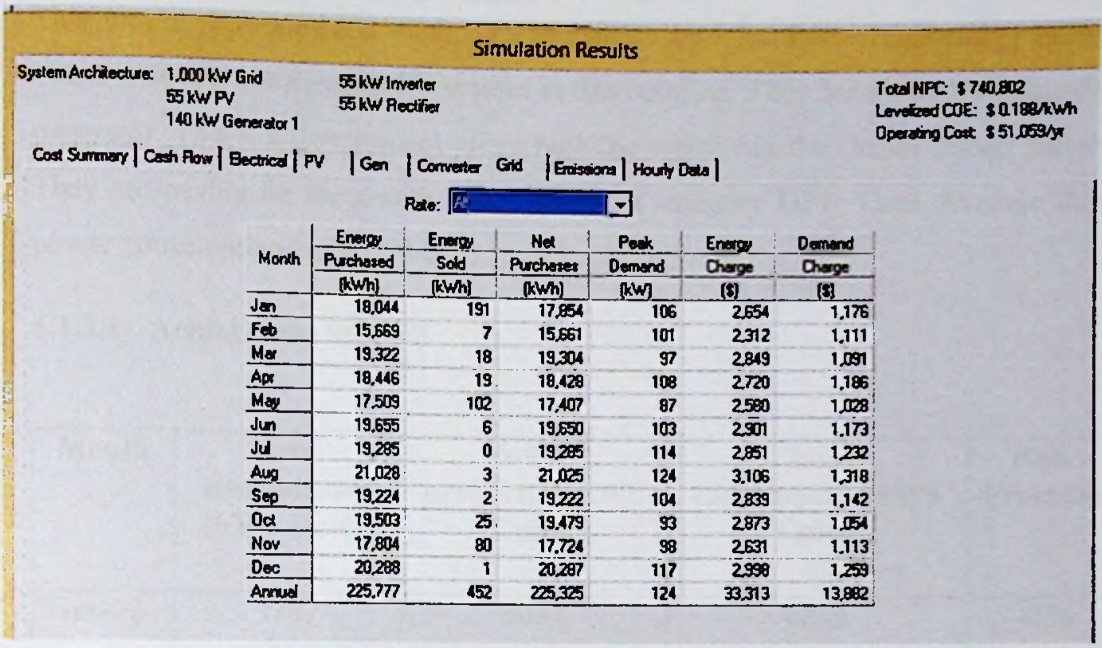


Figure 6-2 : Simulation results on monthly average electricity production for study 1



Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)	Peak Demand (kW)	Energy Charge ($)	Demand Charge ($)
Jan	18,044	191	17,854	106	2,654	1,176
Feb	15,669	7	15,661	101	2,312	1,111
Mar	19,322	18	19,304	97	2,849	1,091
Apr	18,446	19	18,428	108	2,720	1,186
May	17,509	102	17,407	87	2,580	1,028
Jun	19,655	6	19,650	103	2,901	1,173
Jul	19,285	0	19,285	114	2,851	1,232
Aug	21,028	3	21,025	124	3,106	1,318
Sep	19,224	2	19,222	104	2,839	1,142
Oct	19,503	25	19,479	93	2,873	1,054
Nov	17,804	80	17,724	98	2,631	1,113
Dec	20,288	1	20,287	117	2,998	1,259
Annual	225,777	452	225,325	124	33,313	13,882

Figure 6-3 : Simulation results on power consumption for study 1

Figure 6-3 shows how the energy consumption from the grid and the average peak demand is 100 kW.

6.1.1.3 Simulation results comparison – study 1

Table 6-3 compares actual data and simulation results on grid consumption and renewable energy fraction which validate the simulation.

Parameter	Actual data	Simulation Results
Average Renewable energy fraction with 55 kW PV	28 %	28 %
Average Renewable energy fraction with 25 kW PV	14 %	13 %
Average energy purchased from grid per month	19082 kWh	18815 kWh (225777 / 12)

Table 6-3 : Results comparison for study 1 on simulation validation

6.1.2 Study 2: ELS Lanka (Pvt) Ltd

This building is located at no 62/3, Neelammahara road, Katuwawala, Boralesgsmuwa. There is 30 kW net metered PV system in this building. They have a 50 kVA standby generator. This is a government office building which has the cluster 2 load pattern. They are paying for electricity under the tariff category GP1. Their Average daily power consumption is 260 kWh.

6.1.2.1 Actual data- Study 2

Month	Grid consumption (kWh Units)	Solar production(kWh Units)	Total consumption(kWh Units)	Ren. Fraction
Jan-15	3767	3091	6858	45%
Feb-15	3205	3124	6329	49%
Mar-15	2544	3940	6484	61%
Apr-15	3682	3703	7385	50%
May-15	4332	2254	6586	34%
Jun-15	4332	2730	7062	39%
Jul-15	3582	2454	6036	41%
Aug-15	5254	2260	7514	30%
Sep-15	5096	2039	7135	29%
Oct-15	5220	664	5884	11%
Nov-15	4826	2304	7130	32%
Dec-15	4170	2558	6728	38%
Jan-16	4685	2703	7388	37%
Feb-16	4933	3290	8223	40%
Mar-16	4935	3858	8793	44%
Apr-16	3386	4082	7468	55%
May-16	5466	2795	8261	34%
Average	**4319**	**2815**	**7133**	**45 %**

Table 6-3: Actual data for study 2 for simulation validation

Table 6-3 shows actual data solar PV generation and electricity consumption for the year 2015 and till May 2016. Average grid consumption, average solar production and average renewable fraction is shown in the table 6-3. Electricity bill and solar generation details at ELS Lanka (Pvt) Ltd are attached as annexure 4.

6.1.2.2 Simulation results – Study 2

Table 6-4 summaries the simulation results for ELS Lanka (Pvt) Ltd building which shows the COE, renewable fraction and simple payback period. Figure 6-4 shows simulation results on electricity production and figure 6-5 shows simulation results on power consumption.

PV capacity (kW)	COE ($)	Ren. Fraction	Simple payback period (years)
70	0.098	79 %	5.49
60	0.101	75%	5.2
80	0.107	82%	6.2
50	0.112	69%	5.17
40	0.125	60%	5.21
30	0.137	47%	5.26
25	0.143	40%	5.31
15	0.156	25%	5.53

Table 6-4 : Simulation results for study 2 for simulation validation

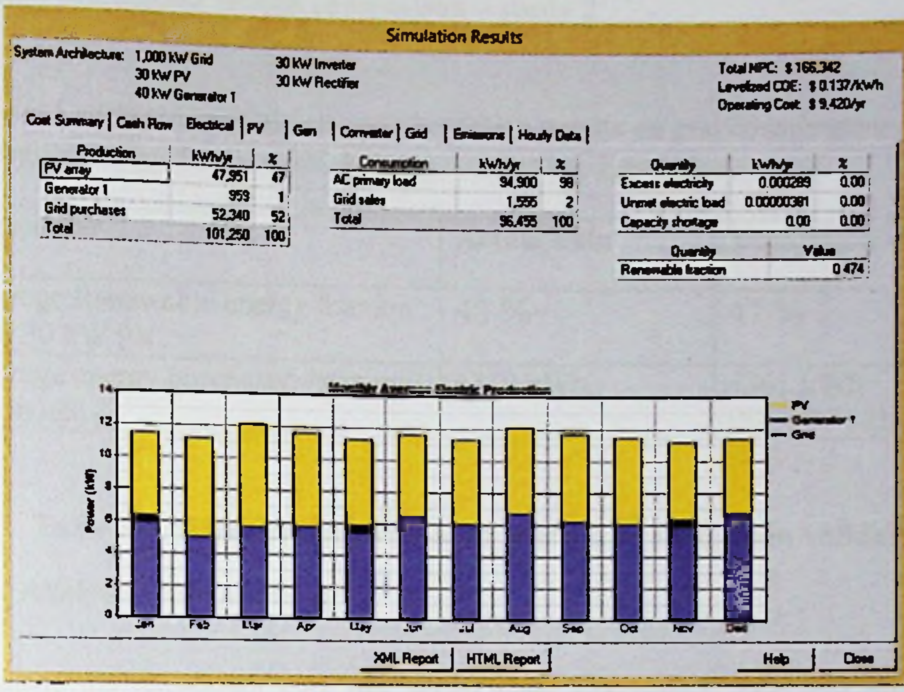


Figure 6-4 : Simulation results on electricity production for study 2

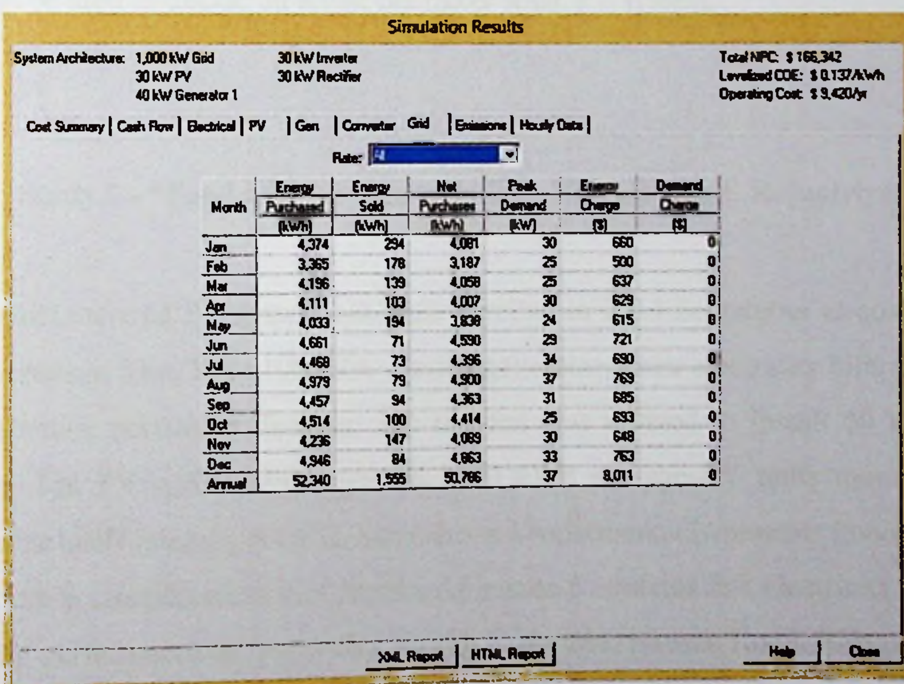


Figure 6-5 : Simulation results on power consumption for study 2

6.1.2.3 Simulation results comparison – study 2

Table 6-5 compares actual data and simulation results on grid consumption and renewable energy fraction which again validate the simulation.

Parameter	Actual data	Simulation Results
Average Renewable energy fraction with 30 kW PV	45 %	47 %
Average energy purchased from grid per month	4319 kWh	4361 kWh (52340 / 12)

Table 6-5 : Results comparison for study 2 on simulation validation

6.2 Analysis tool validation

To verify the developed tool, two actual cases considered. This tool gives techno economical details on energy system which is much similar to actual situation. This verifies that the user can use this tool to get correct idea on their building energy system and can be used to decide on future net meter solar PV system.

6.2.1 Study 1 - "Food City Nawala": No 264, Nawala Road, Rajagiriya

60 kW net metered PV system has been installed in 2014 September at cost of 11.8 million rupees. They have 100 kVA standby generator. Their electricity bills shows 75 kVA average maximum demand. 396 m^2 area was utilized to install 60 kW solar system. The PV system was expected 6900 kWh average PV units monthly. The applicable tariff category is GP-2. Since this is a supermarket (consumer goods) cluster 14 pattern is considered as load profile. Annexure 5 contains few electricity bills and solar PV performance at "Food City Nawala": No 264, Nawala Road, Rajagiriya.

6.2.1.1 Actual data – study 1

Table 6-6 summaries grid consumption at (electricity account number: 0103133008) at Cargills food city Nawala and also average consumption is shown and table 6-7 summaries solar power generation for one year period. Electricity bill and solar generation details at Cargills food city Nawala are attached as annexure 5.

Stage	Month	Grid consumption (kWh)			kVA units
		Day	Peak	Off-peak	
Without solar net metering system	November 2013	19,720	7,092	5381	80
	March 2014	21,153	7,466	6160	80
	April 2014	19,465	6492	5632	77
	August 2014	19,597	6545	5654	84
With 60 kW solar net metering system	September 2014	12308	6308	5191	75
	October 2014	12031	6266	5152	72
	December 2014	13002	6047	5445	72
	January 2015	11456	6137	5051	71
Average		12200	6190	5210	73

Table 6-6 : Electricity bill summary at Cargills food city Nawala

Simple calculation is done to find out average annual grid consumption, renewable fraction, CoE and simple payback period. Standby generator is not considered for this calculations.

Average monthly grid consumption = (12200 + 6190 + 5210)
= 23,600 kWh

Average annual grid consumption = 23,600 * 12 = 283,200 kWh

Month	PV units production (kWh)
September 2014	5968
October 2014	6570
November 2014	5377
December 2014	5195
January 2015	7034
February 2015	6912
March 2015	8022
April 2015	7734
May 2015	6854
June 2015	5803
July 2015	7105
August 2015	7259
Total for 1 year period	79833

Table 6-7 : Solar system performance

As shown in the table 6-7, annual PV unit production is 79,833 kWh units

$$\text{Ren. Fraction} = (\text{Annual PV unit production}) / (\text{Average annual grid consumption} - \text{Annual PV unit production})$$

= 79,833/ (283,200 – 79,833) = 39 %

According to the electricity bills, average monthly electricity bill after PV installation is Rs. 570,000.00.

CoE =(Average monthly electricity bill / Average monthly grid consumption)

= 570,000/23,600 = Rs. 24.15

6o kW solar system is expected to generate 6900 kWh units per month. By considering the day time tariff rate average saving per year can be calculated.

Average saving per year= 6900 * 21.8 *12= Rs. 1,805,040.00

Simple payback period = (Project cost / Annual saving)

Simple payback period =11,800,000 / 1,805,040 = 6.53 years

6.2.1.2 Tool output for study 1

According to the Electricity bill (Acc: 0103133008) at Cargills food city Nawala, their maximum demand is around 75 kVA and they are under GP2 tariff category. Foodcity is a consumer goods supermarket which is belong to cluster 14 which has load variation pattern shown in figure 6-6.

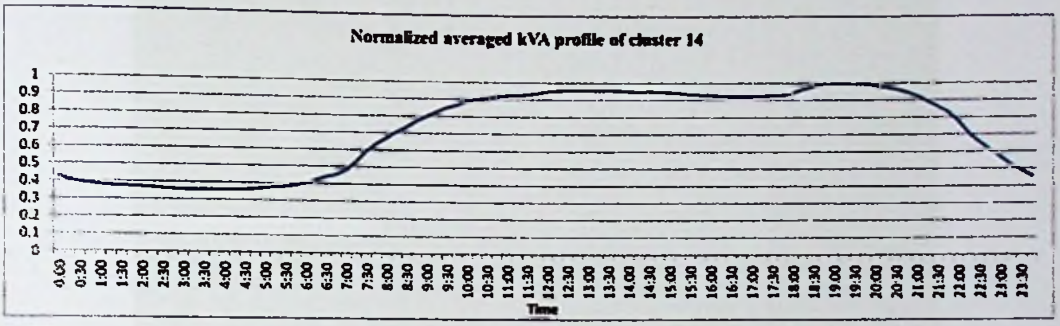


Figure 6-6 : Load variation pattern related to study 1 for tool validation

Figure 6-7 shows tool output for grid connected solar PV system which contain optimum PV capacity and other feasible system capacities as well. According to the tool output for CoE & payback period shown in figure 6-8 optimum solar PV capacity which minimize the CoE is 80 kW. But they have installed 60 kW due to the area limitation. It is also feasible.

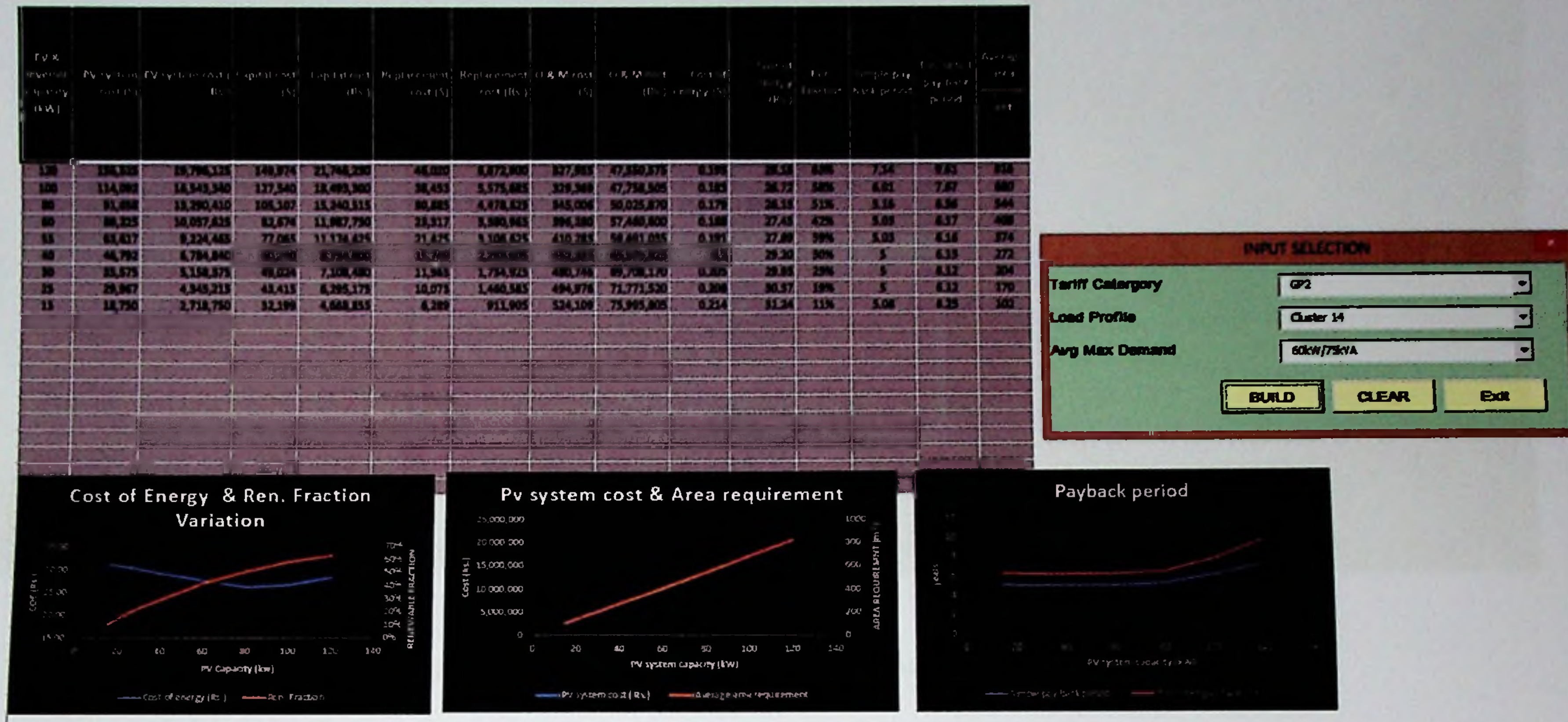


Figure 6-7 : Tool output for study 1 for tool validation

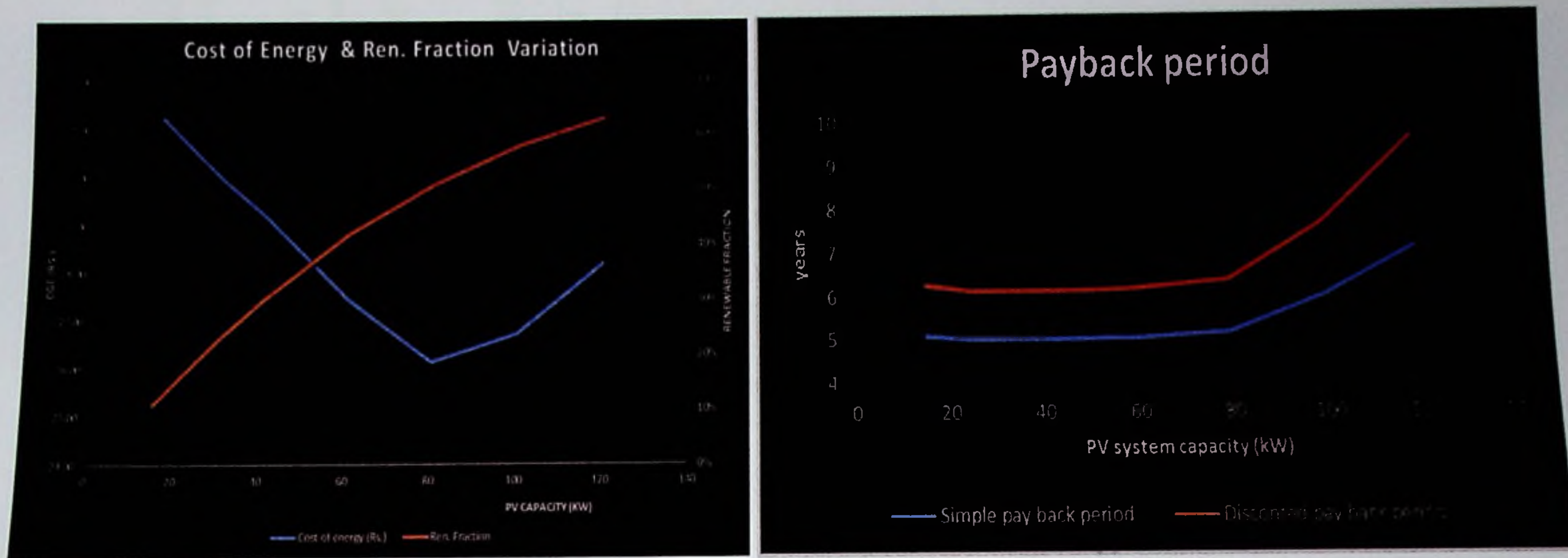


Figure 6-8 : Tool output for CoE & payback period for study1

6.2.1.3 Comparison of Actual data and too output for study 1

Table 6-8 compares actual data and simulation results on PV system cost, CoE, renewable, average area requirement and simple payback period for PV system which validate the developed tool.

Parameter	Actual data	Tool Results
PV system cost (Rs.)	11,800,000 (in 2014)	10,037,625
Cost of energy (Rs.)	24.15	27.45
Renewable Fraction	39 %	42%
Average area requirement (m^2)	396	408
Simple payback period for PV system (years)	6.53 (If project cost is 10,037,625 this become 5.56)	5.03
Discounted payback period for PV system (years)	-	6.17

Table 6-8 : Comparison of actual and tool output for study 1

6.2.2 Study 2 – Geological survey & mines bureau – 569, Epitamulla road Pitakotte

25 kW net metered PV system was installed since 2014 investing 4.2 million rupees and expected monthly solar PV generation is 2,750 kW. Then they have added another two 15 kW systems in 2016 at a cost of 5.15 million rupees with 3400 kWh units monthly production. Expected total PV generation is 6150 kWh per month. This is a government office building which has the cluster 2 load pattern shows in figure 6-1. They are paying for electricity under the tariff category GP2. Their electricity bills shows average maximum demand of 175 kVA. Annexure 3 shows few electricity bills and solar PV generation at Geological survey & mines bureau – Pitakotte.

6.2.2.1 Actual data – study 2

Table 6-1 shows the actual data for study 2 Geological survey & mines bureau – 569, Epitamulla road, Pitakotte. It shows average monthly grid consumption as 19,082 kWh and actual renewable fraction as 28 %. With reference to their electricity bills average monthly electricity bill after PV installation is Rs. 425,000.00.

Simple calculation is done to find out CoE and simple payback period. Standby generator is not considered for this calculations.

CoE = (Average monthly electricity bill / Average monthly grid consumption)
= 475,000/19,082 = Rs. 24.89

55 kW solar system is expected to generate 6150 kWh units per month. By considering the day time tariff rate average saving per year can be calculated.

Average saving per year = 6150 * 21.8 *12= Rs. 1,608,840.00

Simple payback period = (Project cost / Annual saving)
Simple payback period =9,350,000/1,608,840 = 5.81 years

6.2.2.2 Tool output for study 2

Figure 6-9 shows tool output for grid connected solar PV system which contain optimum PV capacity and other feasible system capacities as well. According to the tool output for CoE & payback period shown in figure 6-10 optimum solar PV capacity which minimize the CoE is 180 kW. But they have installed 55 kW.

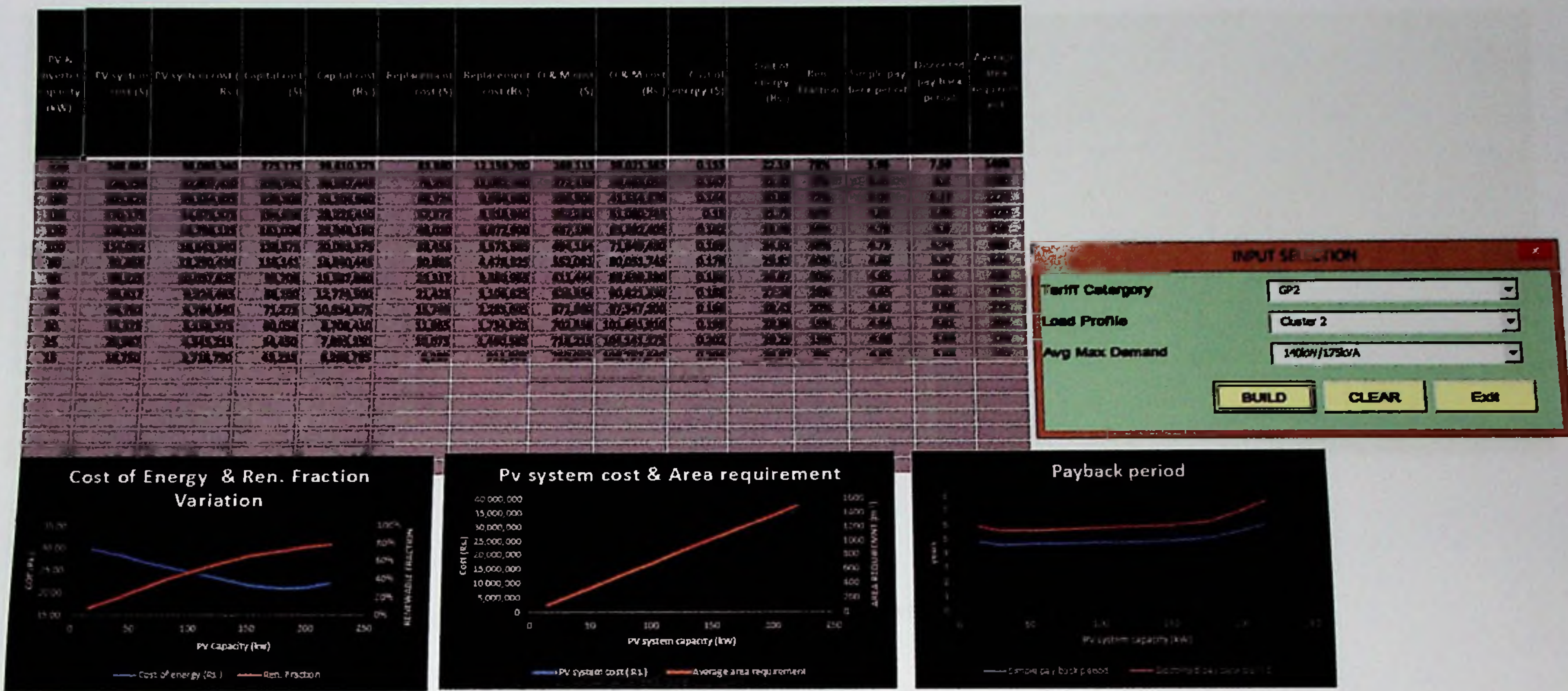


Figure 6-9 : Tool output for study 2 for tool validation

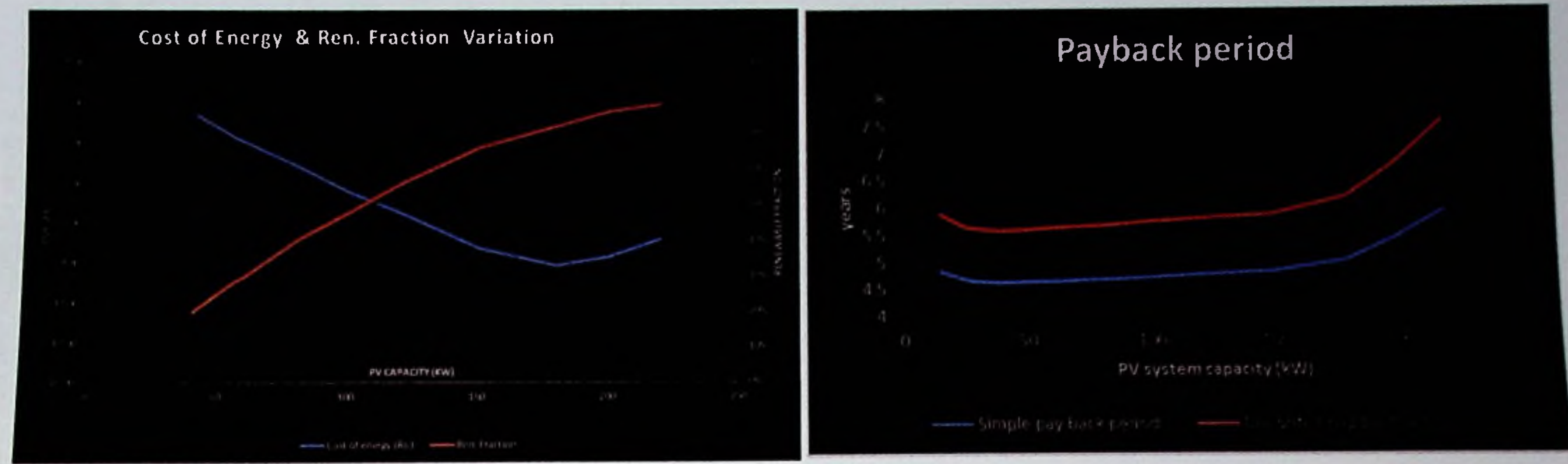


Figure 6-10 : Tool output for CoE & payback period for study 2

6.2.2.3 Comparison of actual data and tool output for study 2

Table 6-9 compares actual data and simulation results at GSMB on PV system cost, CoE, renewable, average area requirement and simple payback period for PV system which again validate the developed tool.

Parameter	Actual data	Tool Results
PV system cost (Rs.)	9,350,000	9,224,465
Cost of energy (Rs.)	24.48	27.26
Renewable Fraction	28 %	28 %
Average area requirement (m^2)	363	374
Simple payback period for PV system (years)	5.81	4.65
Discounted payback period for PV system (years)	-	5.61

Table 6-9 : Comparison of actual and tool output for study 1

CHAPTER 7

7 CONCLUSION & DISCUSSION

This research was done to analyze building energy system with net meter solar PV technically and economically. Various types of buildings are considered in this research.

Optimum solar PV capacity to be installed is depend on tariff category, solar irradiation, building load profile and maximum demand of the building. But there was no user friendly method to analyze the feasibility of PV installation and its outcomes for commercial buildings in Sri Lanka without doing an analysis by an expert. From this research intelligent tool is developed which is very easy to use by anyone without expertise.

- User can select optimum solar PV capacity to be installed and get details on investment cost, cost of energy, payback period etc.
- If the user cannot go for the optimum PV capacity due to the limitations such as cost or area, then he can select whatever the possible capacity using this tool. It can be used to decide whether to install solar and if installed what the payback period is.
- This tool can be used even with the conceptual design stage of the building with estimated electrical demand. That will help to utilize the area for solar panels and project cost also.
- When consider the government sector projects, this tool will help to do proper budgetary allocations for net meter solar PV system at the initial stage. This will avoid extra bud
- Any user without much knowledge on net meter solar PV installations, can see the feasibility of it without having consultancy from soar panel providers.

In this research only the net meter solar PV installation is considered. In 2016 government introduced a concept called "Battle for solar energy" which has three options; net metering, net accounting and net plus. In net plus, the electricity production and the consumption are independent. So no need to optimize the capacity.

But this can be included net accounting concept using the same simulation software HOMER which has the provision for this concept as well. Further this tool can be developed to decide the most feasible soar installation method; net metering, net accounting and net plus.

Sensitivity analysis are not included in this tool. But this tool can be further developed by adding sensitivity analysis for solar irradiation, tariff scheme changes etc.

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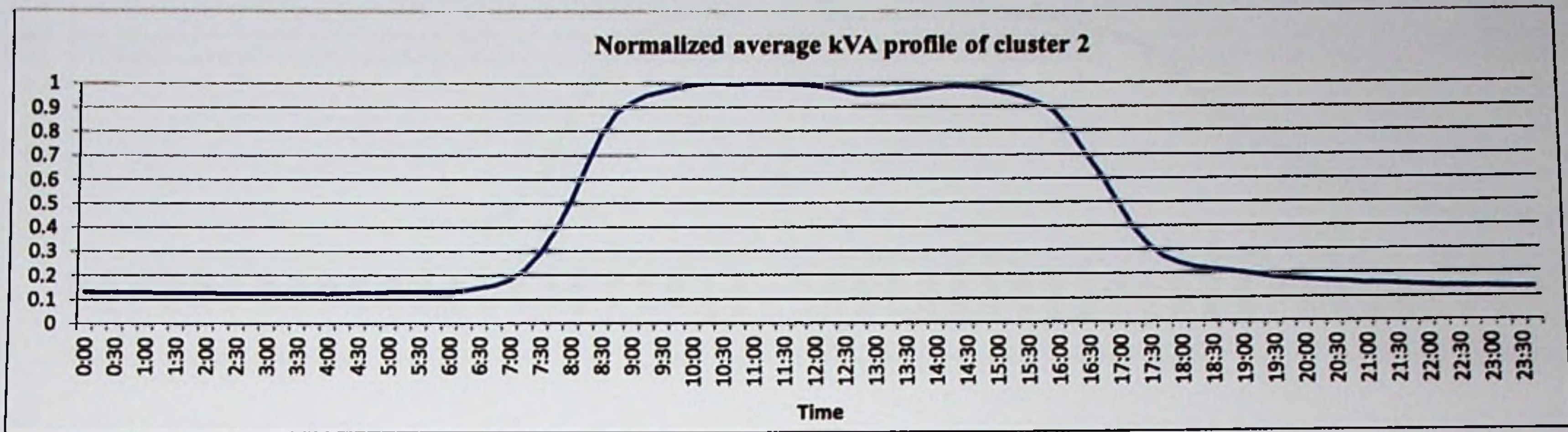
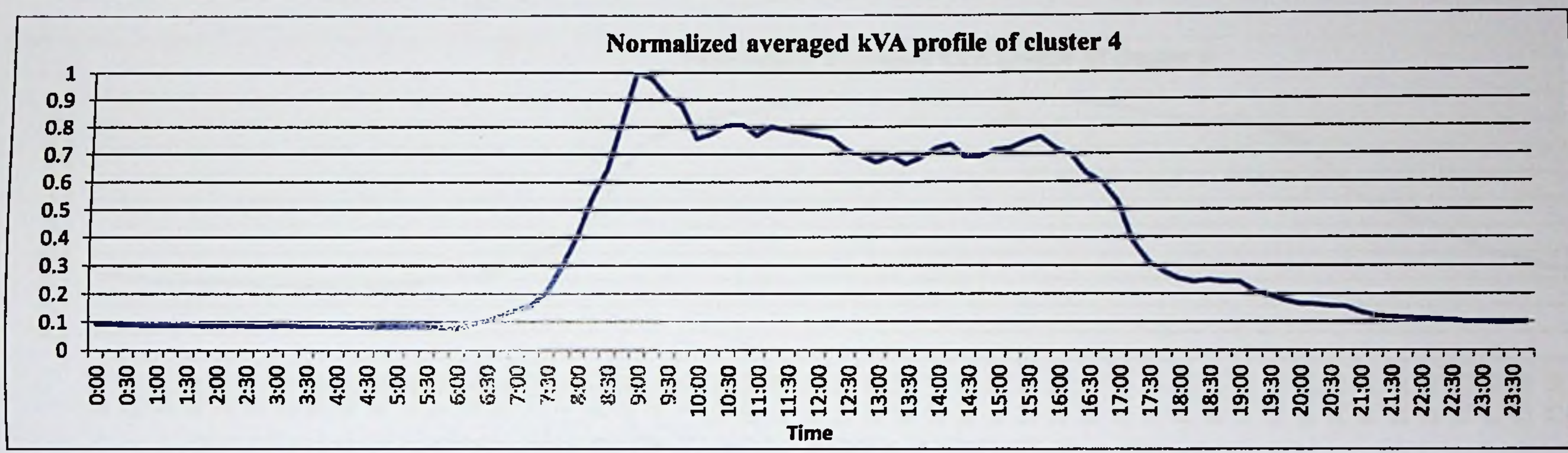
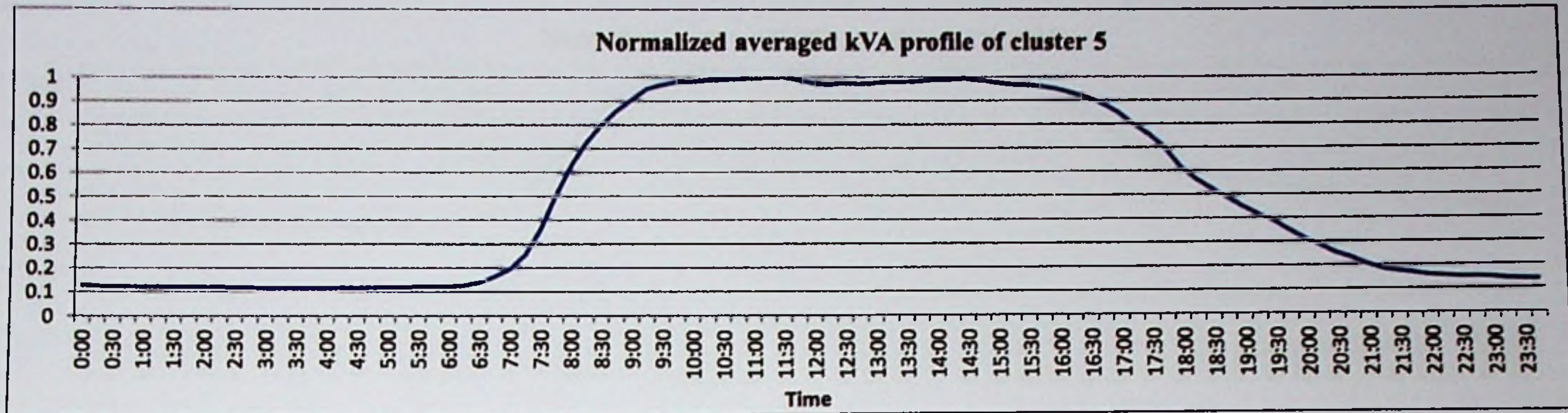
ANNEXURE 1: Load profile for clusters



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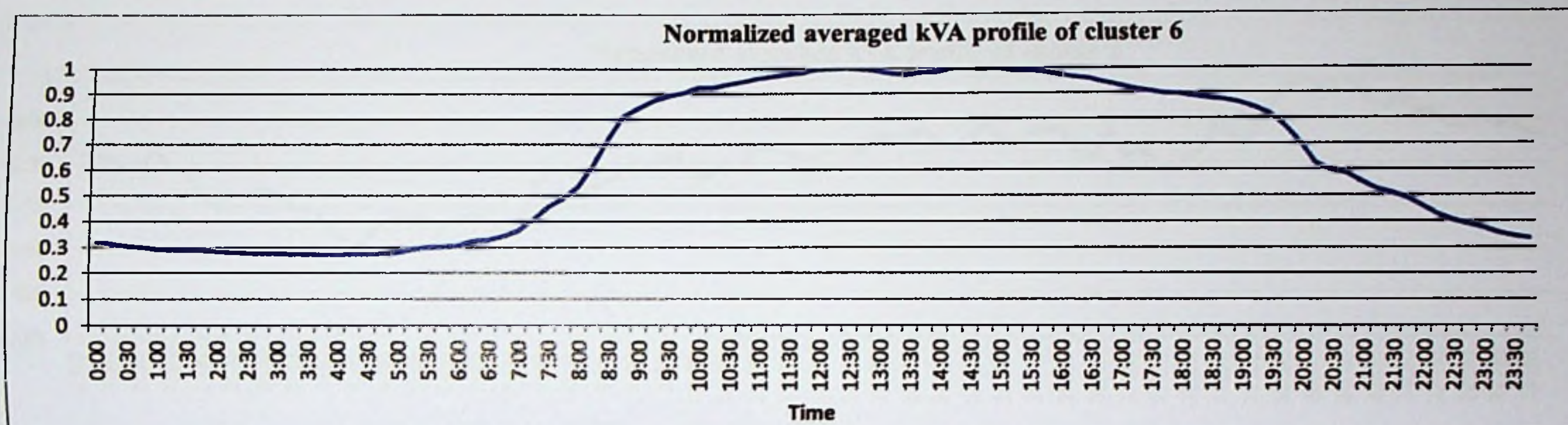
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0:00 0:30 1:00 1:30 2:00 2:30 3:00 3:30 4:00 4:30 5:00 5:30 6:00 6:30 7:00 7:30 8:00 8:30 9:00 9:30 10:00 10:30 11:00 11:30 12:00 12:30 13:00 13:30 14:00 14:30 15:00 15:30 16:00 16:30 17:00 17:30 18:00 18:30 19:00 19:30 20:00 20:30 21:00 21:30 22:00 22:30 23:00 23:30
Time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0
0:00 0:30 1:00 1:30 2:00 2:30 3:00 3:30 4:00 4:30 5:00 5:30 6:00 6:30 7:00 7:30 8:00 8:30 9:00 9:30 10:00 10:30 11:00 11:30 12:00 12:30 13:00 13:30 14:00 14:30 15:00 15:30 16:00 16:30 17:00 17:30 18:00 18:30 19:00 19:30 20:00 20:30 21:00 21:30 22:00 22:30 23:00 23:30
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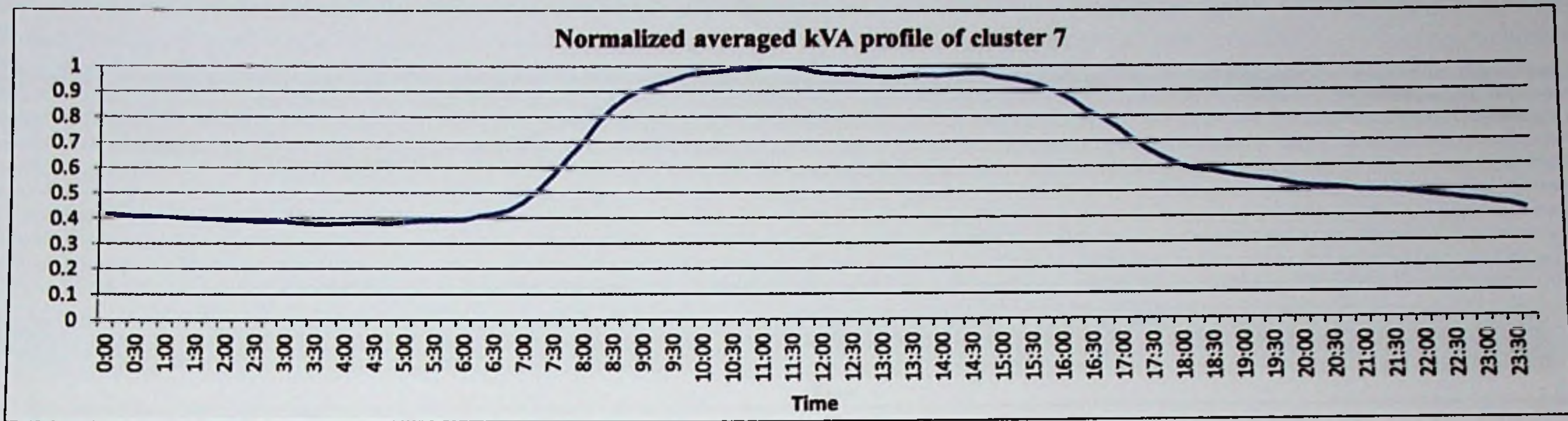
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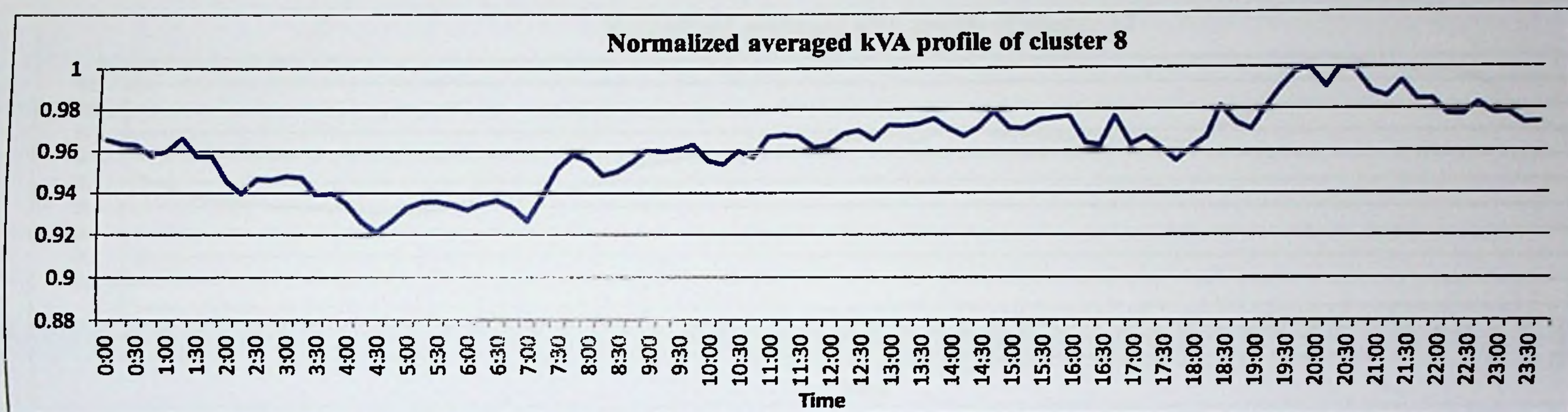
Time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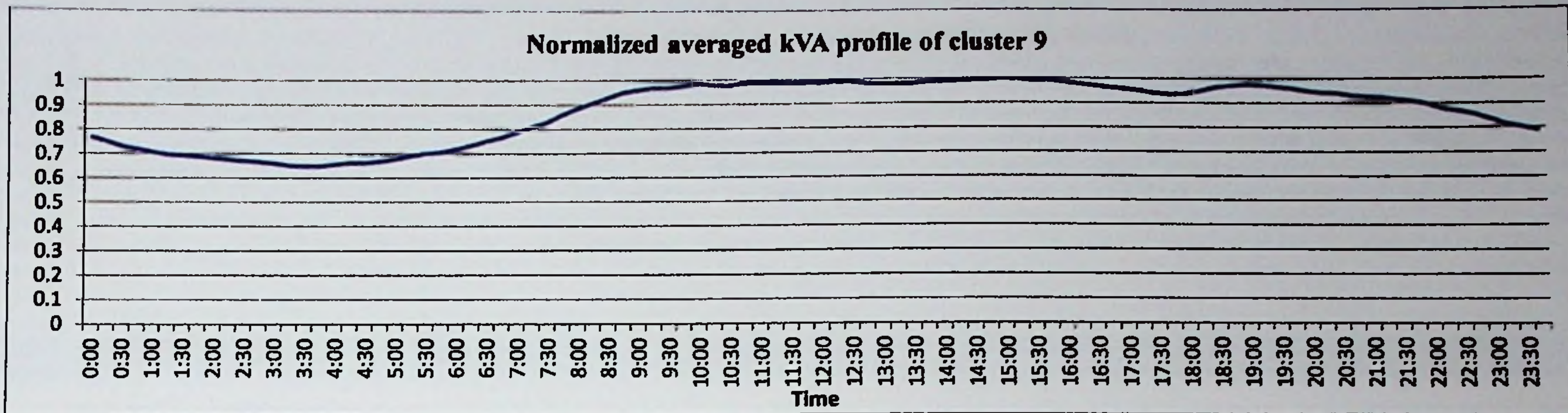
Time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0.4
0.3
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0:00 0:30 1:00 1:30 2:00 2:30 3:00 3:30 4:00 4:30 5:00 5:30 6:00 6:30 7:00 7:30 8:00 8:30 9:00 9:30 10:00 10:30 11:00 11:30 12:00 12:30 13:00 13:30 14:00 14:30 15:00 15:30 16:00 16:30 17:00 17:30 18:00 18:30 19:00 19:30 20:00 20:30 21:00 21:30 22:00 22:30 23:00 23:30
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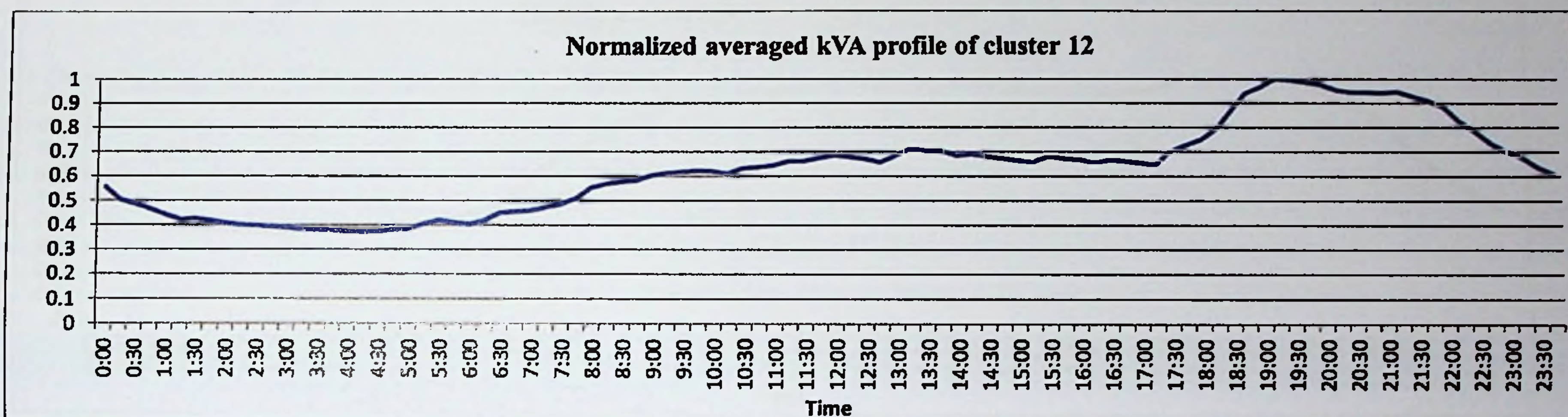
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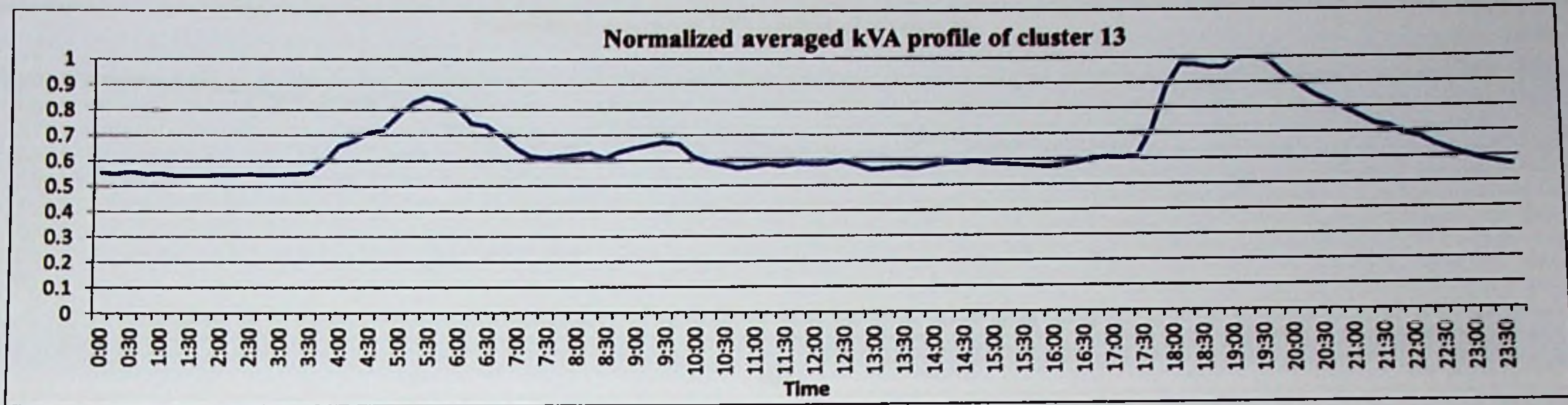

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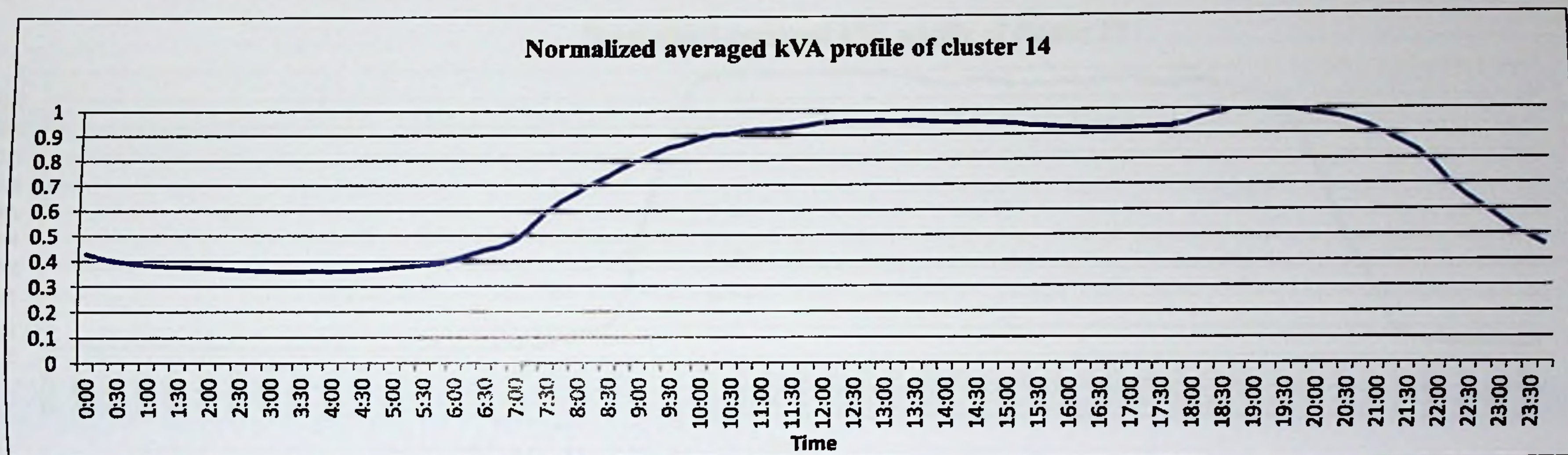

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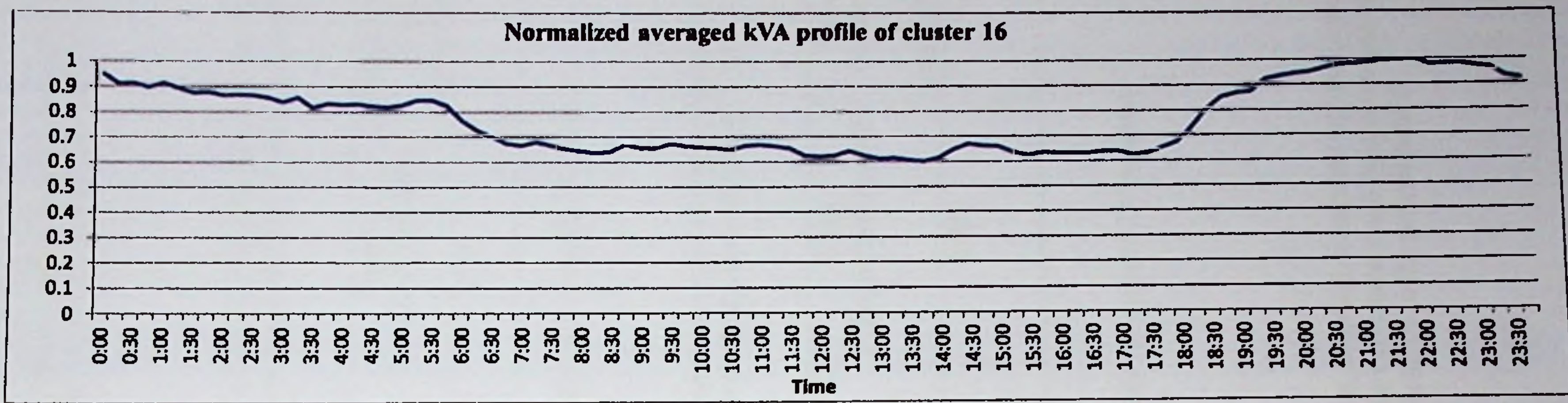
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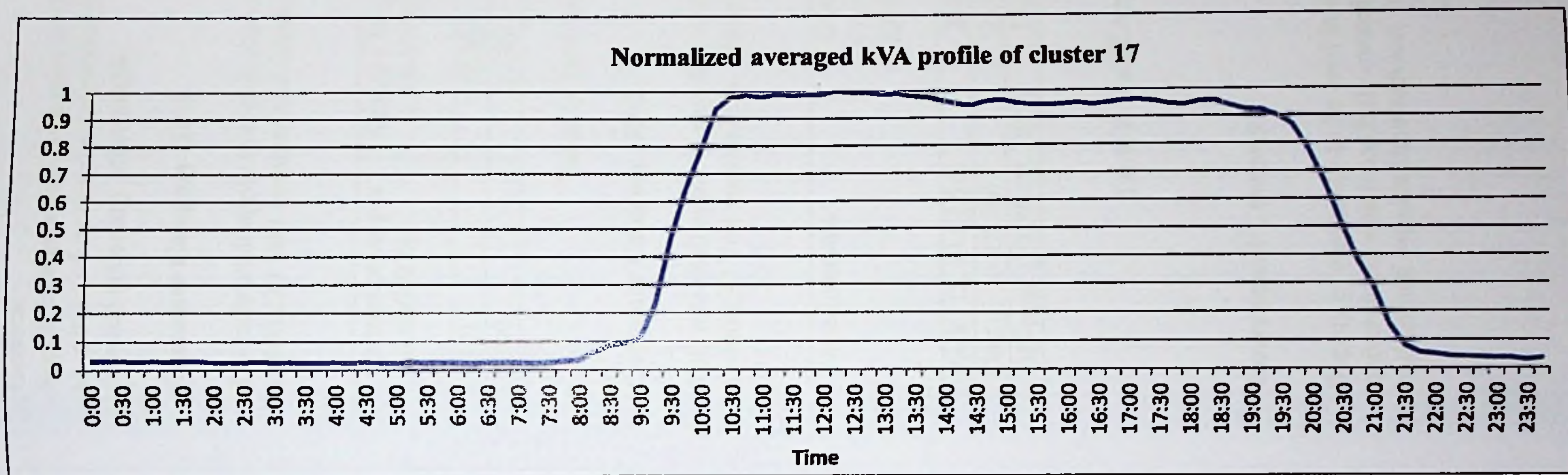
Time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Time

ANNEXURE 2: Tariff category description

General

Supply of electricity to be used in shops, offices, banks, warehouses, public buildings, hospitals, educational establishments, places of entertainment and other premises not covered under any other tariffs.

Customer Category GP-1

This rate shall apply to supplies at each individual point of supply delivered and metered at 400/230 Volt nominal and where the contract demand is less than or equal to 42 kVA.

Consumption per month(kWh)	Energy Charge (LKR/kWh)	Fixed Charge(LKR/month)	Maximum Demand Charge per month(LKR/kVA)
<301	18.30	240	-
>300	22.85		

Table 1- Tariff Applicable for General-1 Customers

Customer Category GP-2

This rate shall apply to supplies at each individual point of supply delivered and metered at 400/230 Volt nominal and where the contract demand exceeds 42 kVA.

Time Intervals	Energy Charge (LKR/kWh)	Fixed Charge(LKR/month)	Maximum Demand Charge per month(LKR/kVA)
Peak (18.30-22.30)	26.60	3,000	1,100
Day (5.30-18.30)	21.80		
Off-peak (22.30-05.30)	15.40		

Table 2- Tariff Applicable for General-2 Customers

Government Category

Supply of electricity to be used in schools, hospitals, vocational training institutions, and universities, which are fully owned by the Government and funded through the national budget and provide their services free of charge to the general public.

Customer Category GV-2

This rate shall apply to supplies at each individual point of supply delivered and metered at 400/230 Volt nominal and where the contract demand exceeds 42 kVA.

Energy Charge (LKR/kWh)	Fixed Charge(LKR/month)	Maximum Demand Charge per month(LKR/kVA)
14.55	3,000	1,100

Table 3- Tariff Applicable for Government-2 Customers

Hotel
Supply of electricity used for hotels approved by the Sri Lanka Tourism Development Authority.

Customer Category H-2

This rate shall apply to supplies at each individual point of supply delivered and metered at 400/230 Volt nominal and where the contract demand exceeds 42kVA.

Time Intervals	Energy Charge (LKR/kWh)	Fixed Charge(LKR/month)	Maximum Demand Charge per month (LKR/kVA)
Peak (18.30-22.30)	23.50	3,000	1,100
Day (5.30-18.30)	14.65		
Off-peak (22.30-05.30)	9.80		

Table 4- Tariff Applicable for Hotel-2 Customers

ANNEXURE 3: GSMB electricity bills and PV system performance

GSMB Monthly report

Devices/PV system	Gesamtertrag Meter Change [kWh] November 2015	Gesamtertrag Meter Change [kWh] 2015
GSMB	2586.32	25129.03
	2586.32 [Total]	25129.03 [Total]

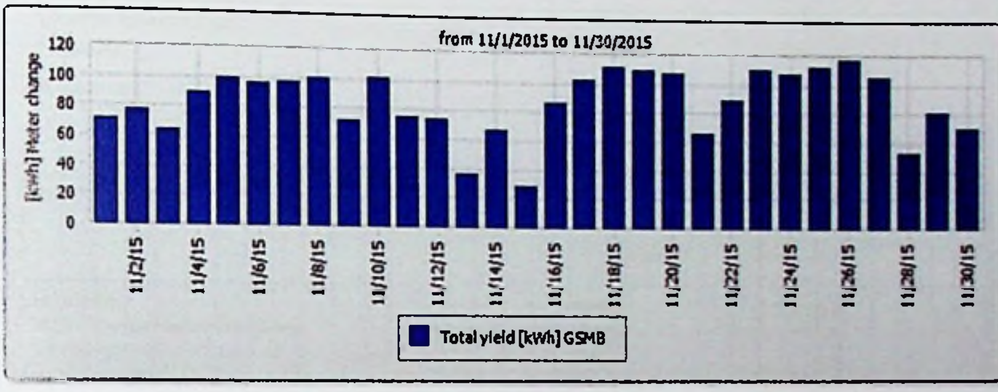


Figure 1- PV system performance in November 2015

GSMB Monthly report

Devices/PV system	Gesamtertrag Meter Change [kWh] January 2016	Gesamtertrag Meter Change [kWh] 2016
GSMB	3056.77	3056.77
	3056.77 [Total]	3056.77 [Total]

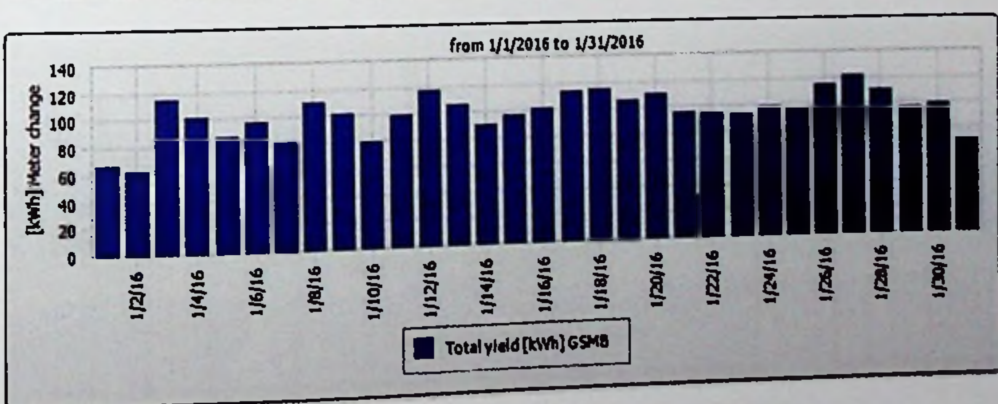


Figure 2- PV system performance in January 2016

VINSETH ENGINEERING (PVT) LTD

[illegible]

Tel: 011 [illegible] Fax: 011 [illegible]

[illegible]

Invoice

Invoice No	[illegible]
Date	[illegible]/2015
Customer Order Ref	PP/10/DQ/46/15
Payment Term	After Installation
Ref	Dn. B
Date of Installation	05/01/2016
Our Job Ref	PV/2015/[illegible]

Customer's Name and Address

Geological Survey & Mines Bureau
No 569, Epitamulla Road,
Pitakotte
Contact no

Place of installation

VAT Registration no 114441760-7000

Description	Quantity	Total (Incl)
255W "Canadian Solar" Solar Modules	120 Nos	00.00
15.0kW "SMA" On Grid Inverter With Web Monitoring	02 Nos	00.00
Delta AC & DC Surge Protection Devices	DC-00 /AC-02	00.00
Al Roof Mounting Structure	07 Sets	00.00
AC & DC Isolators, Wiring & Installation Accessories	03 Sets	00.00

Total 5,150,000.00

Total (Incl) Rs 5,150,000.00

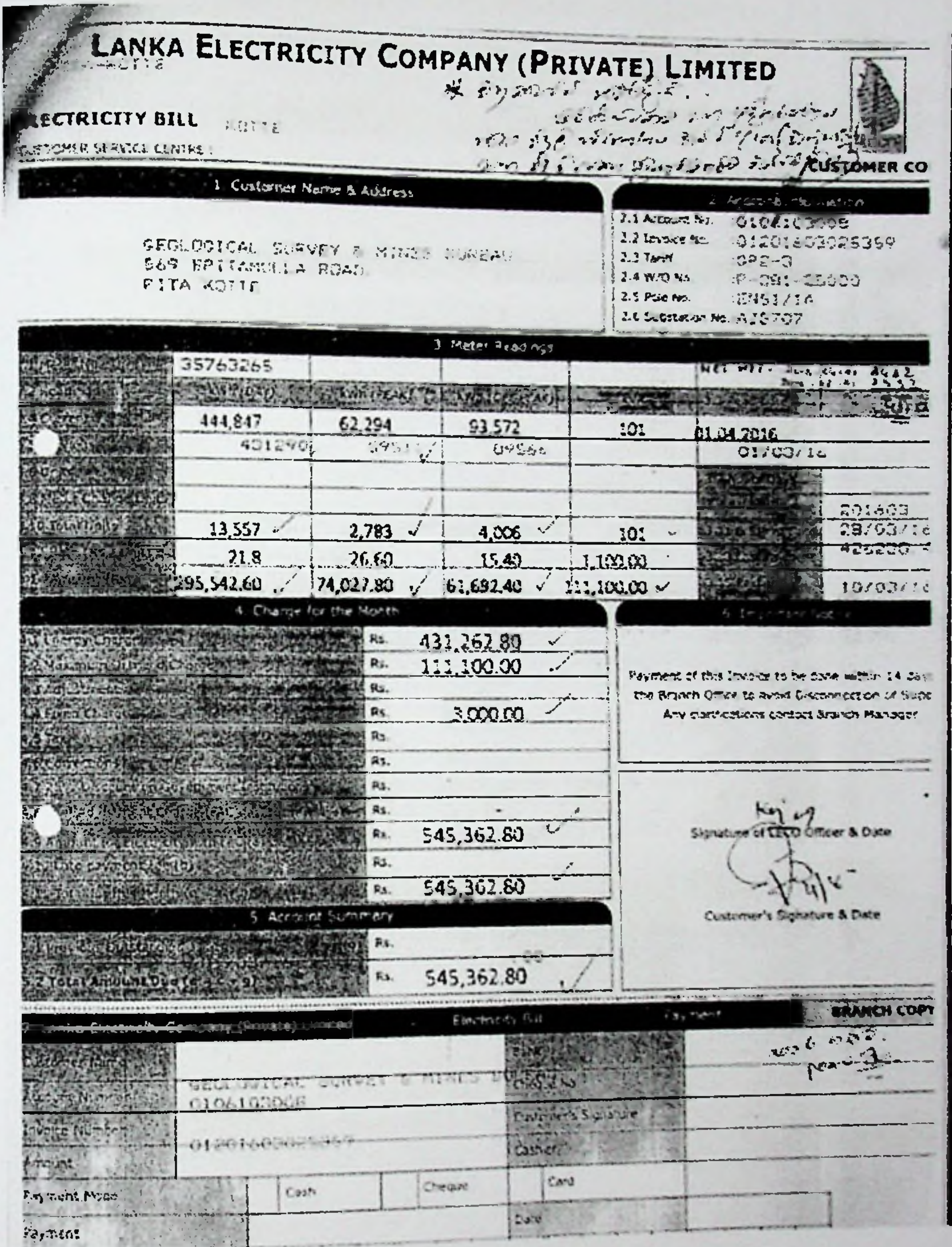
Please draw cheques in favour of Vinseth Engineering (Pvt) Ltd
Direct deposit to Sampath Bank A/C No 012710000652

Sales Executive
15/02/2016 11:23:06 AM

Authorized By
VINSETH ENGINEERING (PVT) LTD.
No. 63-1/1, Jethawana Road,
Colombo - 14.

Customer's Signature

Figure 3- Quotation of PV system at GSMB


LANKA ELECTRICITY COMPANY (PRIVATE) LIMITED

ELECTRICITY BILL KOTTE

CUSTOMER SERVICE CENTRE :

CUSTOMER COPY

1. Customer Name & Address

GEOLOGICAL SURVEY & MINES BUREAU
569 EPITAMULLA ROAD
PITA KOTTE

2.1 Account No.	0106103008
2.2 Invoice No.	01201603025369
2.3 Tariff	GP2-3
2.4 W/O No.	P-091-25000
2.5 Pole No.	DN51/14
2.6 Substation No.	AJ5707

3. Meter Readings

	35763265				
	kWh (DAY)	kWh (PEAK)	kWh (OFF PEAK)		
	444,847	62,294	93,572	101	01.04.2016
	431290	59511	09566		01/03/16
	13,557	2,783	4,006	101	201603
	21.8	26.60	15.40	1,100.00	28/03/16
	295,542.60	74,027.80	61,692.40	111,100.00	10/03/16

4. Charge for the Month

Energy Charge	Rs. 431,262.80
Maximum Demand Charge	Rs. 111,100.00
	Rs.
Fixed Charge	Rs. 3,000.00
	Rs.
	Rs.
	Rs.
	Rs. -
	Rs. 545,362.80
Late payment	Rs.
	Rs. 545,362.80

5. Account Summary

	Rs.
Total Amount Due	Rs. 545,362.80

Payment of this Invoice to be done within 14 days the Branch Office to avoid Disconnection of Supply. Any clarifications contact Branch Manager.

Signature of LECO Officer & Date

Customer's Signature & Date

BRANCH COPY

Lanka Electricity Company (Private) Limited — Electricity Bill — Payment

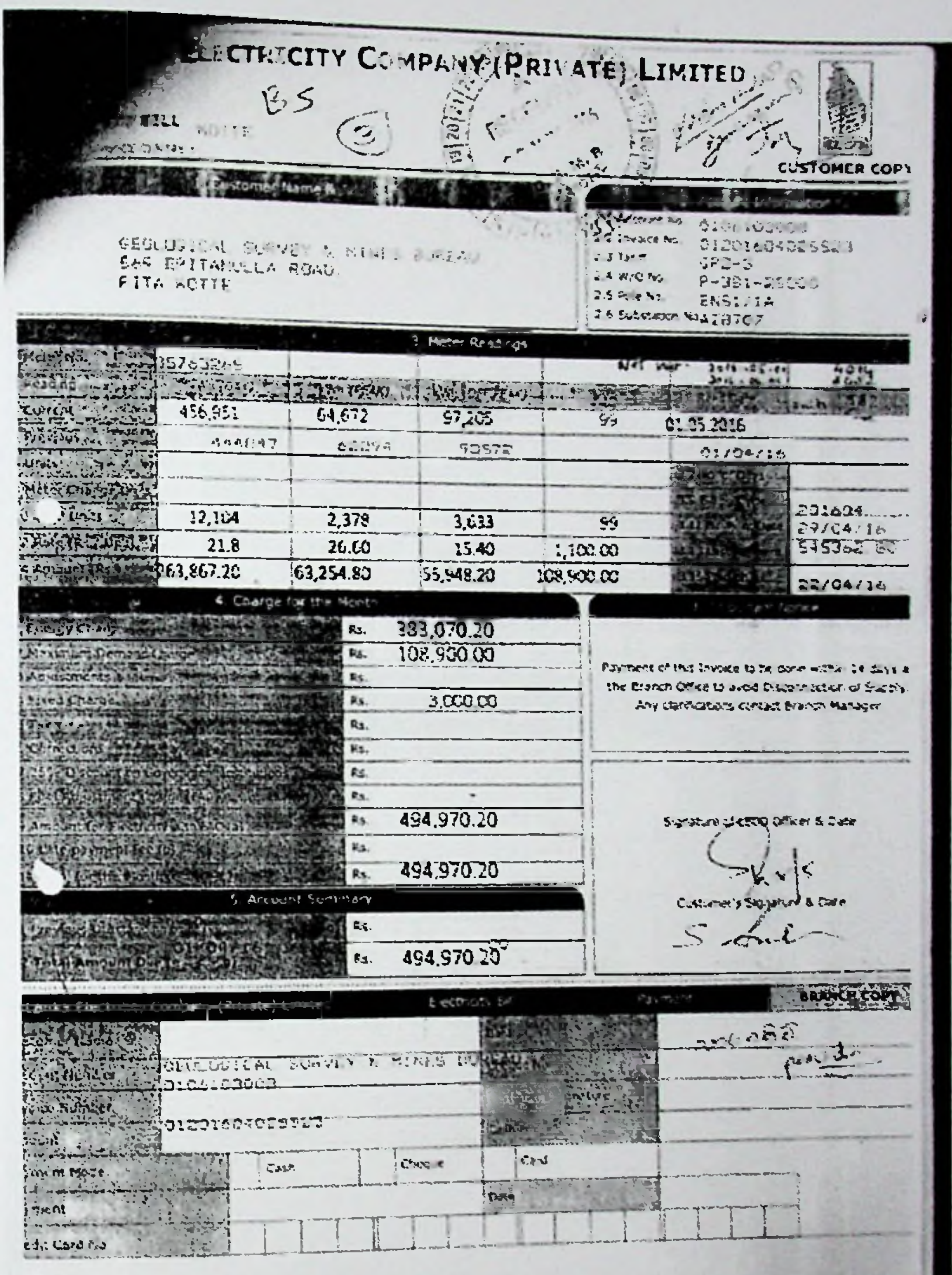
Customer Name	GEOLOGICAL SURVEY & MINES BUREAU
Account Number	0106103008
Invoice Number	01201603025369
Amount	
Payment Mode	Cash / Cheque / Card
Payment	

Customer's Signature

Cashier

Date

Figure 3- March 2016 electricity bill for GSMB



ELECTRICITY COMPANY (PRIVATE) LIMITED

CUSTOMER COPY

GEOLOGICAL SURVEY & MINES BUREAU
569 EPITAMULLA ROAD
PITA KOTTE

2.3 Tariff GP2-3
2.5 Pole No. ENS1/1A

3. Meter Readings

Current	456,951	64,672	97,205	99	01.05.2016	
					01/04/16	
Units	12,104	2,378	3,633	99		201604
Rate	21.8	26.60	15.40	1,100.00		29/04/16
Amount (Rs.)	263,867.20	63,254.80	55,948.20	108,900.00		22/04/16

4. Charge for the Month

Energy Charge	Rs. 383,070.20
Maximum Demand Charge	Rs. 108,900.00
Adjustments	Rs.
Fixed Charge	Rs. 3,000.00
	Rs.
	Rs.
	Rs.
	Rs. -
Amount	Rs. 494,970.20
	Rs.
	Rs. 494,970.20

Payment of this Invoice to be done within 14 days at the Branch Office to avoid Disconnection of Supply. Any clarifications contact Branch Manager.

Signature of Officer & Date

Customer's Signature & Date

5. Account Summary

	Rs.
Total Amount Due	Rs. 494,970.20

Electricity Bill Payment BRANCH COPY

GEOLOGICAL SURVEY & MINES BUREAU

Payment Mode: Cash | Cheque | Card

Date

Credit Card No

Figure 4- April 2016 electricity bill for GSMB

ANNEXURE 4: ELS Lanka (Pvt) Ltd electricity bills and PV system performance

SUNNY PORTAL US-English

ELS CONSTRUCTION (PVT ...

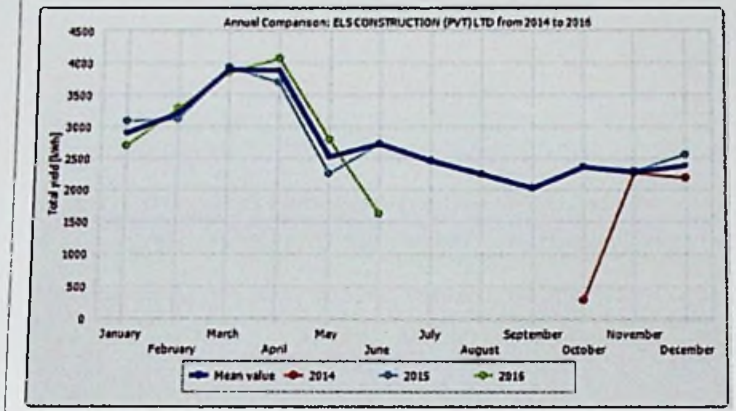
- PV System Overview
- PV System Profile
- Energy and Power
- Annual Comparison
- PV System Monitoring
- PV System Logbook: 8732
- Analysis

Visualization

Configuration

Annual Comparison | ELS CONSTRUCTION (PVT) LTD

Total yield   Specific PV System Yield



Total yield [kWh]

	January	February	March	April	May	June	July	August	September	October	November	December	Total
2014										297.07	2279.08	2197.91	4774.06
2015	3091.69	3124.39	3940.17	3703.03	2254.31	2730.90	2454.02	2260.07	2038.96	2373.57	2303.90	2558.01	32833.00
2016	2702.88	3290.62	3858.35	4082.05	2795.30	1636.85							18366.04
													55973.10
Mean value	[illegible]	[illegible]	[illegible]	[illegible]	2524.81	2730.90	2454.02	2260.07	2038.96	2373.57	2291.49	2377.96	32948.34
Year portion	[illegible]	[illegible]	[illegible]	[illegible]	7.66%	8.29%	7.45%	6.86%	6.19%	7.20%	6.95%	7.22%	100.00%

Commissioning: 10/27/2014

Figure 1- PV system performance from 2014 November to 2016 June

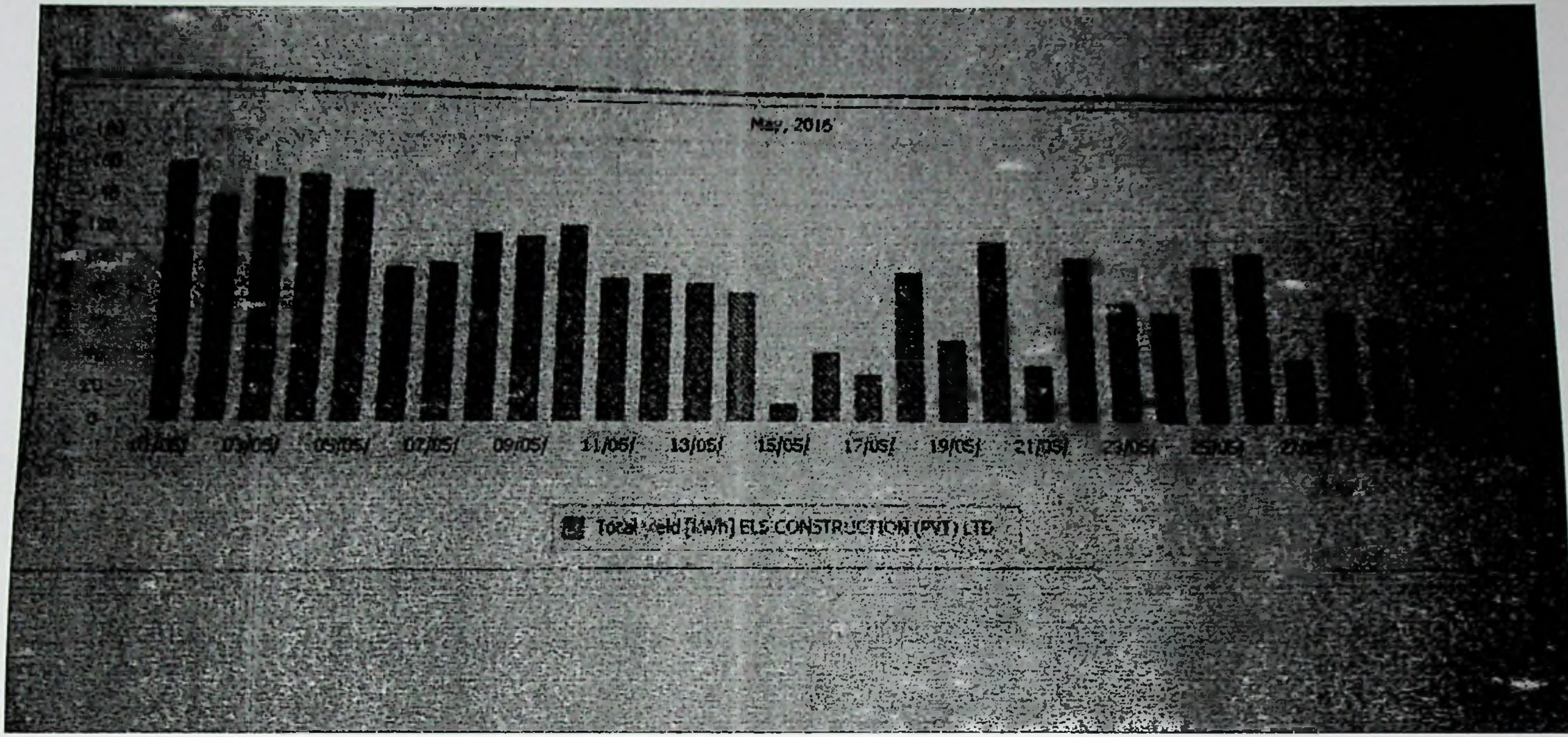


Figure 2- PV system performance in May 2016

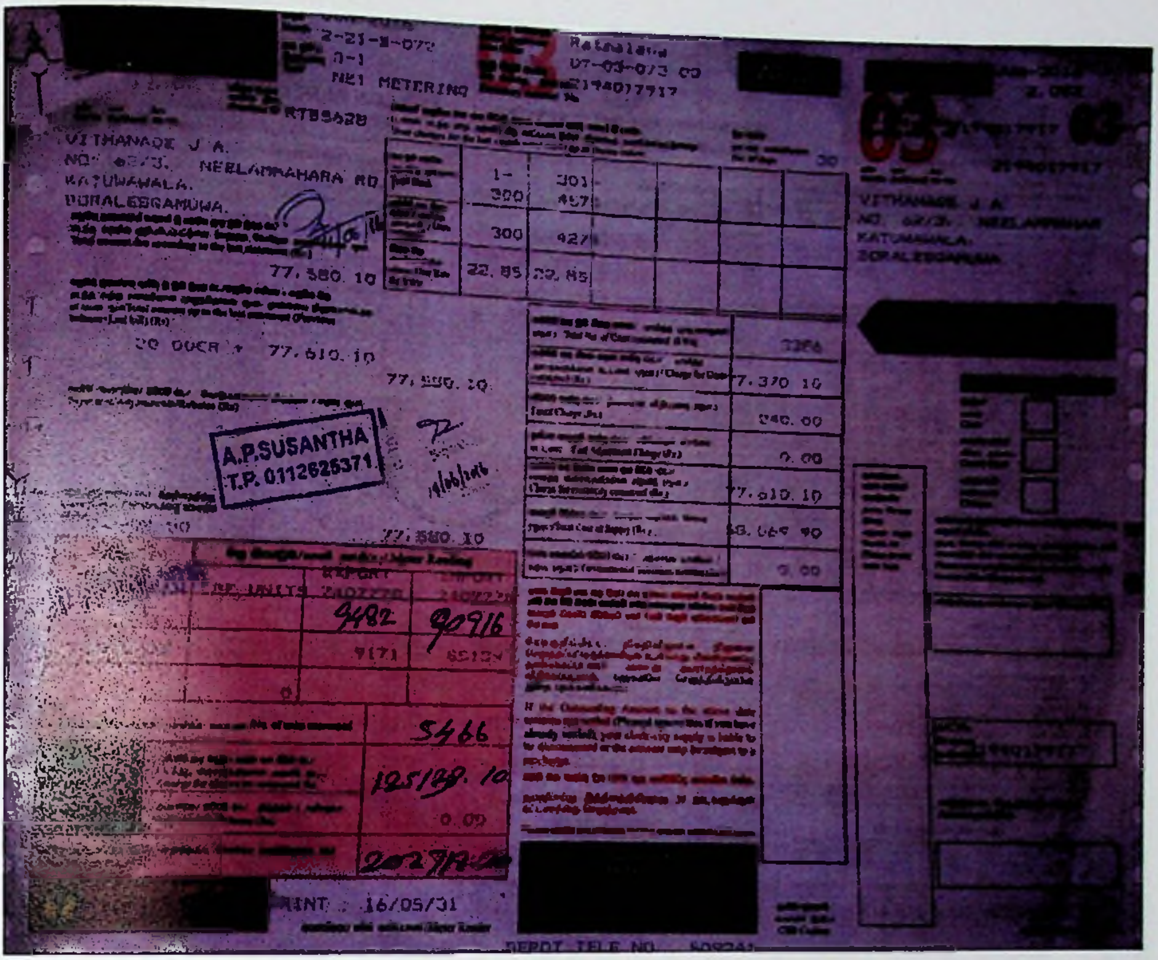


Figure 3- June 2016 electricity bill for ELS Lanka (Pvt) ltd

ANNEXURE 5: Cargills foodcity, Nawala electricity bill and PV system performance

Daily production of the 60 kW solar system for the Month of October, 2014

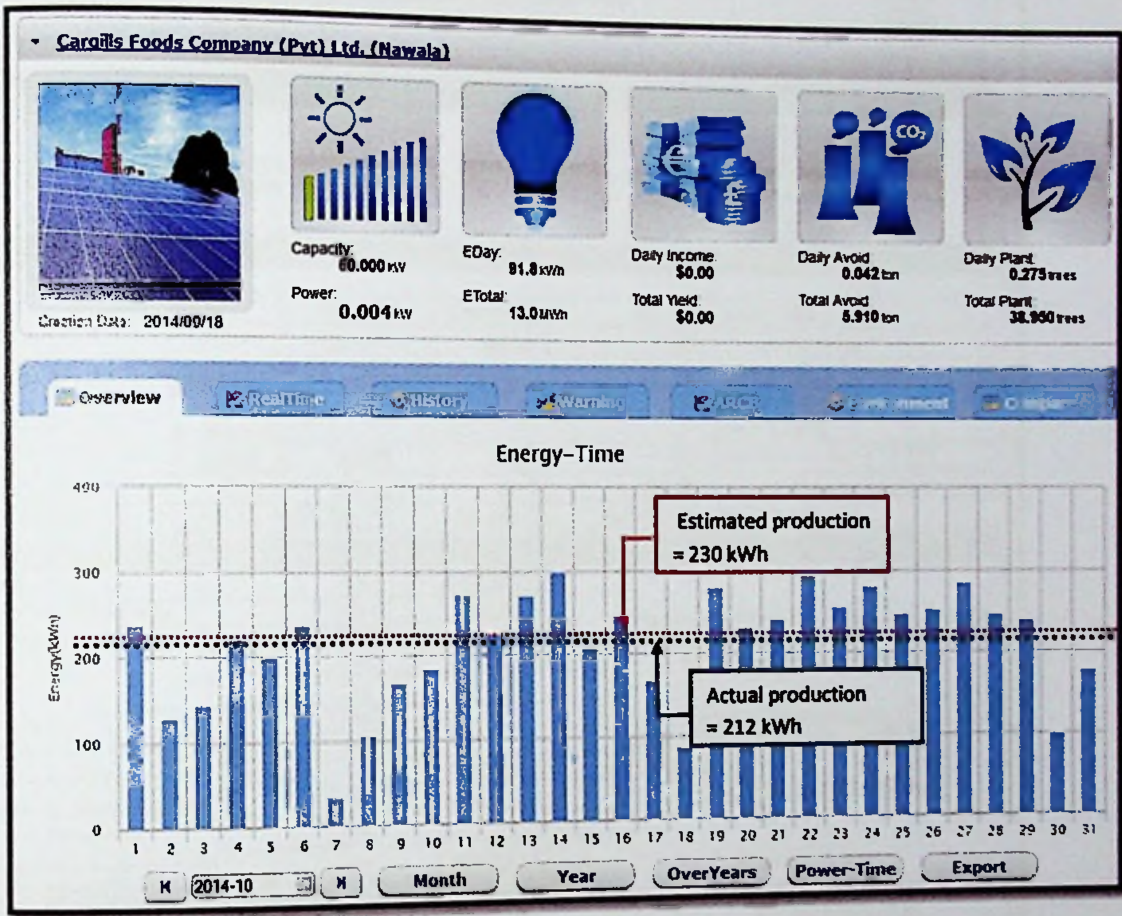
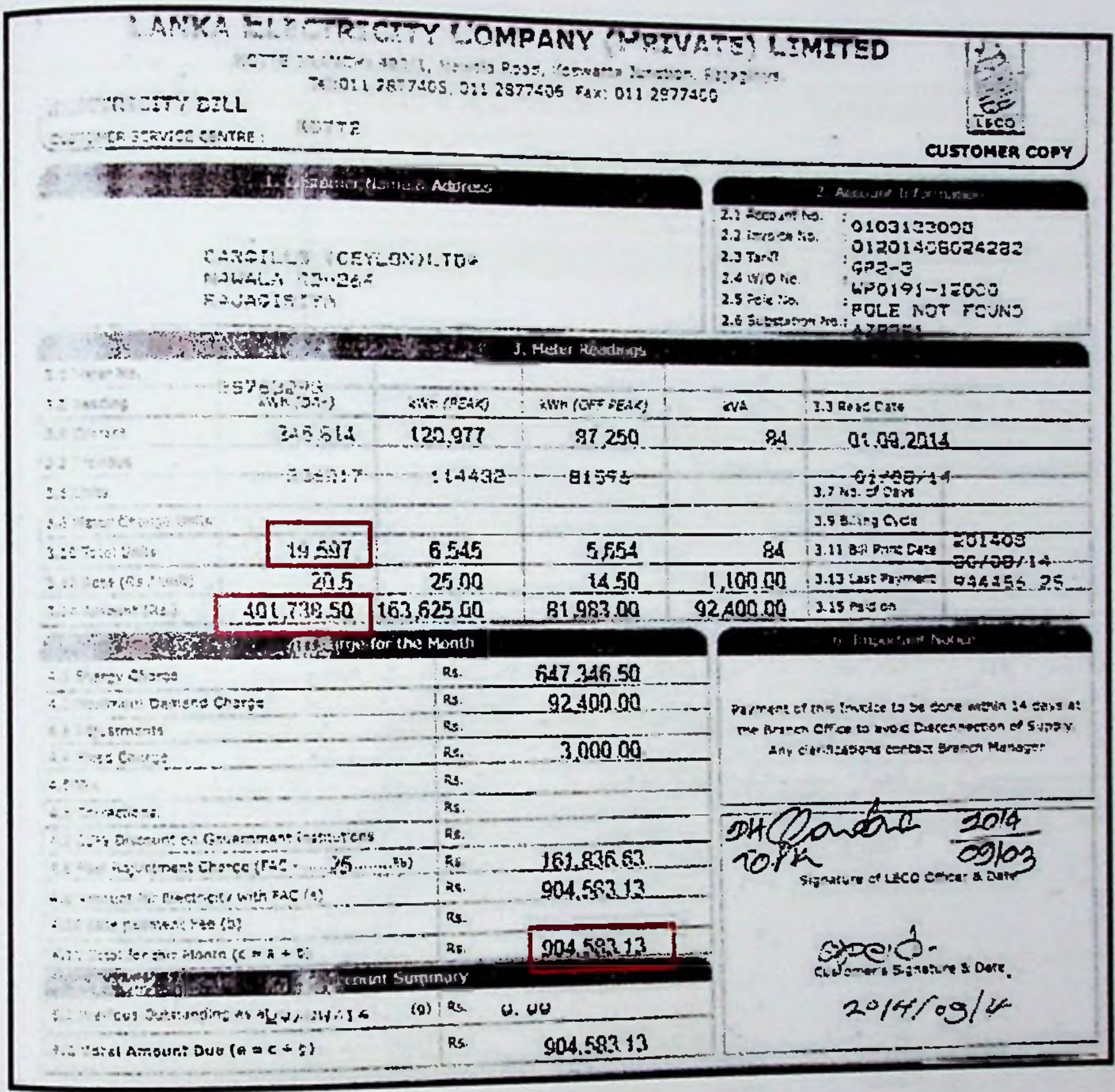


Figure 1- PV system performance in October 2014

August, 2014 Electricity bill

The last bill received before solar system began to function on 4th September, 2014



LANKA ELECTRICITY COMPANY (PRIVATE) LIMITED

Tel: 011 2877405, 011 2877406 Fax: 011 2877400

CITY BILL

CUSTOMER SERVICE CENTRE : KOTTE

CUSTOMER COPY

1. Customer Name & Address

CARGILLS (CEYLON) LTD
NAWALA
RAJAGIRIYA

2. Account Information

2.1 Account No.	0103133008
2.2 Invoice No.	01201408024282
2.3 Tariff	GP2-3
2.4 W/O No.	WP0191-12000
2.5 Pole No.	POLE NOT FOUND
2.6 Substation No.	

3. Meter Readings

	kWh (DAY)	kWh (PEAK)	kWh (OFF PEAK)	kVA	
Current	345,614	120,977	87,250	84	3.3 Read Date 01.09.2014
Previous	326017	114432	81596		3.7 No. of Days
					3.9 Billing Cycle 201408
3.10 Total Units	19,597	6,545	5,654	84	3.11 Bill Print Date 06/08/14
Rate (Rs./Unit)	20.5	25.00	14.50	1,100.00	3.13 Last Payment 944456.25
Amount (Rs.)	401,738.50	163,625.00	81,983.00	92,400.00	3.15 Paid on

Charge for the Month

Energy Charge	Rs.	647,346.50
Maximum Demand Charge	Rs.	92,400.00
Adjustments	Rs.	
Fixed Charge	Rs.	3,000.00
	Rs.	
Transactions	Rs.	
Discount on Government Institutions	Rs.	
Fuel Adjustment Charge (FAC = 25 %)	Rs.	161,836.63
Amount for Electricity with FAC (A)	Rs.	904,583.13
Late payment Fee (B)	Rs.	
Total for this Month (C = A + B)	Rs.	904,583.13

Account Summary

Previous Outstanding	(D)	Rs.	0.00
Total Amount Due (E = C + D)		Rs.	904,583.13

Important Notice

Payment of this invoice to be done within 14 days at the Branch Office to avoid Disconnection of Supply. Any clarifications contact Branch Manager.

2014 09/03

Signature of LECO Officer & Date

Customer's Signature & Date

2014/09/4

Figure 2- August 2014 electricity bill for Cargills food city, Nawala

September, 2014 Electricity bill

The first ever bill received after solar system began to function from 4th September, 2014

LANKA ELECTRICITY COMPANY (PRIVATE) LIMITED

KOTTE BRANCH: 490/1, Nawala Road, Koswatta Junction, Rajagiriya.
Tel:011 2877405, 011 2877406 Fax: 011 2877400

ELECTRICITY BILL

CUSTOMER SERVICE CENTRE : KOTTE

CUSTOMER

1 Customer Name & Address

CARGILLS (CEYLON) LTD
NAWALA RD #264
RAJAGIRIYA

2.1 Account No.	: 0103133008
2.2 Invoice No.	: 01201409023??
2.3 Tariff	: GP2-S
2.4 W/O No.	: WP0191-12000
2.5 Pole No.	: POLE NOT FOU
2.6 Substation No.	: AZ8251

3 Meter Readings

3.1 Meter No	25763??3					
3.2 Reading	kWh (DAY)	kWh (PEAK)	kWh (OFF PEAK)	kVA	3.3 Read Date	
3.4 Current	358,122	127,285	92,441	75	01.10.2014	
3.5 Previous	345814	120977	87250		01/09/14	
3.6 Units					3.7 No. of Days	
3.8 Meter Change Units					3.9 Billing Cycle	20141
3.10 Total Units	12,308	6,308	5,191	75	3.11 Bill Print Date	30/0
3.12 Rate (Rs / Unit)	20.5	25.00	14.50	1,100.00	3.13 Last Payment	94,44
3.14 Amount (Rs.)	252,314.00	157,700.00	75,269.50	82,500.00	3.15 Paid on	29/0

4 Charge for the Month

4.1 Energy Charge	Rs.	485,283.50
4.2 Maximum Demand Charge	Rs.	82,500.00
4.3 Adjustments	Rs.	
4.4 Fixed Charge	Rs.	3,000.00
4.5 Tax	Rs.	
4.6 Corrections.	Rs.	
4.7 25% Discount on Government Institutions	Rs.	
4.8 Fuel Adjustment Charge (FAC - ....25.....%)	Rs.	121,320.88
4.9 Amount for Electricity with FAC (a)	Rs.	692,104.38
4.10 Late payment Fee (b)	Rs.	
4.11 Total for this Month (c = a + b)	Rs.	692,104.38

5 Account Summary

5.1 Previous Outstanding as at 29/09/14	(g)	Rs.	904583.13
5.2 Total Amount Due (e = c + g)		Rs.	1,596,687.51

Payment of this Invoice to be done within [illegible] the Branch Office to avoid Disconnection [illegible] Any clarifications contact Branch Man[illegible]

Signature of LECO Officer & Date

Customer Signature & Date

Figure 3- September 2014 electricity bill for Cargills food city, Nawala

ANNEXURE 6: Visual basic code used for tool development

```
Private Sub CommandButton1_Click()
Dim a, b, c, d As String
Dim e, f, g, h As Integer
g = 2
For h = 1 To 100
Sheet1.Cells(h, 1).Value = ""
Sheet1.Cells(h, 2).Value = ""
Sheet1.Cells(h, 3).Value = ""
Sheet1.Cells(h, 4).Value = ""
Sheet1.Cells(h, 5).Value = ""
Sheet1.Cells(h, 6).Value = ""
Sheet1.Cells(h, 7).Value = ""
Sheet1.Cells(h, 8).Value = ""
Sheet1.Cells(h, 9).Value = ""
Sheet1.Cells(h, 10).Value = ""
Sheet1.Cells(h, 11).Value = ""
Sheet1.Cells(h, 12).Value = ""
Sheet1.Cells(h, 13).Value = ""
Sheet1.Cells(h, 14).Value = ""
Sheet1.Cells(h, 15).Value = ""
Next h
For e = 2 To 1500
'a = ComboBox1.Text
a = ComboBox2.Text
b = ComboBox3.Text
c = ComboBox4.Text
If Sheet3.Cells(e, 1).Value = a And Sheet3.Cells(e, 2).Value = b And Sheet3.Cells(e,
3).Value = c Then

For f = g To g

Sheet1.Cells(1, 1).Value = "PV & inverter capacity (kW)"
Sheet1.Cells(1, 2).Value = "PV system cost ($)"
Sheet1.Cells(1, 3).Value = "PV system cost ( Rs.)"
Sheet1.Cells(1, 4).Value = "Capital cost ($)"
Sheet1.Cells(1, 5).Value = "Capital cost (Rs.)"
Sheet1.Cells(1, 6).Value = "Replacement cost ($)"
Sheet1.Cells(1, 7).Value = "Replacement cost (Rs.)"
Sheet1.Cells(1, 8).Value = "O & M cost ($)"
Sheet1.Cells(1, 9).Value = "O & M cost (Rs.)"
Sheet1.Cells(1, 10).Value = "Cost of energy ($)"
Sheet1.Cells(1, 11).Value = "Cost of energy (Rs.)"
Sheet1.Cells(1, 12).Value = "Ren. Fraction"
```

```
Sheet1.Cells(1, 13).Value = "Simple pay back period"
Sheet1.Cells(1, 14).Value = "Disconted pay back period"
Sheet1.Cells(1, 15).Value = "Average area requirement"


Sheet1.Cells(f, 1).Value = Sheet3.Cells(e, 4).Value
Sheet1.Cells(f, 2).Value = Sheet3.Cells(e, 5).Value
Sheet1.Cells(f, 3).Value = Sheet3.Cells(e, 6).Value
Sheet1.Cells(f, 4).Value = Sheet3.Cells(e, 7).Value
Sheet1.Cells(f, 5).Value = Sheet3.Cells(e, 8).Value
Sheet1.Cells(f, 6).Value = Sheet3.Cells(e, 9).Value
Sheet1.Cells(f, 7).Value = Sheet3.Cells(e, 10).Value
Sheet1.Cells(f, 8).Value = Sheet3.Cells(e, 11).Value
Sheet1.Cells(f, 9).Value = Sheet3.Cells(e, 12).Value
Sheet1.Cells(f, 10).Value = Sheet3.Cells(e, 13).Value
Sheet1.Cells(f, 11).Value = Sheet3.Cells(e, 14).Value
Sheet1.Cells(f, 12).Value = Sheet3.Cells(e, 15).Value
Sheet1.Cells(f, 13).Value = Sheet3.Cells(e, 16).Value
Sheet1.Cells(f, 14).Value = Sheet3.Cells(e, 17).Value
Sheet1.Cells(f, 15).Value = Sheet3.Cells(e, 18).Value
g = g + 1
Next f
'Else
'MsgBox ("Not Available")
'Exit For
End If

Next e
If Sheet1.Cells(1, 1).Value = "" Then
MsgBox ("NOT REAL.Check your input parameters as the given table in front page")
End If

Sheet1.Activate
End Sub

Private Sub CommandButton2_Click()
Unload Me
End Sub

Private Sub CommandButton3_Click()
Dim h As Integer
For h = 1 To 500
Sheet1.Cells(h, 1).Value = ""
Sheet1.Cells(h, 2).Value = ""
Sheet1.Cells(h, 3).Value = ""
```

```
Sheet1.Cells(h, 4).Value = ""
Sheet1.Cells(h, 5).Value = ""
Sheet1.Cells(h, 6).Value = ""
Sheet1.Cells(h, 7).Value = ""
Sheet1.Cells(h, 8).Value = ""
Sheet1.Cells(h, 9).Value = ""
Sheet1.Cells(h, 10).Value = ""
Sheet1.Cells(h, 11).Value = ""
Sheet1.Cells(h, 12).Value = ""
Sheet1.Cells(h, 13).Value = ""
Sheet1.Cells(h, 14).Value = ""
Sheet1.Cells(h, 15).Value = ""
Next h
End Sub

Private Sub UserForm_Activate()
'ComboBox1.AddItem "Colombo"
ComboBox2.AddItem "GV2"
ComboBox2.AddItem "GP2"
ComboBox2.AddItem "H2"
ComboBox3.AddItem "Cluster 2"
ComboBox3.AddItem "Cluster 4"
ComboBox3.AddItem "Cluster 5"
ComboBox3.AddItem "Cluster 6"
ComboBox3.AddItem "Cluster 7"
ComboBox3.AddItem "Cluster 8"
ComboBox3.AddItem "Cluster 9"
ComboBox3.AddItem "Cluster 12"
ComboBox3.AddItem "Cluster 13"
ComboBox3.AddItem "Cluster 14"
ComboBox3.AddItem "Cluster 16"
ComboBox3.AddItem "Cluster 17"
ComboBox4.AddItem "140kW/175kVA"
ComboBox4.AddItem "100kW/125kVA"
ComboBox4.AddItem "120kW/150kVA"
ComboBox4.AddItem "80kW/100kVA"
ComboBox4.AddItem "60kW/75kVA"
ComboBox4.AddItem "40kW/50kVA"
End Sub

Sub Macro1()
' Macro1 Macro
' Keyboard Shortcut: Ctrl+d
UserForm1.Show
End Sub
```