Cost Implications of Rooftop Solar PV with Batteries on Industrial and Commercial Customers in Sri Lanka

Degree of Master of Science in Electrical Engineering

Department of Electrical Engineering

University of Moratuwa

Sri Lanka

DECEMBER 2022

Cost Implications of Rooftop Solar PV with Batteries on Industrial and Commercial Customers in Sri Lanka

S V Herath

(178510R)

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

Department of Electrical Engineering

University of Moratuwa

Sri Lanka

DECEMBER 2022

DECLARATION

I declare that this thesis is my work and to the best of my knowledge and belief there is no material incorporated therein previously submitted for a Degree or Diploma in any other university or institute of higher learning, without giving the proper acknowledgement to that effect. It also does not contain any material previously published or written by another person except where due acknowledgement is made in the text.

Also, I hereby grant to the University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part, in print, electronic or other media. I retain the right to use the content of this thesis in whole or part of that in my future works (such as articles or books).

Signature: Date:23-12-2022

UOM Verified Signature

S V Herath

The above candidate has carried out the research for the Master thesis under my supervision.

Signature of the supervisor: Date: 25-12-2022

UOM Verified Signature

… ……………………..

Prof. J. R. Lucas

ABSTRACT

Electricity is one of the key factors for the business of industrial and commercial customers in a particular location. Therefore, the Government and local authorities have introduced special tariff schemes to provide electricity in a cost-effective manner. On the other hand, the tariff structures are focused to reduce the stress for the grid operation by the utility provider.

With the advantage of being a tropical country, Sri Lanka is having higher solar irradiation throughout the year and most of the electricity consumers are willing to install rooftop solar systems into their facility. The excess solar production can be sold back to the utility provider by several methods, as preferred by the consumer.

However, the utility provider is facing many difficulties related to the technical and financial perspective, to absorb the total solar production by the consumers. Therefore, in this research, the management of the own solar production by the consumer, either grid connected or in islanded operation mode, has been speculated.

The research is primarily focused on real-time based management of solar generation which is allocated for loads, charging, controllable load dispatching, and shedding is decided. Finally, the load is matched with the available power sources in the basis of optimum cost. As the optimization technique, quadrature optimization has been used.

A selected industrial purpose customer and a general-purpose customer were used to analyze the data. Calculation of the unit costs for the solar energy and battery bank was done based on the LCOE formula and this represents the lifecycle cost of the energy sources based on the lifetime energy generation. The program is used to calculate the optimum battery capacity for an industrial and a general-purpose customer in Sri Lanka with the financial values in 2018 as indicated in annex 7. Also, in both cases the effect of the solar energy generation was varied to identify the change of the profit of the installations. It could be observed that when reducing the daily solar power generation, profit was drastically reduced. As an example, in relation to the data for Case B and Case E when solar generation was reduced by 17% profit was reduced by 24% for GP customer. Furthermore, the calculations were made to identify the profit changes for BST which represent the actual cost for the utility in 2018. In this case the average profit for each case was reduced by 150% ending with a loss for the investment. Also, the calculation was done for the new financial figures in 2022 November and the profits were reduced by 330% and the investment is found to be not feasible with the available figures.

In conclusion, the method proposed is feasible to use to evaluate the initial investment for solar PV systems and battery energy storage (BES) systems. However, the tariff rates as well as the financial figures like fuel cost, exchange rate formulate a considerable impact on the result. Therefore, the financial figures provided in 2018 provides a profit generation but in 2022 the optimized solutions are not feasible due to changes of the financial figures. However, the method provided in this thesis can be used to calculate feasibility of solar and battery installation for any customer.

ACKNOWLEDGEMENT

I would like to convey my heartfelt gratitude to the supervisor of the project Prof. J R Lucas in the Department of Electrical Engineering, University of Moratuwa. His encouraging, enthusiastic advice motivated me to complete the project during this difficult time periods.

Without the guidance's and comments provided by the beloved academic staff of the Department of Electrical Engineering, the project would not be enhanced to this level. So, I would like to thankful to them from the bottom of my heart.

The CEO of West Coast power (Pvt) Limited Mr. J A S Perera, who provided great support to the project with valuable advice, need to be mentioned here. All the Staff members including CEO Mr. U D Jayawardena of LTL Holdings were a great strength for me to complete my project and academic work.

Finally, I would like to acknowledge the dedication provided by my family members during the period to allow me to successfully complete the project. My beloved father, mother, wife, and sister were always behind me for the success.

TABLE OF CONTENTS

List of Tables

List of Figures

List of Abbreviations

CEB - Ceylon Electricity Board

PV - Photovoltaic

IP - Industrial Purpose

GP - General Purpose

LOCE - Levelized Cost of Energy

BSES - Battery Stored Energy Systems

DERs - Distributed Energy Resources

GA -Generic Algorithm

DE -Diesel Engines

BS -Battery Storage

SOC - State of Charge

RES - Renewable Energy Sources

DOD -Depth of Discharge

DC -Direct Current

DR - Demand Response

MD - Maximum Demand

BST - Bulk Supply Tariff

1.0 Introduction

In consideration to the contribution that is provided by the electrical consumers for the national economy in Sri Lanka, the commercial and industrial customers play a vital role. However, due to higher energy consumption the cost for electricity is crucial for the profitability of their business. In addition to the cost concerns, the problems related to reliability of the power supply has massive impact for the business operation.

The tariff structures for the Commercial and Industrial Purpose customers that existed in 2018 are as given in Table 1 and Table 2.

Table 1 - IP Customer Tariff

Time Intervals	Energy Charge (LKR/kWh)	Fixed Charge (LKR/month)	Maximum Demand Charge (LKR/kVA/month)
Peak (18.30-22.30)	23.5	3,000.00	1,100.00
Day (5.30-18.30)	10.25		
Off-peak (22.30-05.30)	5.9		

Table 2 - GP Customer Tariff

Time Intervals	Energy Charge (LKR/kWh)	Fixed Charge (LKR/month)	Maximum Demand Charge (LKR/kVA/month)
Peak (18.30-22.30)	26.6	3,000.00	1,100.00
Day (5.30-18.30)	21.8		
Off-peak (22.30-05.30)	15.4		

In both the structures shown in table 1and table 2, the three-tire tariff and maximum demand is used for the calculations, where the peak cost is the highest. In consideration to the energy bills of several customers in both structures the energy bill, as well as maximum demand cost, has contributed, by considerable amounts, for higher energy bills.

Several studies have been conducted to find solutions to reduce the energy cost of industrial and general-purpose customers, but most of them are related to the demand management programs. Here the customers introduce the energy management programs to improve the efficiencies of the energy usage in their facilities.

On the other hand, to improve the reliability of the power supply most of the customers adhere to installation of emergency diesel generators.

1.1 Roof Top Solar Installation

Roof Top Solar systems are considered as a key energy source in many countries in the world. In Sri Lanka the Ceylon Electricity Board (CEB) has introduced attractive methods like net metering and net accounting to motivate consumers to install roof top solar into their facilities. This approach has added 367 MW of power to the system with 16, 472 (121 MW) installations at net metering 14,392 (113.5 MW), 1,547 (132 MW) from net accounting and net plus respectively at the end of the April 2021.

In the global approach, the European Union is targeting to add online over 320 GW of Solar Energy by 2025 and 600 GW by 2030. Additionally, they have mentioned rooftop PV could provide approximately 25% of electricity consumption in the region, more than the share of natural gas today.

However, the distribution system needs to be facilitated to cater this solar energy ingression to the network to overcome some technical issues. There can be over voltage situations in the low voltage distribution network, which is a frequent problem in the urban areas where several rooftop solar systems are installed.

On the other hand, as per the CEB Least Cost Generation Plan, 70% of the electricity generation to be added is by clean energy sources by 2030. Among them, 50% of the generation is to be provided through renewable energy sources. 2338 MW of solar power plants and 765 MW of wind power are to be added to the system in this approach by 2030. In this approach, several challenges are to be overcome with different innovative solutions to the systems.

1.2 Battery Bank Installation

The problem of the solar and wind power is the intermittent nature of the generation. Therefore, in power system theory, to balance supply and demand an alternative source is required. To compensate for the supply fluctuations due to renewables and extreme weather conditions, aeroderivative type gas turbine generators have been proposed by most of the utility providers. However, the best solution for these variations is the Battery Bank installations. Due to high operational and maintenance cost of the battery bank systems, it is calculated that the unit cost for battery stored energy is significantly higher. However, it can be noted that the battery bank installing capital cost has reduced drastically during the last decade and it is predicted it will reduce further in the coming years.

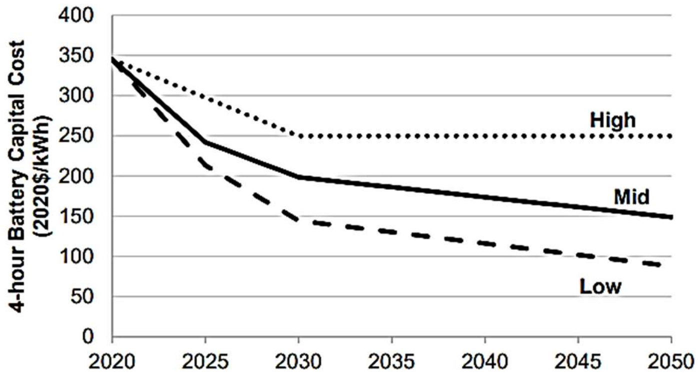


Figure 1 - Battery Cost Prediction

In consideration of the above facts, it is advisable to use battery storage systems to address the generation fluctuations in a system due to the renewable energy sources. Currently, in the European Union, the storage capacity is around 40 GW and by 2030 are planning to install around 108 GW electricity storage including batteries and pumped storages to cater for the intermittency of the renewable energy.

1.3 Diesel Engine Generators

Most of the industrial purpose (IP) and general purpose (GP) consumers in Sri Lanka have currently invested in diesel engine generators with adequate capacity to fulfill the power requirement, during unavailability of grid power. These generators have huge operational and maintenance costs in comparison to the renewable energy sources. Furthermore, the frequent preventive maintenance activities and test running incurs additional cost for the consumer. On top of that, most of the customers complain that the generators are not reliable enough due to technical issues.

1.4 Controllable Loads

In most of the commercial and industrial consumer load profiles, there are loads that can be dispatched in a controllable manner. During the time periods where the energy cost is a minimum, these loads can be dispatched to reduce the costs. These applications can be observed with reference to some islands where microgrid systems are installed. In these locations, desalination plants are operated during the daytime where the solar energy is highly available. In many demands side management approaches, this method is widely used to switch on the loads that are non-critical to off peak hours.

1.5 Prediction of Solar Generation

In the present situation, there exists several applications to forecast and simulate the solar energy production for a particular location to calculate the expected energy generation. This data would be used to calculate the viability of the investment and to justify it to the investor. Most of the predictions are based on the historical solar data captured by the satellite images. Other than that, there are some applications which are developed to forecast the solar generation for the next couple of minutes. Modern day technologies of latest weather satellite imagery, machine learning, computer vision and the database available are used to function these applications. One of them is "SolarCast" which handles more than 600 million new forecasts in each hour and the data is kept accessible in the cloud-based database to the customers. This kind of technology is vital, since accurate prediction of the solar generation in the next minute can predict the requirement of the power from the other sources in the system. Thereby the reliable and cost-effective dispatch of a power system can be conducted.

2.0 Project Overview

2.1 Problem Statement

Cost of Electricity for the Industrial and Commercial Customers can be reduced using the available energy resources in the installation. Roof top Solar is nowadays popular in Sri Lanka, and it is widely installed in the considered customer premises as per Net metering, Net accounting, and Net plus schemes. However, the customer expectation for the investment return is not achieved as per the predetermined targets due lower plant factor. The major reason is that Solar power generation is obstructed due to grid unavailability and nowadays it seems not resilient for the investment. However, it can be understood that the real time usage of the solar power is the most efficient method, and the customers can feed their inhouse loads from that. But the balance energy generated need to be properly managed using available technologies. With the emerging battery technology and reduction trend of the battery cost, it can be used to combine with rooftop solar. The excess solar energy can be stored in the battery storage and can be used when the power requirement is raised. The loads that can be dispatched at any time of the day can be used to enhance the real time consumption of the solar power generation. Such loads can be identified in the industrial and commercial customers more frequently. Nowadays, the technology is available to predict the solar generation for next 5-15 minutes where the rapid changes of solar generation can be identified.

So, in consideration of the above facts, it can be observed that there is an opportunity to reduce the electricity cost of the consumers combining the energy sources available using a program that balances the supply and demand through the optimum cost.

2.2 Objective

- Reducing the Electricity cost of Industrial Purpose /General purpose customers, introducing Solar PV and Battery Storage systems to the existing energy mix of grid supply and diesel generators
- To develop an economic dispatch program to optimize PV generation, Battery storage, grid power and diesel generators in an IP customer installation and GP customer

2.3 Methodology

The methodology of the project can be split to the following steps

- Select optimum solar PV capacity for the installation based on the available roof area
- Simulate using the software PVsyst, to forecast the solar generation in kWh/ year in order to use for calculation of the levelized cost of energy
- Select the battery bank capacity to cater the maximum demand and auxiliary consumption of the installation
- Select the loads that can be dispatched in any time during the day
- Determine the unit costs of the selected generation sources: Solar PV output, Battery charging/discharging, controllable loads using levelized cost of energy method
- Determine the input and outputs for the program which can be used as flexible to any customer in IP and GP basis
- Create a program to create and indicate, in the process flow chart, the determinationof the optimal dispatch of the power sources
- Develop the optimum cost program model for the system using Quadrature Programming in the MATLAB
- For IP customers ,validate the program by comparing the results in different conditions of the Yugadanavi Power Plant
- For GP customer validate the results for a Supermarket center in Wattala

3.0 Literature review

3.1 Levelized Cost of Energy (LCOE)

The approach of this research is to reduce the costs of the general purpose (commercial) customer and Industrial purpose customer in Sri Lanka, using roof top solar and battery installations combining with the other sources (Grid power, Diesel Generator) through a cost optimizing program. In addition to that the controllable loads, which can be operated in flexible manner during the time of the day, are used.

As per the [1], Levelized cost of Energy is widely used for the unit cost calculation of the renewable energy sources. The life cycle energy cost and production of the power plants are used in this approach to compare and evaluate the investment return. This LCOE equation can be used as a comparison tool for different operation periods, scales of operation as well as investments for a particular approach. In accordance with the [1] the equation 1 and equation 2 elaborated below.

$$LCOE = \frac{Life\ cycle\ cost\ (LRR)}{Lifetime\ Energy\ Production(kWh)} \qquad 1$$

$$LCOE = \frac{initial\ investment \quad (\sum_{n=1}^{N} \frac{AO}{(1+r)^n}) - \frac{RV}{(1+r)^N}}{\sum_{n=1}^{N} (initial\ kWh \times (1-SDR)^n \frac{1}{(1+r)^n})} \qquad 2$$

where

Initial investment	–	*Capital cost*
AO	–	*Annual operational cost*
r	–	*Discount rate*
RV	–	*Residual value*
SDR	–	*System degradation rate*
N	–	*Operational life of system*
initial kWh	–	*First year cumulative energy*

Further, it is described in the [1] that,

Initial Investment- The initial investment of the PV/ BSES includes the overall project cost and the financing cost for the project. These costs can be identified as follows.

Area Related Costs- Here the size related costs are being considered. The size of the panel and the battery cell, land/ building, mounting, preparation of the site, wiring of the system and related protection implementation.

1. Grid Interconnection Cost- This includes Electrical infrastructures including inverters, transformers, protection devices and switching devices.
2. Project Related Costs- Design and overhead costs

Annual Cost- The maintenance of inverters, panel cleaning, site monitoring, Battery inspection, insurance, field repairs and other related overheads are considered.

System Residual Value- The end-of-life value of the asset to be considered here. Most of the battery system suppliers as well as the PV system suppliers declare the lifetime of the systems.

System Energy Production- This is calculated for the first year and then estimated based on the annual degradation rate of the system. Degradation rate is decided based on the type of the panel/ BSES and the manufacturer, further it is a vital information for the estimation of the life cycle energy production.

Initial kWh- This is mainly dependent on the following factors for the PV systems.

1. Amount of sunshine available for the site throughout the year
2. Harvest of the PV system which is dependent on the temperature and radiation sensitivity of the panel
3. Losses of the inverters and cabling system
4. Downtime of the inverters due to variety of reasons

Levelized Cost of Energy for the PV and Energy Storage systems installed in Grid Scale

3.2 Operation Maintenance Cost Optimization in the Grid Connected Microgrid

The micro grid system, which is operated in the connection mode with the gird, has several advantages in relation to the reliability and cost effectiveness as per [2]. This includes the conventional energy sources integrated with the renewable energy sources. The author of [2] interpreted that this can be identified as a system with distributed energy resources (DERS). In the study it is mentioned that the optimal cost of the operation and maintenances of such a system was derived while meeting with the critical and non-critical load requirements.

In relation to the optimization the author [2] has considered economic dispatch optimization as per equation 3.

$$Min\ (F) = \sum_{i=1}^{NG} FiPi - - - - - - - - - - - \quad 3$$

subject to real power balance

$$\sum_{i=1}^{NG} Pi = D$$

and capacity limits of each source $\qquad Pimin \leq Pi \leq Pimax$

P_i^{min}, P_i^{max} are the minimum and maximum output power of the source i,

NG is number of sources, pi is the power output of the source i,

D is the total system demand, Fi is the total production cost of the source.

$F_i(P_i) = \alpha_i + \beta_i P_i + \gamma_i P_i^2$ (α, β, ϒ, cost coefficients of the energy sources).

This formula is to be used in this research selecting a suitable optimizing technique form several techniques available. Here the author [2] has used the reduced gradient method for the optimization. In the discussion the writer [2] has interpreted that introduction of wind, battery storage system in to the microgrid does not affect the cost but improves the reliability of the system.

3.3 Selection of an Optimization Technique

Before selecting the optimization technique for the research several optimization approaches are evaluated. In research [3] where the Generic and Anti bee colony algorithm was compared it is mentioned that the ABC technology is much faster than the generic algorithm. In this paper [3] they have considered the two-tariff grid power system into the consideration for the cost optimization. Same approach to be used for this research when including the three tariff systems in industrial and general-purpose customers in Sri Lanka.

In the study carried out for the microgrid in DonAo Island in China[4] GA technique has been applied to determine the unit commitment and the generation levels of WT (wind) , PV(solar), DE (diesel engine) and BS(battery). The author in [4] has proposed dispatch strategy was integrated with two different control modes, where diesel engines (DE) and Battery storage (BS) units alternate to operate as the master unit to maintain the system operation stability as well as maximize the RES generation utilizations and minimize the fuel and emission cost resulted from DE.

The economic dispatch strategy control process used in [4] to be is to be followed for the research. The operation power limits of each unit, battery SOC, the controllable load dispatching, shedding of the PV and load curtailing was key concepts used in this research. The overall program flowchart is identified as in figure 2.

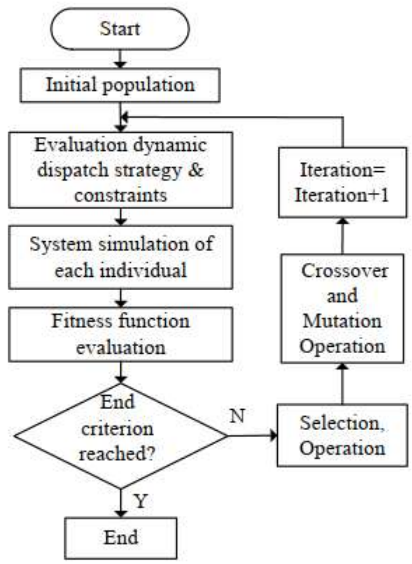


Figure 2 - Economic Dispatch Strategy Control Process

Application of quadrature optimization for a micro grid system dynamic dispatch is widely discussed in [5]. The mix of distributed generation with the energy storage is used to maximize the usage of renewable energy. The daily load is supplied with the optimized operation of the energy sources and the battery bank using dynamic dispatch model developed by quadrature optimization. In this research this quadrature optimization is selected to be used since it has several types of flexibility in application. As discussed in [5] objective function is taken as a quadratic function and the constrains in the form of linear. The constrains are selected in equality or inequality form.

The objective function is defined in equation 4.

$$F(x) = f + g^T x + \frac{1}{2} x^T H \text{----------} \quad 4$$

Inequality constraints

$$lb \leq Ax \leq ub$$

$$x_{min} \leq x \leq x_{max}$$

Equality Constraints

$$lb = u_b = beq$$
$$Ax = beq$$

In this research [5], as the objective function, the total operation cost for a selected time is defined as bellows.

The cost function is defined as

$$CF(p) = \sum_{t=1}^{T} CF(P_i)$$

with quality constraints

$$P_{Ioad} = \sum_{i=1}^{N} p_i$$

and inequality Constraints

$$P\text{i}^{min} \leq P_i \leq P_i^{max}$$

$$E_{ESmin} \leq E_{ES}(t) \leq E_{Esmax}$$

$$E_{Es}(t) = E_{ES}(t-1) - P_{Es\,\mathrm{d}smax}$$

3.4 Battery Energy Storage (BES) Selection and Operation

In most of the microgrid applications, the BES plays an important role to address the intermittency of the renewable energy sources. The operation cost is dependent on the lifetime of the battery and the energy storage during the lifetime. In most cases, the battery bank is selected to store excess solar energy. As described in the research [7], cost benefit analysis was used to determine the optimum BES for a particular installation. The input data has been provided using the forecasted wind and solar availability through a time series method. As per the authors the selection of the battery capacity is decided based on weather island operation or grid connected operation. On the other hand, the microgrid parameters are also key deciding factors for the cost benefit analysis. Therefore, in this research the optimum battery capacity is expected to be decided through a sensitivity analysis of the program output for each battery capacity.

However, the research [6] has been focused on the determining the depth of discharge (DOD) and capacity based on the optimum operation pattern of the system. Thereby it is discussed that the DOD is the limiting range for a BES to operate from a minimum DOD to avoid over charging and to a maximum DOD to over discharge. The selection of DOD is important for the maximum usage of the BES and to optimize the operation cost to the minimum in the micro grid system.

In accordance to [8] DOD is to be maintained as the State of Charge (SOC) the discharging of a cell can be done 100%, however the maximum SOC can be reduced to 95% to 90% and the minimum value of the SOC was suggested to be limited to 5% to 10%. This enhance the cycle life of battery packs and it is recommended to keep the DOD window between 80 to 90%. So, the same recommendation to be followed for the research and the optimization program.

3.5 Charging and Discharging of the Batteries

The charging and discharging of the BES can be modeled using equations and the update of the SOC is illustrated in [9] as per the equation 5 and 6.

SOC Update During Charge $$S(t) = \left((1-\delta)\, S(t-1) + \frac{P_{ch}(t)\times\Delta t\times\eta_{ch}}{C_N}\right) - - - \quad 5$$

SOC Update During Discharge $$S(t) = \left((1-\delta)\, S(t-1) - \frac{P_{dis}(t)\times\Delta t}{C_N\times\eta_{dis}}\right) - - - - \quad 6$$

The parameters are such that, S(t) is the state of charge (SOC) of electrochemical energy storage at a given time t, S(t − 1) is the SOC of electrochemical energy storage at the time (t-1),δ is the self-discharge rate, Pch(t) and Pdis(t) are respectively the charging Power and discharging power of electrochemical energy storage at the moment t, Δt is the time interval (e.g.,1h), η ch and ηdis are respectively the charging and discharging efficiency of electrochemical energy storage ,and CN is the rated capacity of electrochemical Energy storage.

For the program the equations described in [9] will be used.

Rate of Discharge

Battery discharge rate is of primary importance in this report since it decides the power that can be delivered to the system when the renewable energy supply is interrupted. Most of the battery suppliers such as Tesla [10] introduces higher capacity Li-ion battery storage such that, if the battery capacity is C, the maximum discharge rate is C/2. In accordance with research conducted [11] about the battery discharge rates for different values are illustrated as a graph in figure 3.

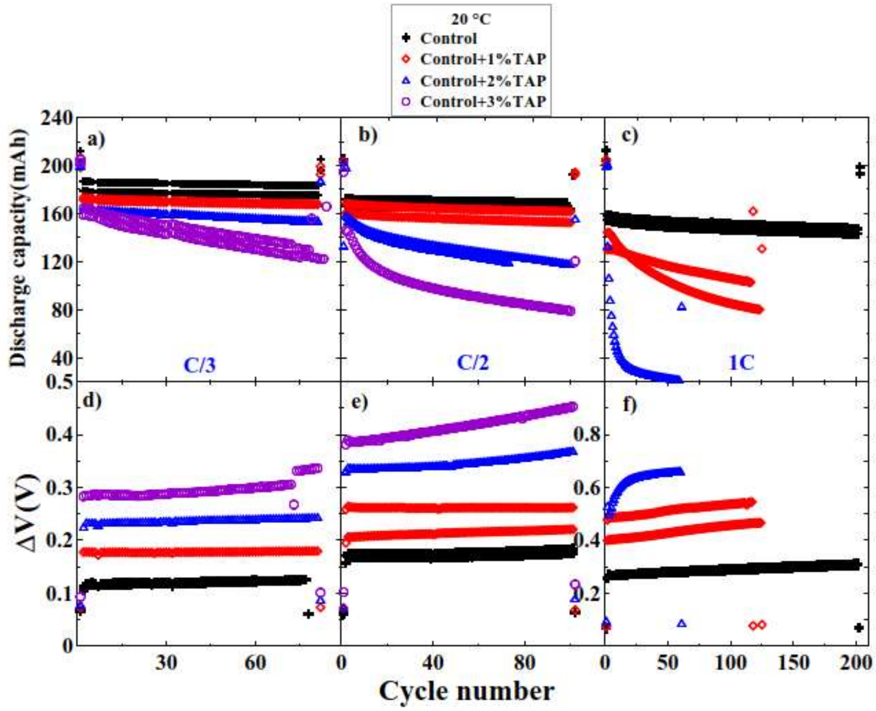


Figure 3 - Effect of Discharging rate for the Battery Life

As per this, for all the cases the discharge capacity is drastically reduced if the discharge rate gets higher. The discharge voltage change also gets exaggerated with the increase of the cycles. However, in order to maximize the lifecycle while utilizing the discharge rating to the distributed energy system, the manufactures recommendation is to be followed for the program. Then the selected discharge rate will be C/2 and the provided lifetime to be considered for economic appraisal.

3.6 MATLAB Algorithm

For MATLAB programming a syntax has been provided in the [15] as bellows for quadratic optimization approach.

x = quadprog(H,f,A,b,Aeq,beq,lb,ub)

subject to the restrictions $A*x \leq b$. The input A is a matrix of doubles, and b is a vector of doubles and restrictions $Aeq*x = beq$. Aeq is a matrix of doubles, and beq is a vector of doubles. If no inequalities exist, set A = [] and b = [] and restrictions $lb \leq x \leq ub$. The inputs lb and ub are vectors of doubles, and the restrictions hold for each x component. If no equalities exist, set Aeq = [] and beq = [].

4.0 Research

4.1 Introduction

With increasing fossil fuel prices, supply of energy requirement for the commercial and industrial purposes, has become a paramount challenge to Sri Lanka. Risk for the industry and commercial related business activities, has risen due to the unavailability of the grid power supply caused by the demand management-based power interruptions. Unprecedented attention for the distributed generation possibility of individual customers to be considered based on the resilient features of the energy mix.

The following generating sources can be identified as probable sources for Industrial purpose (IP) and General purpose (GP) consumers.

1. Diesel Generators
2. Grid supply
3. Solar Energy
4. Battery Storage
5. Controllable Loads

The emergency power requirement is to be supplied from the diesel generating sets by most of the consumers in Sri Lanka. So, most of the facilities are incorporated with diesel generators during the preliminary design stage. In this approach, it is expected to install the solar panels in the available roof area and adequate BES to regulate the intermittency of the solar generation. There are some loads that can be dispatched in controllable manner, and it enables to use the energy sources in an optimum pattern. The grid power supply is based on time of day tariff and the maximum demand charge, availability to be considered during the optimization approach in the research.

4.2 The Control Concept

System model and input outputs

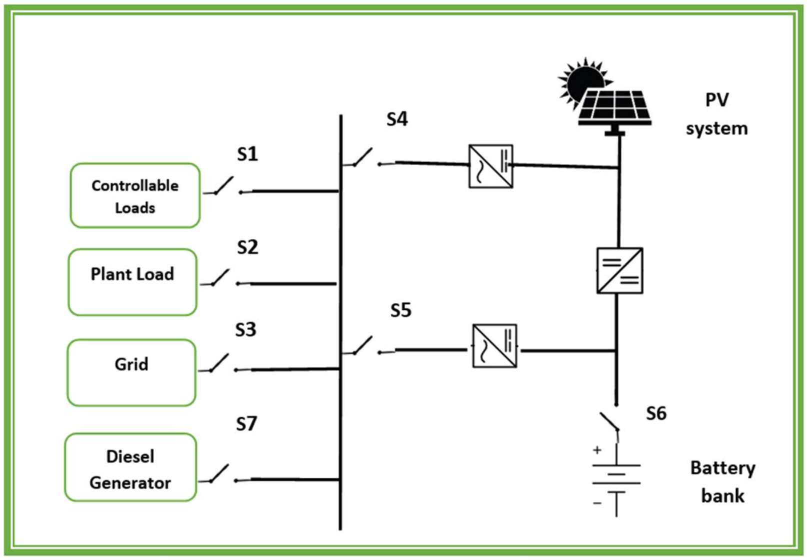


Figure 4 - System Model

As indicated in the Figure 4 all the generating sources as well as loads are connected to a common system and the switching of each component is possible through the control system. The solar energy can be directly provided to the loads or possible to use for battery charging.

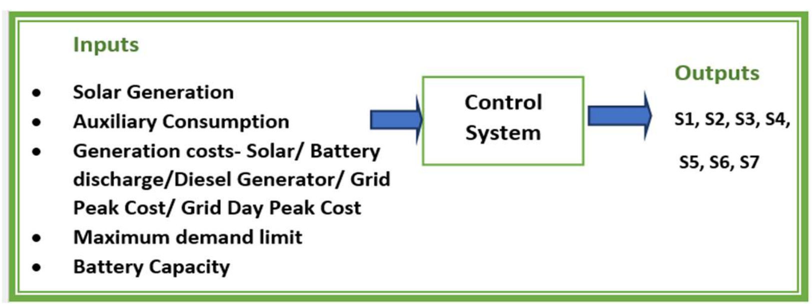


Figure 5 - Process Flow

Since the outputs are defined as the switching of the devices indicated in the Figure 5 inputs are to be decided for greater flexibility of the program. For a selected time frame the predicted solar power rating to be decided and fed to the program. Nowadays there exists programs which are capable to predict the solar generation for the next ten minutes based on the available satellite images for a particular area. ‘Solar Cast’ is one of the forecast and live solar irradiation data providers, as per their information it is possible to provide data for next 5 minutes to 7 days as a forecast.

Auxiliary consumption is the power consumption for a particular installation and that is dependent on the power ratings of the loads in use. For industrial and commercial consumers there are regular trends, and the data can be measured using the energy meters. This data is also fed to the system as same frequency of the solar generation data.

The maximum demand, Battery bank capacity, diesel generator capacities are also provided as inputs to the program thereby these parameters are flexible to be changed based on the availability and optimization requirements.

The unit costs functions of the each generating options are used in the program and the constants of each function to be calculated and fed as inputs to the program. The battery and solar costs are to be decided based on the levelized costs of energy and the grid costs are taken from the rates given by CEB.

Cost functions for the selected Power Generation Options can be illustrated as belows.

1. Diesel Generator $CF(DG) = a + bPdg + cP^2dg$
2. Solar PV system $CF(PV) = Cpv * Ppv$
3. Battery Charging $CF(BC) = Cbc * Pbc$
4. Battery Discharging $CF(BD) = Cbd * Pbd$
5. Solar Power Shedding $CF(PVsh) = Cpvsh * Ppvsh$
6. Controllable loads $CF(DR) = Cdr * Pdr$
7. Grid cost $CF(GR) = Cgr * Pgr$

CF – *Cost function*

Pdg – *Power allocated by the thermal generator*

Pgr – *Power supplied from the Grid*

P – *Solar power generated*

Ppv – *Power portion from Solar to the load*

Pbd – *Power from battery discharge*

Pl – *Power demand in the system*

Ppvsh – *Solar power subjected to shed*

Pch – *Power required for battery charge*

Pdr – *Power allocated for demand response*

4.3 Quadratic Optimization

The objective function for the quadratic optimization discussed in the section 3.3 can be elaborated as bellows where addition of all the costs for each cost categories are considered. The minimum value for the total cost to be estimated here in order to optimize the operation of the system based on the cost.

$$min\, j \sum_{t=1}^{T} CF(DG) + CF(PV) + CF(BD) + CF(PVsh) + CF(BC) + CF(DR) + CF(GR)$$

Equality constraints

In the quadratic optimization approach following equality constraints to be considered based on the system requirements. When considering a single installation, total power balance of the power can be taken into the consideration as following equation.

$$Ppv + Pdg + Pbd + Pgr = PL + Ppvsh + Pbc + Pdr -------- 7$$

The LHS of the equation represents the power generation from the PV, DG, BES, and supply from the grid. RHS indicates the load, shed PV, power for battery charging and power for the distributed loads. This balance is required to be maintained in the program in any circumstances.

Balance of the generated solar power also have an equality constraint and can be indicated as,

$$Ppvsh = P(n) - Ppv - \alpha Pdr - \beta Pbc ------------ 8$$

Here the total solar power generated is equal to addition of the power given by solar to the load, shed solar power, solar power consumed for battery charging and solar power consumed for the distributed loads.

The equation 7 and 8 are to be used as the equality constraints for the optimization algorithm.

Inequality constraints

The inequality constraints for the optimization can be elaborated as bellows based on selected scenarios. Solar generation balance when BES charge on can be considered as,

$$Pch + Ppv \leq P(n)$$

The addition of power used for the battery charge and load is limited to the solar generation. The battery charging is possible with the excess solar generation in accordance to the equation.

The major purpose of controllable load selection is to dispatch them when the excess solar power is available. Based on the principle the inequality constraint has been selected as follows.

$$\alpha Pdr + Ppv + Ppvsh \leq P(n)$$

Generation limit of each generation source has been considered in the program. Each source has its maximum and minimum power rating and those values are to be taken for the optimization. The maximum de mand value from the grid also selected with the same equation.

$P_i^{min} \leq P_i \leq P_i^{max}$

CF	–	*Cost function*
P_i max	–	*Upper bound of the power scheme*
P_i	–	*Power output of each scheme*
P_i min	–	*Lower bound of the power scheme*
Pdg	–	*Power allocated by the thermal generator*
Pgr	–	*Power supplied from the Grid*
P	–	*Solar power generated*
Ppv	–	*Power portion from Solar to the load*
Pbd	–	*Power from battery discharge*
Pl	–	*Power demand in the system*
Ppvsh	–	*Solar power subjected to shed*
Pch	–	*Power required for battery charge*
Pdr	–	*Power allocated for demand response*
α	–	*Binary variable allocated for switching of controllable loads*
β	–	*Binary variable for charge/discharge selection of battery*

4.4 Battery Charging and Discharging

In accordance to the section 3.4 battery charging and discharging equations to be used and based on the charging and discharging SOC level to be updated during each period of time. SOC updating equations are taken from the section 3.5.

Charging Power Rate $CHG = \left(1 - \frac{S}{100}(1-\delta)\right) \times C_N \times \frac{1}{(\Delta t \times \eta_{ch})}$ -------- *9*

Discharging Power Rate $DCH = -\left(S_{min} - \frac{S}{100}(1-\delta)\right) \times C_N \times \frac{\eta_{dis}}{\Delta t}$ ------ *10*

SOC Update During Charge $S(t) = \left((1-\delta)\, S(t-1) + \frac{P_{ch}(t) \times \Delta t \times \eta_{ch}}{C_N}\right)$ --- *11*

SOC Update During Discharge $$S(t) = \left((1-\delta)\, S(t-1) - \frac{P_{dis}(t) \times \Delta t}{C_N \times \eta_{dis}} \right) ---- 12$$

The SOC is kept between a minimum value and 100%. The range for the SOC was selected as 80% as described in the section 3.4.

$$S_{min} \leq S \leq 100$$

The maximum charging rate of the batteries are to be selected as described in section 3.4. The optimum usage of the charging rate and battery life to be obtained with this selection.

$$DCH \leq \frac{C_N}{2}$$

$$CHG \leq \frac{C_N}{2}$$

S	–	State of charge level
δ	–	Self-Discharge Rate of the battery
Δt	–	Time Duration
η_{ch}	–	Charging Efficiency
η_{dis}	–	Discharging Efficiency
$P_{ch}(t)$	–	Charging Power
P_{dis}	–	Discharging power
C_N	–	Rated Capacity

4.5 Logical Conditions for the Program

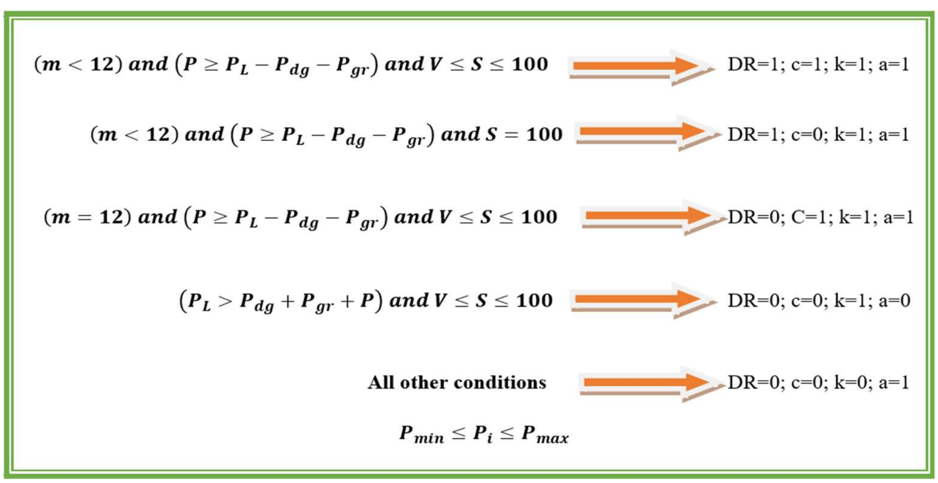


Figure 6 - Operation concept

Operation concept of the program has been illustrated in the Figure 6 and this was broken in the five logical conditions.

Logic 1- If the load is less than the generation and battery SOC is between SOC min and SOC max and amount of switching's for the DR loads is less than 12, the switches for Controllable loads, Charging, Battery, and Shedding is kept on.

Logic 2- All the conditions are same as in the logic 1 except the battery SOC is reached to maximum value (100%), hence charging was kept off while controllable loads, Battery, Shedding kept on.

Logic 3- All the conditions are as logic 1 except the switching of controllable loads has reached to its maximum value m=12. Then the Controllable loads are kept off while Battery, Charging and Shedding are turned on.

Logic 4- If the load is greater than the generation and battery SOC is between maximum and minimum range, battery is kept on to facilitate to discharge for the load fulfillment. All the other switches are kept off.

Logic 5- For all remaining scenarios only shedding kept on in order to provide provision to shed as required.

4.6 Logic Flow Chart

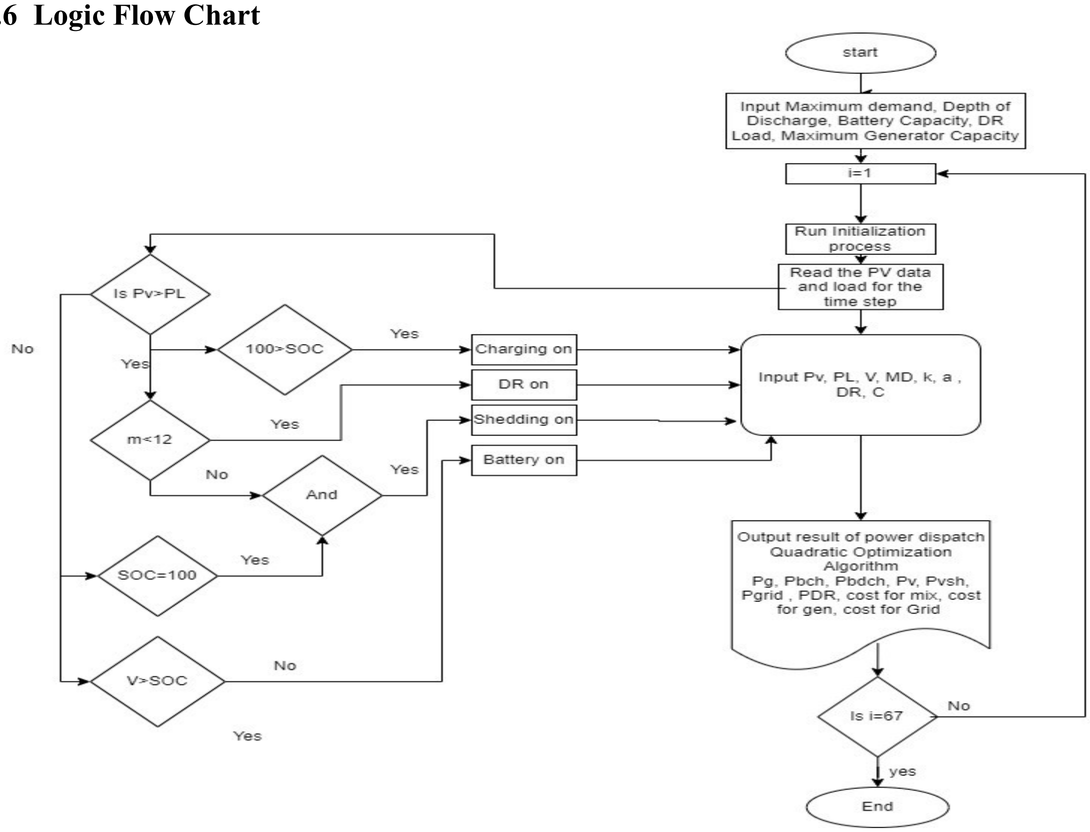


Figure 7 - Logic Flow Chart

The flow chart of figure 7 is designed for a cycle which is repeated until 67 time periods. The time is 15 mins interval and the data of solar generation and load for each interval to be provided. Initially the inputs of Maximum demand, battery capacity, maximum DOD, generator Capacity and DR load to be fed into the program. Then the cycle 1 is started and from the excel sheet the data (load and Solar power) related to cycle 1 is read by the program. Then based on the load and solar generation the logics discussed in the section 4.5 are executed. Based on the logical output the status of the switches are calculated and the quadratic algorithm was run with the provided inputs. The optimum solution for the dispatch of the loads is derived from the algorithm for the cycle. Then the next cycle is executed. This process is continued until it finish the 67 cycles under consideration of the study.

4.7 MATLAB Program for Quadratic Optimization

The function in MATLAB is available for optimization using the quadratic optimization technique and can be illustrated as bellows.

$$\underset{x}{min}\frac{1}{2}x^T Hx + f^T x \quad \text{such that} \quad \begin{cases} Ax \leq b \\ A_{eq}x = b \\ lb \leq x \leq \mathrm{U}b \end{cases}$$

x = quadprog(H,f,A,b,Aeq,beq,lb,ub) solves the preceding problem subject to the additional restrictions lb ≤ x ≤ ub. The inputs lb and ub are vectors of doubles, and the restrictions hold for each x component. If no equalities exist, set Aeq = [] and beq = [].

This algorithm is used in the program and the cost functions and constraints are defined accordingly.

5.0 Case Study 01-General Purpose (GP) Customer

5.1 Generation Unit Cost Calculation

The cost for each generation option is calculated and used as inputs for the program. LOCE method discussed in chapter 3.1 to be applied for this. The financial data has been taken from the annex-07.

5.1.1 Solar PV

For the selected site a rooftop solar installation to be designed and the simulation results are to be used for the LOCE calculations. The daily average energy consumption for the selected customer is around 2000 kWh. The available roof area for the solar panel installation is around 1600 m^2 which can be affordable for only 320 kWp solar panel capacity. So the optimum solar panel capacity is limited with the available roof area. This has been further verified by Homer software and calculations are attached in Annex- 01.

Solar PV System Simulation

- Software- PVSYST V7.2.8
- Geographical Site- Arpico Super Centre Wattala- Sri Lanka
- Latitude 7.01 0N, Longitude 79.87 0E
- Solar DC Capacity- 321 kWp (535 Wpx600)
- Optimum Ac output- 260 kWp
- Area of the solar panels= 1550 m2
- Annual Generation= 497,500 kWh
- For the cost Calculation 75% of the generation used

Selection of the Optimum Inverter Capacity

Table 3- Case Study 1-Optimum Inverter Capacity

Power		System Production (MWh/Year)	Specific Yield (kWh/kWp/year)
DC (kWp)	AC (kW)		
321	340	531.6	1614
321	320	531.45	1614
321	300	531.15	1613
321	280	530.85	1612
321	260	529.2	1607
321	240	518.1	1573

The simulation was run for different inverter capacities although the panel DC capacity was kept in a constant figure. Therefore, the best system production for the investment is brought by 260 kWp inverter capacity. The simulation for 321 kWp Solar panel and 260 kW inverter capacity is attached in Annex 02.

The parameters described in Chapter 3.1 are estimated as Table 4.

Table 4 - Case Study 1-Parameters for the Solar Installation

Term	**Description**	**Solar Installation**
Initial investment	Capital cost (LKR)/(kW)	140,000
AO	Annual operational cost (LKR)	500
r	Discount rate	10%
RV	Residual value per kW (LKR)	500
	Operation Cost per kW (LKR)	500
	Cost of 50 kW inverter	550,000
SDR	System degradation rate	1%
N	Operational life of the system	25

The equation can be applied for each year and the calculated results can be tabled as in the table Table 5 given below.

Table 5 - Case Study 1-Results per Year

Year	**Cash flow (LKR)**	**NPV (LKR)**	**Expected Energy (kWh)**	**Degraded Energy**	**25% Shedded**	**Degraded**	**Discounted Energy**	**NPV shed**
0	42,000,000	42,000,000	427,146				-	-
1	150,000	136,364	427,146	427,146	320,360	320,360	388,315	291,236
2	150,000	123,967	427,146	426,719	320,360	320,039	352,660	264,760
3	150,000	112,697	427,146	426,292	320,360	319,719	320,280	240,691
4	150,000	102,452	427,146	425,866	320,360	319,400	290,872	218,810
5	150,000	93,138	427,146	425,440	320,360	319,080	264,165	198,918
6	150,000	84,671	427,146	425,015	320,360	318,761	239,910	180,835

7	150,000	76,974	427,146	424,590	320,360	318,442	217,882	164,395
8	150,000	69,976	427,146	424,165	320,360	318,124	197,876	149,450
9	150,000	63,615	427,146	423,741	320,360	317,806	179,708	135,864
10	3,450,000	1,330,124	427,146	423,317	320,360	317,488	163,207	123,513
11	150,000	52,574	427,146	422,894	320,360	317,170	148,222	112,284
12	150,000	47,795	427,146	422,471	320,360	316,853	134,612	102,076
13	150,000	43,450	427,146	422,049	320,360	316,536	122,252	92,797
14	150,000	39,500	427,146	421,626	320,360	316,220	111,027	84,361
15	150,000	35,909	427,146	421,205	320,360	315,904	100,833	76,692
16	150,000	32,644	427,146	420,784	320,360	315,588	91,575	69,720
17	150,000	29,677	427,146	420,363	320,360	315,272	83,167	63,381
18	150,000	26,979	427,146	419,943	320,360	314,957	75,530	57,619
19	150,000	24,526	427,146	419,523	320,360	314,642	68,595	52,381
20	3,450,000	512,821	427,146	419,103	320,360	314,327	62,297	47,619
21	150,000	20,270	427,146	418,684	320,360	314,013	56,577	43,290
22	150,000	18,427	427,146	418,265	320,360	313,699	51,382	39,355
23	150,000	16,752	427,146	417,847	320,360	313,385	46,664	35,777
24	150,000	15,229	427,146	417,429	320,360	313,072	42,380	32,525
25	150,000	13,844	427,146	417,012	320,360	312,759	38,489	29,568
		45,124,373		10,551,488		7,913,616	3,848,477	2,907,917

From the LOCE Equation in chapter 3.1,

The LOCE of The Solar power = 11.72 LKR

If the charger efficiency is = 0.92%

The charging cost = 12.74 LKR

If the 25% of the PV is shed the LOCE is changed

Then the LOCE = 15.51 LKR

5.1.2 Distributed Loads

The Distributable Loads will be fed Realtime form the Solar Energy. Therefore, the cost for electricity is same as the LOCE Solar

5.1.3 Battery Discharging

LOCE parameters described in the Chapter 3.1 are given in Table 6 for the battery bank.

Table 6 - Case Study 1- LOCE parameters for Battery Bank

Term	Description	Battery Bank
Initial investment	Capital cost (LKR) per kWh	51,375.60
AO	Annual operational cost (LKR)	500.00
r	Discount rate	10%
RV	Residual value per kW (LKR)	750
SDR	System degradation rate	1%
N	Operational life of the system	10

The LOCE cost calculation for a battery bank of 200 kWh is shown in the following table. It is expected to replace the quarter of the battery bank capacity during each two years. The 80% of the battery bank capacity is discharged daily to calculate the LOCE.

Table 7 - Case Study 1- LOCE for a battery bank of 200 kWh

Year	Cash flow(cost) (LKR)	Benefit (LKR)	Net NPV (LKR)	Expected kWh	Expected Energy Degraded kWh	Discounted Energy kWh
-	10,275,120	-	10,275,120			
1	60,000	-	56,075	57,600	57,600	57,313
2	2,628,780	-	2,296,078	57,600	57,542	56,971
3	60,000	-	48,978	57,600	57,485	56,631
4	2,628,780	-	2,005,484	57,600	57,427	56,293
5	60,000	-	42,779	57,600	57,370	55,957
6	2,628,780	-	1,751,667	57,600	57,313	55,623
7	60,000	-	37,365	57,600	57,255	55,291
8	2,628,780	-	1,529,974	57,600	57,198	54,961
9	60,000	-	32,636	57,600	57,141	54,633
10	2,628,780	-	1,336,338	57,600	57,084	54,306
		Total	19,412,494		**Total**	557,979

From the LOCE Equation in chapter 3.1,

The LOCE of the Battery Power = 34.24 LKR

5.1.4 Summary

The summary of each source energy unit costs are indicated in the Table 7 for the General-purpose customer installation.

Table 8 - Case Study 1- Summary of Source Energy Unit Costs (GP)

Type		**LKR/kWh**
Solar power (levelized Cost)		11.72
Battery charging		12.74
Battery discharging (levelized Cost)		34.24
PV shedding (25% shed)		15.51
Load shifting controllable loads		11.72
Grid energy cost	peak	26.6
	off peak	21.8
	Day peak	15.4

5.2 Battery Charging/ Discharging

Battery SOC will be kept between 20 % to 100% as described in the chapter 3.4.

The constants for the efficiencies are taken from the battery suppliers technical specification and has been illustrated bellow.

Charging efficiency = 0.92

Discharging efficiency = 0.95

Self-Discharge rate of the battery = 0.023%

5.3 Controllable Loads

Several loads that can be dispatched in controllable manner have been identified and the details are,

The identified Controllable Loads = 10 kW

The Energy Requirement for the Load = 30 kWh

Then the loads need to be switched 12 times when excess solar is available.

5.4 Diesel Generator

The capacity of the Generator =200 kW

The generator cost function to be used in the bellow formula.

$$\text{Cost} = 0.012\, P_g^2 + 37.55\, P_g + C_{Start}$$

5.5 Grid Power Supply

The grid power supply was taken in to consideration based on the three tire tariff which has been illustrated in the table 1. The maximum demand for the installation to be limited to certain value.

The maximum demand limit- 100 kW

5.6 Load Profile

The measured load profile of the GP customer is as follows and it indicates a peak load demand during the commercial hours (from around 8:00 am to 10:00 pm). There exist a base load value around 45 kW throughout the day.

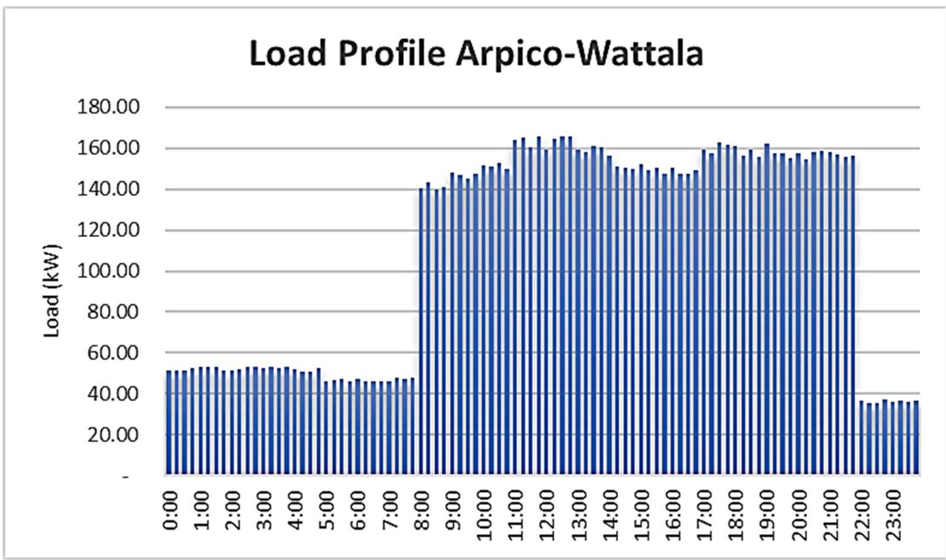


Figure 8 - Case Study 1- Load Profile (Arpico- Wattala)

5.7 Matlab Code

The MATLAB code is in the Annex 3

5.8 The Solar Data for the Simulation

Since the Program is running in 15 mins time interval and the solar generation is changing in different days, several combinations are considered for the simulation. In the simulation some days have higher solar generation while in some days the pattern is similar, but values are lesser. There are some days where the solar generation was obstructed due to the clouds and that kind of solar curves are also taken into consideration for the program.

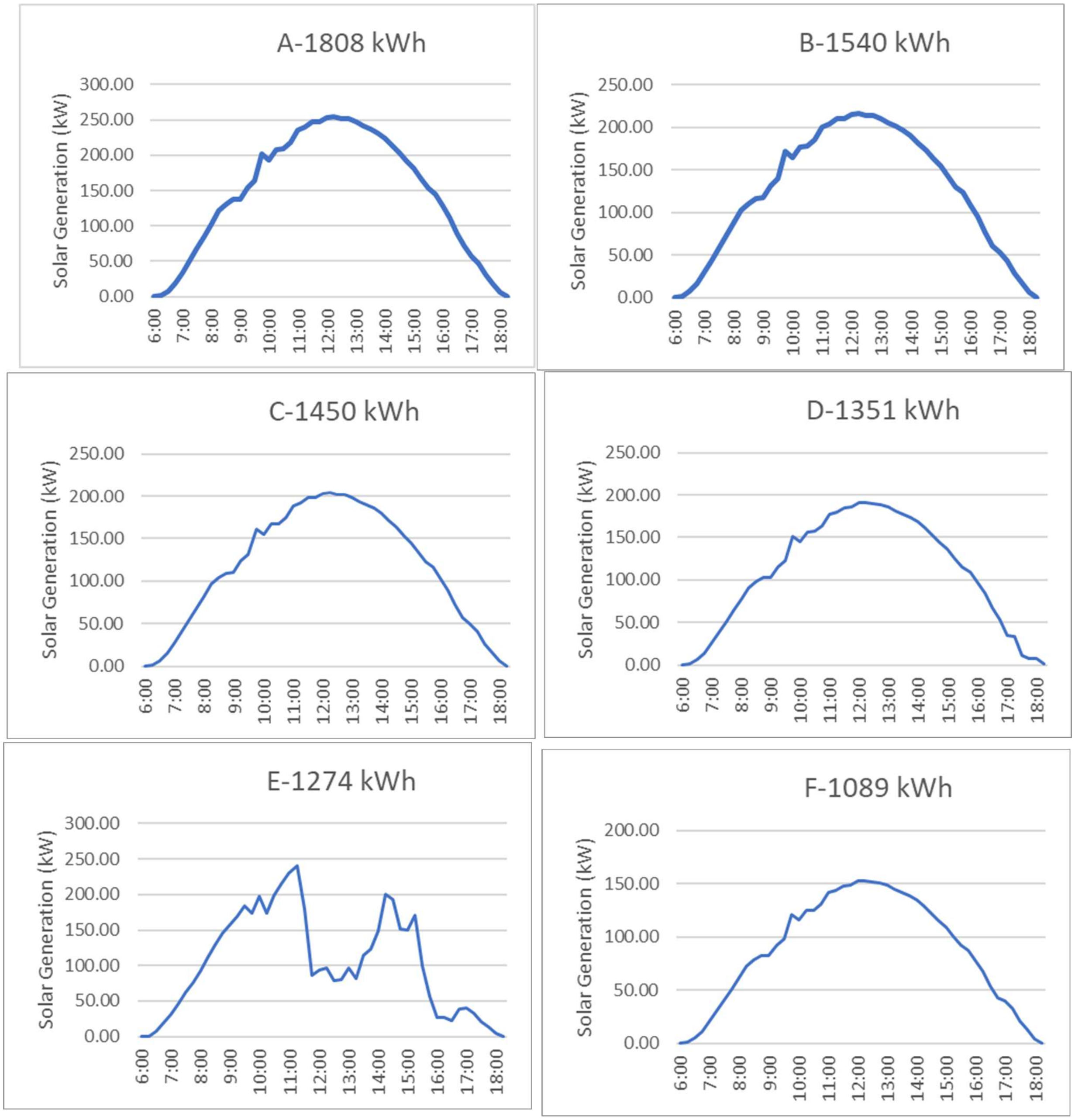


Figure 9- Case Study 1- Solar Data (A-F)

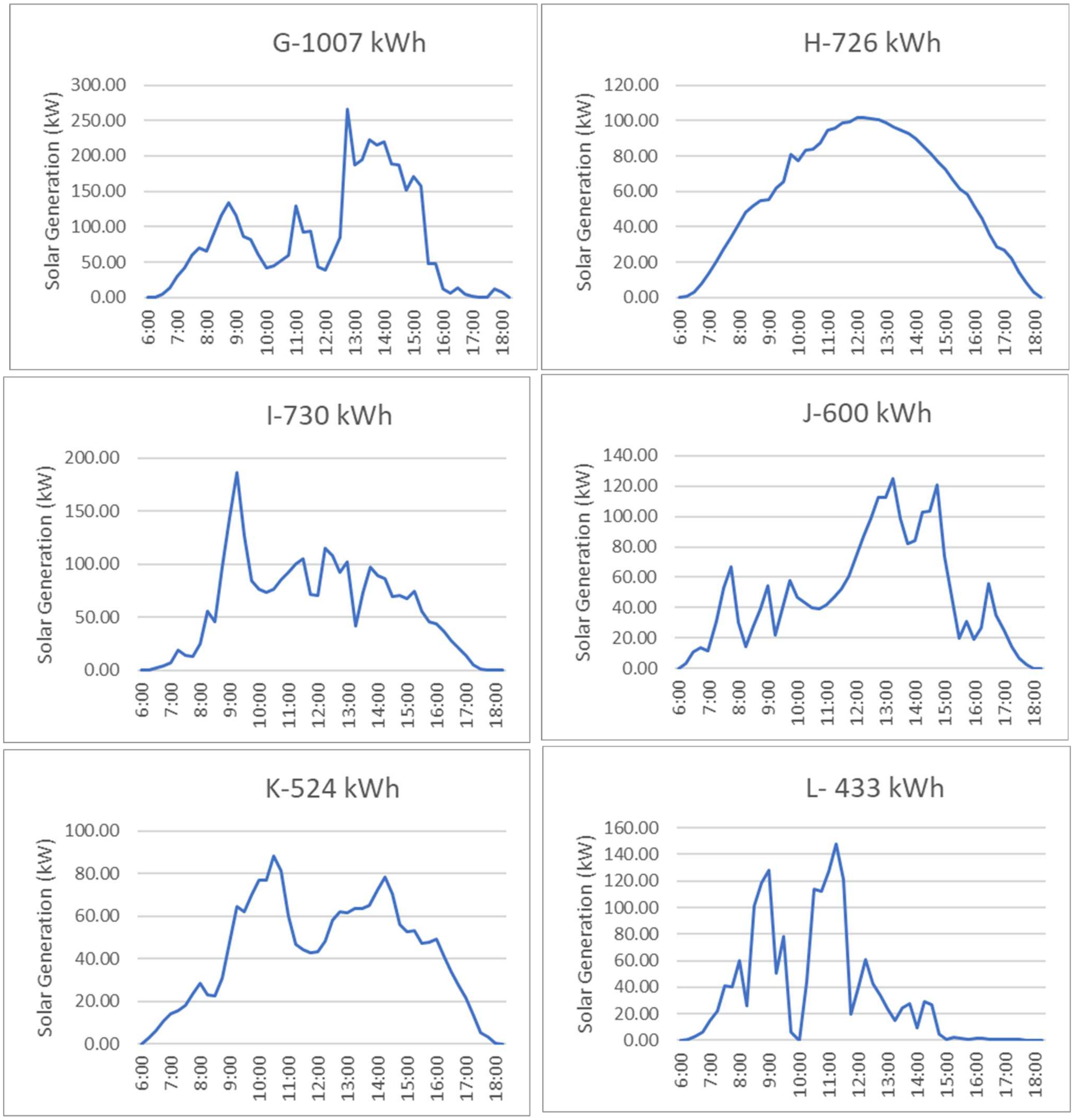
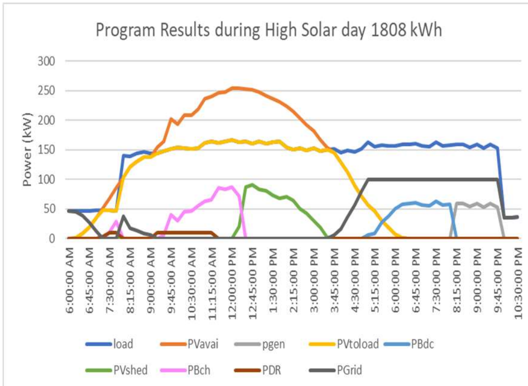
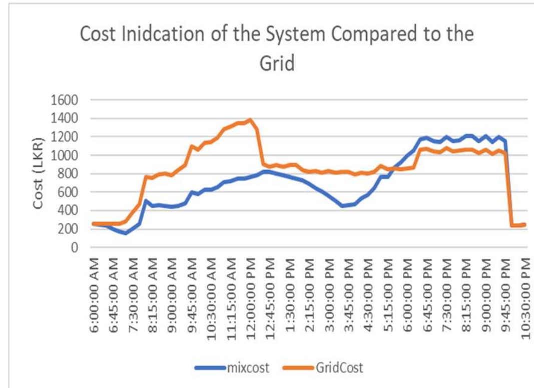


Figure 10 - Case Study 1- Solar Data (G- L)

5.9 Simulation Data of the Each Solar Generation

5.9.1 Case- A





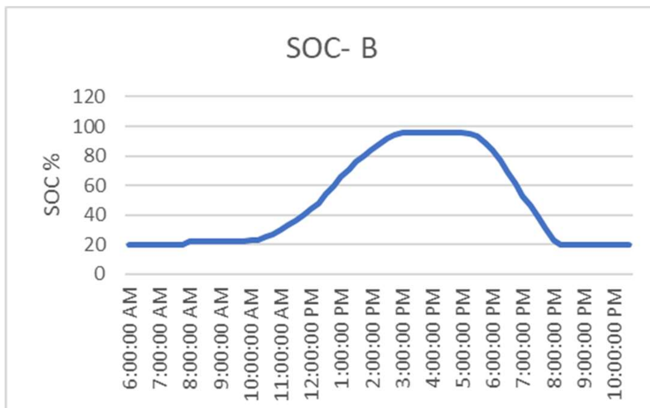


Figure 11- Case Study 1- Simulation Data- Case A

During a High Solar day generated solar energy is used in maximum possible manner. Battery has been fully charged and DR Loads are fully dispatched. Excess solar energy has been shed. And during the peak hours the while limiting the maximum demand at 100 kW from the grid, battery bank and the diesel generator has been dispatched as per the cost order.

When considering the day if the total load is supplied as per the program from 6:00 am to 10:30 pm the cost is 46, 610 LKR. If that energy is supplied from the grid the cost is 56,290 LKR and the gross profit is 10,679 LKR for the day.

5.9.2 Case- B

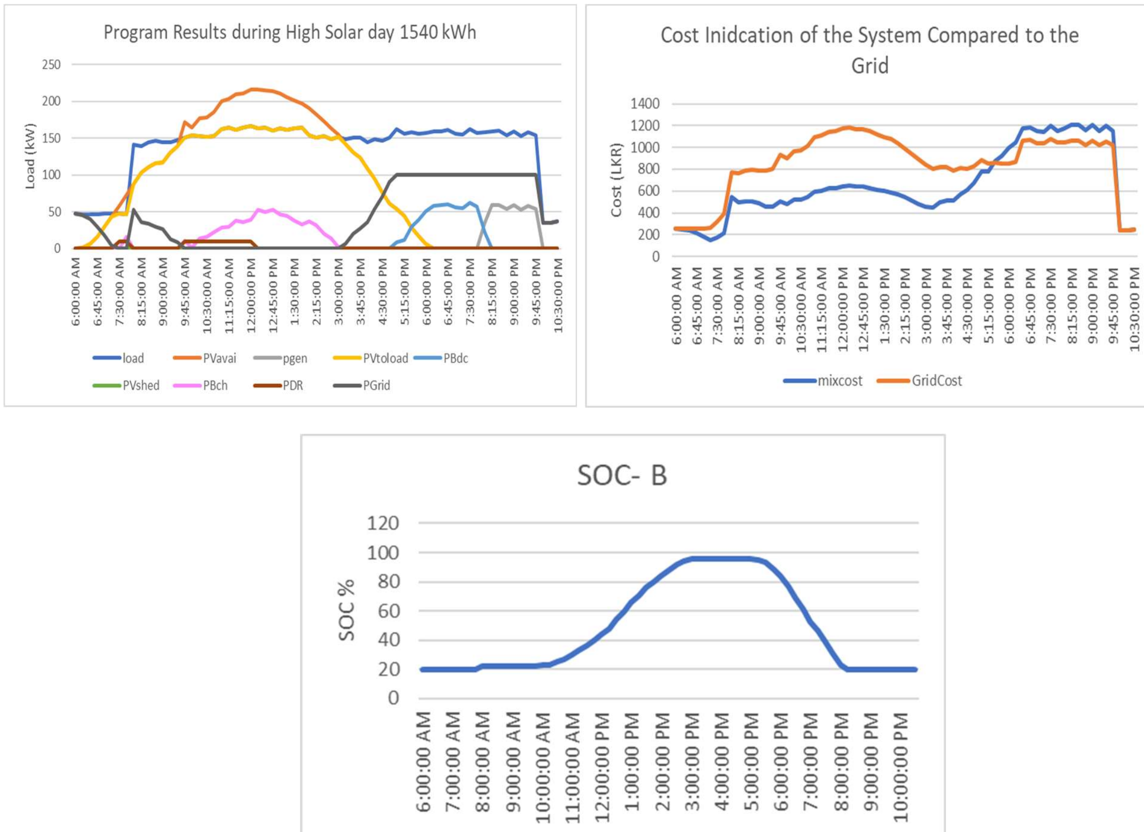


Figure 12- Case Study 1- Simulation Data- Case B

In this case the characteristic is mostly same as Case-A but the solar generation has been managed without going for a Shedding. Battery has been fully charged and discharged during the peak hours.

Here when considering the day if the total load is supplied as per the program from 6:00 am to 10:30 pm the cost is 44, 117 LKR. If that energy is supplied from the grid the cost is 57,079 LKR and the gross profit is 12,962 LKR for the day.

5.9.3 Case-E

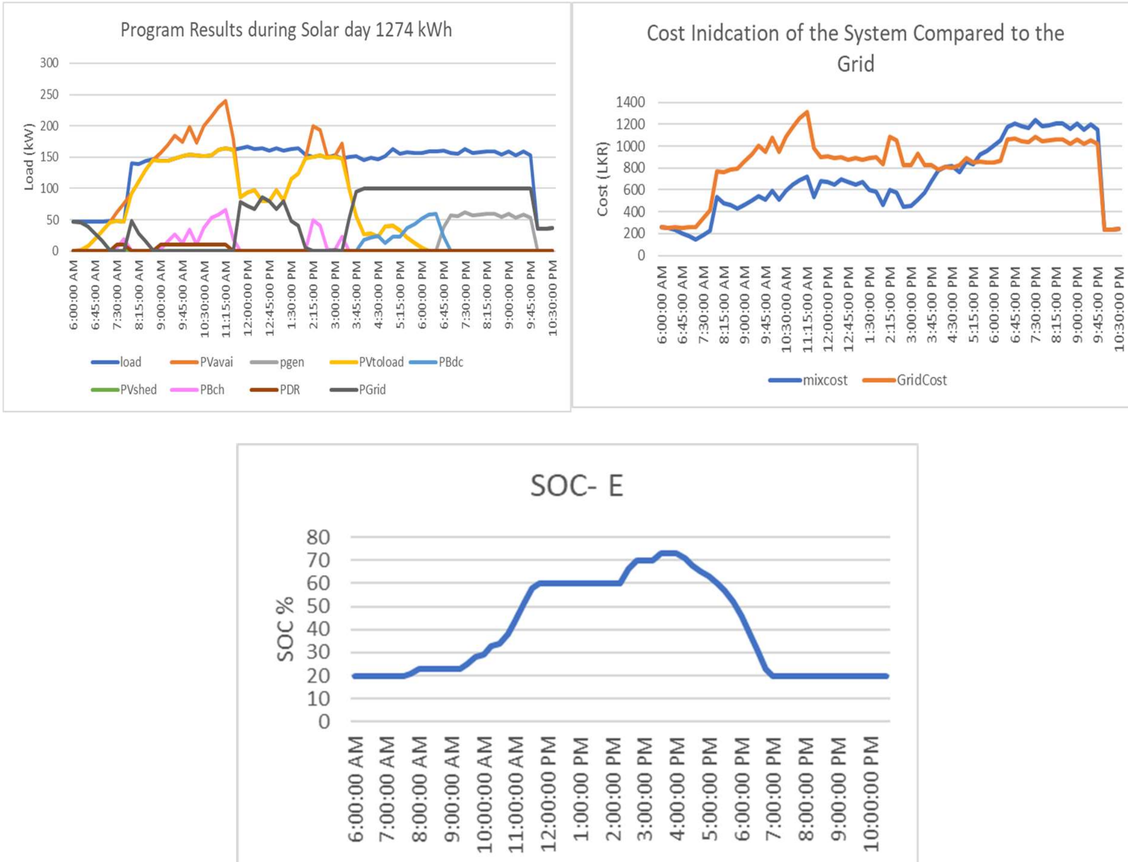


Figure 13 - Case Study 1- Simulation Data- Case E

In this case the Solar power generation has been interrupted due to the shadows of the clouds. The battery has charged to 72% and during peak hours it is discharged to manage the maximum demand.

In this case when considering the day if the total load is supplied as per the program from 6:00 am to 10:30 pm the cost is 46, 174 LKR. If that energy is supplied from the grid the cost is 55,985 LKR and the gross profit is 9,811 LKR for the day.

5.9.4 Case-F

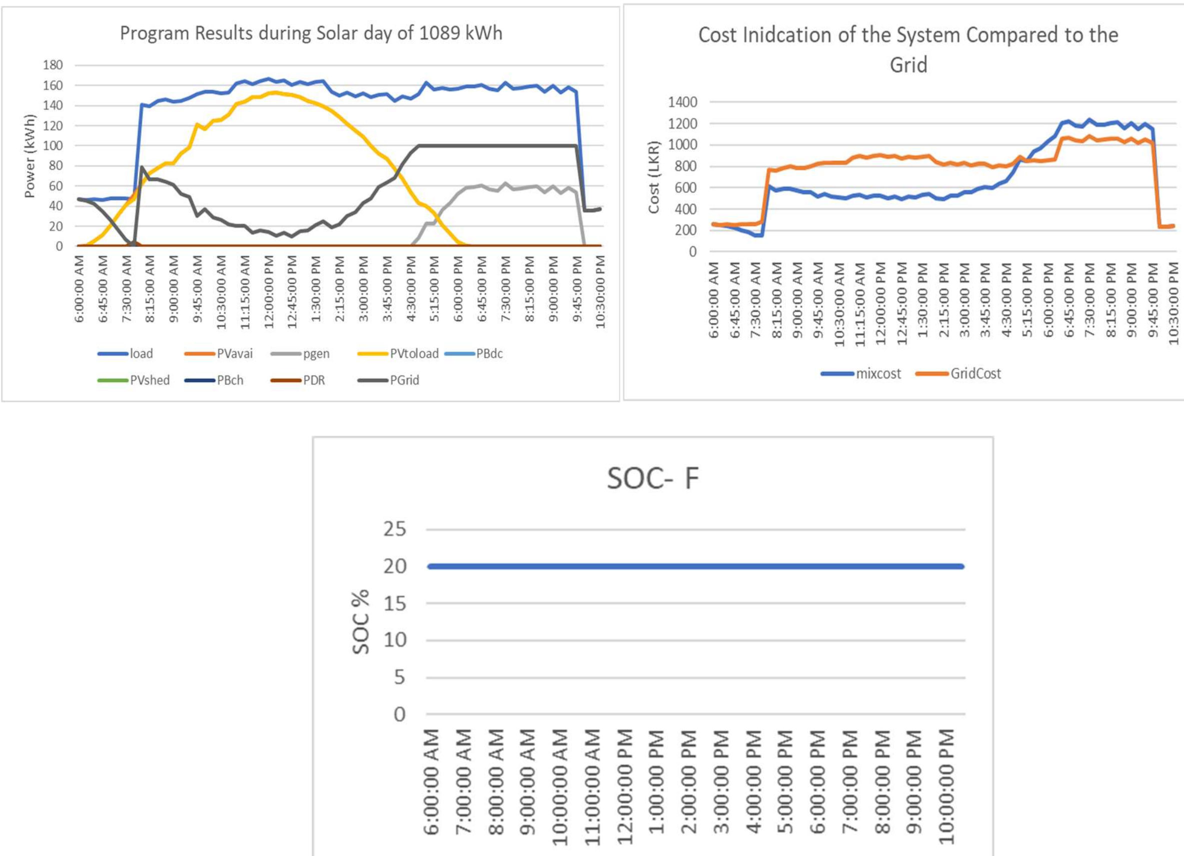


Figure 14 - Case Study 1- Simulation Data- Case F

In this case the solar energy generation is less, and the battery charging is not possible. During peak hours the generator is turned on to maintain the maximum demand at 100 kW.

Here when considering the day if the total load is supplied as per the program from 6:00 am to 10:30 pm the cost is 44, 664 LKR. If that energy is supplied from the grid the cost is 52,769 LKR and the gross profit is 8,106 LKR for the day.

5.9.5 Case-G

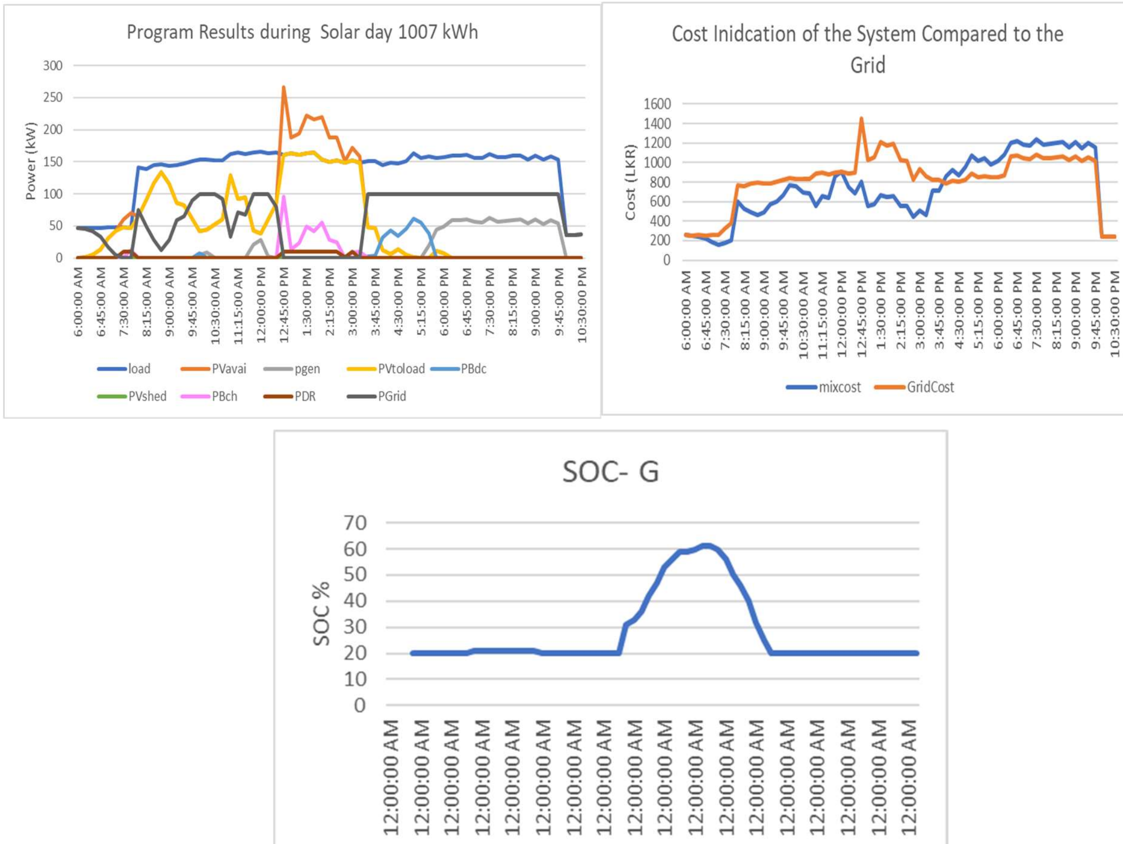


Figure 15 - Case Study 1- Simulation Data- Case G

In this case the solar generation is fluctuating and battery charging, DR load turning on has been done in a limited time. Battery has charged to 60% and 6,204 LKR the gross profit is 8,106 LKR for the day.

5.9.6 Case-K

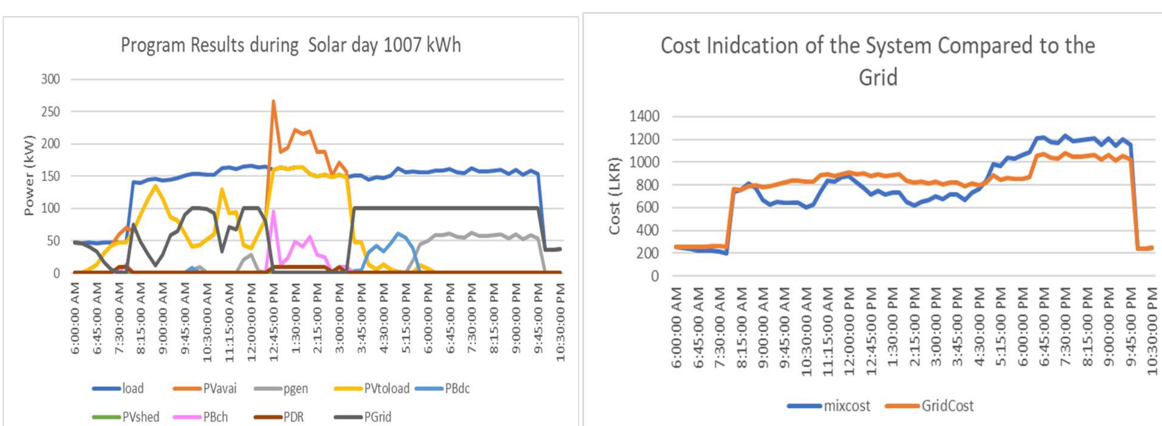
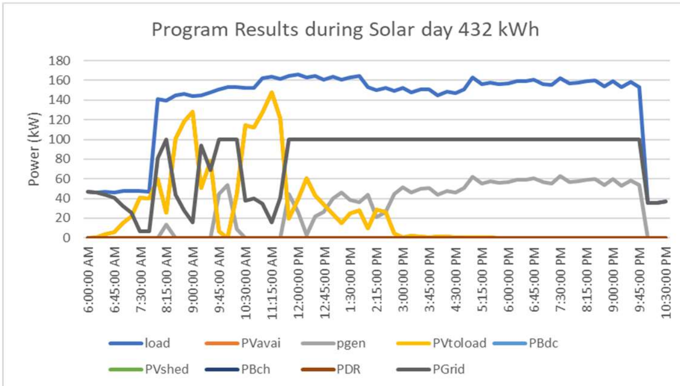


Figure 16 - Case Study 1- Simulation Data- Case K

In this approach the dispatch is quite similar to case G and the gross profit is 1,392 LKR.

5.9.7 Case- L



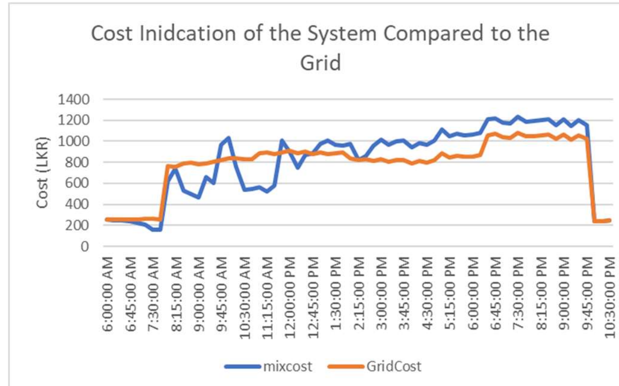


Figure 17 - Case Study 1- Simulation Data- Case L

In this scenario the solar generation is minimum, and the Diesel generator is required to keep the maximum demand at 100 kW. Here there is a net loss and value of it is 2,247 LKR.

5.10 The Summary of the Profit/Loss

In all the cases of Solar generation the total profit has been calculated by the program. If the solar generation is more than 500 kWh the system generates profit.

Table 9 - Case Study 1- Summary of the Profit/Loss

Option	Generation (kWh)	Profit (LKR)
A	1808	10,679.08
B	1540	12,961.92
C	1450	11,958.06
D	1351	10,770.18
E	1274	9,811.25
F	1089	8,105.87
G	1007	6,203.87
H	726	4,204.11
I	730	3,810.76
J	600	1,898.63
K	524	1,392.85
L	432	(2,247.49)

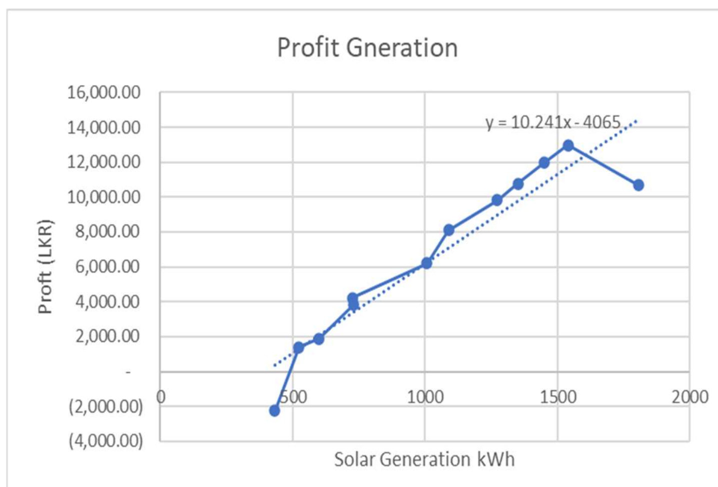


Figure 18 - Case Study 1- Profit Generation

5.11 Optimum Battery Bank Capacity

To calculate the optimum battery bank capacity fixed solar generation curve is to be used and for this study Case B is selected.

Table 10 - Case Study 1- Profit (Case B)

Battery Bank Capacity (kWh)	Profit (LKR)
100.00	10,856.00
125.00	11,449.00
150.00	12,087.00
175.00	12,566.00
200.00	12,962.00
225.00	12,649.00
250.00	12,649.00

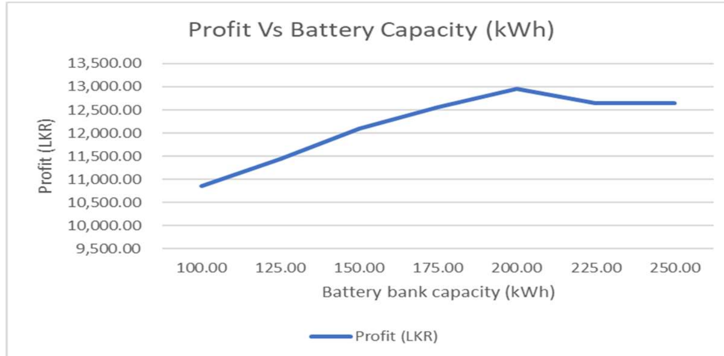


Figure 19- Case Study I - Profit vs Battery Capacity (Case B)

As per the curve the maximum profit is generated when 200 kWh battery bank relates to the system.

6.0 Case Study 02- Industrial (IP) Customer

6.1 Generation Cost Calculation

Cost values for each generating sources related to the IP customer is calculated here. The financial values were taken from the Annex-07.

6.1.1 Solar PV System

The average energy consumption for the day is around 65 MWh. However, the limiting factor for the solar PV capacity for this installation is the roof area, which is around 10,600 m^2 and is only adequate to install 2196 kWp Solar panels. This was illustrated using the Homer software and the details are in Annex 04.

Solar PV System Simulation has been conducted for the site and the detail report is attached in the Annex 05.

- Software- PVSYST V7.2.8
- Geographical Site- Yugadanavi Power Plant-Sri Lanka
- Meteo data- Meerawaramulla-Sri Lanka
- Latitude 7.01 0N, Longitude 79.87 0E
- Solar DC Capacity- 2196 kWp (535 Wp x 4104)
- Optimum Ac output- 1600 kWp
- Area of the solar panels= 10,583 m2 (The roof area- 14,750 m2)
- Annual Generation= 3,528,000 kWh
- For the cost Calculation 80% of the generation used

Selection of the Optimum Inverter Capacity

Table 11 - Case Study 2- Optimum Inverter Capacity

Power		System Production (MWh/Year)	Specific Yield (kWh/kWp/year)
DC (kWp)	AC (kW)		
2196	2400	3544	1614
2196	2200	3543	1614
2196	2000	3541	1613
2196	1800	3539	1612
2196	1600	3528	1607
2196	1400	3454	1573

For the same DC capacity of the panels different options for the inverter capacities were evaluated and best option is selected as 1600 kWp.

The inputs for the LOCE equation under chapter 3.1 for this installation is used in table 12.

Table 12 - Case Study 2 - Parameters for the Solar Installation

Term	**Description**	**Solar Installation**
Initial investment	Capital cost (LKR)/(kW)	140,000
AO	Annual operational cost (LKR)	500
r	Discount rate	10%
RV	Residual value per kW (LKR)	500
	Operation Cost per kW (LKR)	500
	Cost of 50 kW inverter	550,000
SDR	System degradation rate	1%
N	Operational life of the system	25

From the LOCE Equation in chapter 3.2 the values are calculated for each year and has been indicated in the table 13 below.

Table 13- Case Study 2-Results per Year

year	**Cash flow (LKR)**	**NPV (LKR)**	**Expected Energy (kWh)**	**Degraded Energy**	**25% Shed**	**Degraded**	**Discounted Energy**	**NPV shed**
0	280,000,000	280,000,000	2,847,622				-	0
1	1,000,000	934,579	2,847,622	2,847,622	2,135,716	2,135,716	2,661,329	1,995,997
2	1,000,000	873,439	2,847,622	2,844,774	2,135,716	2,133,581	2,484,736	1,865,417
3	1,000,000	816,298	2,847,622	2,841,929	2,135,716	2,131,447	2,319,861	1,743,381
4	1,000,000	762,895	2,847,622	2,839,087	2,135,716	2,129,316	2,165,926	1,629,328
5	1,000,000	712,986	2,847,622	2,836,248	2,135,716	2,127,186	2,022,206	1,522,736
6	1,000,000	666,342	2,847,622	2,833,412	2,135,716	2,125,059	1,888,022	1,423,118
7	1,000,000	622,750	2,847,622	2,830,579	2,135,716	2,122,934	1,762,742	1,330,017
8	1,000,000	582,009	2,847,622	2,827,748	2,135,716	2,120,811	1,645,775	1,243,006
9	1,000,000	543,934	2,847,622	2,824,920	2,135,716	2,118,690	1,536,569	1,161,688
10	23,000,000	11,692,034	2,847,622	2,822,095	2,135,716	2,116,572	1,434,610	1,085,690
11	1,000,000	475,093	2,847,622	2,819,273	2,135,716	2,114,455	1,339,416	1,014,663
12	1,000,000	444,012	2,847,622	2,816,454	2,135,716	2,112,341	1,250,539	948,284
13	1,000,000	414,964	2,847,622	2,813,638	2,135,716	2,110,228	1,167,560	886,246

14	1,000,000	387,817	2,847,622	2,810,824	2,135,716	2,108,118	1,090,086	828,268
15	1,000,000	362,446	2,847,622	2,808,013	2,135,716	2,106,010	1,017,753	774,082
16	1,000,000	338,735	2,847,622	2,805,205	2,135,716	2,103,904	950,220	723,441
17	1,000,000	316,574	2,847,622	2,802,400	2,135,716	2,101,800	887,168	676,113
18	1,000,000	295,864	2,847,622	2,799,598	2,135,716	2,099,698	828,300	631,881
19	1,000,000	276,508	2,847,622	2,796,798	2,135,716	2,097,598	773,338	590,543
20	23,000,000	5,943,637	2,847,622	2,794,001	2,135,716	2,095,501	722,023	551,910
21	1,000,000	241,513	2,847,622	2,791,207	2,135,716	2,093,405	674,113	515,803
22	1,000,000	225,713	2,847,622	2,788,416	2,135,716	2,091,312	629,382	482,059
23	1,000,000	210,947	2,847,622	2,785,628	2,135,716	2,089,221	587,619	450,523
24	1,000,000	197,147	2,847,622	2,782,842	2,135,716	2,087,131	548,628	421,049
25	1,000,000	184,249	2,847,622	2,780,059	2,135,716	2,085,044	512,224	393,504
		308,522,486		70,342,771		52,757,078	32,900,146	24,888,748

From the equation in 3.1 the LOCE can be calculated as,

The LOCE of The Solar power = 9.37 LKR

If the charger efficiency is =0.92%

The charging cost = 10.19 LKR

If the 25% of the PV is shed the LOCE is changed

Then the LOCE = 12.39 LKR

6.1.2 Distributed Loads

The Distributable Loads will be fed Realtime form the Solar Energy. Therefore, the cost for electricity is same as the LOCE Solar

6.1.3 Battery Discharging

Table 14- Case Study 2- LOCE parameters for Battery Bank

Term	Description	Battery Bank
Initial investment	Capital cost (LKR) per kWh	51,375.60
AO	Annual operational cost (LKR)	500.00
r	Discount rate	10%
RV	Residual value per kW (LKR)	750
SDR	System degradation rate	1%
N	Operational life of the system	10

The LOCE cost calculation for a battery bank of 6000 kWh is shown in the following table. It is expected to replace the quarter of the battery bank capacity during each two years. The 80% of the battery bank capacity is discharged daily to calculate the LOCE.

Table 15 - Case Study 2- LOCE for a battery bank of 6000 kWh

Year	Cash flow(cost) (LKR)	Benefit (LKR)	Net NPV (LKR)	Expected (kWh)	Expected Energy Degraded (kWh)	Discounted Energy (kWh)
-	308,253,600	39,600,000	268,653,600	1,728,000		
1	3,000,000	39,600,000	(34,205,607)	1,728,000	1,728,000	1,719,403
2	80,063,400	39,600,000	35,342,301	1,728,000	1,726,272	1,709,138
3	3,000,000	39,600,000	(29,876,502)	1,728,000	1,724,546	1,698,934
4	80,063,400	39,600,000	30,869,334	1,728,000	1,722,821	1,688,791
5	3,000,000	39,600,000	(26,095,294)	1,728,000	1,721,098	1,678,709
6	80,063,400	39,600,000	26,962,472	1,728,000	1,719,377	1,668,687
7	3,000,000	39,600,000	(22,792,641)	1,728,000	1,717,658	1,658,724
8	80,063,400	39,600,000	23,550,067	1,728,000	1,715,940	1,648,822
9	3,000,000	39,600,000	(19,907,975)	1,728,000	1,714,224	1,638,978
10	80,063,400	39,600,000	20,569,541	1,728,000	1,712,510	1,629,193
11		Total	273,069,295		Total	16,739,379

From the LOCE Equation in chapter 3

The LOCE of the Battery Power = 15.40 LKR

6.1.4 Summary

The summary of each source energy unit costs are as below.

Table 16 - Case Study 2- Summary of Source Energy Unit Costs (IP)

Type		LKR/kWh
Solar power (levelized Cost)		9.37
Battery charging		10.19
Battery discharging (levelized Cost)		15.40
PV shedding (25% shedded)		12.39
Load shifting controllable loads		9.37
Grid energy cost	peak	23.5
	off peak	5.9
	Day peak	10.25

6.2 Battery Charging/ Discharging Rates

The battery is expected to be charged during the off peak hours and the energy to be discharged for the power plant loads during the peak hours and day time.

Battery SOC will be kept between 20 % to 100% as per chapter 3.4.

Charging efficiency = 0.92

Discharging efficiency = 0.95

Self-Discharge rate of the battery = 0.023%

6.3 Controllable Loads

The identified Controllable Loads = 500 kW

The Energy Requirement for the Load = 1500 kWh

Then the loads need to be switched 12 times when excess solar is available.

6.4 Diesel Generator

The capacity of the Generator =2000 kW

$$\text{Cost} = 0.012\, P_g^2 + 37.55\, P_g + C_{Start}$$

6.5 Grid Power Supply

The maximum demand limit for the power plant to be kept as 2500 kW and expected saving from the maximum demand cost is 6500-2500 kW= 4000 kW and the financial value is 4000x1100= 4,400,000 LKR per month.

6.6 Load Profile

The measured load profile of the IP customer is shown below and there is a base load of 2100 kW throughout the day. The load changes are occurring due to the lighting, ventilation and other 6.6 kV boiler feed water pump operation during the standby mode of the power plant. However, it should be noted that the standby operation of the Yugadanavi plant is unpredictable and in order to validate the program for IP customer this load profile was selected.

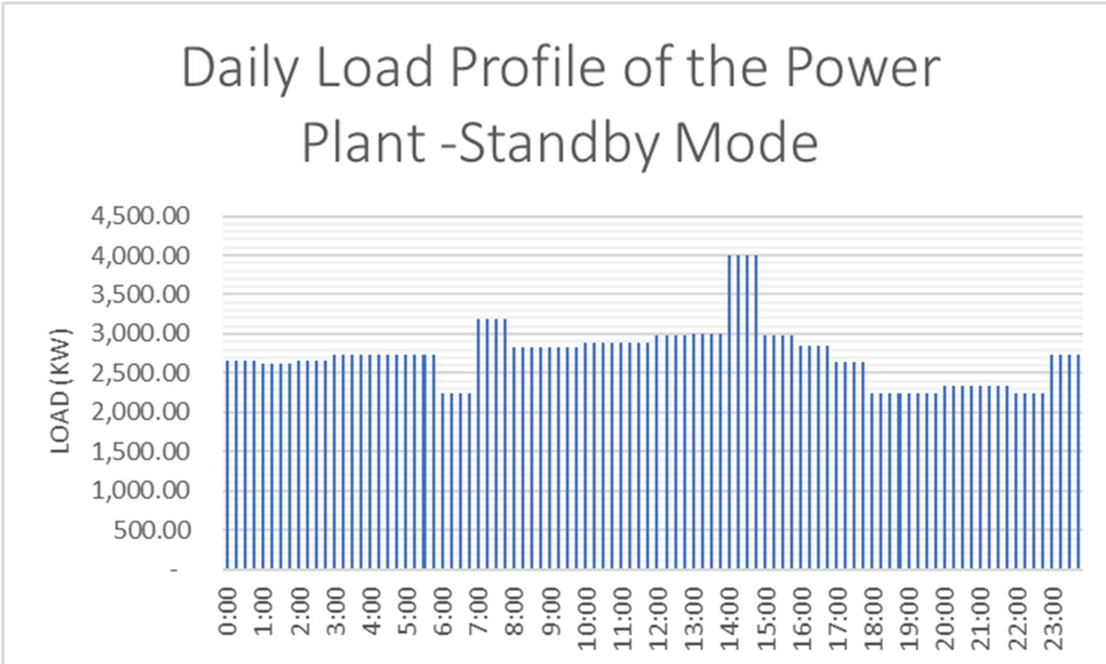


Figure 20 - Case Study 2- Daily Load Profile of Power Plant

6.7 Matlab Code

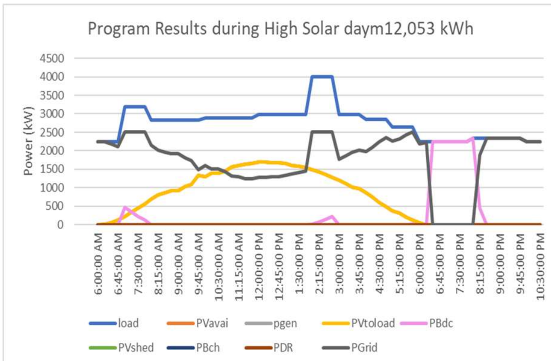
The MATLAB code is in the Annex 06.

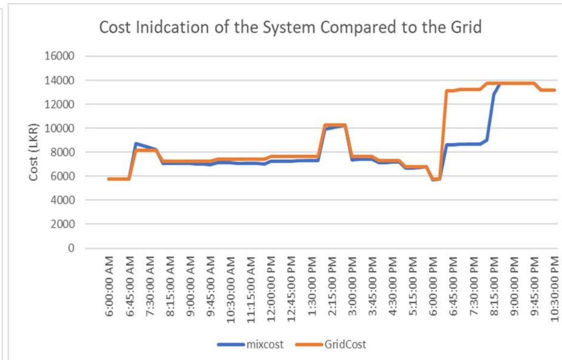
6.8 The Solar Data for the Simulation

Since the Program is running in 15 mins time interval and the solar generation is changing in different days, several combinations are considered for the simulation. In the simulation some days have higher solar generation while in some days the pattern is similar, but values are lesser. There are some days where the solar generation was obstructed due to the clouds and that kind of solar curves are also taken into consideration for the program.

6.9 Simulation Data of the Each Solar Generation

6.9.1 Case- A





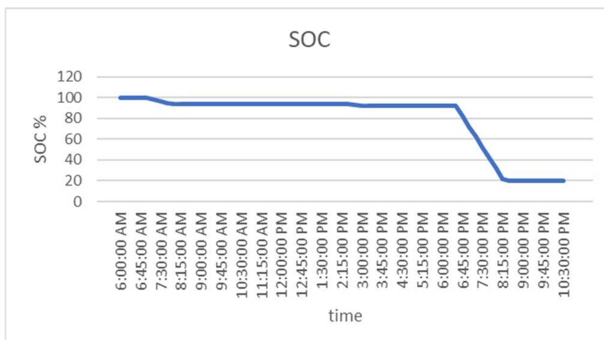


Figure 21 - Case Study 2- Simulation Data- Case A

In this approach solar generation is totally used for the load fulfillment because there is no excess solar generation for battery charging and DR load dispatching. The strategy used is to charge the batteries during the off-peak period and discharge in the economical manner. In this regard as can be seen in the graph when limiting the maximum demand battery is discharged. Other significance is during the peak charging hours battery cost becomes lower and dispatched to reduce the cost. In accordance to the cost curve during the solar available period the mix cost is always bellow the grid cost and during peak hours there is a considerable reduction in the cost.

During the day the cost for energy mix is 560,730 LKR and if the energy is totally supplied from the grid the cost would be 602,182 LKR ultimately the profit is 41,451 LKR.

6.9.2 Case- B

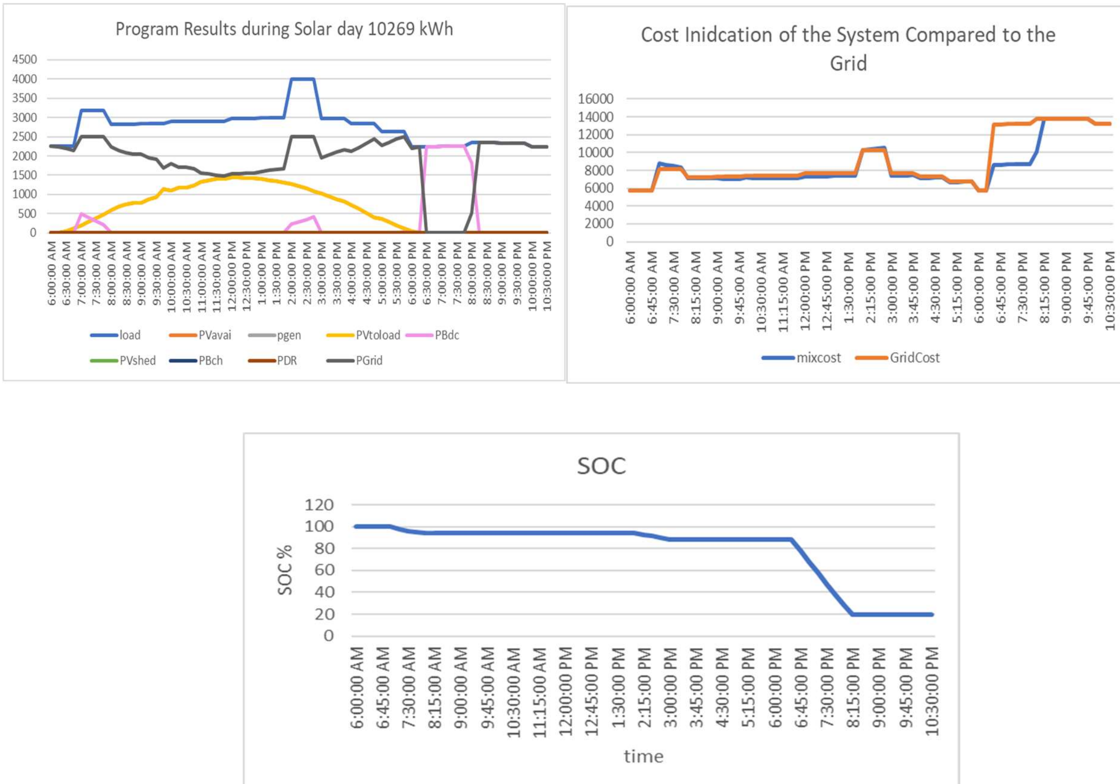


Figure 22 - Case Study 2- Simulation Data- Case B

The characteristic is same as the case A only difference is the solar generation is lesser. And maximum demand limiting is supported by the battery energy discharge. The cost for energy with the mix cost is 565,665 LKR and the cost if taken from grid is 602,182 LKR. The profit is 36,516 LKR.

6.9.3 Case-E

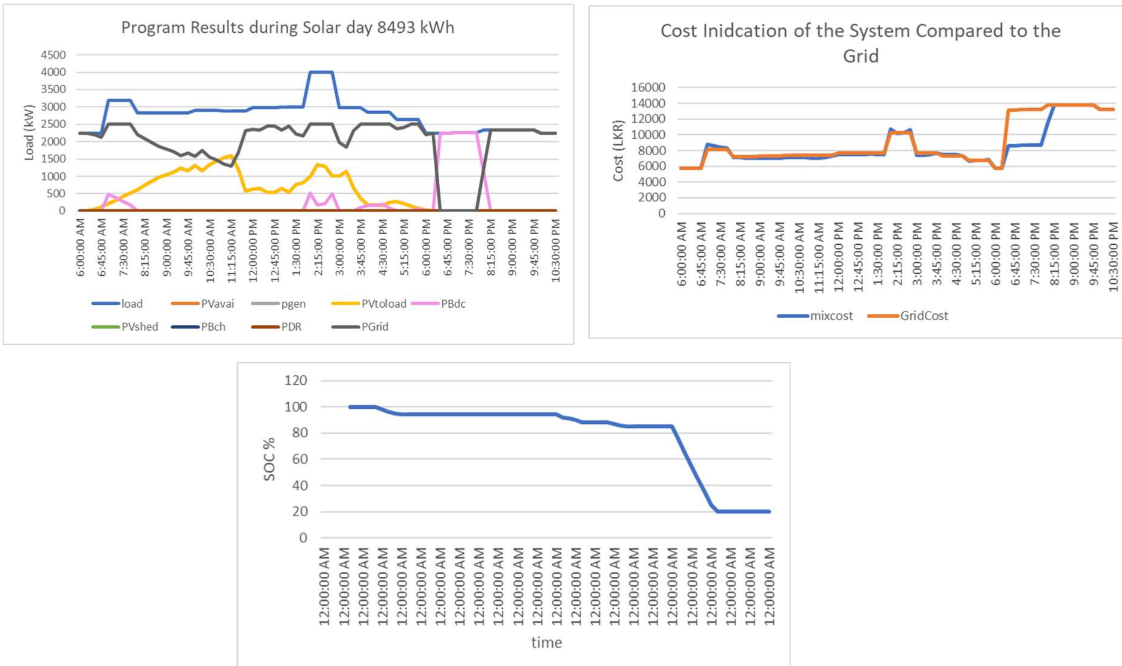


Figure 23- Case Study 2- Simulation Data- Case E

Here the solar generation is interrupted due to covering by the clouds. The mix generation cost is 569,606 LKR and the cost if power is supplied from the gird is 602,181 LKR. Finally, the profit is 32,575 LKR.

6.9.4 Case-G

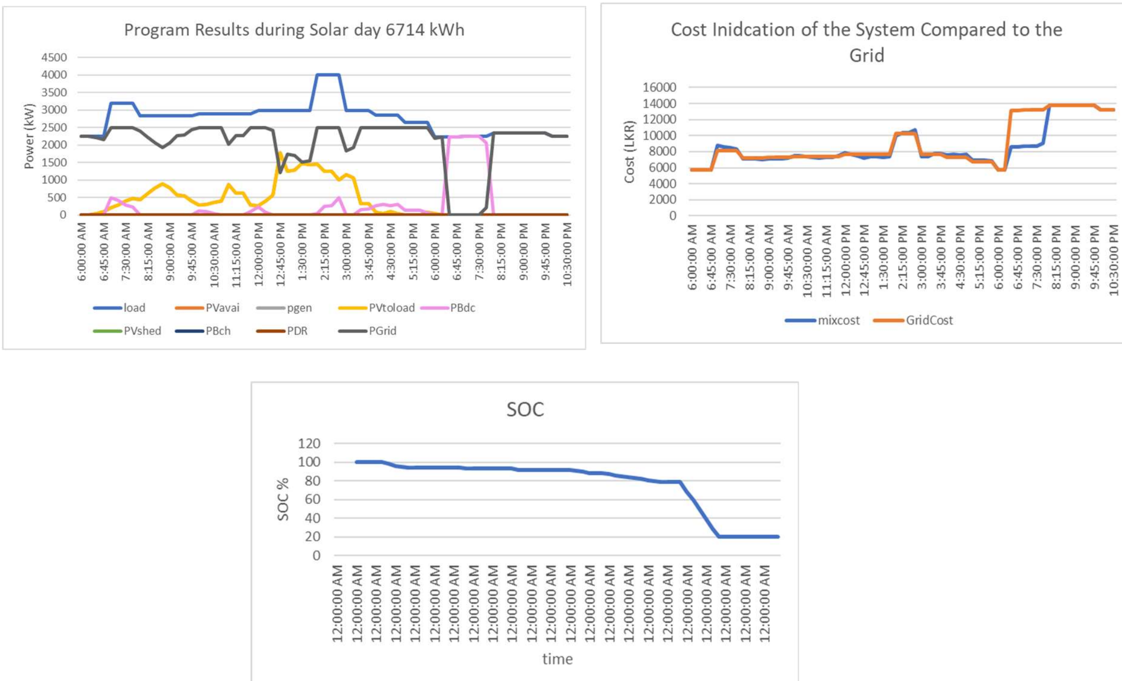


Figure 24 - Case Study 2- Simulation Data- Case G

The fluctuating solar generation is compensated with the battery discharging to keep the maximum demand limit.

In this case the cost for distributed generation sources is 575,865 LKR and cost when only taking from the grid is 602,182 LKR. Expected profit from the scheme is 26,316 LKR.

6.9.5 Case-K

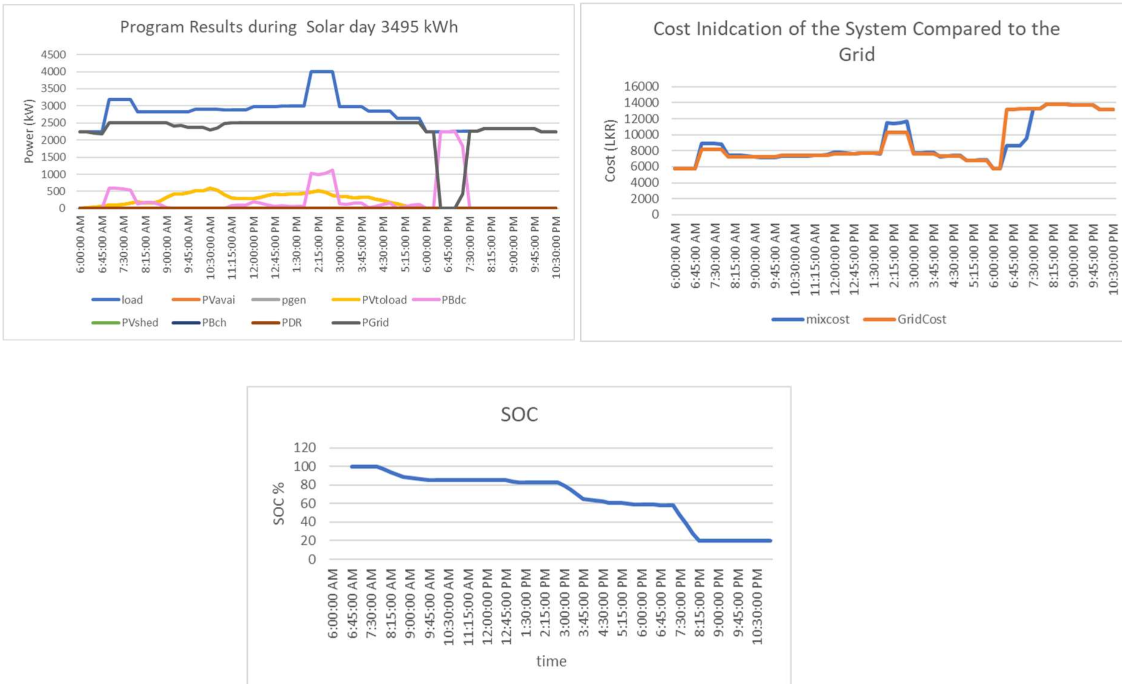


Figure 25 - Case Study 2- Simulation Data- Case K

Here the cost for the new energy mix is 593,824 LKR and profit is only 8357 LKR.

6.9.6 Case-L

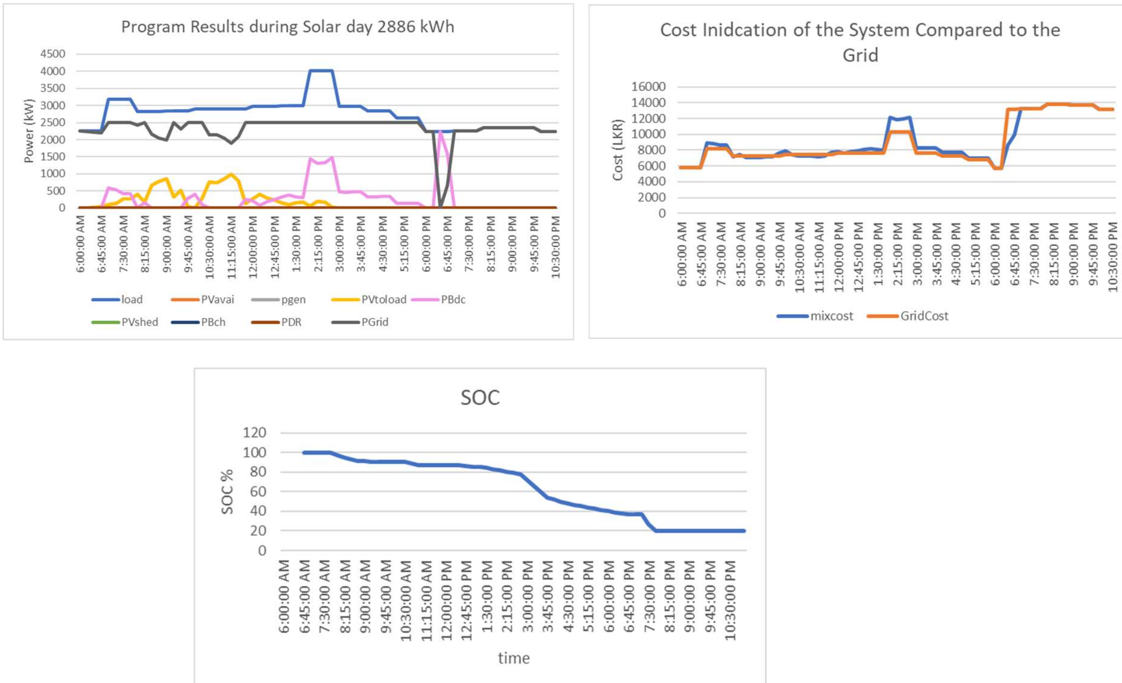


Figure 26 - Case Study 2- Simulation Data- Case L

As per the program calculations in this solar profile the system is generating loss of 8480 LKR.

6.10 The Summary of the Profit/Loss

Case-L the energy cost for the distributed system is 610,662 LKR and there is a loss of 8480 LKR.

In all the cases of Solar generation the total profit has been calculated by the program. If the solar generation is more than 500 kWh the system generates profit.

Table 17- Case Study 2- Summary of the Profit/Loss

Generation	Daily Solar Generation kWh	Profit (LKR)
A	12053.1	41,451.30
B	10269.4	36,516.30
C	9664.4	35,052.90
D	9005.3	32,941.80
E	8493.1	32,575.40
F	7260.0	27,762.70
G	6714.6	26,316.30
H	4840.0	20,341.00
I	4866.1	14,064.00
J	4002.2	12,760.70
K	3495.4	8,357.90
L	2885.7	(8,480.10)

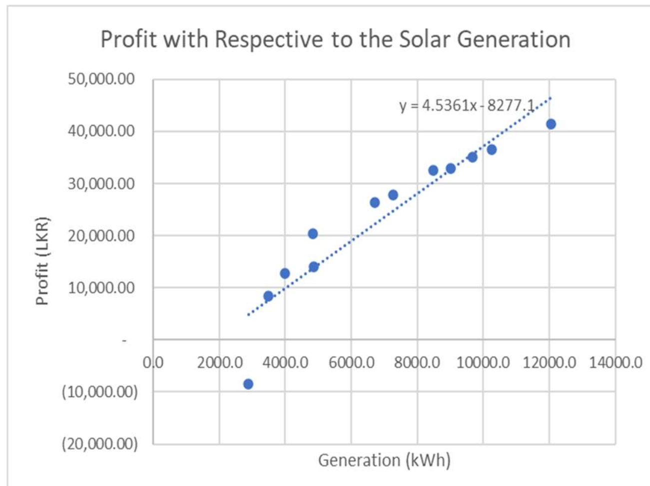


Figure 27- Case Study 2- Profit Generation

6.11 Optimum Battery Bank Capacity

To calculate the optimum battery bank capacity fixed solar generation curve is to be used and for this study Case B is selected. When considering the optimum battery capacity here the strategy is to charge the batteries during off peak and use them during the peak hours. In this case the maximum demand from the grid to be limited to 2500 MW.

With reference to the energy bills of the installation it could be observed that the maximum energy demand value was 7000 kVA (5600 kW with a power factor of 0.8). In this case the possible maximum demand reduction is 3100 kW using the battery bank.

Table 18- Case Study 2- Profit (Case B)

Battery Capacity (MWh)	LOCE Cost (LKR)	Profit (LKR)
3	14.76	19,832.00
4	15.08	25,796.00
5	15.27	30,675.00
6	15.40	36,516.00
7	17.76	31,139.00
8	19.83	22,736.00
9	21.52	13,032.00
10	22.87	4,796.00

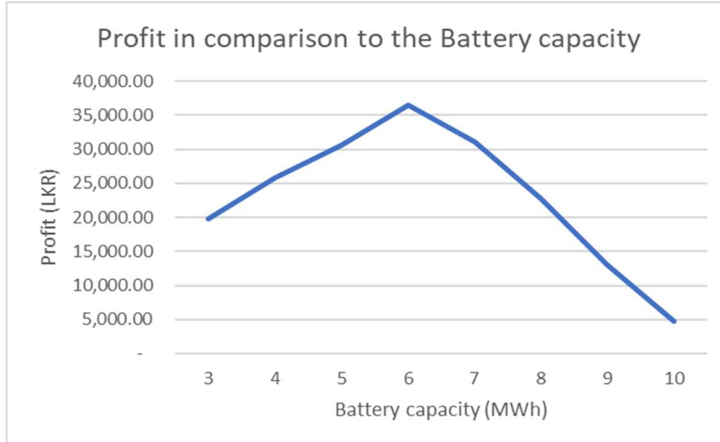


Figure 28 - Case Study 2- Profit vs Battery Capacity (Case B)

As per the curve the maximum profit is generated when the battery bank capacity is 6MW.

7.0 Sensitivity Analysis

7.1 Application the BST values 2018

The GP and IP tariffs considered in the table 1 and table 2, are not reflecting the actual financial cost for the utility. Therefore, the bulk supply tariffs approved by PUCSL in 2018 was considered and recalculated to evaluate the profitability of the investment.

Table 19- BST Approved in 2018 by PUCSL

Bulk supply tariff	**Transfer price (LKR)**	**Price After Adjusting for 3% loss (LKR)**
Day peak	12.44	12.82
Peak	16.27	16.77
Off Peak	7.42	7.65

Different scenarios in the Chapter 5 were simulated to calculate the benefit if the generation mix is replaced against the grid supply. As can be seen in the table 19 for all the solar curves a loss to the consumer could be observed. The maximum demand limitation was kept at the same value as 100 kW and the balance power requirement was provided by the battery and the diesel generators.

Table 20 -BST Tariff Related Profit

Option	**Generation (kWh)**	**Profit (LKR)**
A	1808	(5,516.12)
B	1540	(3,300.15)
C	1450	(3,507.77)
D	1351	(3,907.59)
E	1274	(4,307.36)
F	1089	(4,203.04)
G	1007	(6,088.08)

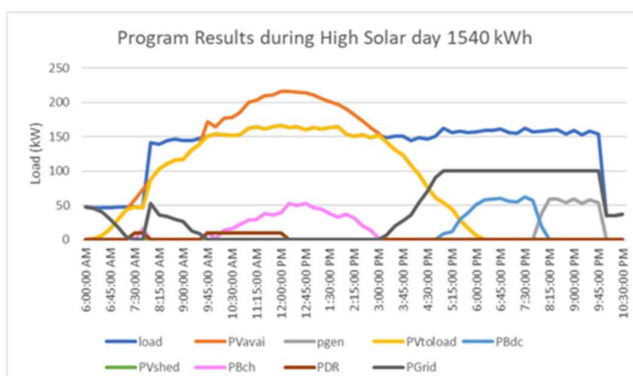


Figure 29 -Sample dispatching pattern of B

However, when the maximum demand is raised to 150 kW the losses are narrowed and shown in the table below for cases A, B, C. In this case the dispatching of the generator was reduced.

Table 21- Profit with increased Maximum demand

Option	Generation (kWh)	Profit (LKR)
A	1808	628.28
B	1540	1,009.89
C	1450	968.58

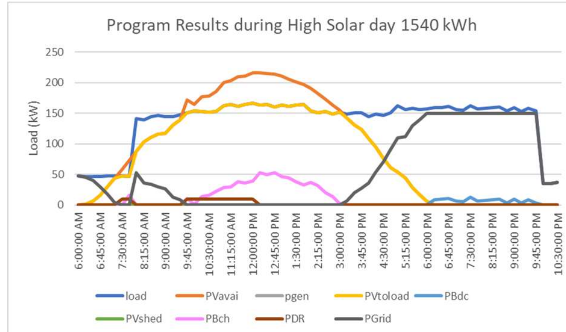


Figure 29 -sample dispatching pattern of B

7.2 Application of the 2022 Exchange rate and Fuel Prices

The fuel prices and the exchange rates changed significantly in 2022 and the levelized costs were recalculated to evaluate the profitability.

Table 22- Exchange rates

	2018 June	2022 November
Exchange rate USD (LKR)	155	370
Diesel price (LKR)	118	420

The new LOCE values were calculated as the formula given in the chapter 3.1.

Table 23- LOCE Values 2022 November

Type		LKR/kWh
Solar power (levelized Cost)		31.81
Battery charging		34.58
Battery discharging (levelized Cost)		78.58
PV shedding (25% shed)		42.13
Load shifting controllable loads		31.81
Grid energy prices	Day Peak	29.00
	Peak	34.50
	Off Peak	15.00

Then the profits were recalculated, for each case in the case study 1 to compare the benefit of the investment during different solar availability options.

Table 24- Profit as of November 2022

Option	Generation(kWh)	Profit (LKR)
A	1808	(29,422.03)
B	1540	(21,478.88)
C	1450	(23,848.17)
D	1351	(26,503.17)
E	1274	(25,610.66)
F	1089	(27,940.15)
G	1007	(31,832.75)
H	726	(28,570.36)
I	730	(31,243.80)
j	600	(35,309.27)
k	524	(33,370.55)
L	432	(51,525.36)

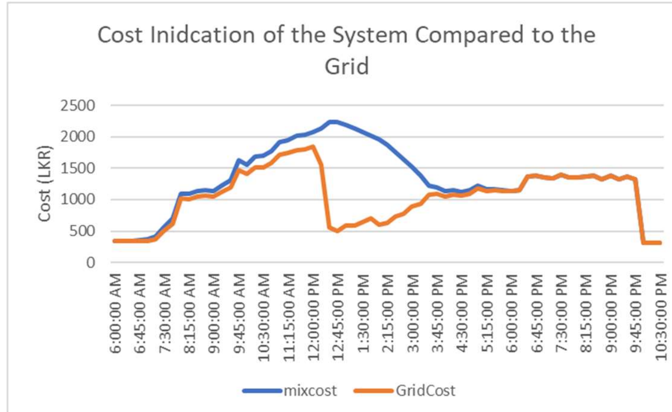


Figure 30- Profit and loss comparison for 2022 November Values for solar curve B

Therefore, it could be observed that the due to increased exchange rates and the fuel prices the generation cost of the energy mix is higher compared with the grid prices. The day grid rate is less than the LOCE cost of the solar. And from the perspective of the consumer the maximum demand control become costlier.

8.0 Conclusions

Electricity cost reduction for IP and GP customer was focused on this study. In order to achieve that, usage of different energy sources like Solar, Battery, Grid power, Diesel generators has been considered. The sources were dispatched on real time, based on the optimum costs and for optimization quadratic optimization technique was used. The program can be loaded with the inputs like unit costs of each source, tariff, maximum demand from the grid, maximum capabilities of each generation sources. Based on the availability of the solar energy, the program manages the dispatching of all the sources to optimize the cost. For calculation of the unit costs of the battery and solar generation, LCOE formula was used based on the financial figures in annex 7.

With reference to the results of the Case 1 and 2, it has been indicated that in year 2018, customer was able to invest for a profitable hybrid energy system. The profit margins were increased with the increment of the Solar energy generation. However, the results are always dependent on the financial figures like exchange rate and fuel cost. Therefore, a sensitivity analysis was conducted and in accordance with the Sensitivity analysis in chapter 7, the profit were declined, for the BST tariffs on 2018. As per the calculations, average profit for each case was reduced by 150% ending with a loss for the investment. For financial figures in 2022 November, the profits were reduced by 330% and the investment was found to be not feasible with the available figures.

Therefore, due to the financial crisis in Sri Lanka the investment for hybrid solar and battery systems has become unviable in 2022. However, in consideration to the increment of the reliability this hybrid systems can be used.

On the other hand, following advantages of the optimization program would be highlighted. The program has the flexibility for providing different unit costs, tariffs, maximum demand values as inputs for verification of the profitability.

8.1 Investment Verification

Before selecting the Solar panel size and the battery bank size, the program developed in this study can be used to estimate the optimum capacity based on the load curve for a particular installation. The program has the flexibility to check the dispatch of the sources, varying the parameters. The inconsistent solar generation can be predicted in different scenarios and fed into the program as done in both the cases. The risk for the investment due to highly fluctuating solar generation can be analyzed using this program.

8.2 Select Maximum Demand Control Value

Maximum demand is important parameter for the consumer as well as to the utility provider. Limiting value of the maximum demand create unprecedented benefits for both the parties. For the consumer it reduces the cost and for the utility it reduces the stress on the grid, and ultimately provide economic benefits. In this program changing the maximum demand (MD) value provides the opportunity to the customer for selecting the optimum MD for a particular load profile.

8.3 Optimum Operation

After installation of PV and battery system this program is created to optimize cost through an operation pattern of the Solar system, battery bank, DR loads, Diesel Generators, and Grid power. This ensures the optimum economic dispatch of the sources.

8.4 Reliability

The power supply reliability is improved due to usage of multiple sources in parallel with the optimum cost implication. The system is not depending on the grid power supply but keeps its reliability via different sources.

8.5 Different Applications

The program developed can be used for both Industrial purpose and General-purpose customers to identify the optimum solution. The program has the flexibility to provide the different tariff rates as inputs which enables the flexibility to use for any type of customer. Due to the variation of the operational costs of the system the revision of tariff is possible, and the program has the flexibility to conduct the sensitivity analysis for the tariff changes.

References

[1] Matt Campbell, SunPower Corp., San Jose, California, US “Minimizing utility-scale PV power plant levelized cost of energy using high-capacity factor configurations” online,

[2] Sundari Ramabhotla, Stephen Bayne, Michael Giesselmann, “Operation and Maintenance Cost Optimization in the Grid Connected Mode of Microgrid” IEEE Green Technologies Conference 2016

[3] Ninan, J., Othman, Y., Aldhuhoori, S., Meegahapola, L. And Akmal, Muhammad ”Microgrid cost optimization: a case study on Abu Dhabi. 2018 8th International Conference on Intelligent Systems, Modelling and Simulation (ISMS), 2018, 120-125”

[4] Y Ma, P Yang, H Guo,Y Wang “Dynamic Economic Dispatch and Control of a Stand-alone Microgrid in DongAo Island ” J Electr Eng Technol.2015;30-40

[5] R S Wibowo, K R Firmansyah, N K Aryani, A Soeprijanto, “Dynamic Economic Dispatch of Hybrid Microgridwith Energy Storage Using Quadratic Programming” IEEE Region 10 Conference (TENCON),2016

[6] P. Wang, L Setyawan, and J. Xiao, “Optimal Depth-of-Discharge Range and Capacity Settings for Battery Energy Storage in Microgrid Operation” IEEE 2017

[7] S. X. Chen, H. B. Gooi, and M. Q. Wang, "Sizing of Energy Storage for Microgrids," Smart Grid, IEEE Transactions on, vol. 3, pp. 142-151, 2012

[8] Environment and Health Safety office, “Lithium Ion Battery Safety Guidance” 2017 March

[9] C. W. X. Z. Bo Zhao, Grid-Interconnected and Standalone Photovoltaic Distributed Generation Systems: Analysis, Design, And Control, River Street, Hoboken: WILEY, 2017

[10]Tesla.com/Energy “Tesla Mega pack brochure”, 2020 Rev 1.8

[11] Chun Sing Lai and M.D. McCulloch, “Levelized Cost of Energy for PV and Grid Scale Energy Storage Systems”,2016

[12] D Bo, L Wenzhou “Research on Control of Energy Storage by Intelligent Micro-grid for Wind/Photovoltaic/Energy Storage” 12th IEEE Conference on Industrial Electronics and Applications (ICIEA),2017

[13] M Alsmadi , Y Dababneh, A Al-Salaymeh “Utilizing PV System for Auxiliary Energy Demand in Conventional Power Plant ”, Int. J. of Thermal & Environmental Engineering Volume 14, No. 2 (2017) 119-124

[14] A A Hadi, C A S Silva ,E Hossain, and R Challoo “Algorithm for Demand Response to Maximize the Penetration of Renewable Energy”, 2020

[15] The MathWorks, Inc., "Math Works," The MathWorks, Inc., 1994. [Online]. Available: https://in.mathworks.com/help/optim/ug/quadprog.html. [Accessed 05 03 2021].

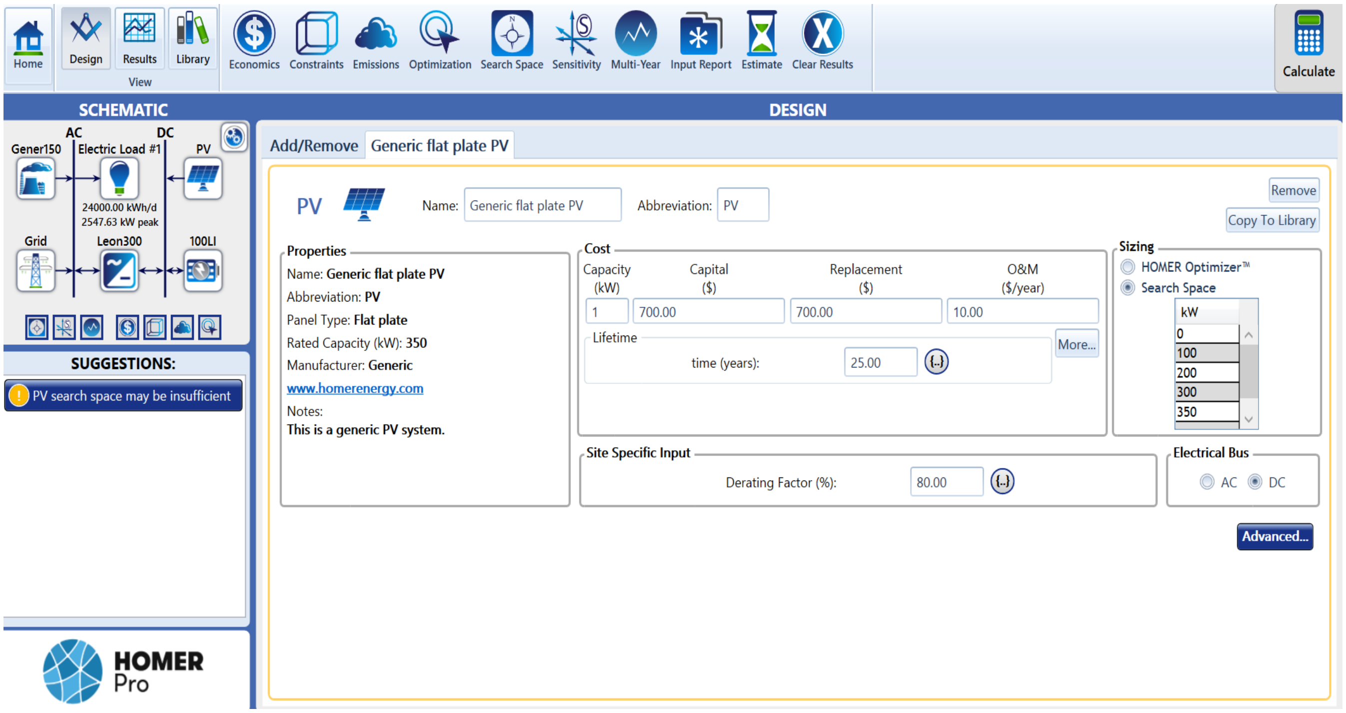
[16]K. Thirumavalavan, Mathi Ramalingam and Jayalalitha Subbaiahan, 2014. Energy Efficiency of Thermal Power Station Auxiliary Power Consumption and Cost Savings in Carbon Footprint in India. Journal of Applied Sciences, 14: 1606-11.

[18]Sundari Ramabhotla, Stephen Bayne, Michael Giesselmann, “Operation and Maintenance Cost Optimization in the Grid Connected Mode of Microgrid” IEEE Green Technologies Conference 2016

Annex 01

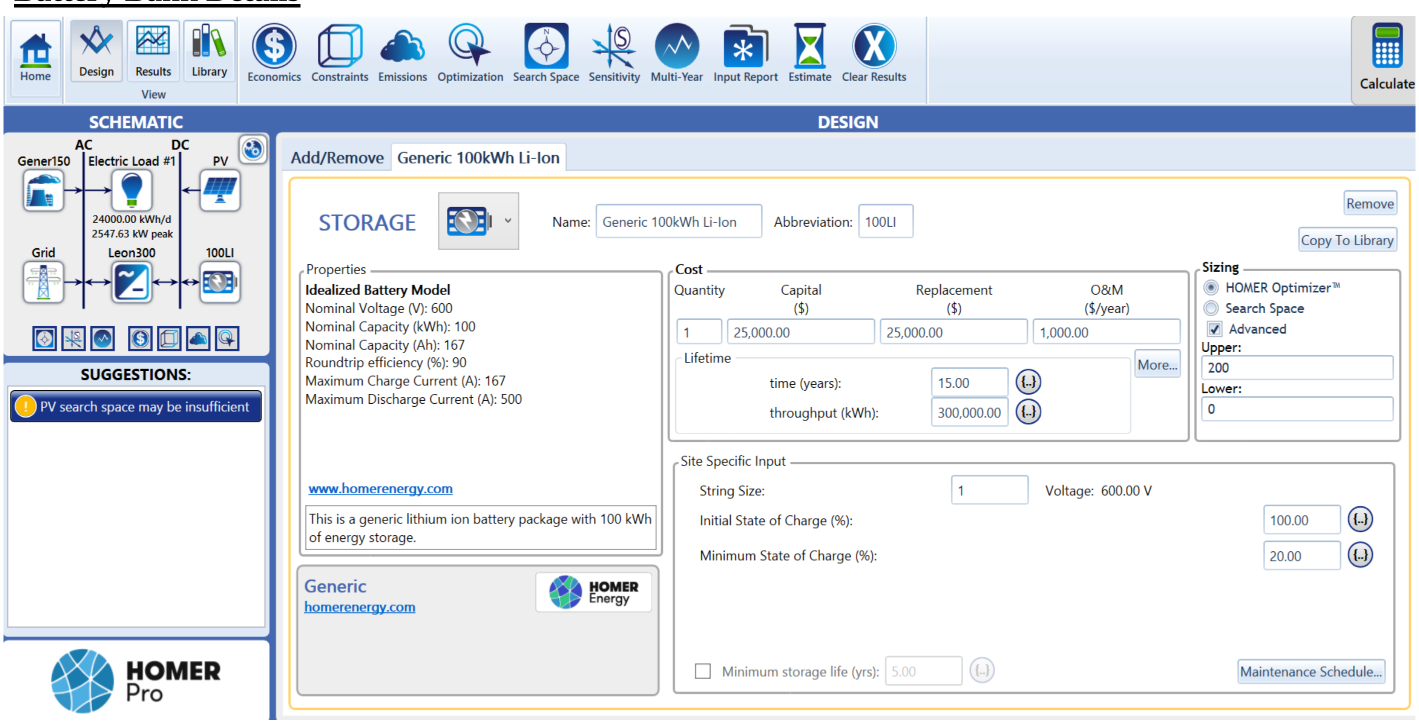
Homer Software Simulation for the Yugadanavi

Solar PV Data

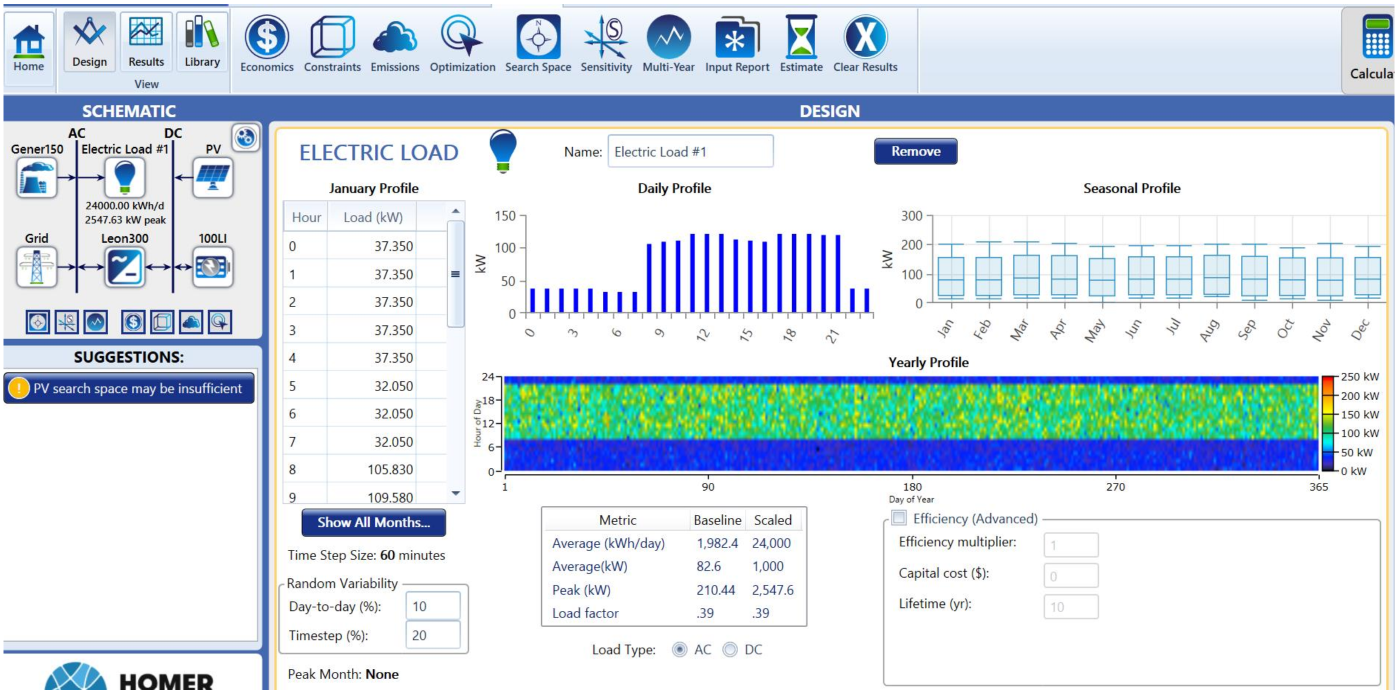


In the search space mode, the selected search space is reached to available maximum value due to the roof space limitation. Hence the maximum possible roof soar capacity is limited to 300- 350 kWp.

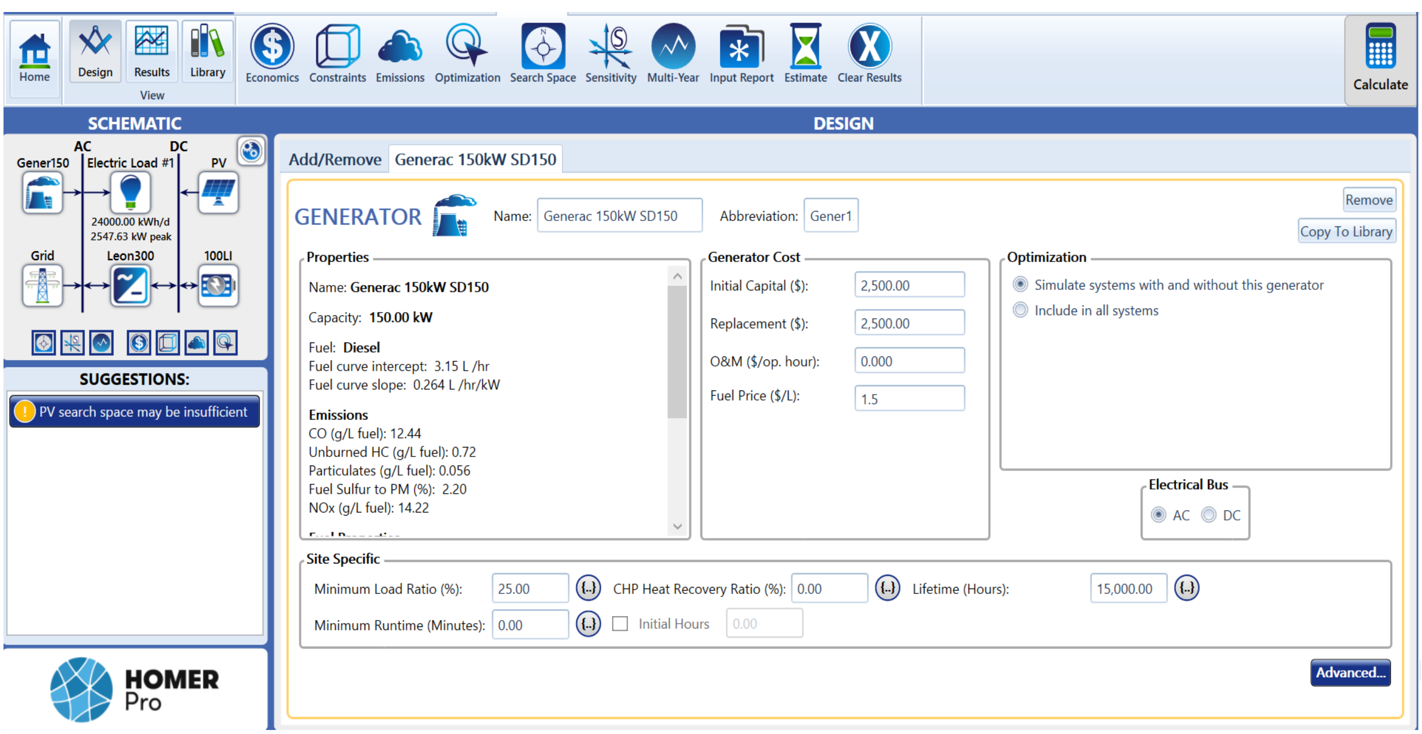
Battery Bank Details



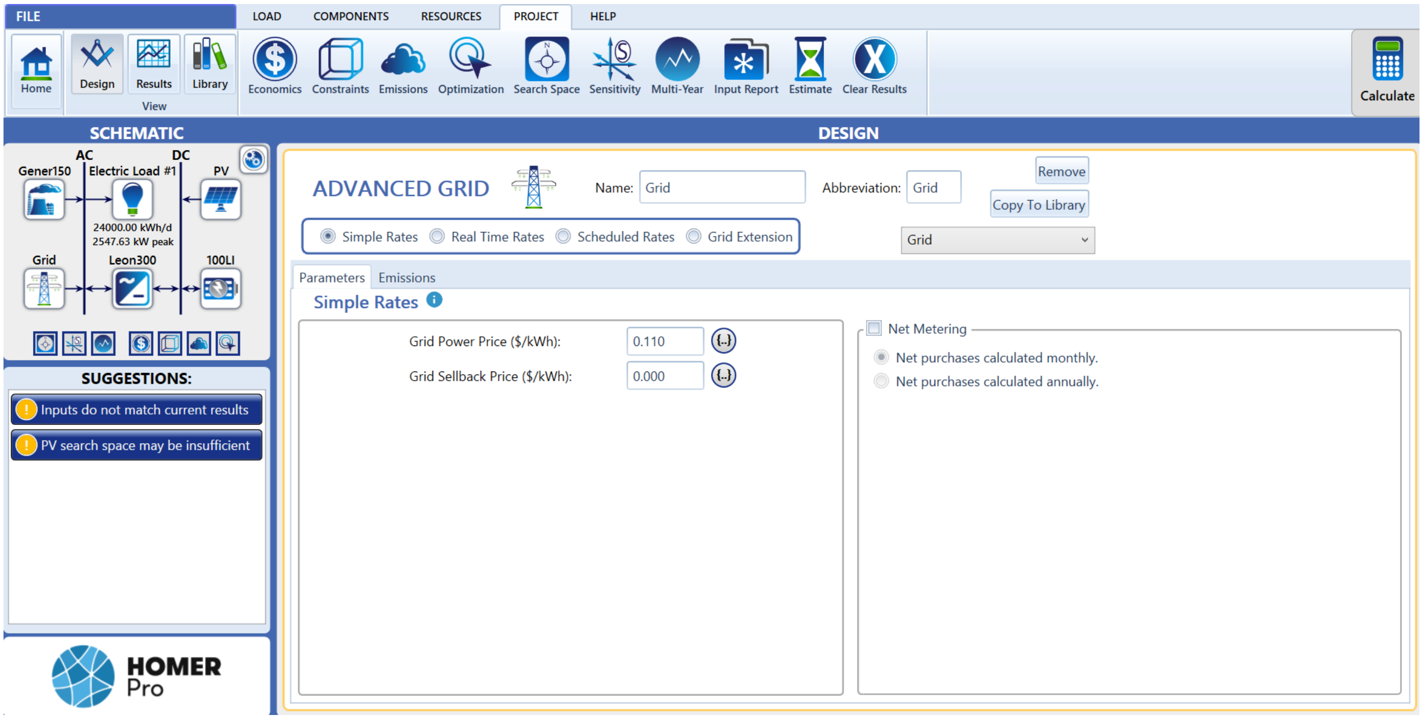
Load Profile



Diesel Generator Details

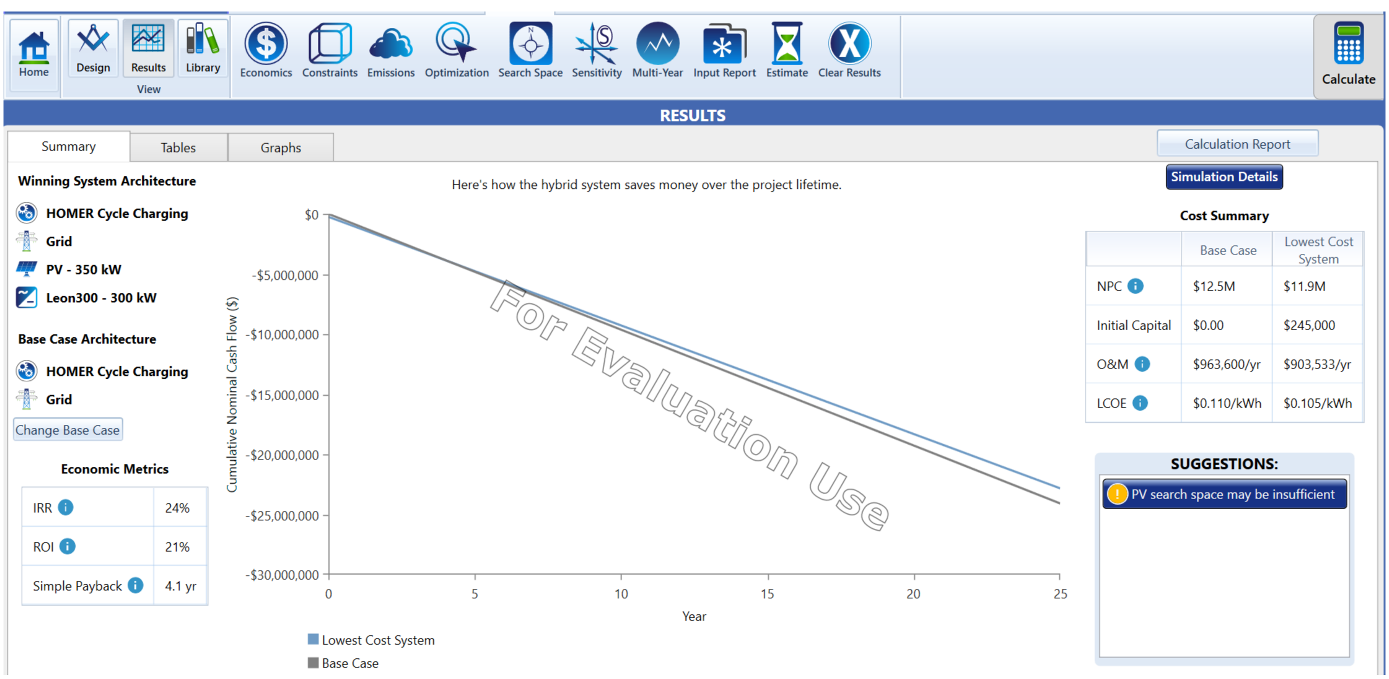


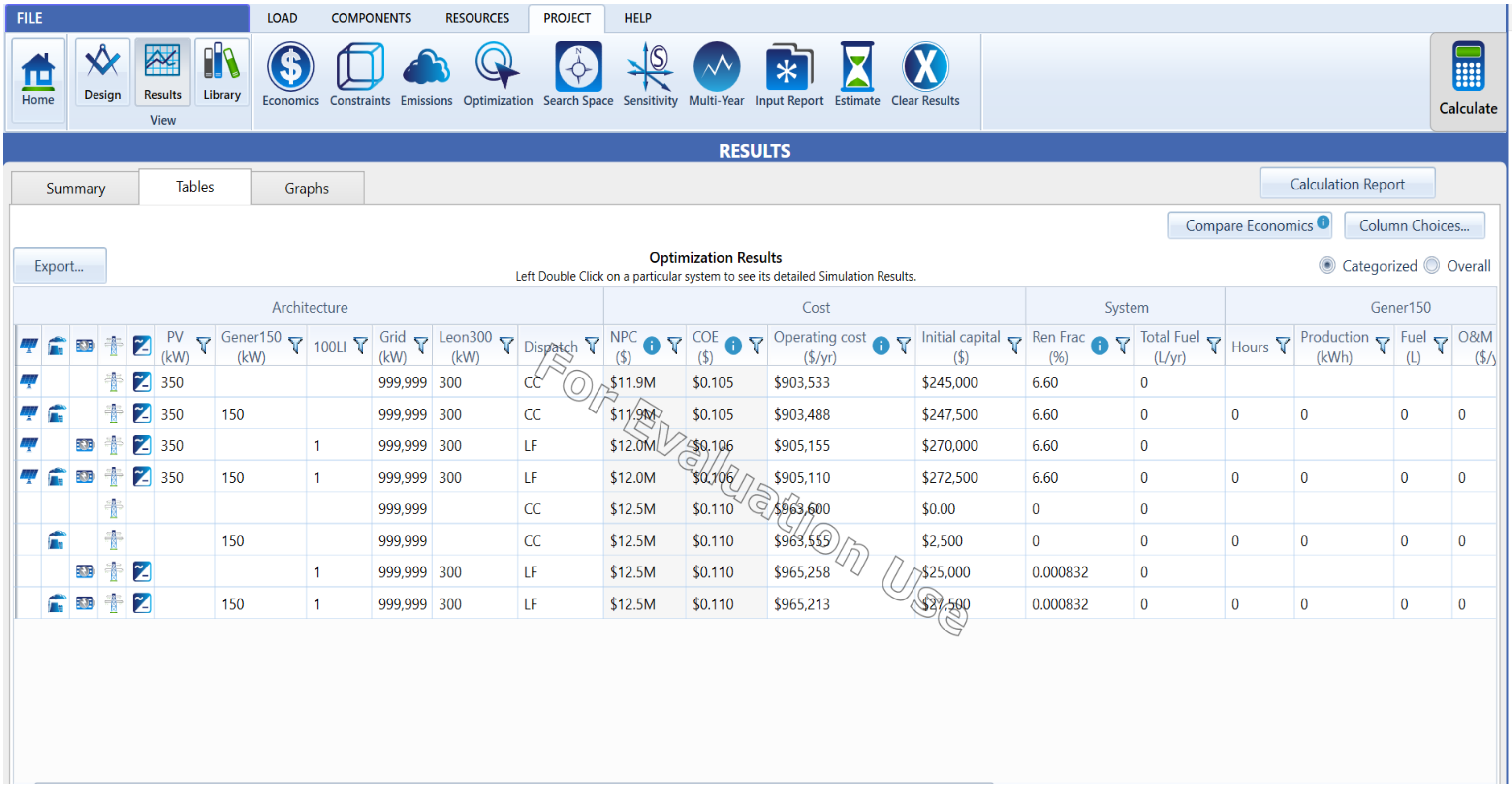
Grid Cost Details



The software only provides options for single tariff input. So, the day time cost is selected. (22 LKR= 0.11 USD)

The Simulation results





Architecture						Cost				System		Gener150			
PV (kW)	Gener150 (kW)	100LI	Grid (kW)	Leon300 (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Hours	Production (kWh)	Fuel (L)	O&M ($/y
350			999,999	300	CC	$11.9M	$0.105	$903,533	$245,000	6.60	0				
350	150		999,999	300	CC	$11.9M	$0.105	$903,488	$247,500	6.60	0	0	0	0	0
350		1	999,999	300	LF	$12.0M	$0.106	$905,155	$270,000	6.60	0				
350	150	1	999,999	300	LF	$12.0M	$0.106	$905,110	$272,500	6.60	0	0	0	0	0
			999,999		CC	$12.5M	$0.110	$963,600	$0.00	0	0				
	150		999,999		CC	$12.5M	$0.110	$963,555	$2,500	0	0	0	0	0	0
		1	999,999	300	LF	$12.5M	$0.110	$965,258	$25,000	0.000832	0				
	150	1	999,999	300	LF	$12.5M	$0.110	$965,213	$27,500	0.000832	0	0	0	0	0

Annex 02

Version 7.2.14

PVsyst - Simulation report

Grid-Connected System

Project: Arpico Wattala

Variant: New simulation variant

Sheds on ground

System power: 321 kWp

Wattala - Sri Lanka

Author

Ceylex Renewables (Pvt)Ltd (Sri lanka)

Project: Arpico Wattala

Variant: New simulation variant

Ceylex Renewables (Pvt)Ltd (Sri lanka)

Project summary

Geographical Site
Wattala
Sri Lanka

Situation

Latitude	6.99 °N
Longitude	79.89 °E
Altitude	9 m
Time zone	UTC+5.5

Project settings

Albedo	0.20

Meteo data
wattala
Meteonorm 8.0 - Synthetic

System summary

Grid-Connected System

Sheds on ground

PV Field Orientation
Fixed plane

Tilt/Azimuth	10 / 0 °

Near Shadings
According to strings

Electrical effect	100 %

User's needs
Unlimited load (grid)

System information

PV Array

Nb. of modules	600 units
Pnom total	321 kWp

Inverters

Nb. of units	4 units
Pnom total	260 kWac
Pnom ratio	1.271

85% of this selected

Results summary

Produced Energy	497.5 MWh/year	Specific production	1631 kWh/kWp/year	Perf. Ratio PR	82.42 %

Table of contents

General parameters

Grid-Connected System

Sheds on ground

PV Field Orientation

Orientation

Fixed plane

Tilt/Azimuth 10 / 0 °

Sheds configuration

Nb. of sheds 33 units

Sizes

Sheds spacing 5.00 m

Collector width 2.27 m

Ground Cov. Ratio (GCR) 45.5 %

Shading limit angle

Limit profile angle 8.2 °

Models used

Transposition Perez

Diffuse Perez, Meteonorm

Circumsolar with diffuse

Horizon

Free Horizon

Near Shadings

According to strings

Electrical effect 100 %

User's needs

Unlimited load (grid)

PV Array Characteristics

PV module

Manufacturer	Jinkosolar
Model	JKM535M-72HL4-V
(Custom parameters definition)	
Unit Nom. Power	535 Wp
Number of PV modules	600 units
Nominal (STC)	321 kWp
Modules	30 Strings x 20 In series
At operating cond. (50°C)	
Pmpp	293 kWp
U mpp	704 V
I mpp	416 A

Inverter

Manufacturer	Sungrow
Model	SG60KTL
(Custom parameters definition)	
Unit Nom. Power	20.0 kWac
Number of inverters	13 units
Total power	260 kWac
Operating voltage	570-950 V
Pnom ratio (DC:AC)	1.27

Total PV power

Nominal (STC)	321 kWp
Total	600 modules
Module area	1547 m²
Cell area	1426 m²

Total inverter power

Total power	260 kWac
Number of inverters	13 units
Pnom ratio	1.27

Array losses

Array Soiling Losses

Loss Fraction 2.0 %

Thermal Loss factor

Module temperature according to irradiance

Uc (const) 20.0 W/m²K

Uv (wind) 0.0 W/m²K/m/s

DC wiring losses

Global array res. 29 mΩ

Loss Fraction 1.5 % at STC

LID - Light Induced Degradation

Loss Fraction 1.5 %

Module Quality Loss

Loss Fraction -0.8 %

Module mismatch losses

Loss Fraction 2.0 % at MPP

Strings Mismatch loss

Loss Fraction 0.1 %

IAM loss factor

Incidence effect (IAM): User defined profile

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	1.000	1.000	1.000	0.989	0.965	0.924	0.731	0.000

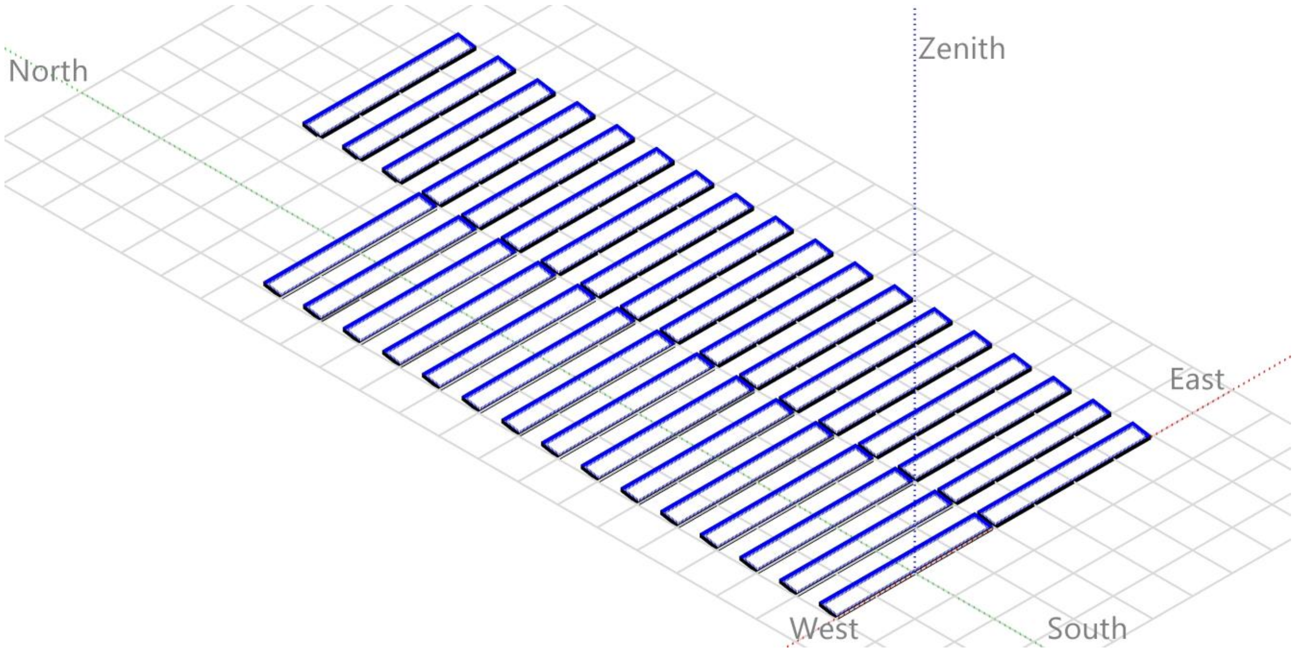
AC wiring losses

Inv. output line up to injection point

Inverter voltage	400 Vac tri
Loss Fraction	0.94 % at STC
Inverter: SG60KTL	
Wire section (4 Inv.)	Alu 4 x 3 x 70 mm²
Average wires length	45 m

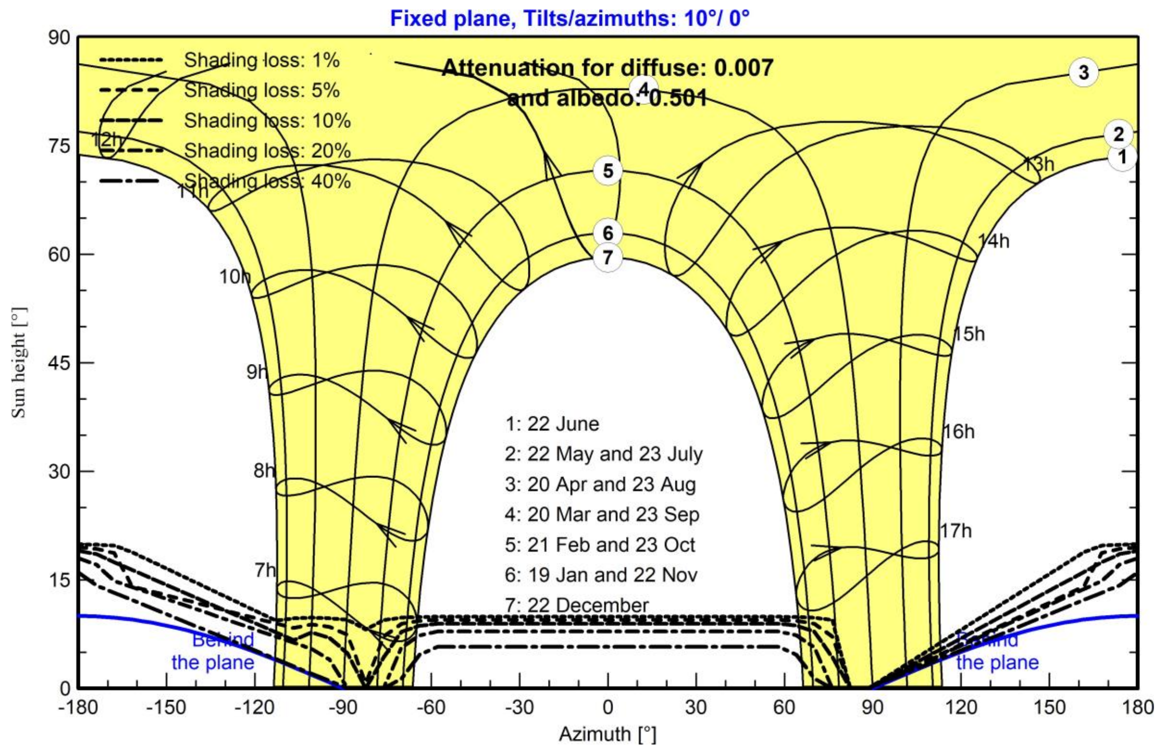
Near shadings parameter

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Orientation #1

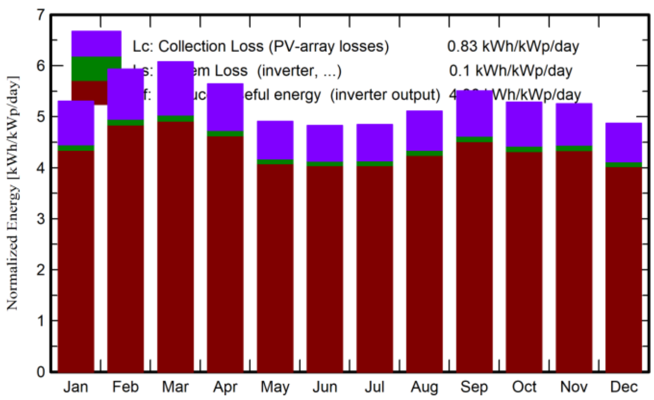


Main results

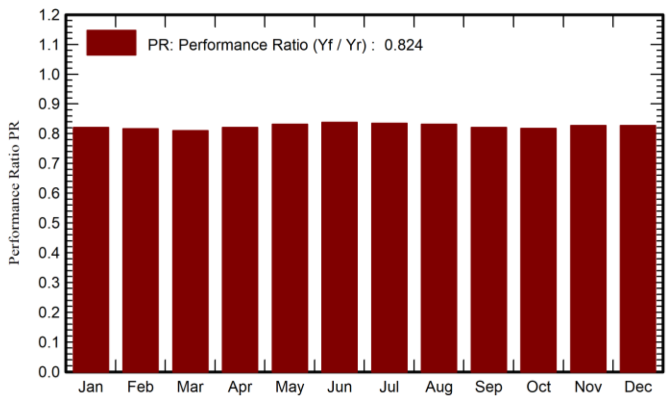
System Production

Produced Energy	485.3 MWh/year	Specific production	1591 kWh/kWp/year
		Performance Ratio PR	82.42 %

Normalized productions (per installed kWp)



Performance Ratio PR



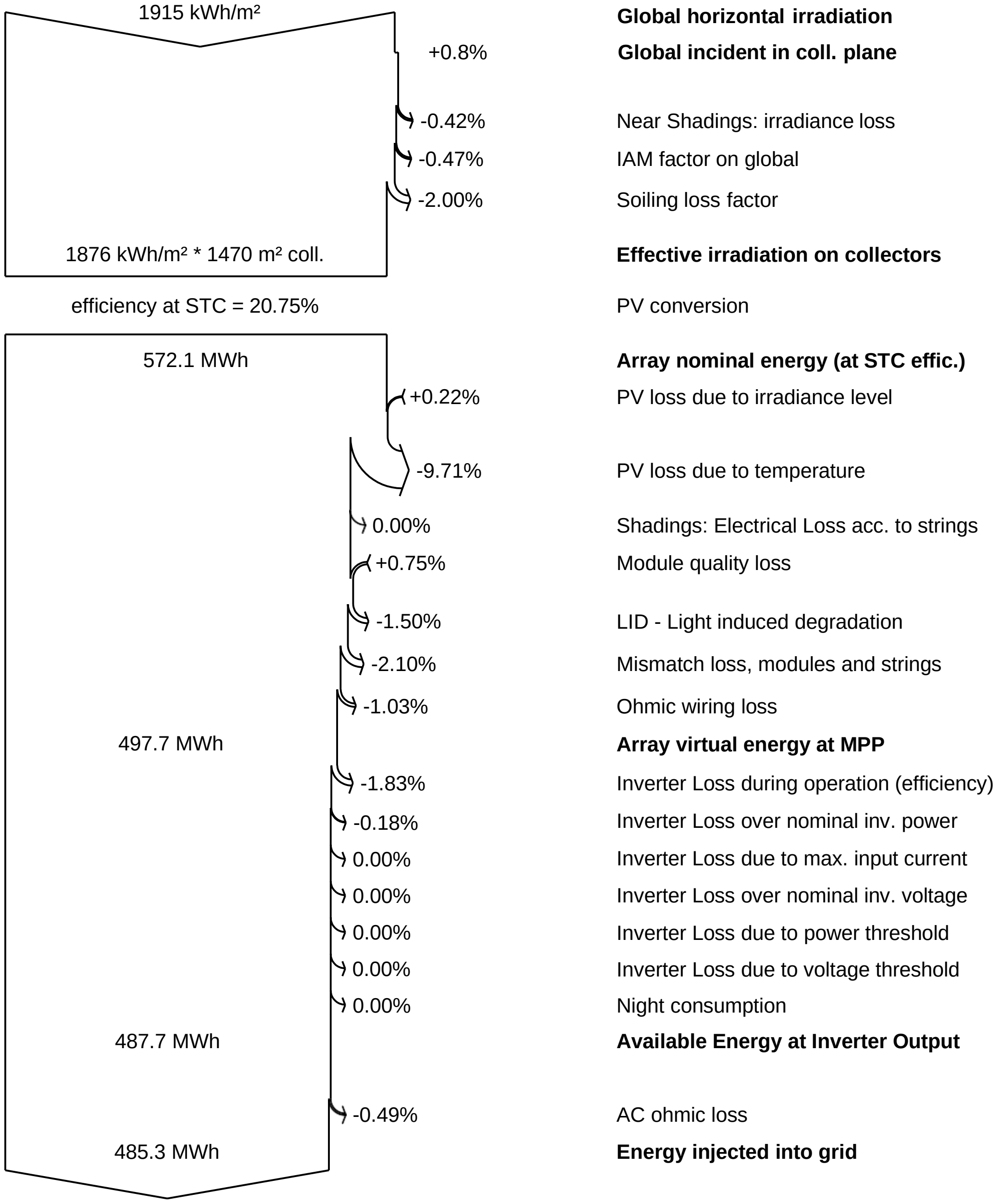
Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	152.8	67.49	26.75	164.4	159.8	42.10	41.13	0.821
February	158.1	72.79	27.41	166.0	161.4	42.32	41.35	0.817
March	185.3	78.25	28.21	188.3	183.2	47.62	46.50	0.810
April	172.7	83.68	28.03	169.3	164.4	43.37	42.36	0.821
May	159.4	92.79	28.81	152.2	147.5	39.48	38.60	0.832
June	153.3	88.53	27.96	144.7	140.3	37.86	37.01	0.839
July	158.3	88.08	28.29	150.3	145.8	39.13	38.24	0.834
August	163.1	93.38	27.99	158.3	153.6	41.10	40.15	0.832
September	164.9	76.18	27.35	165.1	160.4	42.33	41.33	0.821
October	158.7	76.72	27.35	163.8	159.3	41.86	40.86	0.818
November	148.2	74.55	26.50	157.6	153.2	40.72	39.75	0.827
December	140.5	73.21	26.75	151.0	146.7	38.98	38.06	0.827
Year	1915.4	965.65	27.62	1931.0	1875.6	496.86	485.33	0.824

Legends

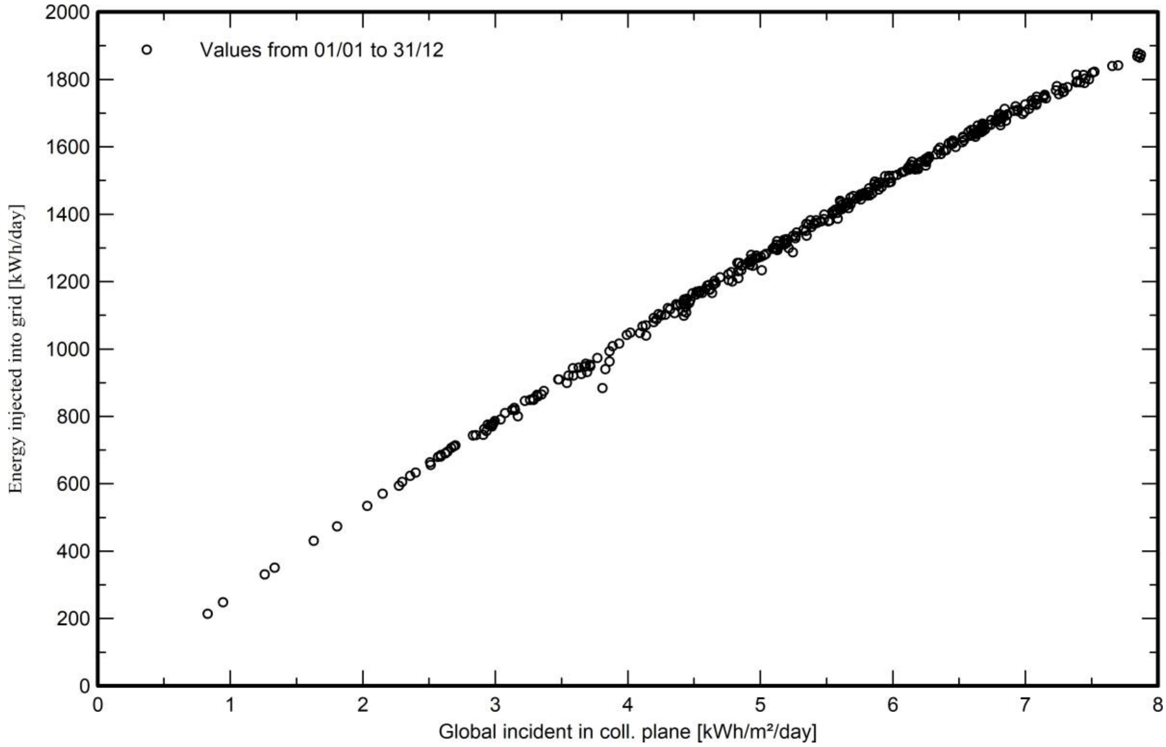
GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

Loss diagram

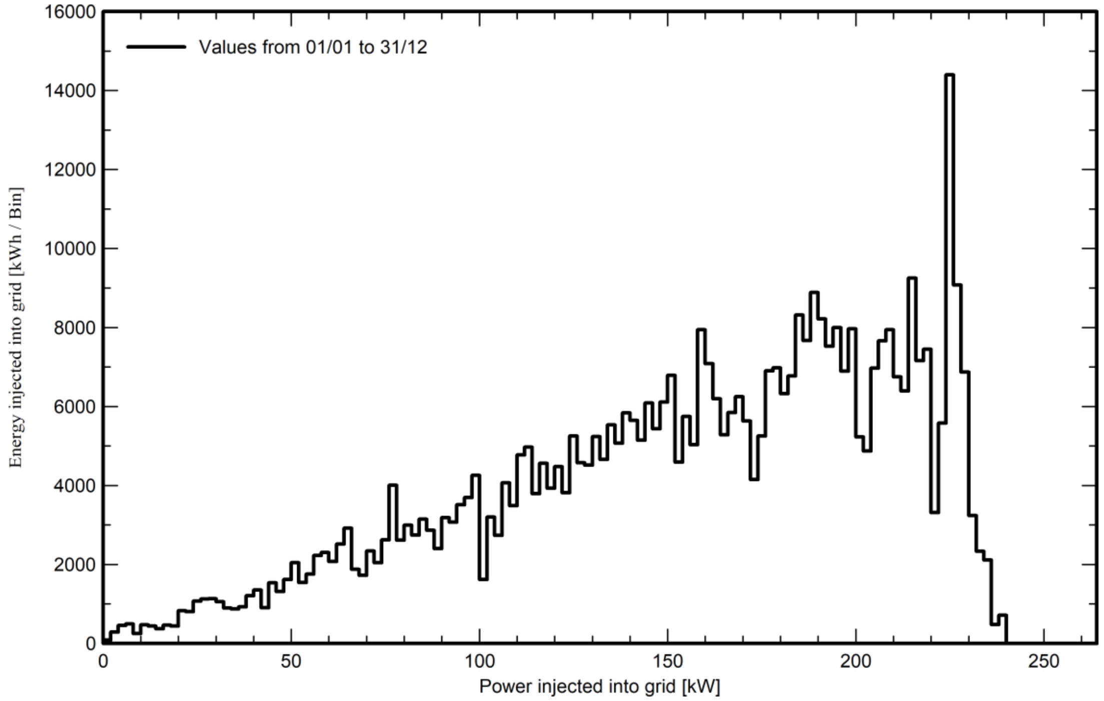


Special graphs

Daily Input/Output diagram



System Output Power Distribution



Annex 03

MATLAB CODE- GENERAL PURPOSE CUSTOMER

```
clear all

%%put power in MW ,15 min data peak
filename = 'S&LdataAPC.xlsx';
sheet=1;
sheet = 1;
xlRange = 'C4:C70';
L= xlsread(filename,sheet,xlRange);
xlRange = 'B4:B70';
P= xlsread(filename,sheet,xlRange);
g=0; %thermal generator operating power 4-20 MW
w=0;
m=0;
E=250; %rated battery energy capacity 4MWh
s=20; %SOC of battery between 50% and 100
v=20;%depth of discharge
GC=35.77;% generator cost
SC=11.72; % Solar pv cost
BDC=42.75; %battery discharge cost
PSC=15.51; %PV shedding cost
BC=12.74; % Battery charging cost
DRC=11.72; %Controlable load shifting cost
PGC=26.6; %Peak grid cost
DGC=21.8; %day peak grid cost
OGC= 15.4; %off peak grid cost
MD=100; %maximum demand limit
GM= 200; %maximum generator power
CL=10;% Controllable load capacity

for n=1:67

      if P(n)>(L(n)-g-w) && m<12 && s>=v && s<100 %cost of Chg<DR<shed
       DR =1;  %on DR
       c=1;    %on charging
       k=1;    %battery on
       a=1;    %on shedding


         %generation is greater than the load
         %battery soc within limit
         %DR switched on less than 12 times
         %on shedding

    elseif P(n)> (L(n)-g-w)&& m<12 && s==100   %cost of DR<shed
       DR =1;  %same as first case.but battery is fully charged
       c=0;    %off charging
       k=1;
       a=1;

    elseif  P(n)> (L(n)-g-w) && m==12 &&  s>=v && s<100   %chg,shed
       DR =0;  %here DR has been switched on 12 times already
       c=1;
       k=1;
```

```
        a=1;

     elseif L(n)> P(n)+g+w && s>v && s<=100   %dsg,all pv used
        c=0;%no charging
        k=1;
        a=1;%off shedding
        DR=0;%off DR

       %elseif L(n)> P(n)+g+w && s==100   %dsg,all pv used
        %c=0;%no charging
        %k=1;
        %a=1;%off shedding
        %DR=0;%off DR

        %load is greater than the generation
        %battery soc within limits

        else %shed
            k=0; %off battery
            a=1; %on shedding
           DR=0; %no DR
            c=0; %no charging

       end


      q=DR; %DR on/off
      z=k*(1-DR)*(1-c);%discharge coefficient
      y=k*c; %charge coefficient
      x=a;%pv shed coefficient
       CHG=(((1-((s/100)*(1-0.00023)))*E)/(0.25*0.9));%max charging power
      DCH= -(((0.01*v-((s/100)*(1-0.00023)))*E*0.95)/0.25);%max discharging
power
      if DCH>0.5*E
          DCH=0.5*E
      else DCH=DCH
      end
        if CHG>0.5*E
          CHG=0.5*E
      else CHG=CHG
        end
   H=2*[0.012 0 0 0 0 0 0;0 0 0 0 0 0 0;0 0 0 0 0 0 0;0 0 0 0 0 0 0;0 0 0 0 0
0 0;0 0 0 0 0 0 0;0 0 0 0 0 0 0] ; %($/15)=$/h*0.25
     if n>50
        h=PGC
   else h=DGC
     end
   % if h<SC && 0<P(n)&& P(n)<L(n);
    %    MD=L(n)-P(n);
    %else
     %   MD=MXD;
    %end

    f=[GC;SC;BDC*z;PSC*x;BC*y;DRC*q;h] ;%($/15)
    %(gen,pv,bdc,pvsh,bchg,pdr,pgrid)
```

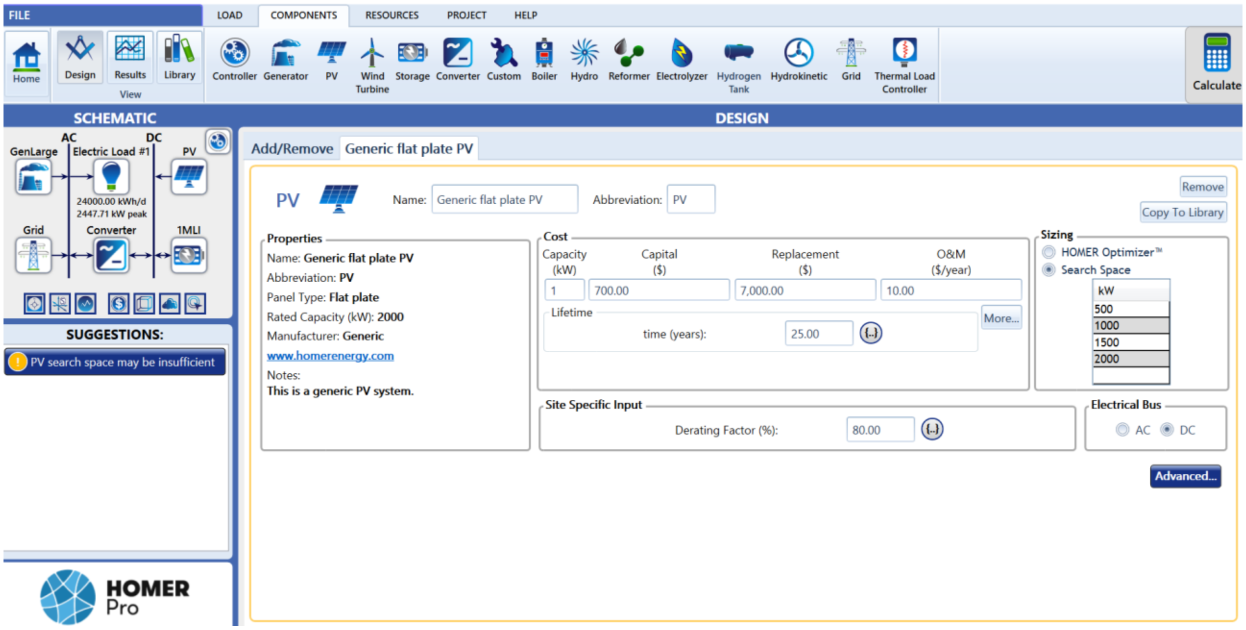
```
   Aeq=[1 1 1*z 0 0 0 1;0 1*x 0 1*x x*y*1 x*q*1 0;0 0 0 0 0 0 0;0 0 0 0 0 0
0;0 0 0 0 0 0 0;0 0 0 0 0 0 0;0 0 0 0 0 0 0]; %-1x*-1*y-1*q

   beq=[L(n);x*P(n);0;0;0;0;0];

   A=[0 1*y 0 0 1*y 0 0;0 0 0 0 0 0 0;0 1*q 0 0 1*y*q 1*q 0;0 0 0 0 0 0 0;0 0
0 0 0 0 0;0 0 0 0 0 0 0;0 0 0 0 0 0 0];

   B=[y*P(n);0;q*P(n);0;0;0;0];

   %lower and upper bound of the variables in the same order
   LB=[g;0;0;0;0;0;w];
   UB=[GM;P(n);DCH*z;x*P(n);y*CHG;q*CL;MD];%DR=5MW

   [x,j]=quadprog(H,f,A,B,Aeq,beq,LB,UB);

   answerA(n,:)=x(1);%gen
   answerB(n,:)=x(2);%pv
   answerC(n,:)=x(3);%battdsg
   answerD(n,:)=x(4);%pvshed
   answerE(n,:)=x(5);%battchg
   answerF(n,:)=x(6);%DR
   answerG(n,:)=x(7);
   answerH(n,:)=(j)*0.25; %mixcost

answerI(n,:)=((GC*(L(n)+x(5)+x(6)))+(((L(n)+x(5)+x(6))^2)*0.012))*0.25;%gen
only cost
   answerJ(n,:)=(L(n)+x(5)+x(6))*h*.25;%grid only cost
   answerK(n,:)=s;
   answerL(n,:)=DCH;
   answerM(n,:)=CHG;
  if P(n)>(L(n)-g) && y==1 && s>=v && s<100 %chg
       s=round((((s/100)*(1-0.00023))+((0.25*0.9*x(5))/E))*100,0);%SOC
updating during charging

   else if L(n)>(P(n)+g) && s>v && s<=100  %dsg
           s=round(((((s/100)*(1-0.00023))-
((0.25*(x(3)))/(E*0.95)))*100),0);%SOC updating during discharging

       else
           s=s+0;%SOC will unchange,if charging or discharging occured

       end
   end

       if round((x(6)),2)>0 %no of times DR is on 3H/0.25H=12
           m=m+1;
       else
           m=m+0;
       end


end
```

```
   summix=sum(answerH)
   sumgen=sum(answerI)
   sumgrid=sum(answerJ)
   Saving=sumgrid-summix

table2=round([L,P,answerA,answerB,answerC,answerD,answerE,answerF,answerG,ans
werH,answerI,answerJ,answerK,answerL,answerM],2);


array2table(table2,'VariableNames',{'load','PVavai','pgen','PVtoload','PBdc',
'PVshed','PBch','PDR','PGrid','mixcost','GENruncost','GridCost','SOC','DCH','
CHG'})
   %writetable(ans,'GP2.xlsx','Sheet',1);
```

Annex 04

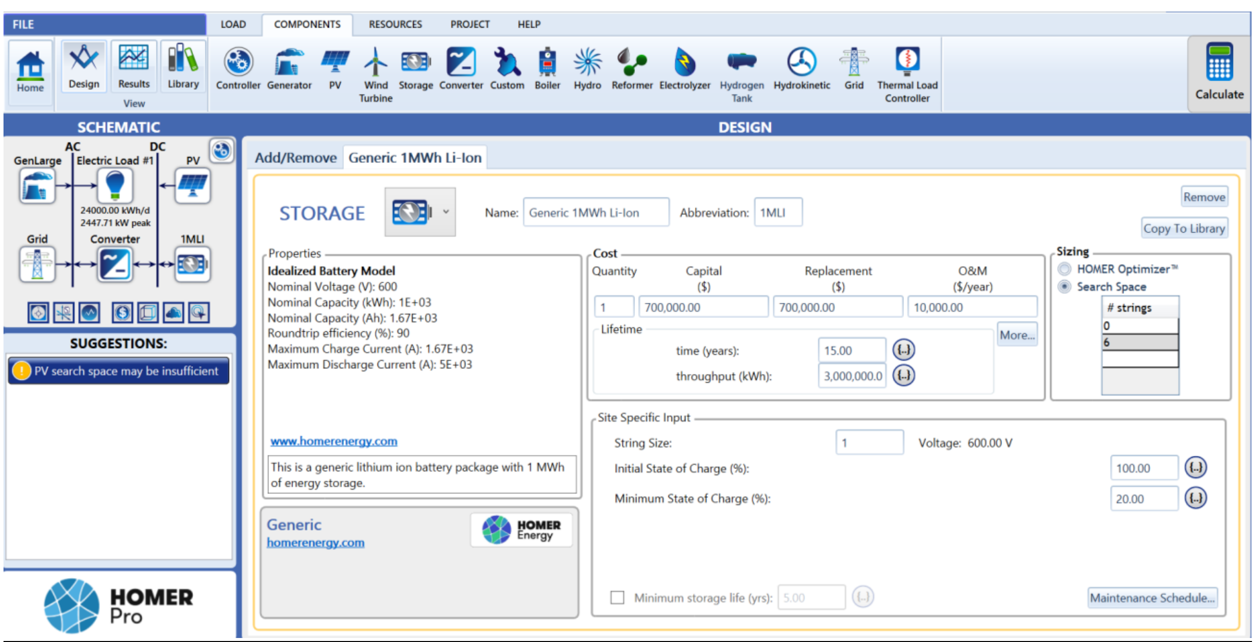
Homer Software Simulation for the Yugadanavi

Solar PV Data

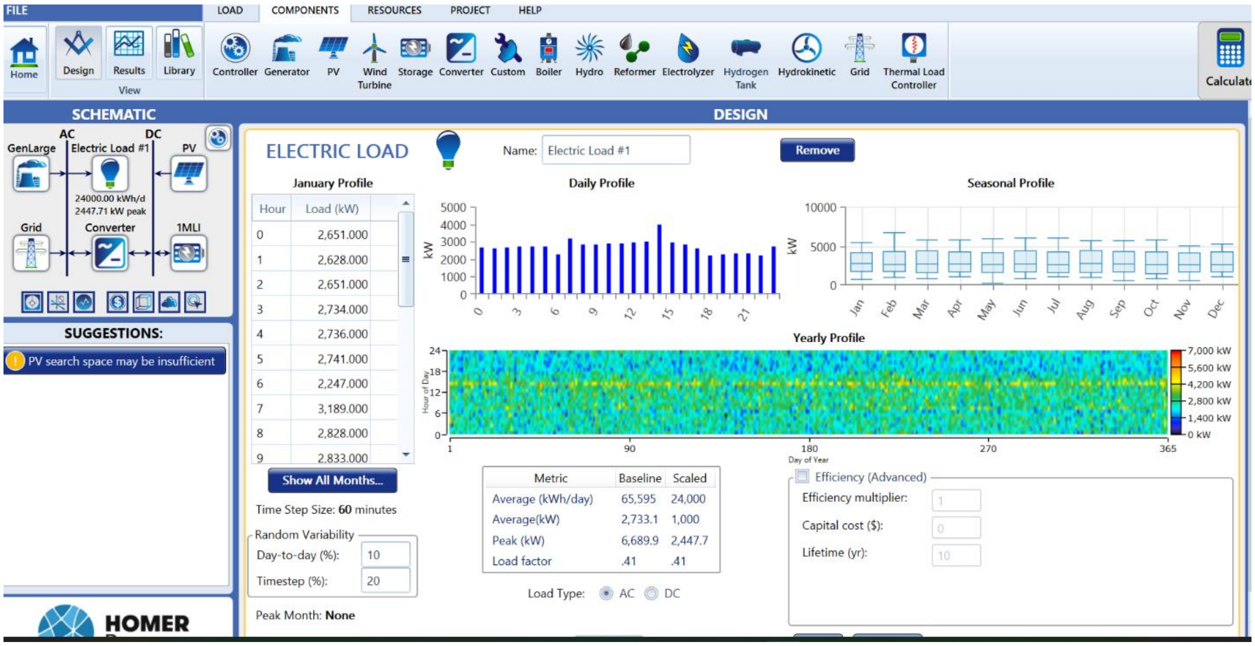


In the search space mode, the selected search space is reached to available maximum value due to the roof space limitation. Hence the maximum possible roof soar capacity is limited to 2000 kWp.

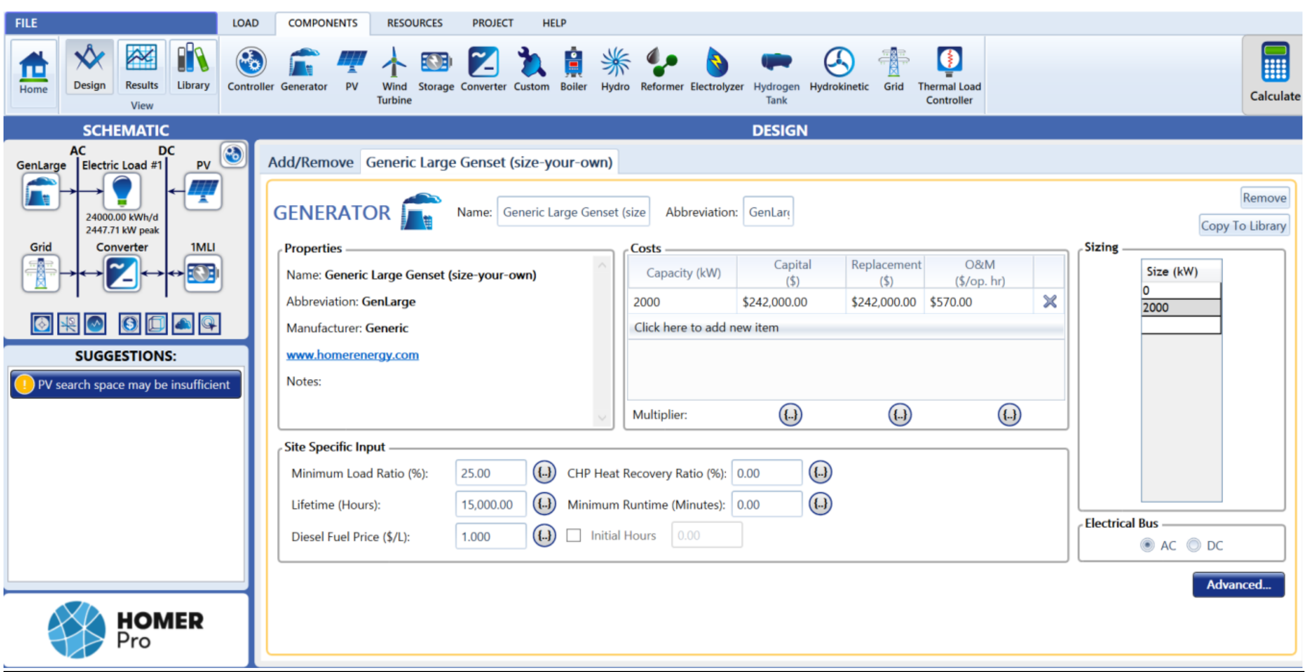
Battery Bank Details



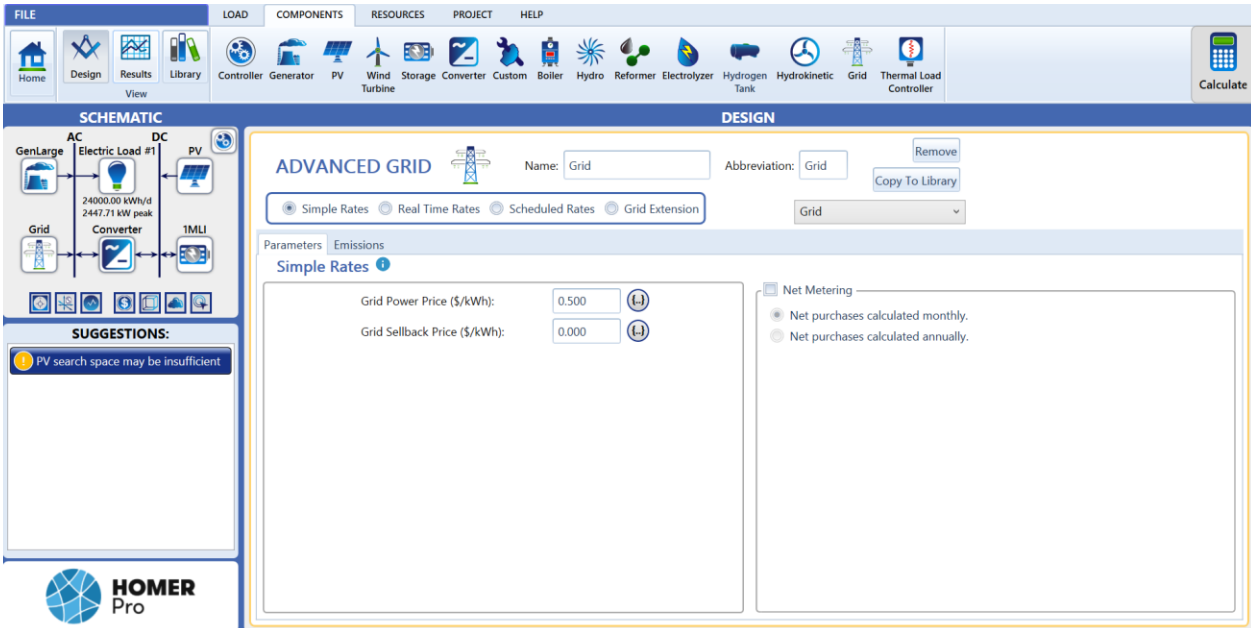
Load Profile



Diesel Generator Details

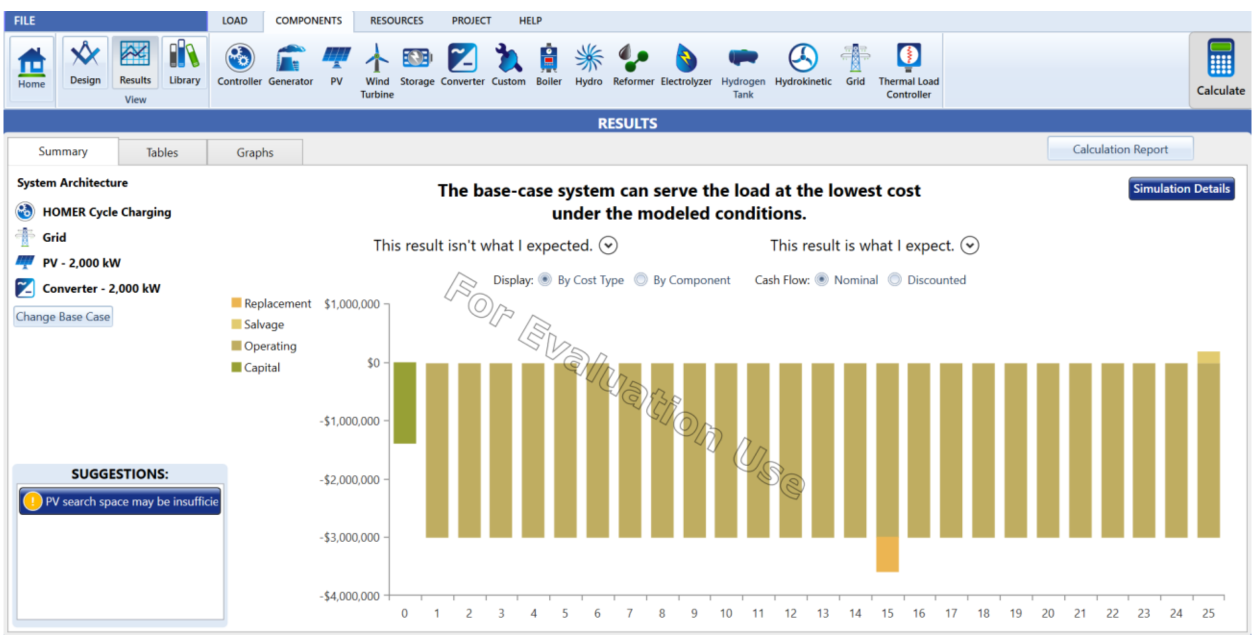


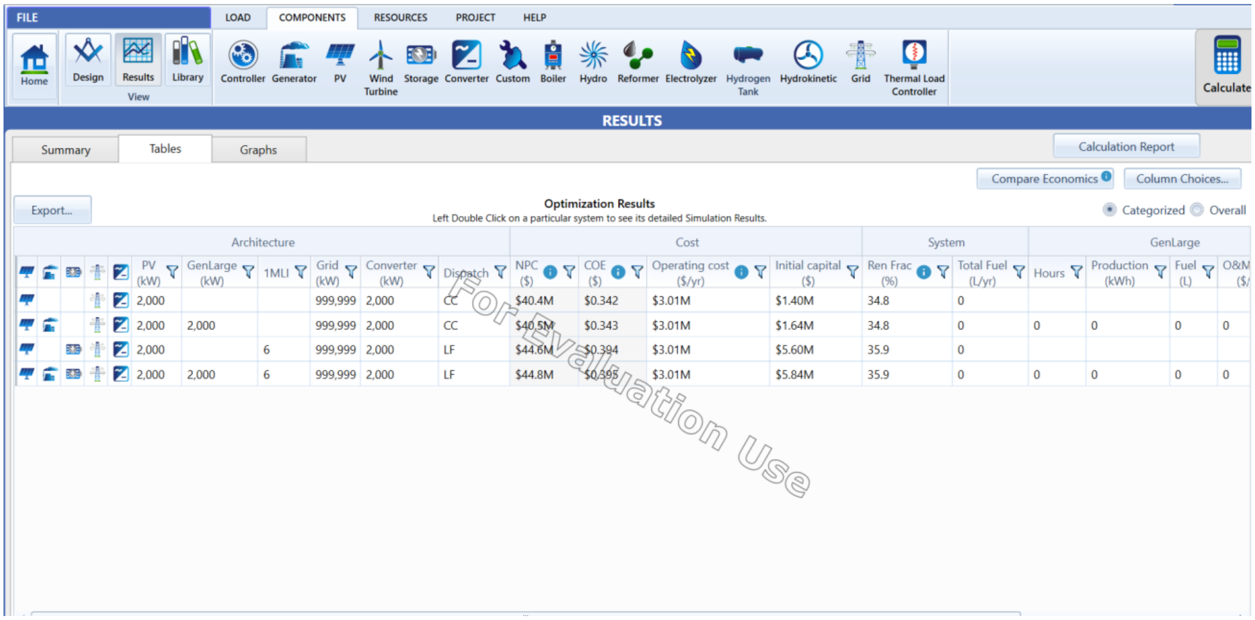
Grid Cost Details



The software only provides options for single tariff input. So, the day time cost is selected. (10 LKR= 0.05 USD)

The Simulation results





Architecture											Cost				System		GenLarge			
					PV (kW)	GenLarge (kW)	1MLI	Grid (kW)	Converter (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Hours	Production (kWh)	Fuel (L)	O&M ($/
					2,000			999,999	2,000	CC	$40.4M	$0.342	$3.01M	$1.40M	34.8	0				
					2,000	2,000		999,999	2,000	CC	$40.5M	$0.343	$3.01M	$1.64M	34.8	0	0	0	0	0
					2,000		6	999,999	2,000	LF	$44.6M	$0.394	$3.01M	$5.60M	35.9	0				
					2,000	2,000	6	999,999	2,000	LF	$44.8M	$0.395	$3.01M	$5.84M	35.9	0	0	0	0	0

Annexure 05

Version 7.2.14

PVsyst - Simulation report

Grid-Connected System

Project: MSc

Variant: New simulation variant

Sheds on ground

System power: 2196 kWp

Merawaramulla - Sri Lanka

Author

Ceylex Renewables (Pvt)Ltd (Sri lanka)

Project: MSc

Variant: New simulation variant

Ceylex Renewables (Pvt)Ltd (Sri lanka)

Project summary

Geographical Site
Merawaramulla
Sri Lanka

Situation

Latitude	7.01 °N
Longitude	79.87 °E
Altitude	8 m
Time zone	UTC+5.5

Project settings

Albedo	0.20

Meteo data
Merawaramulla
Meteonorm 8.0 - Synthetic

System summary

Grid-Connected System

Sheds on ground

PV Field Orientation
Fixed plane

Tilt/Azimuth	10 / 0 °

Near Shadings
According to strings

Electrical effect	100 %

User's needs
Unlimited load (grid)

System information

PV Array

Nb. of modules	4104 units
Pnom total	2196 kWp

Inverters

Nb. of units	10 units
Pnom total	2000 kWac
Pnom ratio	1.098

Results summary

Produced Energy	3541 MWh/year	Specific production	1613 kWh/kWp/year	Perf. Ratio PR	83.55 %

Table of contents

General parameters

Grid-Connected System

Sheds on ground

PV Field Orientation

Orientation
Fixed plane
Tilt/Azimuth 10 / 0 °

Sheds configuration
Nb. of sheds 76 units
Sizes
Sheds spacing 4.30 m
Collector width 2.29 m
Ground Cov. Ratio (GCR) 53.2 %
Shading limit angle
Limit profile angle 11.1 °

Models used
Transposition Perez
Diffuse Perez, Meteonorm
Circumsolar with diffuse

Horizon
Average Height 1.2 °

Near Shadings
According to strings
Electrical effect 100 %

User's needs
Unlimited load (grid)

PV Array Characteristics

PV module
Manufacturer Jinkosolar
Model JKM535M-72HL4-V_After Modification
(Custom parameters definition)
Unit Nom. Power 535 Wp
Number of PV modules 4104 units
Nominal (STC) 2196 kWp
Modules 152 Strings x 27 In series
At operating cond. (50°C)
Pmpp 2003 kWp
U mpp 1005 V
I mpp 1993 A

Inverter
Manufacturer Huawei Technologies
Model SUN2000-215KTL-H0
(Custom parameters definition)
Unit Nom. Power 200 kWac
Number of inverters 10 units
Total power 2000 kWac
Operating voltage 500-1500 V
Max. power (=>33°C) 215 kWac
Pnom ratio (DC:AC) 1.10

Total PV power
Nominal (STC) 2196 kWp
Total 4104 modules
Module area 10583 m²
Cell area 9757 m²

Total inverter power
Total power 2000 kWac
Number of inverters 10 units
Pnom ratio 1.10

Array losses

Array Soiling Losses
Loss Fraction 1.5 %

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 29.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

DC wiring losses
Global array res. 8.3 mΩ
Loss Fraction 1.5 % at STC

Serie Diode Loss
Voltage drop 0.7 V
Loss Fraction 0.1 % at STC

LID - Light Induced Degradation
Loss Fraction 1.5 %

Module Quality Loss
Loss Fraction -0.8 %

Module mismatch losses
Loss Fraction 2.0 % at MPP

Strings Mismatch loss
Loss Fraction 0.1 %

IAM loss factor
Incidence effect (IAM): User defined profile

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.999	0.987	0.962	0.892	0.816	0.681	0.440	0.000

AC wiring losses

Inv. output line up to injection point

Inverter voltage	800 Vac tri
Loss Fraction	0.57 % at STC
Inverter: SUN2000-215KTL-H0	
Wire section (10 Inv.)	Alu 10 x 3 x 185 mm²
Average wires length	100 m

Horizon definition

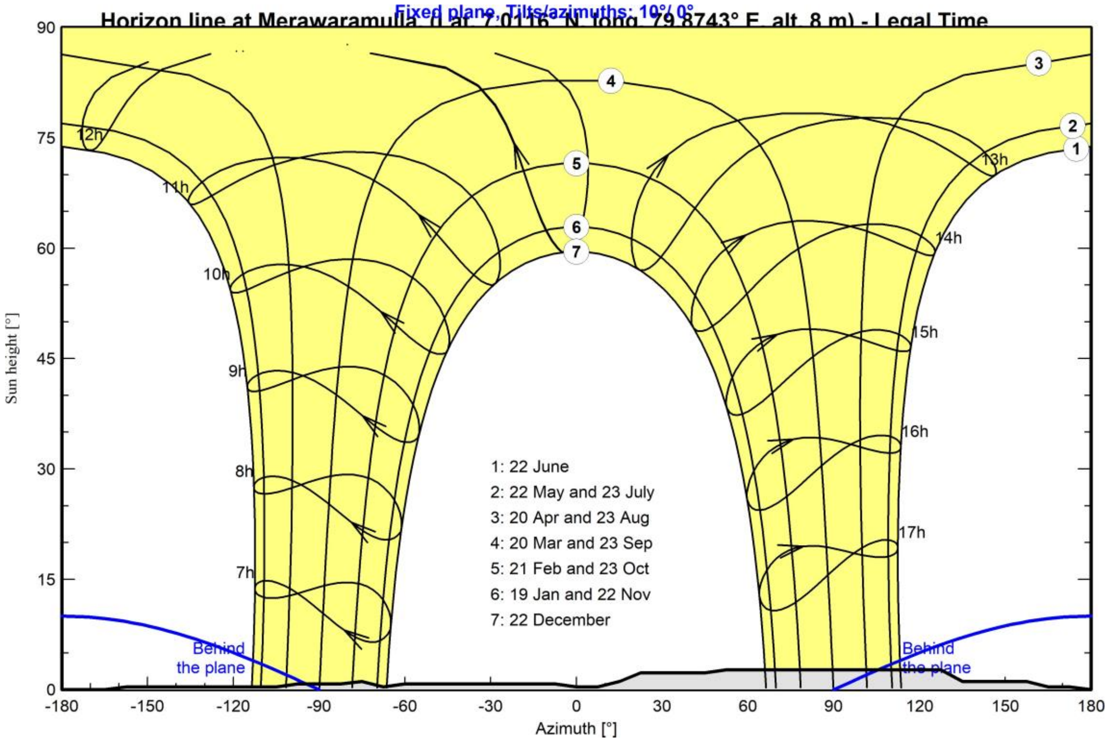
Horizon from PVGIS website API, Lat=7°0"41', Long=79°52"27', Alt=m

Average Height	1.2 °	Albedo Factor	0.94
Diffuse Factor	1.00	Albedo Fraction	100 %

Horizon profile

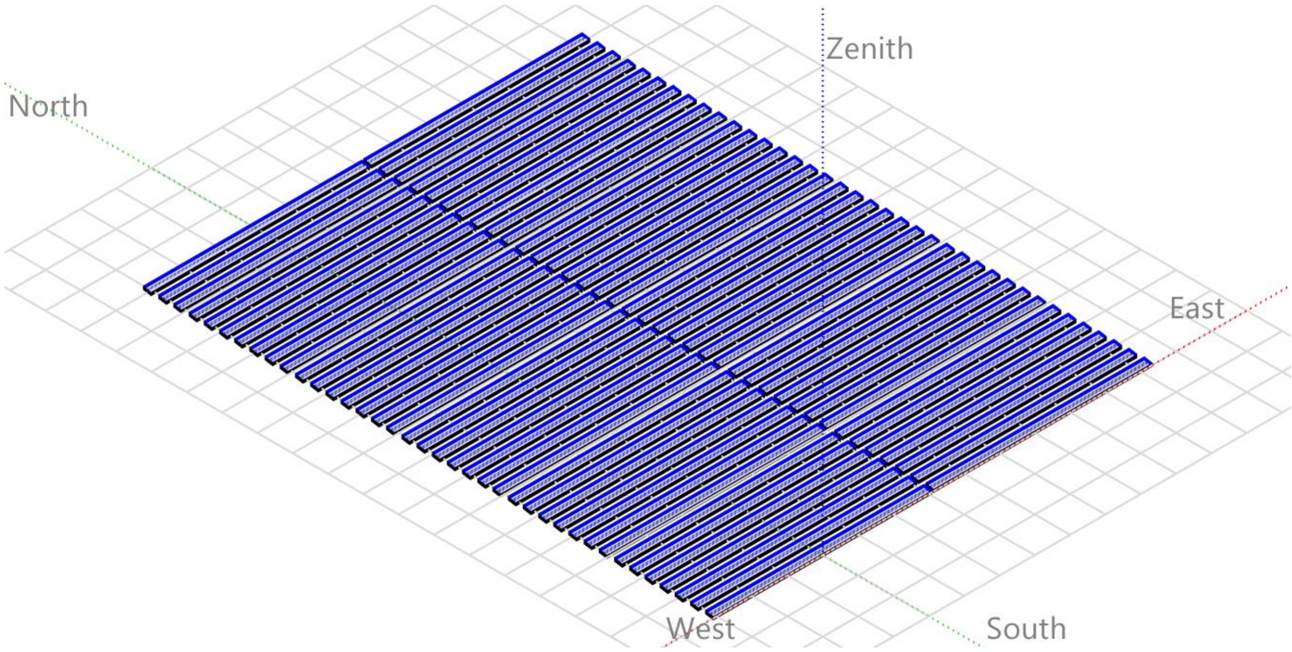
Azimuth [°]	-180	-165	-158	-105	-98	-83	-75	-68	-60	-8	0
Height [°]	0.0	0.0	0.4	0.4	0.8	0.8	1.1	0.4	0.8	0.8	0.4
Azimuth [°]	8	15	23	45	53	128	135	158	165	173	180
Height [°]	0.4	1.1	2.3	2.3	2.7	2.7	1.1	1.1	0.4	0.4	0.0

Sun Paths (Height / Azimuth diagram)



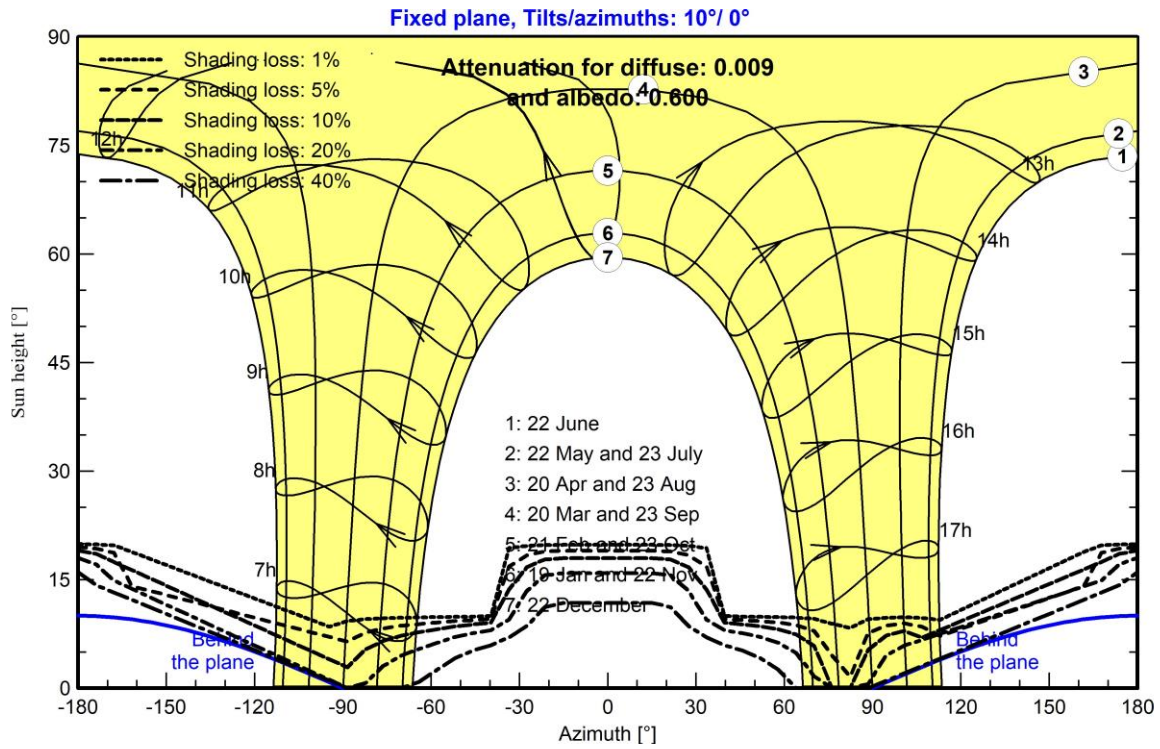
Near shadings parameter

Perspective of the PV-field and surrounding shading scene



Iso-shadings diagram

Orientation #1



Main results

System Production

Produced Energy	3541 MWh/year	Specific production	1613 kWh/kWp/year
		Performance Ratio PR	83.55 %

Normalized productions (per installed kWp)

Performance Ratio PR

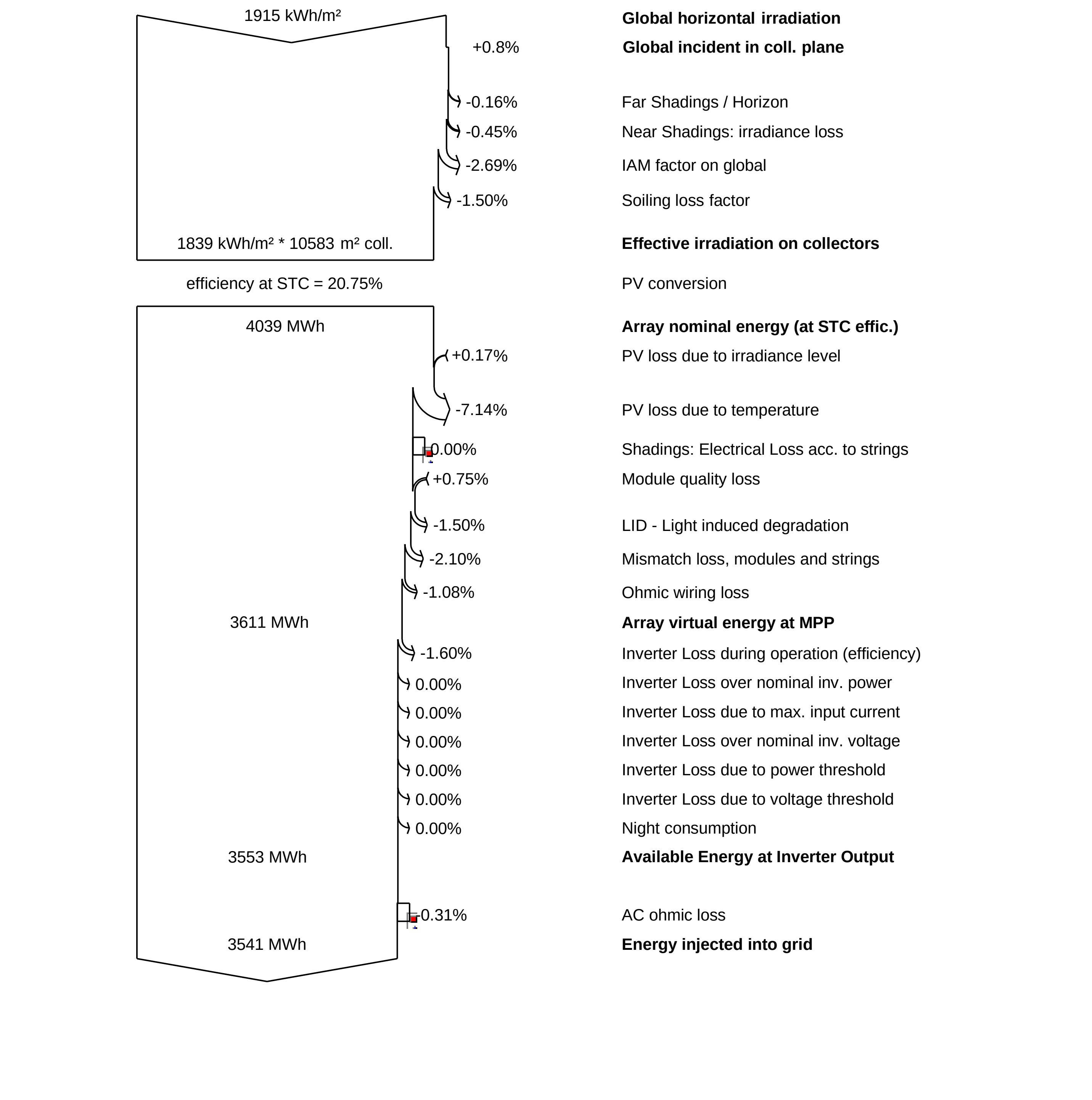
Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	152.8	67.32	26.75	164.4	156.8	307.1	301.1	0.834
February	158.1	72.37	27.41	166.1	158.6	309.3	303.3	0.832
March	185.3	77.22	28.22	188.3	179.8	349.0	342.1	0.827
April	172.8	82.78	27.93	169.2	161.2	315.5	309.4	0.833
May	159.4	81.09	28.73	151.8	144.0	283.4	278.1	0.834
June	153.5	85.77	27.96	144.9	137.2	272.2	267.2	0.840
July	158.5	81.05	28.19	150.0	142.4	281.3	276.1	0.838
August	163.0	89.60	27.89	158.3	150.4	296.8	291.2	0.838
September	164.8	73.55	27.26	165.1	157.6	308.8	302.8	0.835
October	158.5	79.50	27.34	164.0	156.5	307.1	301.1	0.836
November	148.0	70.08	26.40	157.4	150.4	295.9	290.2	0.840
December	140.3	70.55	26.65	151.3	144.2	284.3	278.9	0.840
Year	1915.1	930.89	27.56	1930.6	1839.1	3610.6	3541.5	0.835

Legends

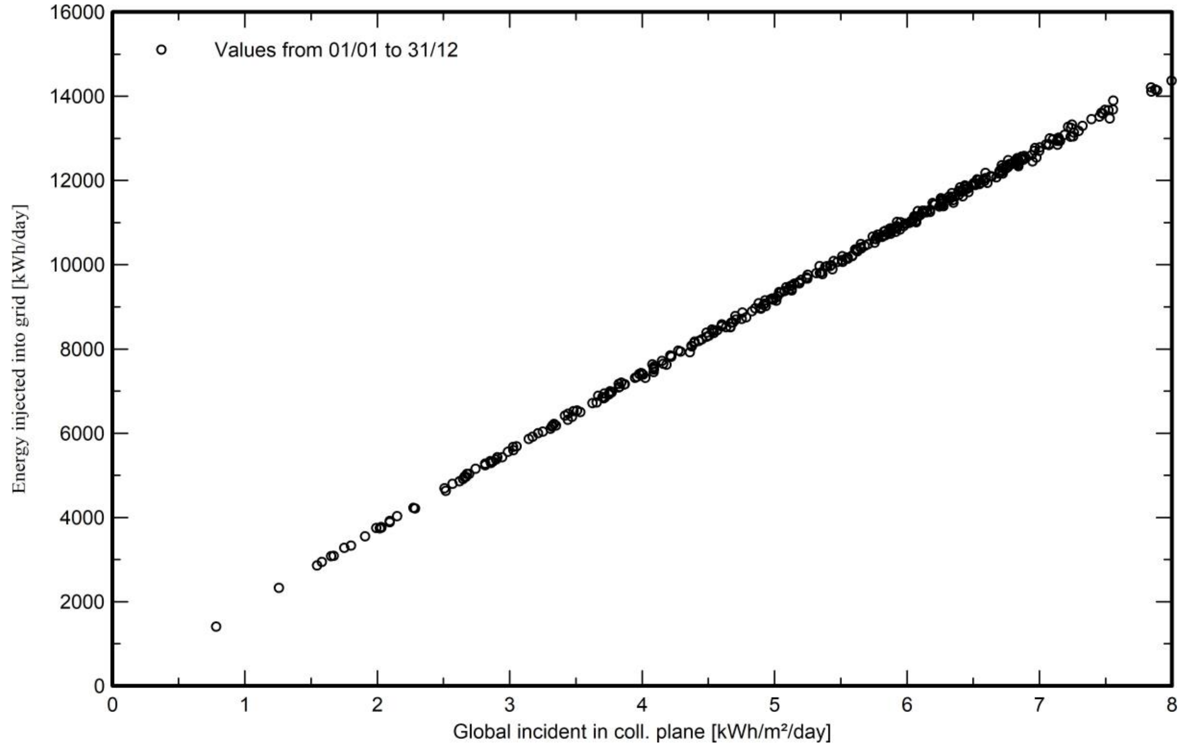
GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

Loss diagram

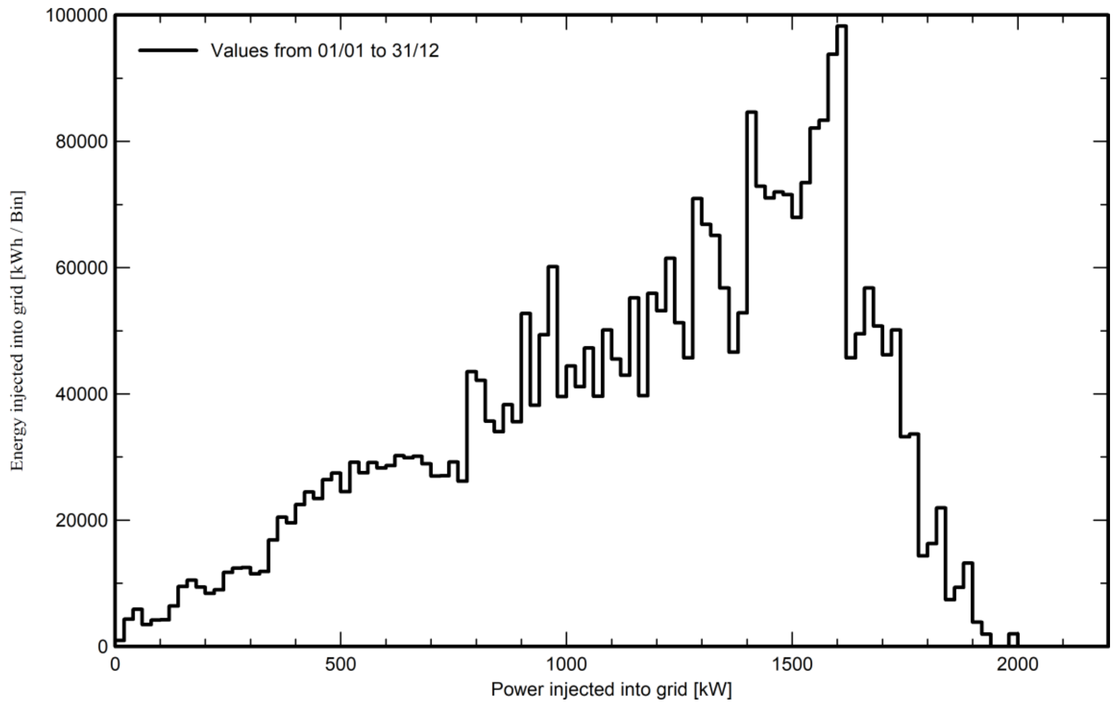


Special graphs

Daily Input/Output diagram



System Output Power Distribution



Annexure 06

```
MATLAB CODE- INDUSTRIAL PURPOSE CUSTOMER

clear all

%%put power in MW ,15 min data peak
filename = 'S&Ldata2MW.xlsx';
sheet=1;
sheet = 1;
xlRange = 'C4:C70';
L= xlsread(filename,sheet,xlRange);
xlRange = 'B4:B70';
P= xlsread(filename,sheet,xlRange);
g=0; %thermal generator operating power 4-20 MW
w=0;
m=0;
E=10000; %rated battery energy capacity 4MWh
s=100; %SOC of battery between 50% and 100
v=20;%depth of discharge
GC=35.77;% generator cost
SC=9.37; % Solar pv cost
BDC=22.87; %battery discharge cost
PSC=12.39; %PV shedding cost
BC=10.19; % Battery charging cost
DRC=9.37; %Controlable load shifting cost
PGC=23.5; %Peak grid cost
DGC=10.25; %day peak grid cost
OGC= 5.9; %off peak grid cost
MD=2500; %maximum demand limit
GM= 2000; %maximum generator power
CL=500;% Controllable load capacity

for n=1:67

      if P(n)>(L(n)-g-w) && m<12 && s>=v && s<100 %cost of Chg<DR<shed
       DR =1;  %on DR
       c=1;    %on charging
       k=1;    %battery on
       a=1;    %on shedding


         %generation is greater than the load
         %battery soc within limit
         %DR switched on less than 12 times
         %on shedding

    elseif P(n)> (L(n)-g-w)&& m<12 && s==100   %cost of DR<shed
       DR =1;  %same as first case.but battery is fully charged
       c=0;    %off charging
       k=1;
       a=1;

    elseif  P(n)> (L(n)-g-w) && m==12 &&  s>=v && s<100   %chg,shed
       DR =0;  %here DR has been switched on 12 times already
       c=1;
       k=1;
```

```
        a=1;

     elseif L(n)> P(n)+g+w && s>v && s<=100   %dsg,all pv used
        c=0;%no charging
        k=1;
        a=1;%off shedding
        DR=0;%off DR

       %elseif L(n)> P(n)+g+w && s==100   %dsg,all pv used
        %c=0;%no charging
        %k=1;
        %a=1;%off shedding
        %DR=0;%off DR

        %load is greater than the generation
        %battery soc within limits

        else %shed
            k=0; %off battery
            a=1; %on shedding
           DR=0; %no DR
            c=0; %no charging

       end


      q=DR; %DR on/off
      z=k*(1-DR)*(1-c);%discharge coefficient
      y=k*c; %charge coefficient
      x=a;%pv shed coefficient
       CHG=(((1-((s/100)*(1-0.00023)))*E)/(0.25*0.9));%max charging power
      DCH= -(((0.01*v-((s/100)*(1-0.00023)))*E*0.95)/0.25);%max discharging
power
      if DCH>0.5*E
          DCH=0.5*E
      else DCH=DCH
      end
        if CHG>0.5*E
          CHG=0.5*E
      else CHG=CHG
        end
    H=2*[0.012 0 0 0 0 0 0;0 0 0 0 0 0 0;0 0 0 0 0 0 0;0 0 0 0 0 0 0;0 0 0 0 0
0 0;0 0 0 0 0 0 0;0 0 0 0 0 0 0] ; %($/15)=$/h*0.25
     if n>50
        h=PGC
    else h=DGC
     end
   % if h<SC && 0<P(n)&& P(n)<L(n);
    %    MD=L(n)-P(n);
    %else
     %   MD=MXD;
    %end

    f=[GC;SC;BDC*z;PSC*x;BC*y;DRC*q;h] ;%($/15)
    %(gen,pv,bdc,pvsh,bchg,pdr,pgrid)
```

```
   Aeq=[1 1 1*z 0 0 0 1;0 1*x 0 1*x x*y*1 x*q*1 0;0 0 0 0 0 0 0;0 0 0 0 0 0 
0;0 0 0 0 0 0 0;0 0 0 0 0 0 0;0 0 0 0 0 0 0]; %-1x*-1*y-1*q

   beq=[L(n);x*P(n);0;0;0;0;0];

   A=[0 1*y 0 0 1*y 0 0;0 0 0 0 0 0 0;0 1*q 0 0 1*y*q 1*q 0;0 0 0 0 0 0 0;0 0 
0 0 0 0 0;0 0 0 0 0 0 0;0 0 0 0 0 0 0];

   B=[y*P(n);0;q*P(n);0;0;0;0];

   %lower and upper bound of the variables in the same order
   LB=[g;0;0;0;0;0;w];
   UB=[GM;P(n);DCH*z;x*P(n);y*CHG;q*CL;MD];%DR=5MW

   [x,j]=quadprog(H,f,A,B,Aeq,beq,LB,UB);

   answerA(n,:)=x(1);%gen
   answerB(n,:)=x(2);%pv
   answerC(n,:)=x(3);%battdsg
   answerD(n,:)=x(4);%pvshed
   answerE(n,:)=x(5);%battchg
   answerF(n,:)=x(6);%DR
   answerG(n,:)=x(7);
   answerH(n,:)=(j)*0.25; %mixcost

answerI(n,:)=((GC*(L(n)+x(6)+x(5)))+(((L(n)+x(6)+x(5))^2)*0.012))*0.25;%gen 
only cost
   answerJ(n,:)=(L(n)+x(6)+x(5))*h*.25;%grid only cost
   answerK(n,:)=s;
   answerL(n,:)=DCH;
   answerM(n,:)=CHG;
  if P(n)>(L(n)-g) && y==1 && s>=v && s<100 %chg
       s=round((((s/100)*(1-0.00023))+((0.25*0.9*x(5))/E))*100,0);%SOC 
updating during charging

   else if L(n)>(P(n)+g) && s>v && s<=100  %dsg
           s=round(((((s/100)*(1-0.00023))-
((0.25*(x(3)))/(E*0.95)))*100),0);%SOC updating during discharging

       else
           s=s+0;%SOC will unchange,if charging or discharging occured

       end
   end

       if round((x(6)),2)>0 %no of times DR is on 3H/0.25H=12
           m=m+1;
       else
           m=m+0;
       end


end
```

```
   summix=sum(answerH)
   sumgen=sum(answerI)
   sumgrid=sum(answerJ)
   Saving=sumgrid-summix

table2=round([L,P,answerA,answerB,answerC,answerD,answerE,answerF,answerG,ans
werH,answerI,answerJ,answerK,answerL,answerM],2);


array2table(table2,'VariableNames',{'load','PVavai','pgen','PVtoload','PBdc',
'PVshed','PBch','PDR','PGrid','mixcost','GENruncost','GridCost','SOC','DCH','
CHG'})
   %writetable(ans,'GP2.xlsx','Sheet',1);
```

Annex-07

Case Study 01 and 02 / Reference Financial Data

The calculations are based on several financial figures and the reference date for the calculation is on 31st of July 2018. The related details are as follows.

1. The rooftop solar Investment price (Reference 1)

   100 kW solar power project was constructed in Yugadanavi Power Plant and commissioned in 2018

Installed capacity	119 kWp DC power/ 100 kWp Ac power
Supplier	J-Lanka Technologies
Cost	14,017,996 LKR
Cost per kW	141,000 LKR (900 USD)
Date of project completion	05-07-2018

Please refer the reference 1.

2. The battery bank investment capacity (reference 2) The offer was taken from Huwei technologies

Installed capacity	18.576 MWh
Supplier	Huwawei technologies
Cost for equipment	323 USD/ kWh
Cost for Civil works	28 USD/ kWh
Total price	351 USD/ kWh
Date of the quotation	05-04-2018

Please refer the reference 2.

3. The fuel prices (reference 3)

   The fuel prices were taken from the Historical prices of the Ceypetco The fuel price for the Lanka Auto Diesel was 118 LKR on 11-07-2018.

   Please refer the reference 3

4. The LKR to USD rates were taken from CBSL Site 1 USD= 155 LKR as at 24-04-2018
   https://www.cbsl.gov.lk/en/rates-and-indicators/exchange-rates/daily-buy-and-sell-exchange- rates

Reference 1

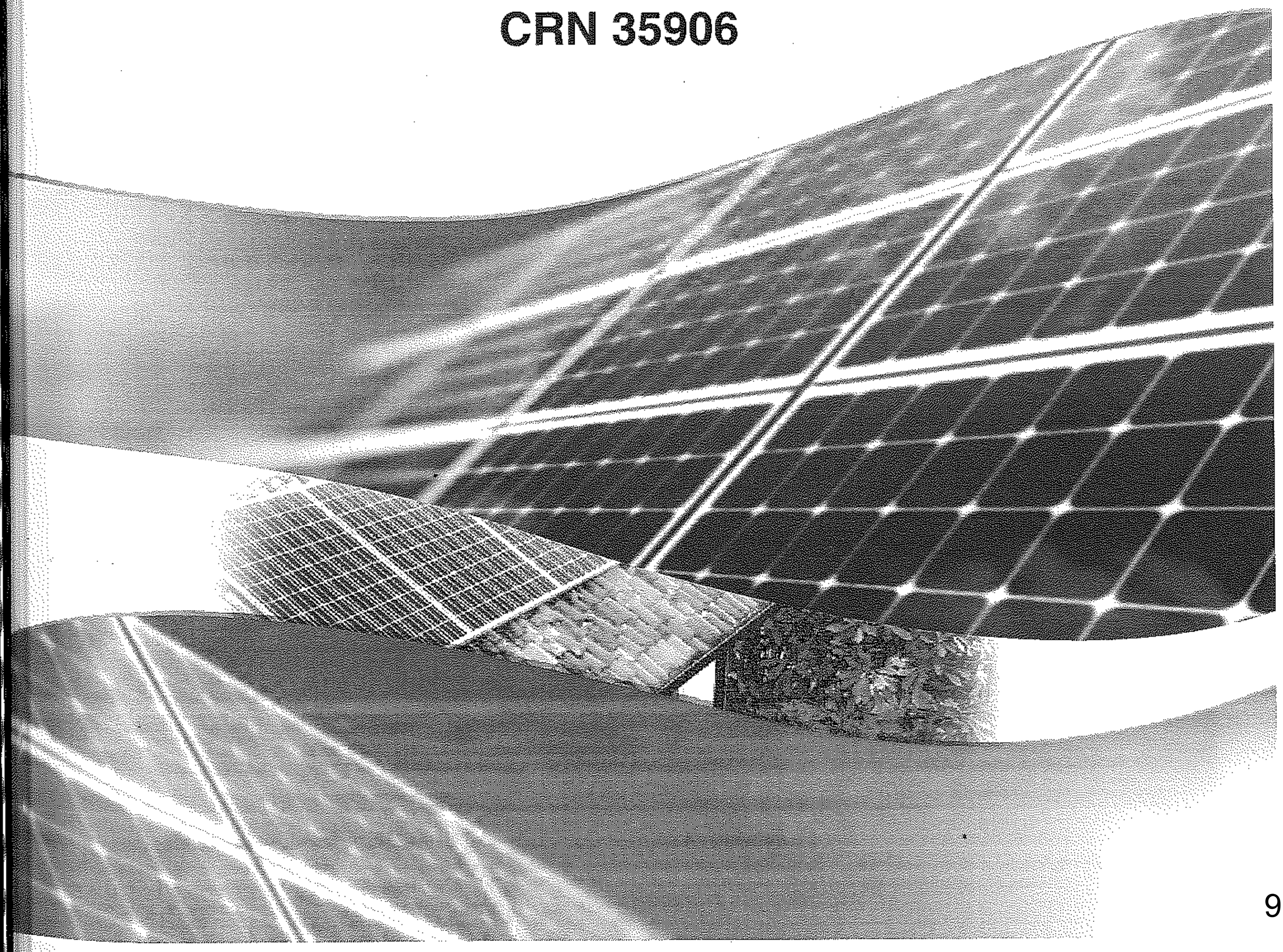
JLANKA TECHNOLOGIES

PROJECT HANDOVER DOCUMENT

Yugadanavi Power Plant – Kerawalapitiya

119 kW_p SOLAR PV SYSTEM

CRN 35906



PROJECT HANDOVER DOCUMENTATION

TABLE OF CONTENTS

www.JLankaTech.com
Phone: +94-11-2787 564
Mobile: +94-77 831 4973
Fax: +94-11-2784 393
Email: support@jlankatech.com

3rd July, 2018
Chief Executive Officer,
West Coast Power (Pvt) Ltd,
No.67, Park Street,
Colombo 2.

Dear Sir,

Completion Certificate – Supply and Installation of 119kW Grid Tied SolarPV System for Yugadanavi Power Plant

I am writing on behalf of JLanka Technologies, to express our sincerest thanks and to congratulate you for the successful commissioning for your solar PV initiative in Sri Lanka. We are very proud to be a part of this move.

As per the requirements of your establishment, JLanka Technologies (Private) Limited has offered the technical specifications for the 119 kWp solar PV system. The design and the installation were done according to the technical specification mentioned in the project proposal.

Starting from the 3rd April 2018 until the date of system completion, 29th June, 2018, the work was carried out under the direct guidance of the installation teams of JLT. The completed project was monitored and approved to be commissioned by the Technical Manager of JLT. Also, the commissioning report and the product serial numbers are attached in the technical specification document.

We are genuinely excited to have you join our esteemed group which includes corporate clients such as Dilmah, Dialog Axiata, Arpico, Aitken Spence and UNICEF CEB, National water Supply and Drainage Board. Large numbers of corporate companies are moving forward with solar electricity and we would like to thank and appreciate you for being a part of this Green movement.

Please feel free to contact us, for any further clarifications. We look forward to carry this relationship further with your future PV and energy management projects.

Thank you.
Best Regards,
J LANKA TECHNOLOGIES (PVT) LTD

Mrs. G. Jayasoma, MRICS (UK), MIQS (SL)
Operations Director/Chartered Quantity Surveyor
J Lanka Technologies (Private) Limited
Mobile: 077 831 4973
E-mail: jayasomag@jlankatech.com

1. PROJECT DETAILS

Project Name	Yugadanavi Power Plant
Date of Commencement	3rd April 2018
Date of System Initiation	29th June 2018
Date of Project Handover	5th July 2018
Project Installation Duration	12 Weeks (Discontinuous)

Parameter	Quantity/Components	Remarks
System Capacity	119 kWp	Roof-top Installation
Solar Module 365Wp (Monocrystalline)	326 nos.	TrinaSolar, Country of Origin - China
Power Optimizer 800 W	163 nos.	SolarEdge, Country of Origin – Israel
SolarEdge Inverter 27.6Kw	4 nos.	SolarEdge, Country of Origin – Israel
Frames and Structure	Anti Corrosive aluminium for Solar PV Monting, Hot dipped galvanized steel structure	
Cables (AC)	Panel Cables	Kelani Cables, Country of Origin –Sri Lanka
Cables (DC)	Solar PV Cables	Prysmian Cables, Country of Origin - Germany
Switchgear	AC and DC Protection and Isolators	Schneider Electric, Country of Origin - France
Surge Protection	AC and DC Surge Protection	Watchful Eye, Country of Origin - USA
Earthing System	Separate earthing system for Solar PV System and Structure	< 10 Ohms
Project Installation	Dis-continuous	Start – 3rd April 2018 End – 29th June 2018

PRODUCT OVERVIEW		
Customer Name	Westcoast Power (Pvt) Ltd	
Project Location	Kerawalapitiya	
CRN Number	35906	
System Provider Name	JLanka Technologies (Private) Limited	
System Size	119	kWp
Total Investment	14,017,966	LKR
Predicted Initial Energy Output	13,916 (± 5%)	kWh/month
	167,000(± 5%) (with 3.9 hrs average sunlight & availability of the grid)	kWh/annum
Roof Area Utilized	700	m^2
Panel Manufacturer	TrinaSolar	
Inverter Manufacturer	SolarEdge	
Mounting System Manufacturer	UI Solar	
Relevant Compliance Standards	• Sri Lanka Standard 703: Part 03: 1998 code of Practice for Electrical installation Part 03: Industrial Building (1st Revision) • Sri Lanka Standards 1261:2004 – Sri Lanka Standard for Lighting Protection Systems • BS 7671: 2008 incorporating amendment No. 01: 2011 or later, requirements for Electrical Installation IET wiring regulation 17th edition	

HUAWEI Commercial Proposal

Sri Lanka ESS Project for Ceylex Renewables Pvt Ltd

Huawei Technologies Co., Ltd.

Quotation

Version: V1 Date: 10th

January 2018 Valid

until: 09th April 2018

From HUAEI

Contact: HassanGaffar

Mobile:+658646517

To

Ceylex Renewables Pvt Ltd (CUSTOMER)

Contact: Mr. Geekiyanage

Dear Sir

Huawei is a leading global provider of information and communications technology (ICT) infrastructure and smart devices. With integrated solutions across four key domains – telecom networks, IT, smart devices, and cloud services – we are committed to bringing digital to every person, home and organization for a fully connected, intelligent world. Huawei's end-to-end portfolio of products, solutions and services are both competitive and secure. Through open collaboration with ecosystem partners, we create lasting value for our customers, working to empower people, enrich home life, and inspire innovation in organizations of all shapes and sizes. At Huawei, innovation focuses on customer needs. We invest heavily in basic research, concentrating on technological breakthroughs that drive the world forward. Our 2017 sales revenue was US$136.7 billion, YoY growth of 11.2%.

We are excited and looking forward to bringing the solar project to its next step. If during the examination of the present proposal non clear points should emerge or something is not aligned with your prospects please do not hesitate to contact us at your earliest convenience.

We thank you for your trust in Huawei. We hope this proposal shall meet all your expectations and remain at your entire disposal should you require any further clarification.

We are looking forward to receiving your feedback!

Yours

Faithfully Hassan

Gaffar, HUAWEI

Huawei Commercial Proposal

Project Name:	Sri Lanka_ESS_5MW_15 MWh_Utility		
Version:	1.0	**Huawei Contact Person**	
Prepared By:	Hassan Gaffar	**Contact:**	Hassan Gaffar
Approved By:		**Email:**	hassan.gaffar@huawei.com
		Tel:	+65-8646 5317

AC Coupled ESS Solution, 2.5 MW/5 MWh, 1 Cycle Per day

Product	**Model**	**Descriptions**	**Unit(PCS)**	**Total Price($)**
Battery Container	LUNA2000-2.0MWH-2H0 Medium Temp.	2.064MWh Battery container, includes 6 battery racks, BMS,HVAC, internal power distribution. More detailed configuration, please refer to “Huawei Smart String ESS Solution Datasheet”	9	6,000,000
Smart PCS	LUNA2000-200KTL-H0	210 KW @ 35 Degrees, IP66 for outdoor installation, Smart Air Cooling, Support WLAN + App, Surge protection for both DC and AC, More detailed configuration, please refer to “Huawei Smart String ESS Solution Datasheet”	30	
DC LV Panel	DCBOX-9/5-H0	1500V Outdoor DC combiner panel, for connection of battery racks and PCS. Maximum 14 connections each. More detailed configuration, please refer to “Huawei Smart String ESS Solution Datasheet”	6	
Smart Transformer Station	STS6000K-H1	6500 kVA@40°C, 50Hz, 33/0.8/0.8 kV, mineral oil,ONAN,Dy11-y11, SF6 MV switchgear DVC or DCV, Type I+II SPD, 2500m max. operating altitude.	1	

Smart Communication Units	SACU2000D	Smartlogger3000B built-in, (1 MBUS) one Unit managing one array, available for maximum 150 inverters, active and reactive power control, IP65 for outdoor installation, more detailed please refer to "Huawei SmartACU2000D Datasheet"	1	

Note

1. Price quoted in US Dollars

Price quotation is in USD, PO will be in EUR. Conversion from USD to EUR will be based on the exchange rate published by the European Central bank on the previous day of PO issuance. If previous day rate is not available then the latest available rate will be used as reference.

2. Price is Excluding any On-Site Services
3. Future Augmentation Price is not included.

Warranty and Services:

Product Code	Descriptions	
Huawei Equipment	Battery Container LUNA2000-2.0MWH-2H0 Medium Temp.	5 Years Standard;
	LUNA2000-200KWH-2H0	5 Years Standard;
	SmartACU2000D	2 Years Standard;
	DC LV Panel - DCBOX-9/5-H0	2 Years Standard;
	Smart Transformer Station, STS6000K-H1	2 Years Standard;

Trade terms:

1. FOB China/Hong Kong

Payment Terms:

This quotation is based on the following payment terms and subject to a credit check and approval.

- 100% of the contract value upon acceptance of the PO and

Issuance of Invoice Notes to payment terms:

1. Payments are 30 calendar days after receipt of Partner company invoice, unless agreed in writing Partner Company.
2. Production will only commence upon receipt of the advance payment or as agreed in writing by Partner Company. Any delay in payments outside of agreed payment terms will result in the suspension of all works.
3. Client shall have the right to suspend or terminate the contract without cause, in which case it shall pay to Partner Company: the amounts due and payable for ordered products and services including the products and services delivered.
4. Regarding other payment conditions, that will be subject to further discussions between Partner Company and Customer.

Validity Period:

This quotation is valid for 30 days from date of issue.

Huawei or Partner company reserve the right to vary the price quoted within this validity period in the case of significant input cost movements/variations and exchange rate.

Transfer of Product Title and Risk:

Title of the Product shall be transferred to Customer upon full payment to Partner Company. Risk of the Product shall be transferred to Customer in accordance with Trade Term (Incoterms 2010 by ICC).

Confidentiality:

All information received with this proposal (quotation) shall be kept in confidence and be used for customer internal review / project contract / PO implementation purposes only.

Intellectual Property Rights:

Neither party is granting its Intellectual Property Rights to the other party under this proposal (quotation). The Customer is granted a non-exclusive and non-transferable license to use the software supplied under this proposal (quotation) for operational purpose only.

Exemption Clause:

Huawei reserves the right to adjust the components and parameters of the products without notifying the customer.

Remark:

Huawei reverses the right of this documents and the information contained in it. Any reproduction without expressed authorization of Huawei is illegal.

HISTORICAL PRICES

Search

	LP 95	LP 92	LAD	LSD	LK	LIK	FUR. 800	FUR 1500 (High)	FUR. 1500 (Low)
11.09.2018	161.00	149.00	123.00	133.00	70.00	110.00	92.00	96.00	96.00
04.09.2018	157.00	145.00	118.00	130.00	70.00	110.00	92.00	96.00	96.00
11.08.2018	157.00	145.00	118.00	130.00	70.00	110.00	82.20	80.00	90.00
11.07.2018	155.00	145.00	118.00	129.00	70.00	110.00	82.20	80.00	90.00
13.06.2018	148.00	137.00	109.00	119.00	70.00	110.00	82.20	80.00	90.00
11.05.2018	148.00	137.00.00	109.00	119.00	101.00	110.00	82.20	80.00	90.00
28.11.2015	128.00	117.00	95.00	110.00	49.00	88.00	82.20	80.00	90.00
29.01.2015	128.00	117.00	95.00	110.00	59.00	88.00	82.20	80.00	90.00
22.01.2015	128.00	117.00	95.00	110.00	65.00	94.00	82.20	80.00	90.00
01.01.2015	158.00	150.00	111.00	133.00	81.00	110.00	82.20	80.00	90.00

« 1 2 3 4 5 6 7 8 9 10 11 12 13 »

REVISION OF BITUMEN PRICE

Search

	Circular No.	Price	Price
		80/100	60/70
		80/100 (Drum/Per Litre/kg)	60/70 (Drum/Per Litre/kg)
2021.01.05	79.00 (Bulk)	79.00 (Bulk)	
2019.10.08	1009	75.50 (Bulk)	75.50 (Bulk)
2018.10.16	1009	77.50 (Bulk)	80.00 (Bulk)
2018.09.22	1007	73.50 (Bulk)	76.00 (Bulk)

2018.09.18	1005	82.00 (Drum/Per Litre/kg)	82.00 (Drum/Per Litre/kg)
2018.09.03		72.00 (Drum/Per Litre/kg)	72.00 (Drum/Per Litre/kg)
2018.09.01	1001	67.50 (Bulk)	70.00 (Bulk)
2017.04.26	977	55.00 (Drum/Per Litre/kg)	56.00 (Drum/Per Litre/kg)

« 1 2 3 4 5 »

Ceylon Petroleum Corporation
ENERGIZING THE FUTURE

Information

Annual Reports
Ceypetco Products Specification
Regional Offices
Projects
Registration of Suppliers
Right to Information

Navigation

Home
About Us
Contact Us
Feedback
Public Tenders
Careers

Quick Link

Refinery
Marketing & Sales
Ceypetco Aviation
Ceypetco Agro Chemicals
CPC Web Mail
Download Mobile App

Media

News
Gallery

No.609, Dr. Danister de Silva Mawatha, Colombo 09.
secratariat[at]ceypetco.gov.lk
+94 11 5455455

Disclaimer Privacy Statement Legal Notice