FEASIBILITY STUDY ON SOLAR PV INTEGRATION IN TO THE GRID CONNECTED CELLULER MOBILE TELEPHONY BASE STATION SITES.

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Degree of Master of Science In Electical Installations.

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2010/2011

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Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree Master of Science in Electrical Installations.

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March 2015

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Abstract

Price of electricity is increasing worldwide with depleting of non renewable sources in global context even true in local. In here it is proposed to integrate Solar PV in scalable on to the telecom Radio Base Stations (RBSes) on to the cabin rooftops, as a shelter to the Outdoor RBS models, and to the tower structures in a context of local telecom operators, to reduce the utility power consumption. The techno economical feasibility of Solar PV integration methodologies in to On-Grid telecom RBSes, basically in to the DC bus by rectifier systems comprising of inbuilt DC to DC converting Solar PV charger controllers or in to the A/C bus through grid tie inverter system facilitate with "Net metering" are discussed and proved its success under sites having domestic tariff rates, one of applicable tariff in to service industry apart from the rates under General Purpose 1 tariff structure. Also benchmark the tariff rates which makes 3 years of payback in each design are discussed with other possible options to inherit future green energy trends.

Acknowledgement

I need to convey my sincere gratitude to for Dr W.D. Asanka S Rodrigo, Senior Lecturer from Electrical Engineering Department in University of Moratuwa, Sri Lanka for directing motivating and providing the knowledge base throughout the time not confined only to this course. Also I would like to convey my sincere gratitude to all the lectures from Electrical Engineering Department in University of Moratuwa about making us as best electrical engineers to the world with best up to date knowledge. Also I would like to convey my sincere gratitude to Thusitha Dissanayake former MSc in Electrical Installations from University of Moratuwa, proving me the resource and knowledge about designing Solar PV systems and to approach industrial reference. Further I would like to convey my sincere gratitude to Mr Srijith De Silva, Owner of Power Management Technologies from Sri Lanka about providing the materials , sharing his experience to implement the trial system in Dialog Axiata PLC, and the Management of Dialog, keeping me as an interface to the industrial communications. Finally I would like to convey my sincere gratitude to my parents and family members helping me in numerous ways to help achieving my targets all the time.

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Chapter 1

1.0 Introduction

1.1 Background

1.1.1 Feasibility Study on Solar PV Integration in to the Cellular Mobile Telephony Base Station sites.

Solar PV & other dominant renewable sources like Wind power are already harnessed & combined with diesel generators with their restricted operation to power up the off grid sites in telecom Radio Base Stations (RBS), practice with most of the telecom operators in worldwide & it is well proven, those projects are economically viable & payback soon rather than extension of grid for most of the time.

Even locally developed hardware , Program Logic Controllers for integration of Solar PV Charger Controllers, Wind turbines, Rectifier systems, i.e. hybrid controllers are developed. Also Voltage Time (V-T) Controllers for Charge Discharge (CDC) models for Generator Deep Cyclic Battery cyclic operations are in common for off grid applications are developed and used in DAP as well as other telecom operators.

Basic schematic diagram of a wind- solar- diesel hybrid energy system, which are already established in remote telecommunication based stations, is shown in the Figure 1.1.1.1.

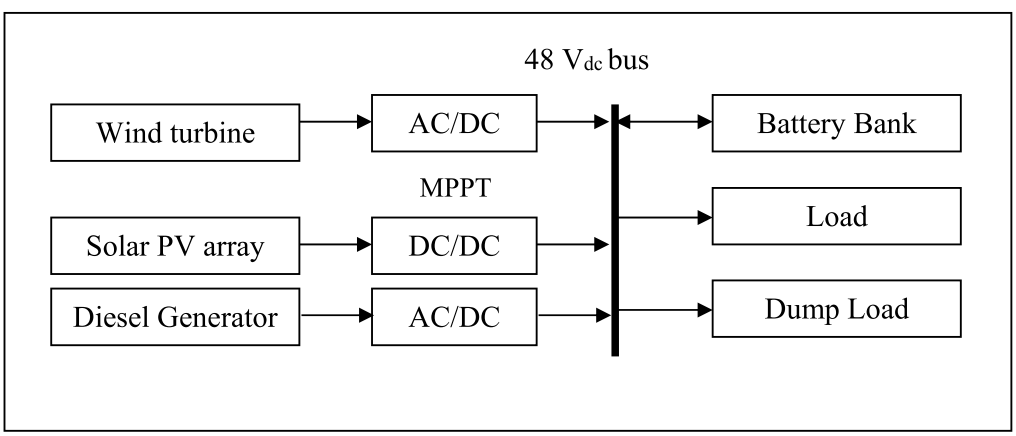


Figure 1.1.1.1.- Schematic diagram of a wind-solar-diesel hybrid energy system

Telecom RBS sites are constructed mostly as green field, self support or guy mast towers, Roof Top sites with towers & mono pole structures, indoor base stations etc. In urban areas, most of the telecom base stations are located as Roof Tops with lesser in space, outdoor models with easy grid access.

Furthermore, outdoor RBS installations reflect a necessity of shelter for attending the operation related activities on rainy or extreme weather conditions for external onsite access.

Efficiencies of the base band processing, transmitting equipments and network elements are being improved during their transformations with lesser in power consumption continuously. In Sri Lankan Context, These telecom base stations are comes under the General Purpose (GP1) tariff structure, also have few sites under domestic (D1) tariff structure and owner imposed tariff rates specially for sites establish for indoor building coverage.

1.2. Motivation

The global trend of moving towards sustainability and green energy generation was a main influence for the telecommunication companies to focus on renewable energy generation for base stations. Some of the Off-Grid renewable energy generation systems proved to be economically viable and were able to provide a green light to focus more on Hybrid energy system for future deployments. However, for On-Grid sites, less effort have been identified and taken for renewable energy integration in to the grid power available RBSes and reasons for this lack of implementation feels worthy taken in to consideration.

1.3. Objective

Objectives of this study are clearly identified and pointed out below.

- Whether it is technically and economically feasible to integrate Solar PV in to the On-Grid Telecommunication Radio Bases Stations.
- Benchmark feasible telecom RBSes with their Power-loading patterns, Space availability and different tariff structures.

Chapter 2

2.0 Problem Statement

2.1 Problem identification.

Price of electricity is hiking worldwide with depleting of non renewable sources true even for the Sri Lankan context. As an initiative to reduce the utility power consumption, Solar PV can be integrated in scalable on to the RBSes. Apart from green fileds, it is also possible to integrate Solar PV on to the cabin rooftops, as a shelter to the Outdoor RBS models, or else on to the tower structures while taking wind loading in to the account.

Presently most of the BTS sites come as an Outdoor Units (ODUs), where base band processing units are inside those outdoors and Remote Radio Units (RRUs) are pole mounted outside and this would be the configuration for most of the deployments.

The effort also taken in account to develop optimum hybrid energy integration model for grid tie RBSes with view of paybacks under applicable tariff rates.

Also equipment placements inside RBSes, re-modifications and elimination of comfort cooling systems have to be done by allocating energy to main purposes of telecommunication.

Chapter 3

3.0 Proposed Solution

3.1 Alternative energy systems for telecommunication Radio Base Stations.

There are several non- conventional energy generating methods, which can be proposed to power up telecommunication base stations. However, the selection of the alternative energy system for a particular site has to be carried out through careful study of the pros and cons of individual energy generating techniques. Most popular alternative energy generating technologies for telecommunication base stations are as follows.

- Solar Photovoltaic energy: Being a country closer to the equator, the possibility of using the solar photovoltaic energy is high in Sri Lanka, as number of daylight hours are high compared to the countries away from the equator and the seasonal variation are almost negligible.

  Figure 3.1.1 shows the Annual average daily total solar resources for fixed flat plate collector tilted at latitude by National Renewable Energy Laboratory.

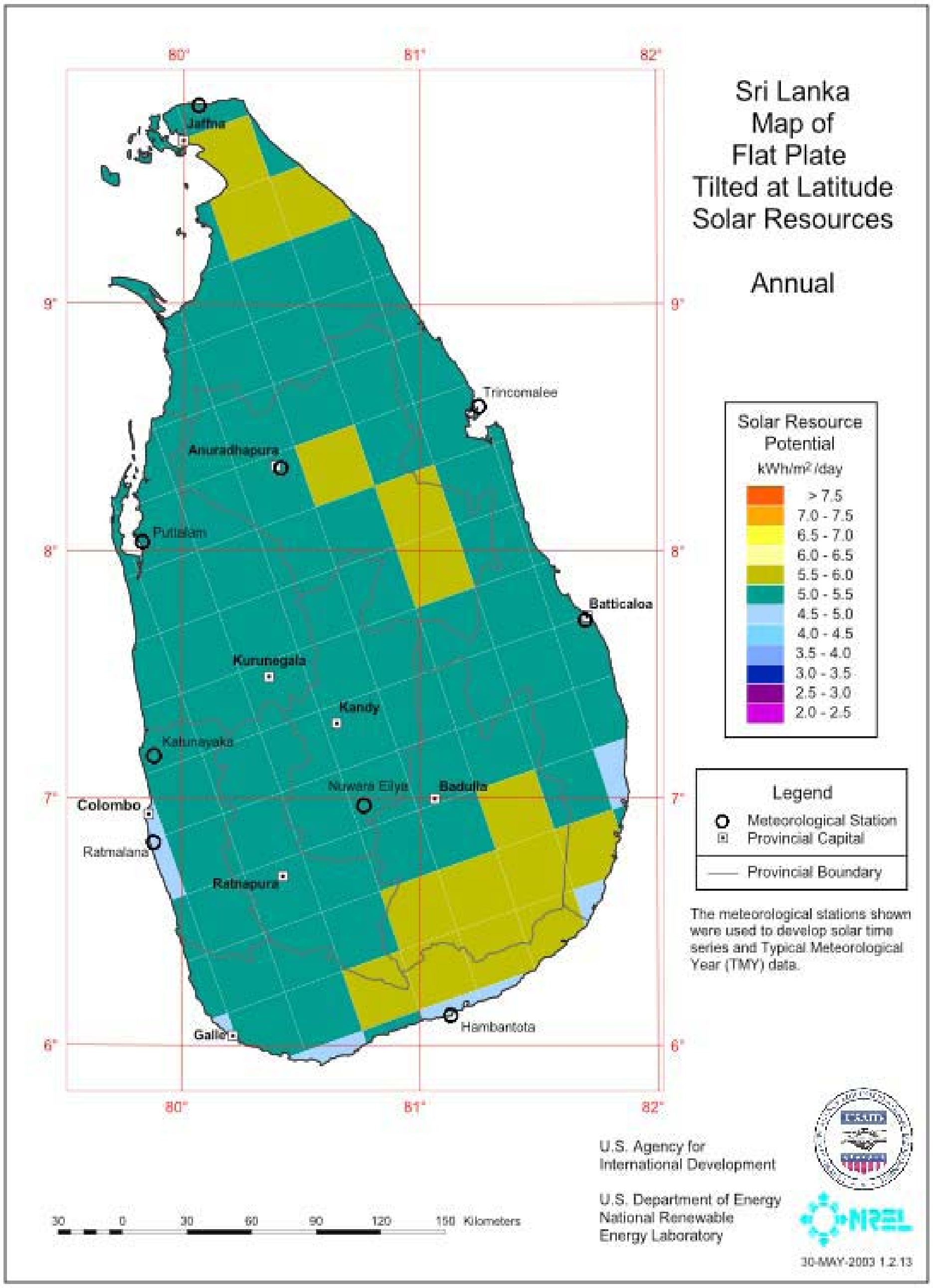


Figure 3.1.1- Sri Lankan Annual average daily total solar resources for fixed flat plate collector tilted at latitude developed. (Source: National Renewable Energy Laboratory)

- Wind energy: Wind energy distribution from point to point may differ depends on the altitude, geographical variations, landscaping of the area and obstacles in the wind flow path. Therefore, it is not predictable unless onsite observations are made. National Renewable Energy Laboratory in the United State together in collaboration with USAID’s South Asia Regional Initiative for Energy Cooperation and Development (SARI/Energy) and Ministry of Power and Energy (Sri Lanka) has analyzed the wind resource availability in Sri Lanka and has developed a wind map, which is highly helpful for study purposes.

  Figure 3.1.2 shows the wind map of Sri Lanka developed by National Renewable Energy Laboratory.

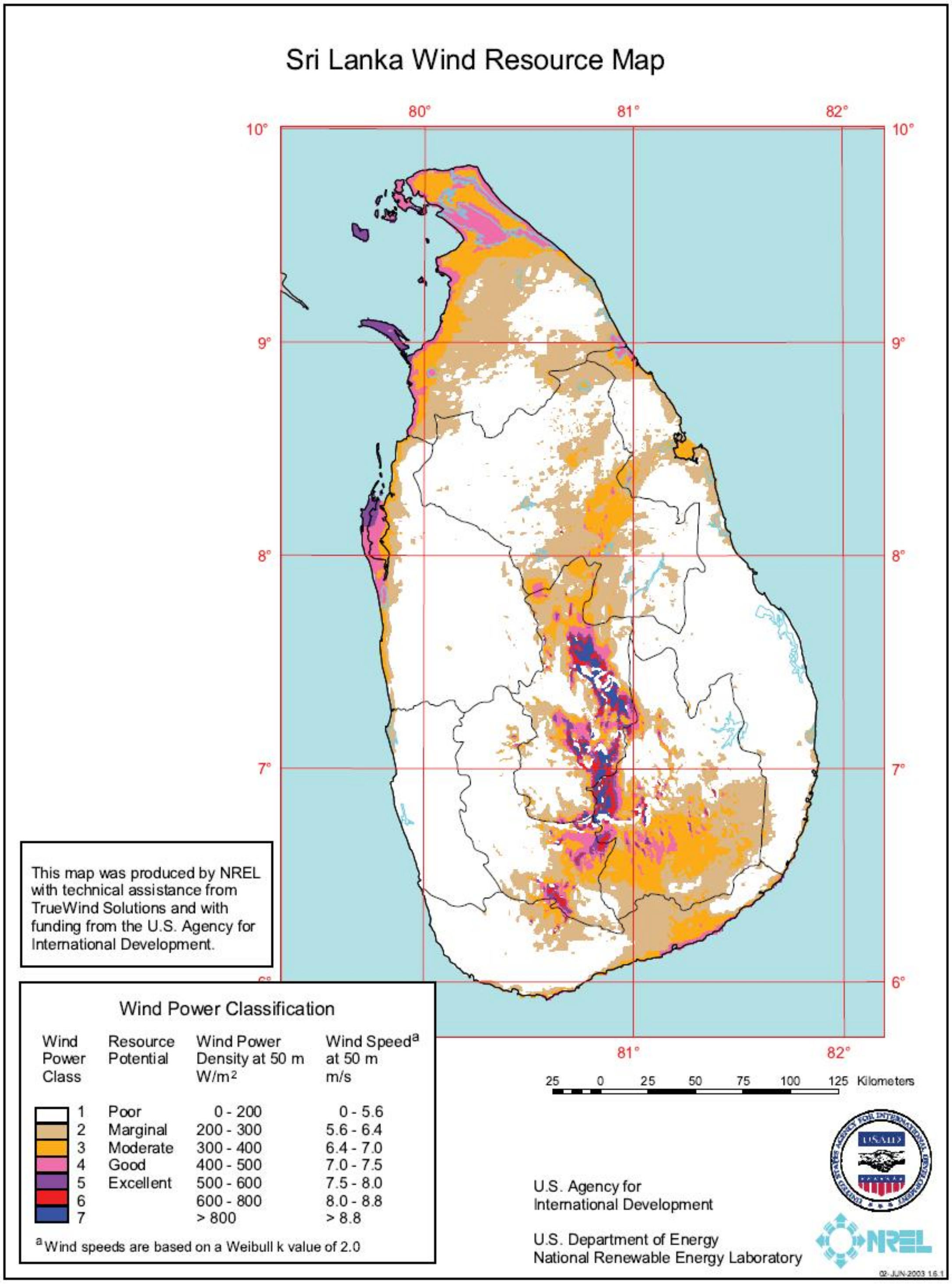


Figure 3.1.2 - Sri Lanka wind map developed. (Source: National Renewable Energy Laboratory)

- Fuel cell: Hydrogen fuel cell technology is used in telecommunication base stations as an alternative power generating method, but the application is mainly used as backup power source. Therefore, it cannot be terms as a retrofitter for diesel generator of a site, which is operating full time on generator.
- Pico hydro: Installing pico hydro plants for telecommunication base stations are not widely used and the initial investment for setting up a pico hydro plant is very high. In most cases, telecommunication base stations are located at higher altitudes such as near the top most area of hills, water resource issue for operating pico hydro plants may be arises.
- Bio fuel: The application of bio fuel to telecommunications must be treated as a case-by-case prospect rather than a universal alternative. The primary consideration will be local access to a regional supply of bio fuel. The impact of biodiesel production upon regional agriculture should also be evaluated.

In Sri Lankan context, most of the Telecom RBSes are constructed mostly as green field, self-support or guy mast towers, Roof Top sites with towers & mono pole structures, indoor base stations etc. In urban areas, most of the telecom base stations are located as Roof Tops with lesser in space, outdoor models with easy grid access. Since majority of RBS sites have sun facing surfaces and simple structural requirements, and the necessity of roof like shelters for most common RBSes available i.e. Outdoor RBS models for operational convenience, it can be proposed integrating Solar PV in to On-Grid Base Stations can be deployed in mass scale than any other technologies discussed.

3.2. Design Parameters for Solar PV power plant.

Its is common in renewable energy world, a 1kW Solar PV installation comprise of 4 nos of 250W Solar PV panels each dimensions around 1.6m x 1m with total surface area of 6.4 m^2, able to generates 4kWh of energy per day under the solar irradiance of 1000 W/m^2 similar to the tropical climate conditions applicable specially in Western, North Central, Northern, Eastern & Southern provinces, most of the areas Island wide and multiples of above can be seamlessly integrated.

For 1 kW Solar PV Installation requires 4 nos of 250W Solar PV panels.

Average dimension of 250W Solar PV Panel (L x W) = 1.6m x 1m = 1.6 m2.

Energy output daily = (250 W x 4) x 0.6 x 6 hrs/day = 4 kWh /day within space 6.4 m2

Energy output monthly = 4 kWh/day x 30days = 120 kWh/ month.

The way of presenting the energy output from Solar PV is, solar irradiated energy for the tropics like Sri Lankan grounds would be on average 4.3 kWh /m^2/day pessimistically [1]. In industry, 1kW Solar PV installation comprise of 4 nos of 250W Solar PV panels each dimensions around 1.6m x 1m with total surface area of 6.4 m^2 with the Solar PV panel energy output efficiencies around 16%. By multiplying the solar irradiated energy by 1 kW Solar PV panel area in to its typical energy output efficiencies around 16% gives us rounded figure 4 kWh per day.

Solar Irradiance in Colombo (pessimistic value) = 4.3 kWh/day/m^2

Panel Area = 1.6 m2 x 4 panels = 6.4 m^2

Module efficiency = 15.1% (according to the common Solar PV data sheets)

Energy output daily = 4.3 x 6.4 x 0.151 = 4.16 kWh/day

Energy output monthly = 4.16 kWh/day x 30days = 124.8 kWh/ month.

In any power plant, plant factor is the ratio of the average power load of an electric power plant to its rated capacity, also known as capacity factor.
Plant factor = Energy produce / Energy could have produced at its full capacity.

For 1 kW Solar PV installation,

PF = E / (1kW x 24hrs/day x 30 days/month)

PF = [E / (720 kWh per month)] * 100.

Monthly average energy output of 1kW Solar PV = 4 kWh/day x 30days = 120 kWh/ month.

PF = [(120 kWh/ month) / (720 kWh/month)] * 100.

PF = 1/6 = 16.67%.

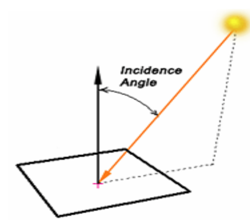
This low plant factor can be improved by improving input energy amount in to the Solar PV panels.

The Day Light availability is around 6.00a.m. to 6.p.m. almost 50% from the total time of the day.

- Daylight availability -> 50% of total time (12 hrs from 6 a.m. to 6 p.m.).

Because of the Sun moving from East to West, The incident angle is varied from 0 degrees to 180 degrees. (It is a function of Incident I Cosθ, hence it's average fraction 1 / 1.414 = 0.6)

- Because of the Incidence Angle, it can be assumed -> daylight availability with its peak (Intensity I) is reduced to 30% of total time. (i.e. 50% x 0.6).



In tropics, there are around hundred of non sunny days for a year in average. So the factor for a sunny days for a year would be around 265/365 = 0.8. Because of that, the day light availability factor with its peak in a day can be further reduced by multiplying factor 0.6.

- Because of Non sunny Days (Clouds) daylight availability with its peak (Intensity I) is reduced to 24% of total time. (i.e. 30% x 0.8).

Because the trees, heights and man made objects, the sun light is blocking. Because of that it is felt sun risen above the horizon is around 7 a.m and set below the horizon around 5 p.m. though its is ideally from 6a.m. to 6.p,m. This is called Blanking effect, cause day light availability factor with its peak in a day is further reduced by factor of 10/12 = 0.8.

- Because of Blanking effect, daylight availability with its peak(Intensity I) is reduced to 19% of total time. (i.e. 24% x 0.8).

It can be seen that, just tracking the sun by rotating the Solar PV panels, the energy input to the panels can be improved to 19%/0.6 = 31%.

It can be seen that, by increasing the Solar PV panel height above tree level, the energy input to the panels can be improved to 19%/0.8 = 23%.

By doing the both, the energy input to the panels can be improved to 38%. (i.e. 31%/0.8).

This is the area a designer has to be followed, and the researches are being carried out to increase the energy conversion efficiencies of Solar PVs, High efficient Solar PVs (HPV), harness the Solar PV energy under low light intensities etc.

3.3 Solar PV integration methodologies in to On-Grid telecom RBSes.

Basically there are two options available and separately discussed below.

3.3.1 Option 1: Solar PV integration in to rectifier systems compricing of inbuilt DC to DC converting Solar PV charger controllers with MPPT plus A/C to DC converting rectifier modules.

The compact rectifier systems comprising of A/C to DC converting rectifier modules & DC to DC converting Solar PV Charger Controllers with Maximum Power Point tracking (MPPT) by introducing a sub rack to conventional rectifier systems to hold Solar PV Charger Controllers plus upgrading the rectifier controller software such a way that to prioritize energy from Solar PV and rest of power requirement through the conventional rectifier modules connected to the gird, provided Solar PV panel installed capacities shouldn't be exceeded the site's max load, is the way of facilitating solar PV integration in to grid connected telecom RBS sites with existing setup with advantages mentioned below.

- No need of separate hardware for integrate Solar PV (PLCs)
- No need of Fast Charging Deep Cyclic Valve Regulated Lead Acid (VRLA) Batteries.

A typical arrangement of Solar PV integration in to Hybrid Controller, DC to DC converting Solar PV charger controllers with MPPT plus A/C to DC converting rectifier modules is shown in below Figure 3.3.1.1.

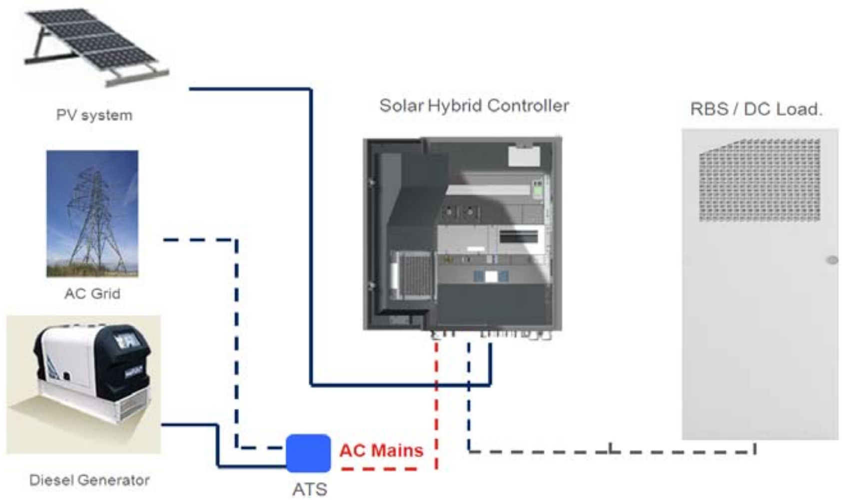


Figure 3.3.1.1 - Solar PV integration in to Hybrid Controller.

3.3.2 Option 2: Solar PV integration through grid tie inverter system facilitate with "Net metering".

Net metering is an electricity policy for consumers who own renewable energy facilities such as wind, Solar PV etc and allows them to use generation whenever possible, instead of just when generated. The word "Net" implies, the balance of metered any energy outflows from energy inflows. Under net metering, the system owner receives retail credit for at least a portion of the electricity they generate.

A typical arrangement of Solar PV integrated grid tie inverter system applicable for "Net metering" is shown in below figure.

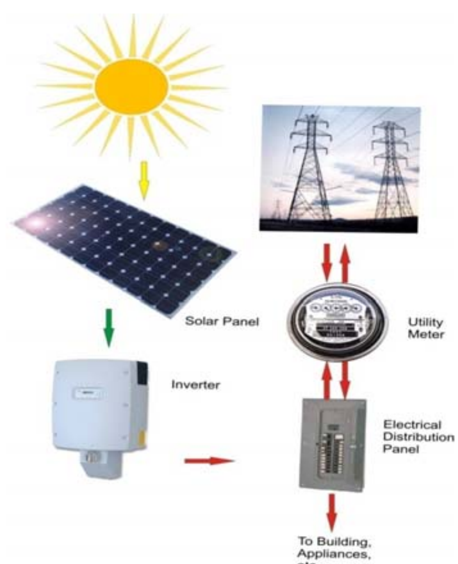


Figure 3.3.2.1 - Solar PV integrated grid tie inverter system applicable for "Net metering"

Advantages：

- High efficient use of the system long life span
- The investment cost is some lower
- The use of the electricity will not restricted by the system itself and the weather condition influence.

Disadvantages：

- The return of the electricity powered by solar will be restricted by the local public electricity net (Ex: Availability of healthy grid Voltage & Frequency, applicable tariff rate etc)

Chapter 4

4.0 Research Design.

4.1 Methodology

This study focuses on Radio Base Stations deploy for Access Network Coverage almost around 2450 numbers belongs to Dialog Axiata PLC scattered island wide among 9 operational regions. Out of them, the sites having sun facing nearby surfaces with sufficient spacing are extracted and categorized them according to their power loadings and respective tariff classes. Then identify best Solar PV sizing & integration methodology for each category and evaluate financial paybacks for the combinations of their power loading and respective tariff classes.

Also It is benchmarked the unit rates which make these designs financially paybacks and viable in practice and obtain the vendor support for pilot scale Solar PV implementation of grid tie site for techno economical justifications.

4.2 Site categorization according to the regional deployments.

There are 2414 sites scattered island wide and can be divided in to 9 geographical boundaries are shown in Table 4.2.1.

Table 4.2.1. - Site categorization according to the regional deployments.

	Region	Site Count	No Space for Solar PV*	Possible for Solar PV by Space
1	Western Central	510	52	458
2	Western North	306	10	296
3	Western South	274	9	265
4	North Western	273	12	261
5	Southern	251	6	245
6	Central	238	11	227
7	North Central	236	8	228
8	Eastern	202	13	189
9	Northern	124	21	103
	Sub Total	2414	142	2272

* - No space on Cabin RT / Sun facing nearby Surface

4.3 Site categorization according to the Power Loading.

Out of 2414 sites there are 2272 sites distributed among 9 regions where possible for solar PV integration, since availability of Sun facing nearby surfaces are categorized according to their power loading levels are shown in Table 4.3.1.

Table 4.3.1. - Site categorization according to the Power Loading.

	Region	Solar PV Integration Possible Site Count	Site Count under different Power Loadings		
			0< Low <2kW	2 kW< Medium <4 kW	4kW <High<
1	Western Central	458	138	286	34
2	Western North	296	48	226	22
3	Western South	265	117	136	12
4	North Western	261	65	178	18
5	Southern	245	52	169	24
6	Central	227	63	143	21
7	North Central	228	72	133	23
8	Eastern	189	58	103	28
9	Northern	103	38	46	19
	Sub Total	2272			

4.4 Site categorization according to the applicable tariffs.

In Sri Lanka, the domestic tariff rate (applicable to house holds) is in bock wise to offer subsidies and it would become average unit cost of 58 Rs/kWh for consumptions around 2000 units per month, since average 2 kW constant loads are available in most telecom RBSes.

The telecom base stations are fallen under the category General Purpose (GP1) where a unit cost would be around 27 Rs/kWh after including 25% of fuel surcharge applicable at present.

Tariff rates applicable to telecom services sector are summarized below in Table 4.4.1[2].

Table 4.4.1. – Applicable Tariff rates to the Telecom service sector.

Tariff category	GP1	GP2 (Demand charge >42 kVA)	D1	SO Avg.
Tariff Rate Rs/kWh	27.00	32.00	58.00	50.00

This Solar PV integration possible 2007 number of sites are categorized to their applicable tariff categories are shown in Table 4.4.2.

Table 4.4.2. - Site categorization according to the applicable tariff categories

	Region	PV Integration Possible Site Count	Site Count under different tariff rates		
			D1	GP 1	Special (Site Owners)
1	Western Central	458	32	414	12
2	Western North	296	17	279	0
3	Western South	265	15	248	2
4	North Western	261	16	245	0
5	Southern	245	14	231	0
6	Central	227	12	215	0
7	North Central	228	18	210	0
8	Eastern	189	11	178	0
9	Northern	103	1	99	3
	Sub Total	2272	136	2119	17

There are 17 nos of RBSes having site owner imposed special unit rates are shown in Table 4.4.3 below. Out of 17 nos of RBSes , 3 nos of sites in Nothern region are covered under special agreement with Ministry of Defense and energy cost for these sites are compensated with other terms.

Table 4.4.3. - Sites under Special - Site Owner imposed tariff rates

	Site Name	Unit cost (Rs/kWh)
1	Dehiwala North	35.00
2	Roxy Garden	50.12
3	Kolpity South	46.20
4	Bandaranayke Mawatha	48.00
5	Rotunda Garden	54.00
6	Liberty Plaza	45.00
7	Saranankara Road	40.00
8	Pepiliyana RT	31.00
9	Crescat Residencies	22.00
10	Watarappala	31.80
11	Torrington	30.00
12	Sri Lanka Navy	28.00
13	Jaic Hilton	52.90
14	Majestic City	50.00

4.5 Hybrid power system simulation tools for Solar PV integration and pay back evaluation.

The pre feasibility study of hybrid electrical energy system is accomplished through either by using complex generic algorithms or by simulation of proposed system using widely accepted software. Manual calculation of the behavior of a hybrid energy system comprises of two or more power conversions are highly complex and time consuming and the possibility of human errors are very high. As more equipment are added to a wind-solar- diesel system such as power quality related equipment, complexity increases and it becomes difficult to predict fuel savings. Therefore, long term logistic computer simulation models are necessary.

When designing energy systems, the range of time to be simulated is an important aspect to consider. The ability of the model to behave exactly as the physical system between certain constraints is defined as its robustness. Short description of more popular simulation hybrid energy system simulation programs currently in use today is given below.

i. Homer

Hybrid Optimization Model for Electric Renewables (HOMER), was developed by National renewable Energy Laboratory (NREL), United State's primary laboratory for renewable energy and energy efficiency research and development, is an optimization tool used to determine energy system configurations for both grid-connected and off-grid power systems [3]. Simulation is compiled in hourly steps and the simulation is fast and comprehensive. HOMER is considered as the state of art in this category and widely used to determine the optimal basic system design. For the simulation of small scale hybrid energy systems, HOMER is one of the best available comprehensive software, which is freely downloadable.

This software is more popular among the other software in designing stand alone or grid connected micro hybrid renewable systems.

ii. Hybrid 2

Hybrid 2, developed by the University of Massachusetts and NREL, operates much like the HOMER software with a much higher degree of detail [4]. Hybrid 2 is a time series model used to predict technical and economic system performance. The user interface is not as straightforward as HOMER, but the degree of flexibility in terms of operational method selection and accuracy of simulated data is superior to HOMER.

iii. RETScreen

CEDRL's RETScreen is a spreadsheet based analysis and evaluation tool used to determine the economics of hybrid energy system projects. RETScreen is publicly available but not as popular as HOMER.

iv. PVSyst

PVsyst is a PC software package for the study, sizing, simulation and data analysis of complete PV systems.

4.6 Modeling using Software.

It is used HOMER software as a design tool for simulating to integrate energy sources for telecom power setup by using its graphical user interface, since its accuracy and available as freeware to download. It includes the below mentioned configurations to customize.

- Equipment configuration, capacities, capital cost, replacement cost, operation and maintenance cost, characteristic curves and lifetime.
- Hourly load profiles.
- Renewable energy resource data with monthly average etc.
- Rates of energy, emissions, cost and characteristics of fuel etc.
- Project economics and constrains.

Most common method of evaluating a renewable energy system is to simulate for an entire life span.

Details of the used version of HOMER software is given below.

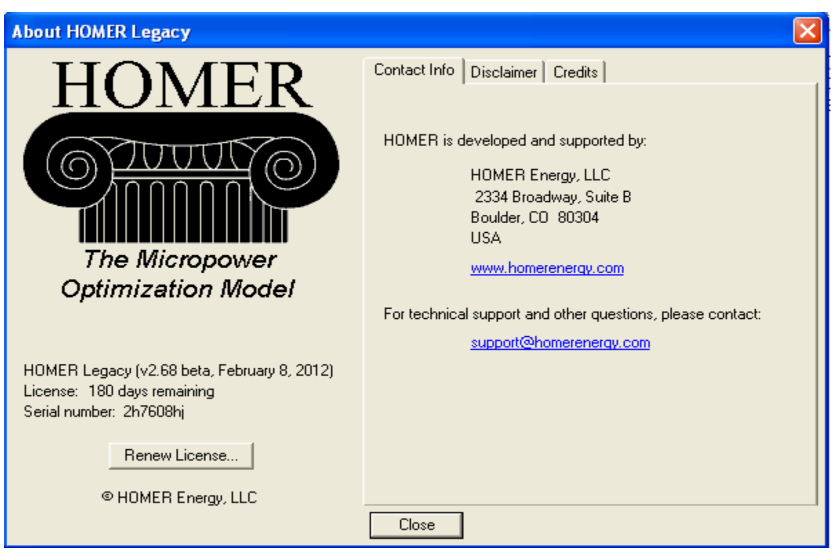


Figure 4.6.1- HOMER preliminary information.

Solar PV integration methodologies in to On-Grid telecom RBSes described earlier (Please refer chapter 3.3 in page no 18) are taken and described separately with assumptions made during analysis from Homer.

There are 6 configurations taken in to analysis, out of them 3 configurations are for Solar PV installed capacities of 1, 2 and 3kW each of integration in to rectifier systems comprising of inbuilt DC to DC converting Solar PV Charger Controllers with MPPT plus A/C to DC converting rectifier modules, and rest of 3 configurations for Solar PV installed capacities of 1, 2 and 3 kW each of integration through grid tie inverter system facilitate with "Net metering" described below with their outputs for each case. Finally shading analysis. It is discussed about calculation of shading due to tower high and other structures for best placement of Solar PV panels to maximize energy harvesting. Also a methodology for implementation, both Solar PV integration on to the DC bus & for Net Metering and benchmark tariff rates payback in 3 years are described below.

4.7 Assumptions made during simulation for Option 1. (i.e. Solar PV integration in to rectifier systems comprising of inbuilt DC to DC converting Solar PV Charger Controllers with MPPT plus A/C to DC converting rectifier modules.)

- The life span of equipments, for batteries assumed to be minimum life of 5 years, each of rectifier modules for 15years, and for each of Solar PV panel lives up to 25 years of liner power output with derating factor 80%, assuming "Eltek" rectifier systems are at the site.

- Tariff rates are considered 27 Rs/kWh for GP1 and 58 Rs/kWh applicable for D1 since the energy consumption for most of the sites having average constant load of 2kW.

- Cost of Solar PV panels are taken 1$/1W basis, 1.5 kW Solar PV DC to DC converting Solar PV Charger Controller module with MPPT is taken 750$ with same replacement costs with 15 years of life span.

- Monthly Averaged Radiation Incident On An Equator-Pointed Tilted Surface (kWh/m2/day) is same for all cases as derived from NASA Surface meteorology and Solar Energy data tables for heart of Colombo City with Latitude 6.54 and Longitude 79.50 as shown in Table 4.7.1 below is chosen.

Table 4.7.1 - Monthly Averaged Radiation Incident On An Equator-Pointed Tilted Surface (kWh/m2/day) with Latitude 6.54 and Longitude 79.50 derived from Surface meteorology and Solar Energy database by NASA.

Lat 6.54 Lon 79.5	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
SSE HRZ	5.5	6.27	6.67	5.96	5.29	5.3	5.4	5.7	5.65	5.3	4.93	5.16	5.58
K	0.58	0.63	0.64	0.56	0.51	0.53	0.5	0.6	0.54	0.5	0.52	0.56	0.56
Diffuse	1.69	1.7	1.83	2.13	2.13	2.03	2	2.1	2.15	2.1	1.9	1.7	1.96
Direct	6.03	6.82	6.92	5.42	4.58	4.83	4.9	5	4.95	4.7	4.72	5.59	5.37
Tilt 0	5.44	6.2	6.59	5.87	5.2	5.21	5.3	5.6	5.57	5.2	4.88	5.11	5.51
Tilt 6	5.69	6.38	6.65	5.89	5.27	5.31	5.4	5.6	5.58	5.3	5.05	5.35	5.62
Tilt 21	6.08	6.6	6.55	5.72	5.25	5.36	5.4	5.5	5.39	5.4	5.3	5.76	5.69
Tilt 90	3.91	3.46	2.39	1.99	2.39	2.63	2.6	2.2	1.84	2.7	3.24	3.88	2.76
OPT	6.16	6.6	6.65	5.89	5.29	5.37	5.5	5.6	5.58	5.4	5.33	5.88	5.76
OPT ANG	32	23	9	5	13	17	15	8	3	17	28	34	16.9

Since most of the RBS cabins are having dimensions, length and width of 3m x 3m on their roof tops with possible structural expansions, and the size of a 250W Solar PV panel (both mono-crystalline and polycrystalline) is with average dimensions, length and width of 1.6m x 1m, the sizing of average 2kW Solar PV installed capacities can be integrated in most of the existing sites, more over extended capacities for sites are having higher areas of nearby sun facing surfaces. Therefore sizes of 1kW, 2kW and 3kW Solar PV installation capacities are considered for integration in each case as discussed below.

4.7.1 Case 1: Size of 1kW Solar PV integration in to Rectifier System.

Figure 4.7.1.1 shows the system configuration and Solar PV panel details of 1kW installed capacity integrated in to On Grid rectifier system.

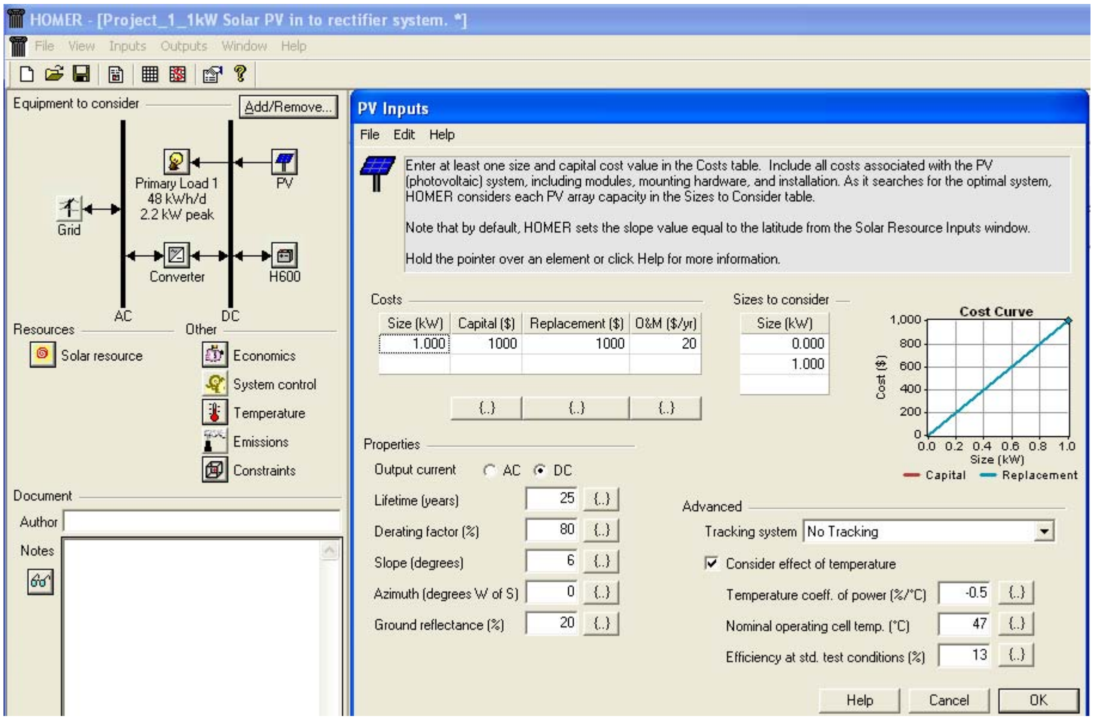


Figure 4.7.1.1- System configuration and Solar PV data for panel size of 1kW.

Solar resource data for the evaluation is taken from NASA Surface meteorology and Solar Energy data tables and monthly averaged annual solar resource data for the site is given in Figure 4.7.1.2.

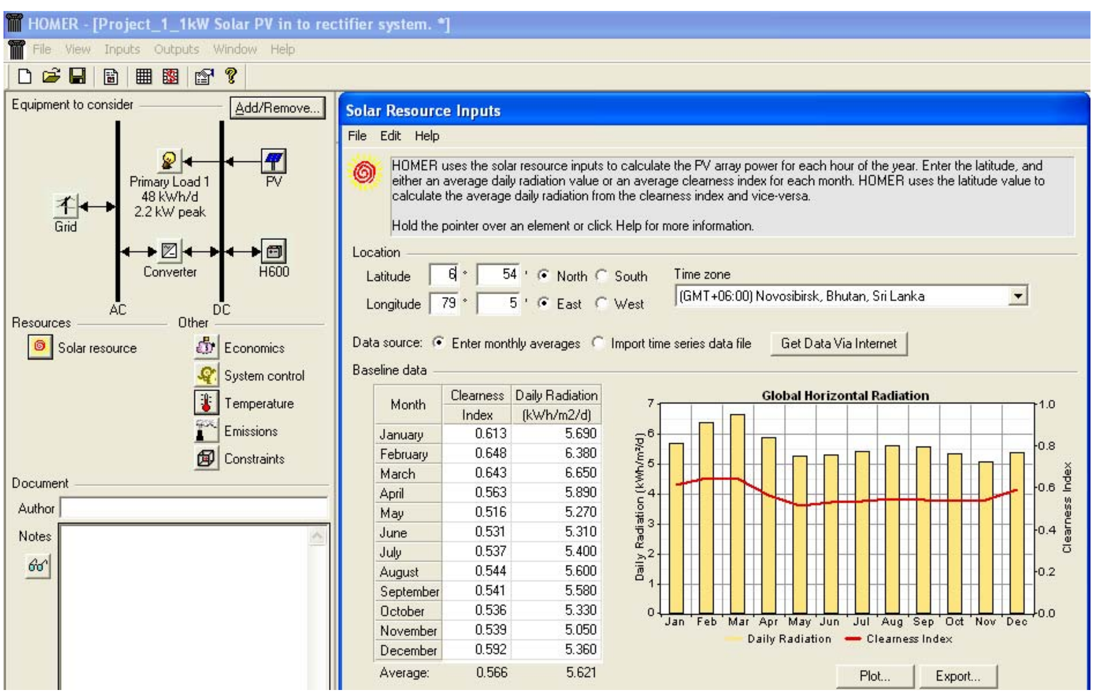


Figure 4.7.1.2- Solar resource data from NASA entered in to Homer.

Daily load curves of the site is taken from the load profile of the site and graphical interpretation of daily load curve is shown in Figure 4.7.1.3.

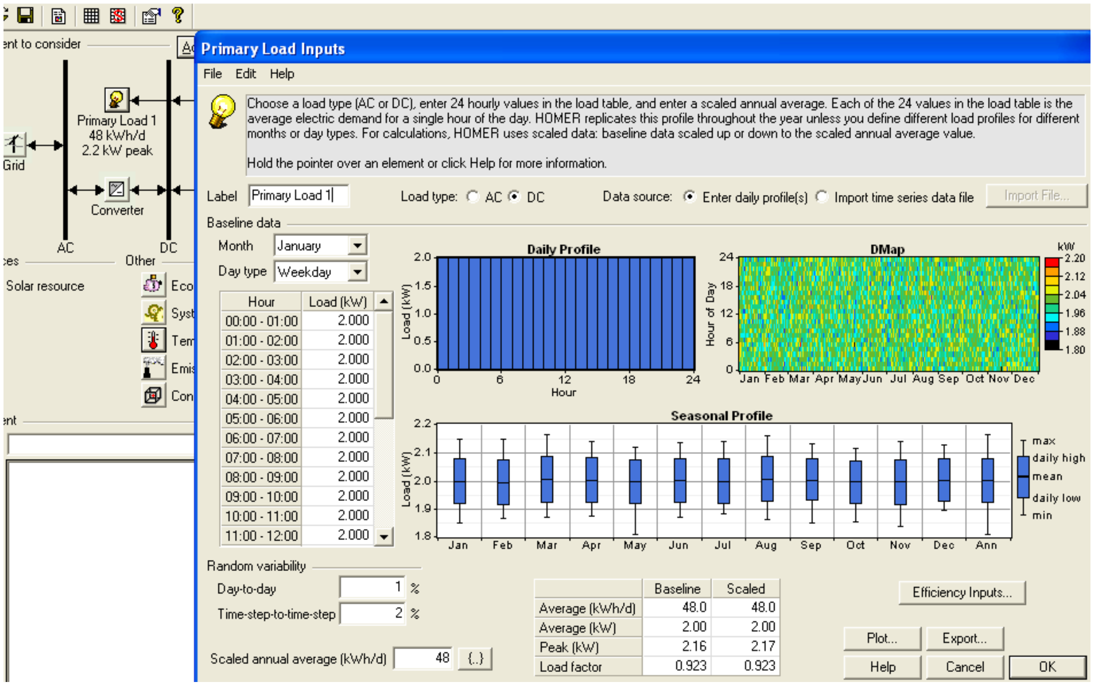


Figure 4.7.1.3- Daily load profile of site load of 2kW.

Applicable tariff rate imposed by the utility is considered 27 Rs/kWh as GP1, is shown in figure 4.7.1.4 below.

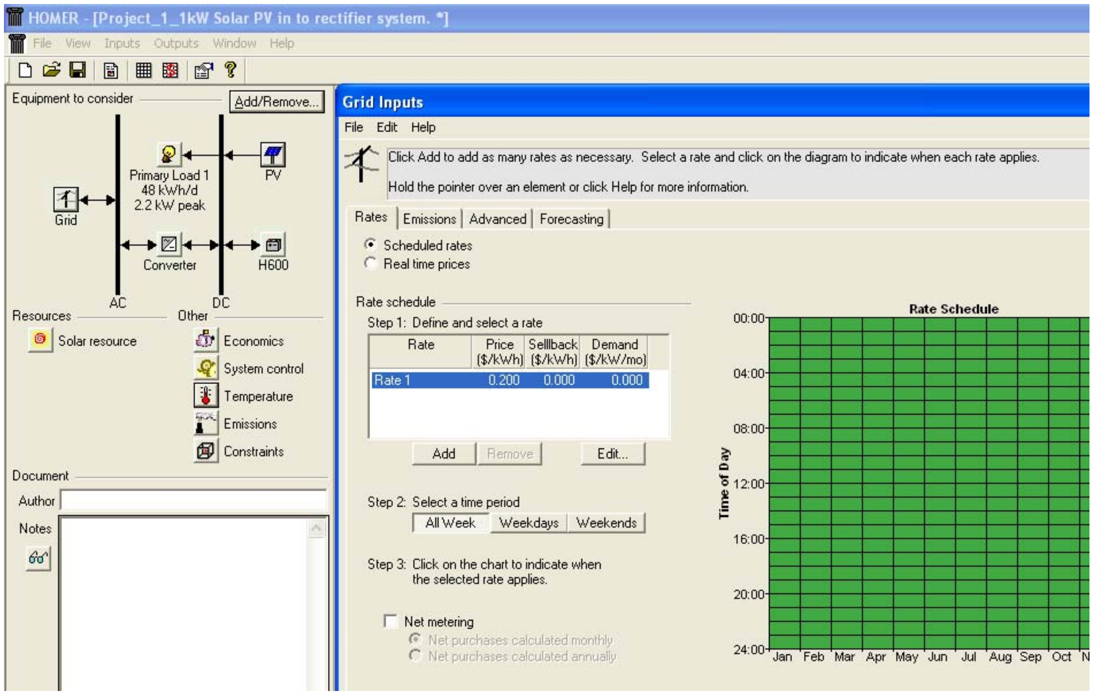


Figure 4.7.1.4 - Applicable tariff rate imposed by the utility GP1 (27 Rs/kWh).

Outcome of the HOMER simulation for the size of 1kW Solar PV Integration in to Rectifier System for this site is shown in Figure 4.7.1.5.

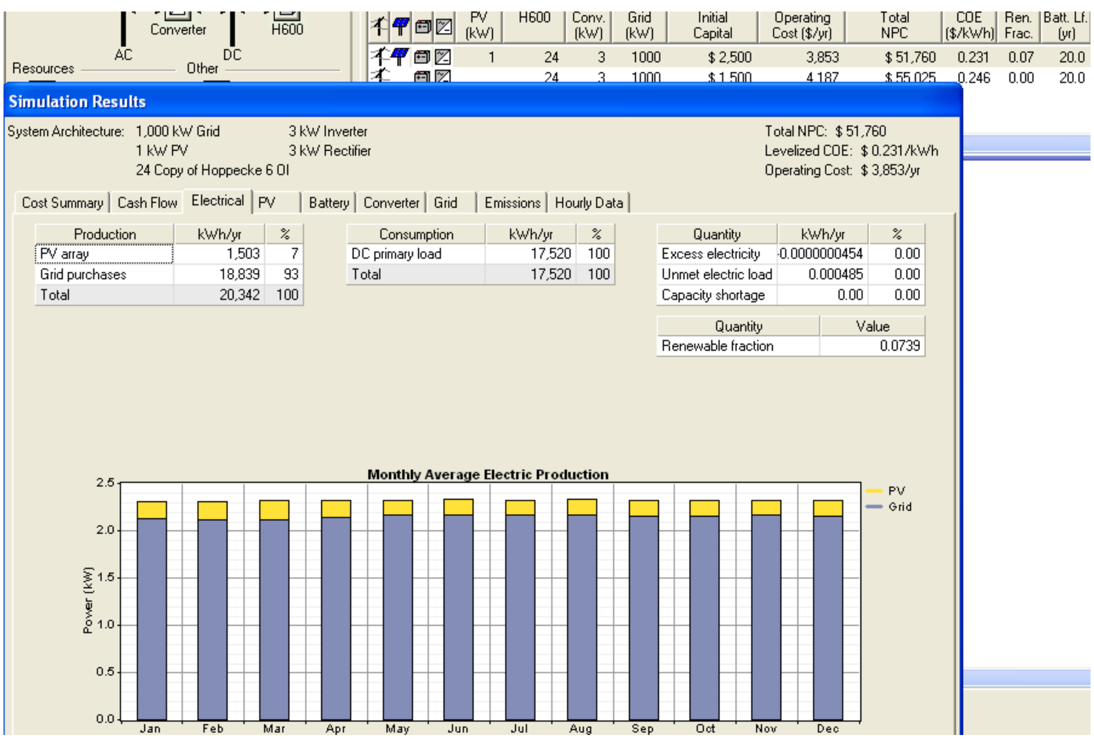


Figure 4.7.1.5- Annual output summary simulated through HOMER software of 1kW Solar PV Integration in to Rectifier System.

This implies the renewable energy fraction of the design is 7.39% out of total energy consumption.

4.7.2 Case 2: Size of 2kW Solar PV integration in to Rectifier System.

Figure 4.7.2.1 shows the system configuration and Solar PV panel details of 2kW installed capacity integrated in to On Grid rectifier system.

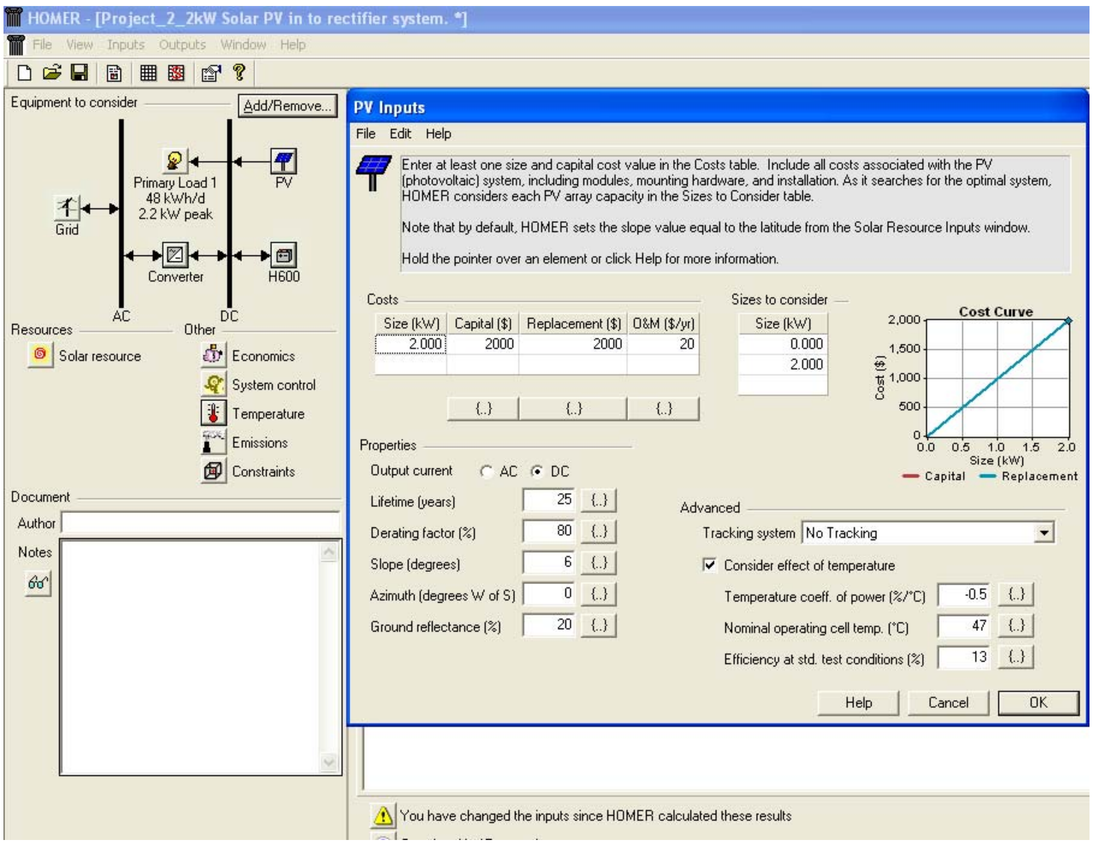


Figure 4.7.2.1 - System configuration and Solar PV data for panel size of 2kW.

Solar resource data for the evaluation is taken from NASA Surface meteorology and Solar Energy data tables and daily load curves of the site is taken with the average constant load of 2kW and applicable tariff rate (i.e. GP1) remains same as earlier.

Hence, outcome of the HOMER simulation for the size of 2kW Solar PV Integration in to Rectifier System for this site is shown in Figure 4.7.2.2.

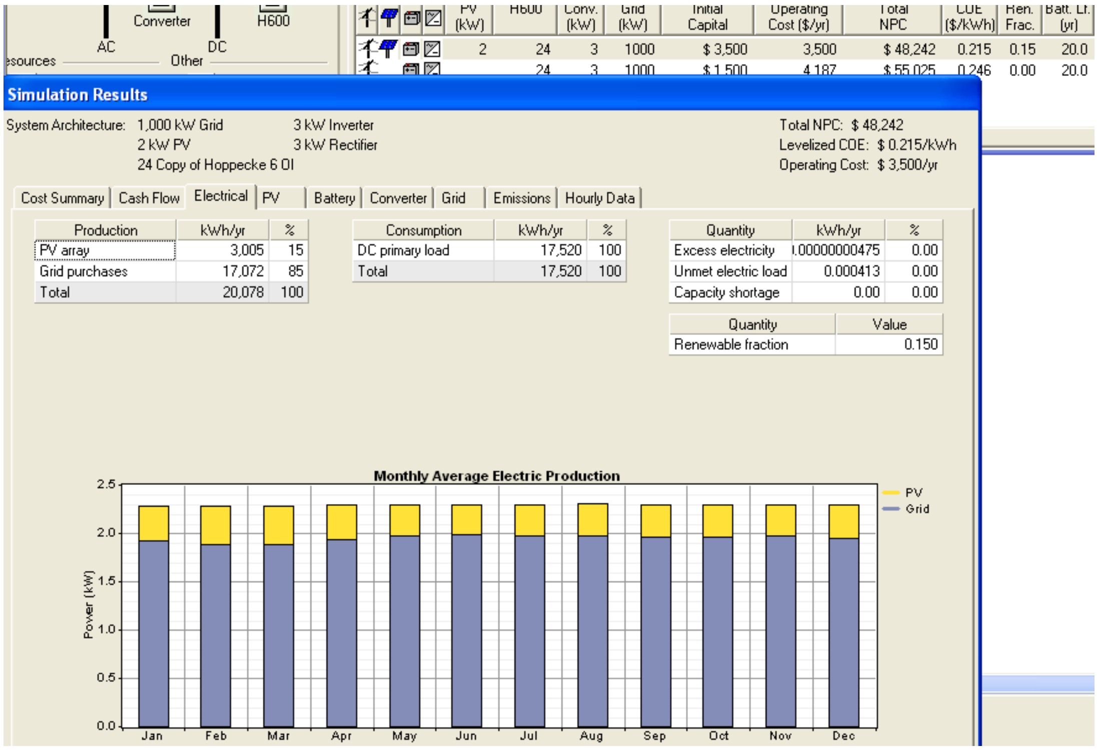


Figure 4.7.2.2- Annual output summary simulated through HOMER software of 2kW Solar PV Integration in to Rectifier System.

This implies the renewable energy fraction of the design is 15% out of total energy consumption.

4.7.3 Case 3: Size of 3kW Solar PV integration in to Rectifier System.

Figure 4.7.3.1 shows the system configuration and Solar PV panel details of 3kW installed capacity integrated in to On Grid rectifier system.

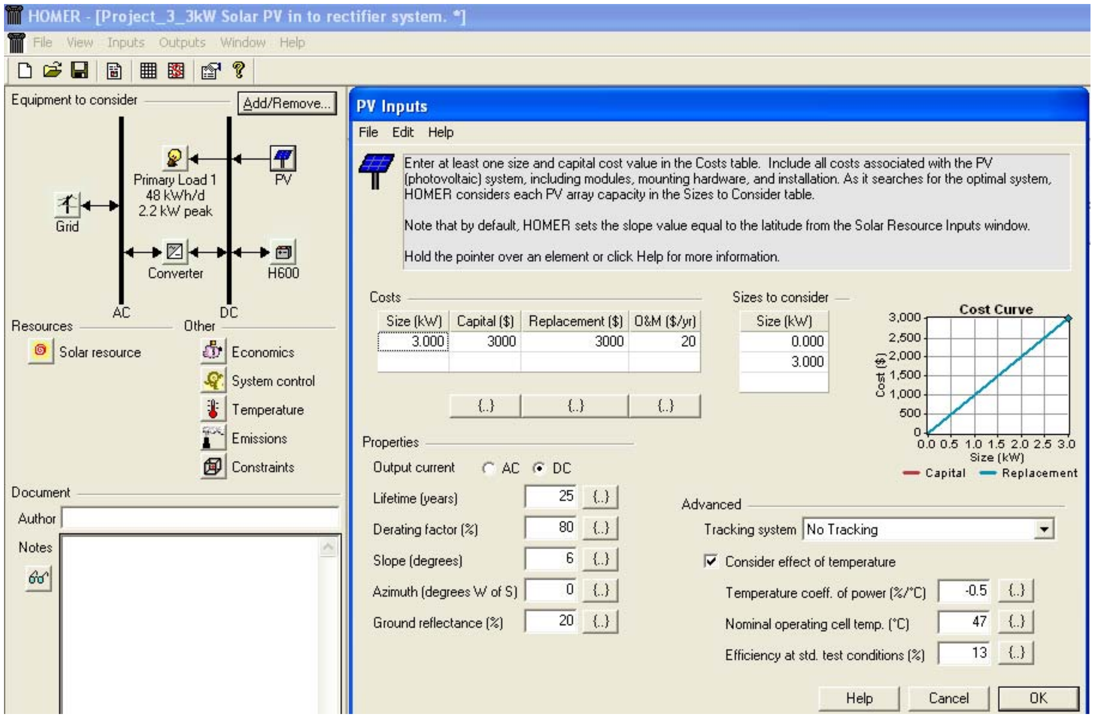


Figure 4.7.3.1- System configuration and Solar PV data for panel size of 3kW.

Solar resource data for the evaluation is taken from NASA Surface meteorology and Solar Energy data tables and daily load curves of the site is taken with the average constant load of 2kW and applicable tariff rate (i.e. GP1) remains same as earlier.

Hence, outcome of the HOMER simulation for the size of 3kW Solar PV Integration in to Rectifier System for this site is shown in Figure 4.7.3.2.

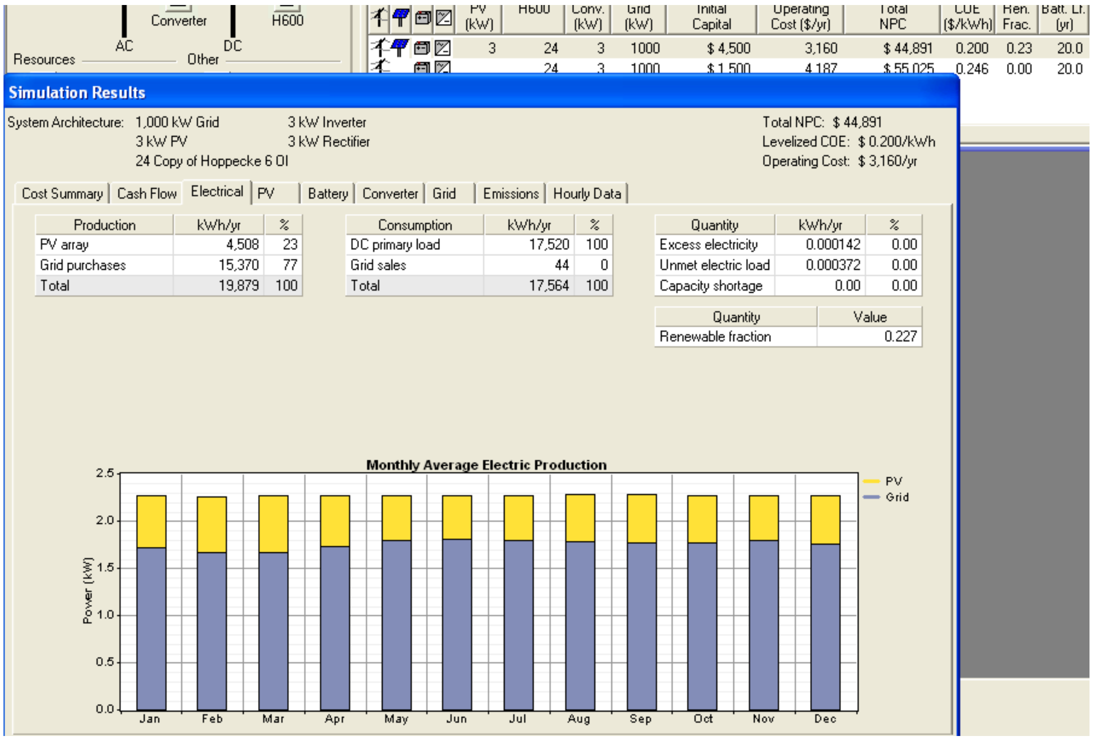


Figure 4.7.3.2- Annual output summary simulated through HOMER software of 3kW Solar PV Integration in to Rectifier System.

This implies the renewable energy fraction of the design is 22.7% out of total energy consumption.

4.8 Assumptions made during simulation for Option 2. (i.e. Solar PV integration through grid tie inverter system facilitate with "Net metering")

- The life span of equipments, Grid tie inverter modules for 15years, and for each of Solar PV panel lives up to 25 years of liner power output with derating factor 80%.
- Tariff rates are considered 27 Rs/kWh for GP1 and 58 Rs/kWh applicable for D1 since the energy consumption for most of the sites having average constant load of 2kW.
- Cost of Solar PV panels are taken 1$/1W basis, 1 kW Grid tie string inverter module with inbuilt MPPT is taken as 1000$ with linear multiples of capacity vs. cost with same replacement costs for 15 years of life span.
- Monthly Averaged Radiation Incident On An Equator-Pointed Tilted Surface (kWh/m2/day) is same for all cases as derived from NASA Surface meteorology and Solar Energy data tables for heart of Colombo City with Latitude 6.54 and Longitude 79.50 as shown in Table 5.2.1. [22] is chosen same as during the Option1.

As in earlier case, option1, cabin dimensions length and width of 3m x 3m on their rooftops with possible structural expansions, average size of 1.6m^2 250W Solar PV panels can be integrated with their capacities of 1 kW, 2kW and 3kW in each case for the common average site load of 2kW, discussed below.

4.8.1 Case 1: Size of 1kW Solar PV integration in to Grid tie inverter for Net Metering.

Figure 4.8.1.1 shows the system configuration and Solar PV panel details of 1kW installed capacity integrated in to Grid tie inverter system.

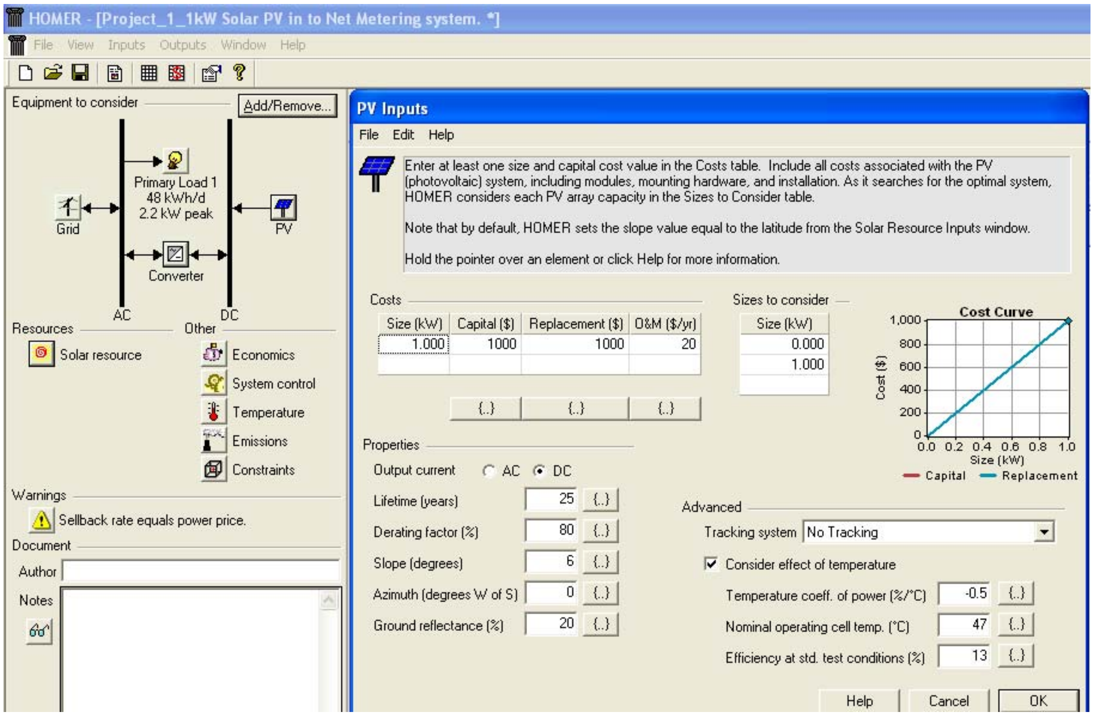


Figure 4.8.1.1- System configuration and Solar PV data for panel size of 1kW.

Solar resource data for the evaluation is taken from NASA Surface meteorology and Solar Energy data tables and monthly averaged annual solar resource data for the site is given in Figure 4.8.1.2.

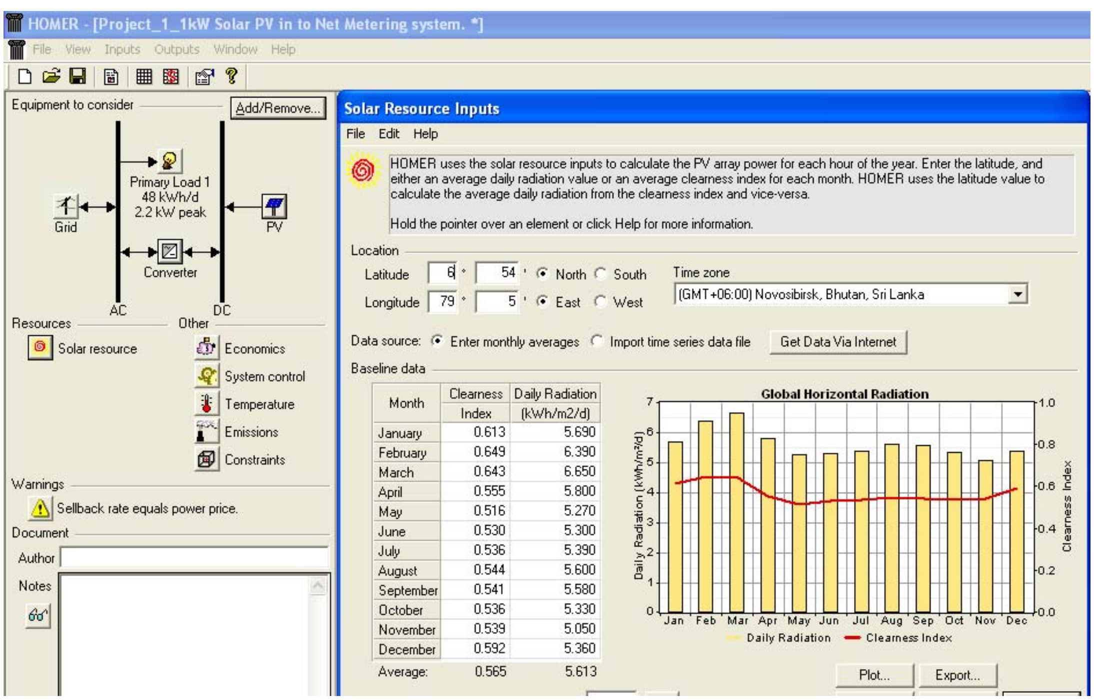


Figure 4.8.1.2- Solar resource data from NASA entered in to Homer.

Daily load curves of the site is taken from the load profile of the site and graphical interpretation of daily load curve is shown in Figure 4.8.1.3.

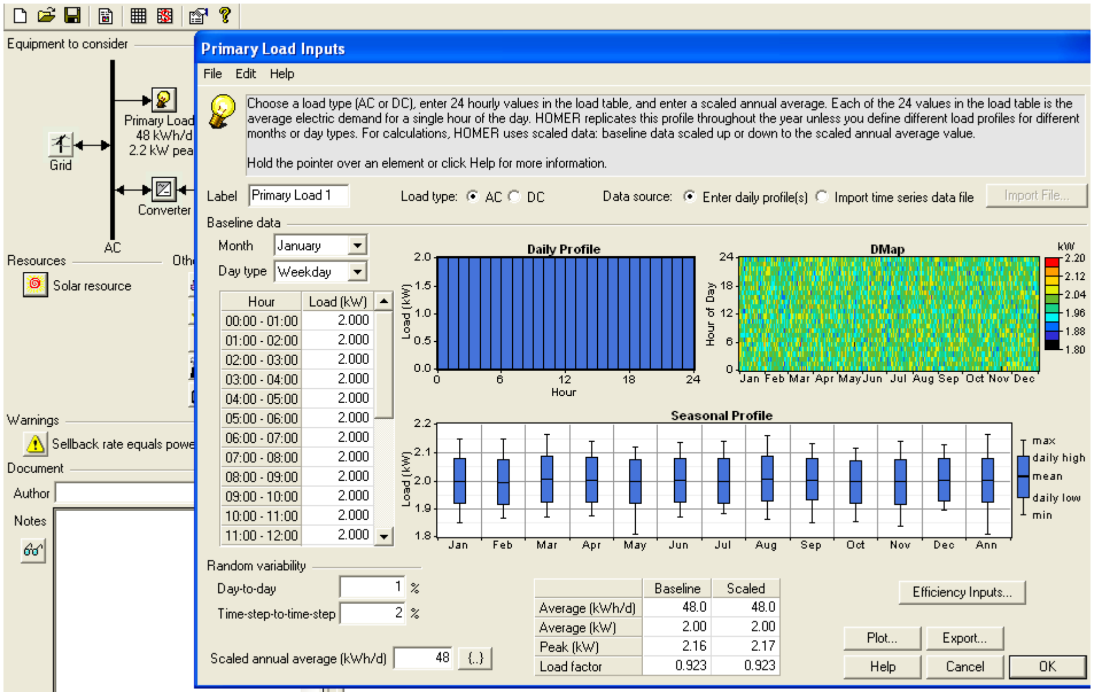


Figure 4.8.1.3- Daily load profile of site load of 2kW.

Applicable tariff rate imposed by the utility is considered 27 Rs/kWh as GP1, is shown in figure 4.8.1.4.

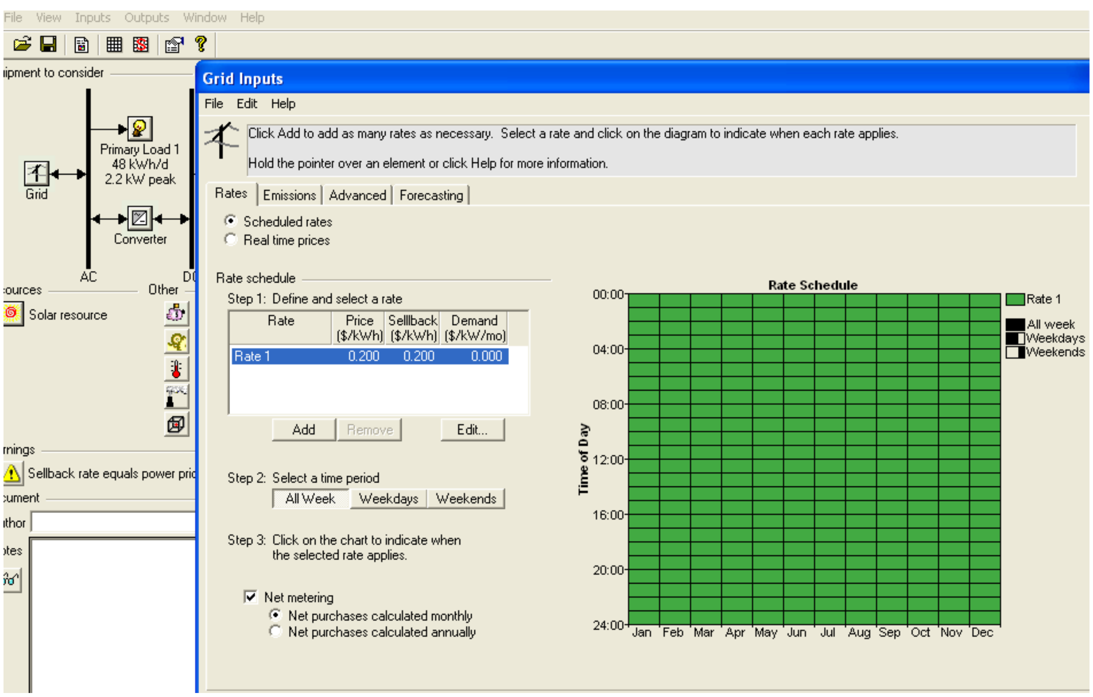


Figure 4.8.1.4 - Applicable tariff rate imposed by the utility GP1 (27 Rs/kWh).

Outcome of the HOMER simulation for the size of 1kW Solar PV integration in to Grid tie inverter system for Net Metering for this site is shown in Figure 4.8.1.5.

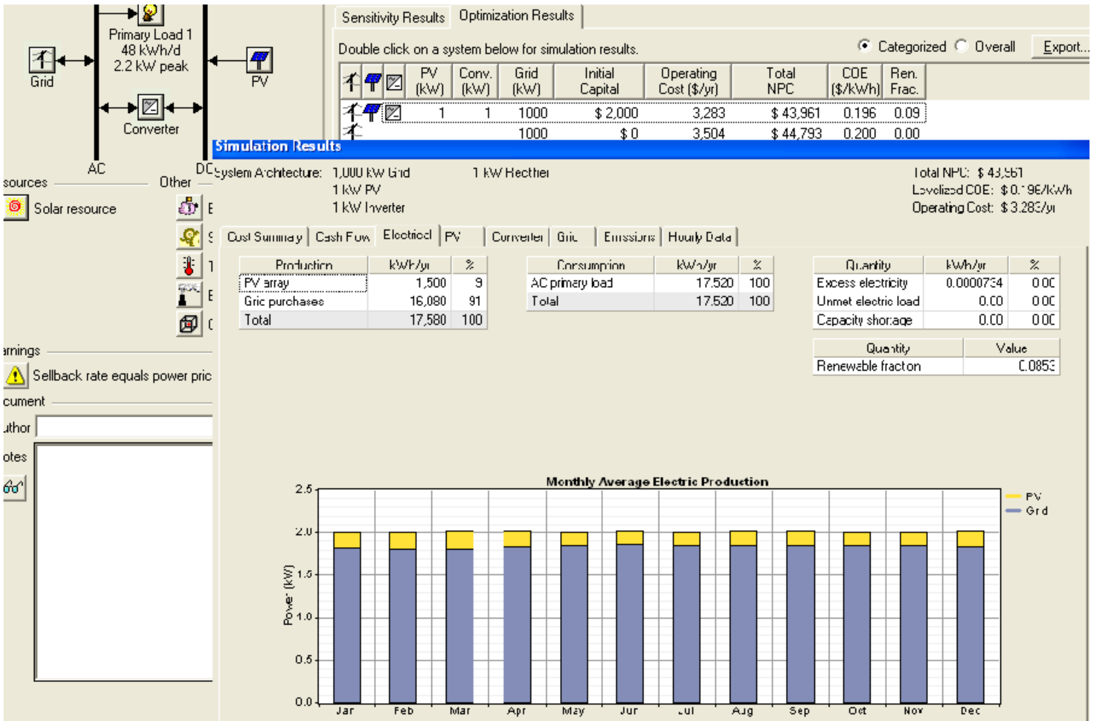


Figure 4.8.1.5- Annual output summary simulated through HOMER software of 1kW Solar PV integration in to Grid tie inverter system.

This implies the renewable energy fraction of the design is 9% out of total energy consumption.

4.8.2 Case 2: Size of 2kW Solar PV integration in to Grid tie inverter for Net Metering.

Figure 4.8.2.1 shows the system configuration and Solar PV panel details of 2kW installed capacity integrated in to Grid tie inverter system to have Net Metering facility.

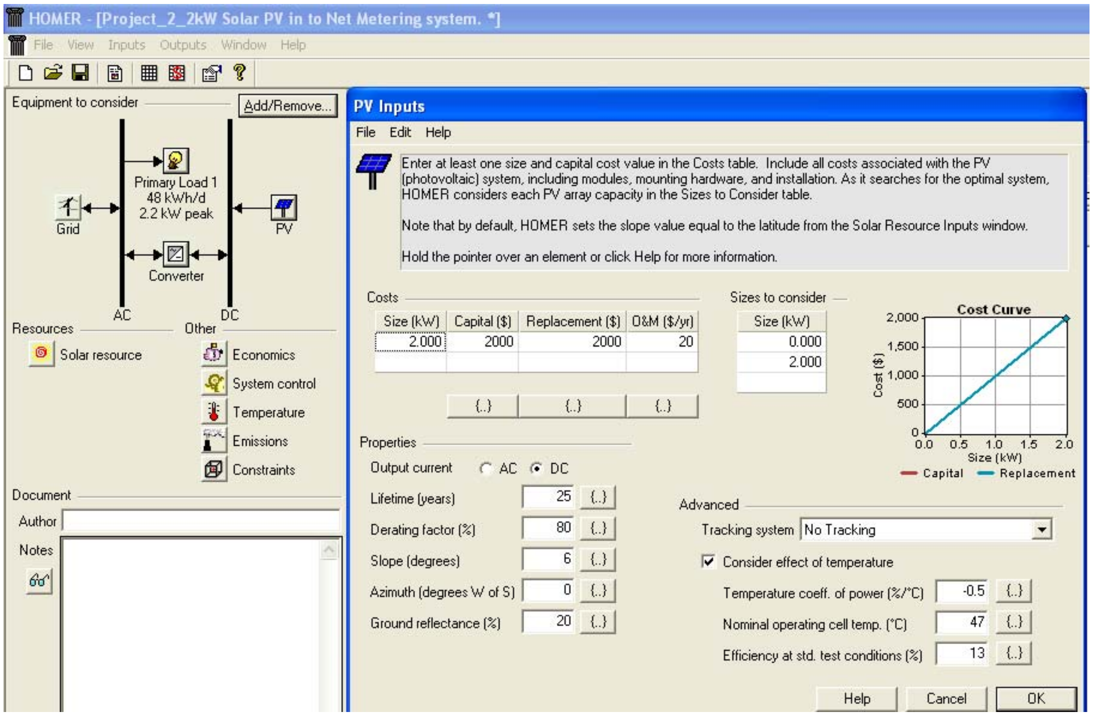


Figure 4.8.2.1- System configuration and Solar PV data for panel size of 2kW.

Solar resource data for the evaluation is taken from NASA Surface meteorology and Solar Energy data tables and daily load curves of the site is taken with the average constant load of 2kW and applicable tariff rate (i.e. GP1) remains same as earlier.

Hence, outcome of the HOMER simulation for the size of 2kW Solar PV Integration in to Grid tie inverter system for Net Metering for this site is shown in Figure 4.8.2.2.

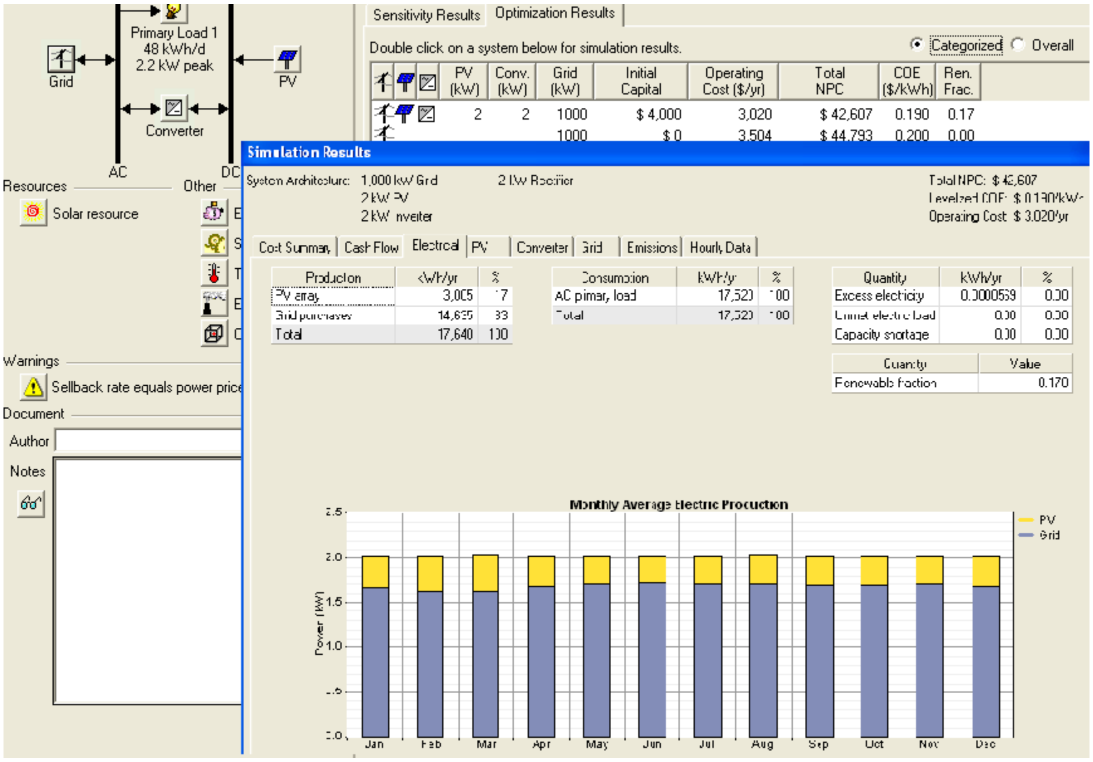


Figure 4.8.2.2- Annual output summary simulated through HOMER software of 2kW Solar PV integration to Grid tie inverter system for Net Metering.

This implies the renewable energy fraction of the design is 17% out of total energy consumption.

4.8.3 Case 3: Size of 3kW Solar PV integration in to Grid tie inverter for Net Metering.

Figure 4.8.3.1 shows the system configuration and Solar PV panel details of 3kW installed capacity integrated in to Grid tie inverter system to have Net Metering facility.

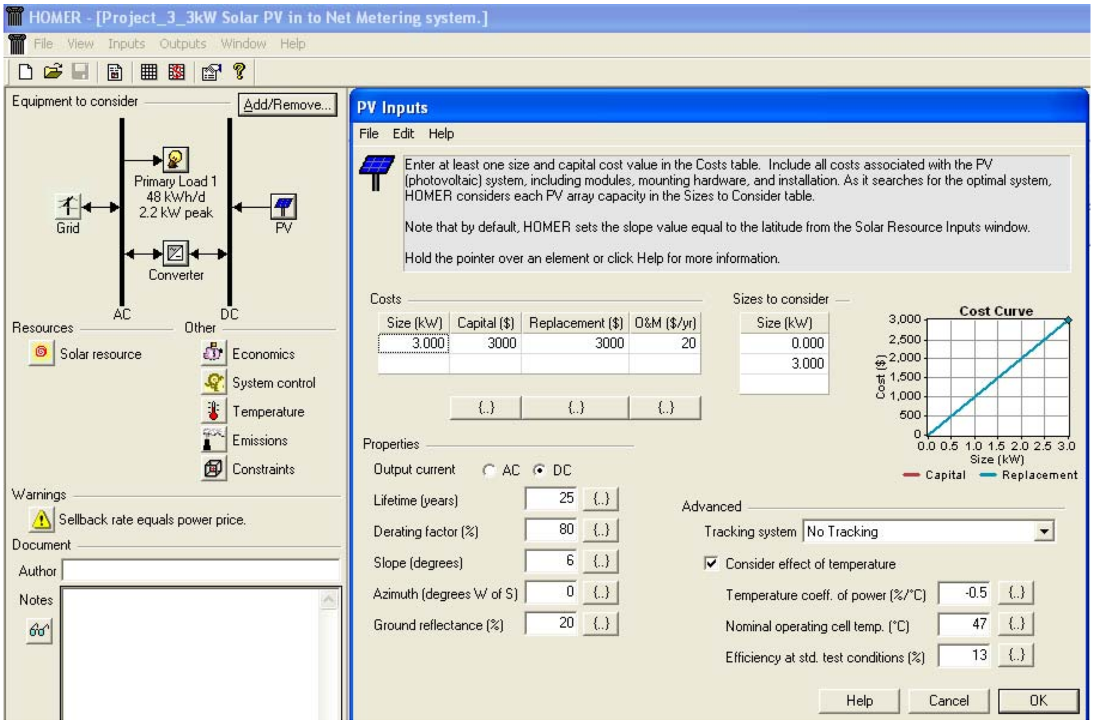


Figure 4.8.3.1- System configuration and Solar PV data for panel size of 3kW.

Solar resource data for the evaluation is taken from NASA Surface meteorology and Solar Energy data tables and daily load curves of the site is taken with the average constant load of 2kW and applicable tariff rate (i.e. GP1) remains same as earlier.

Hence, outcome of the HOMER simulation for the size of 3kW Solar PV Integration in to Grid tie inverter system for Net Metering for this site is shown in Figure 4.8.3.2.

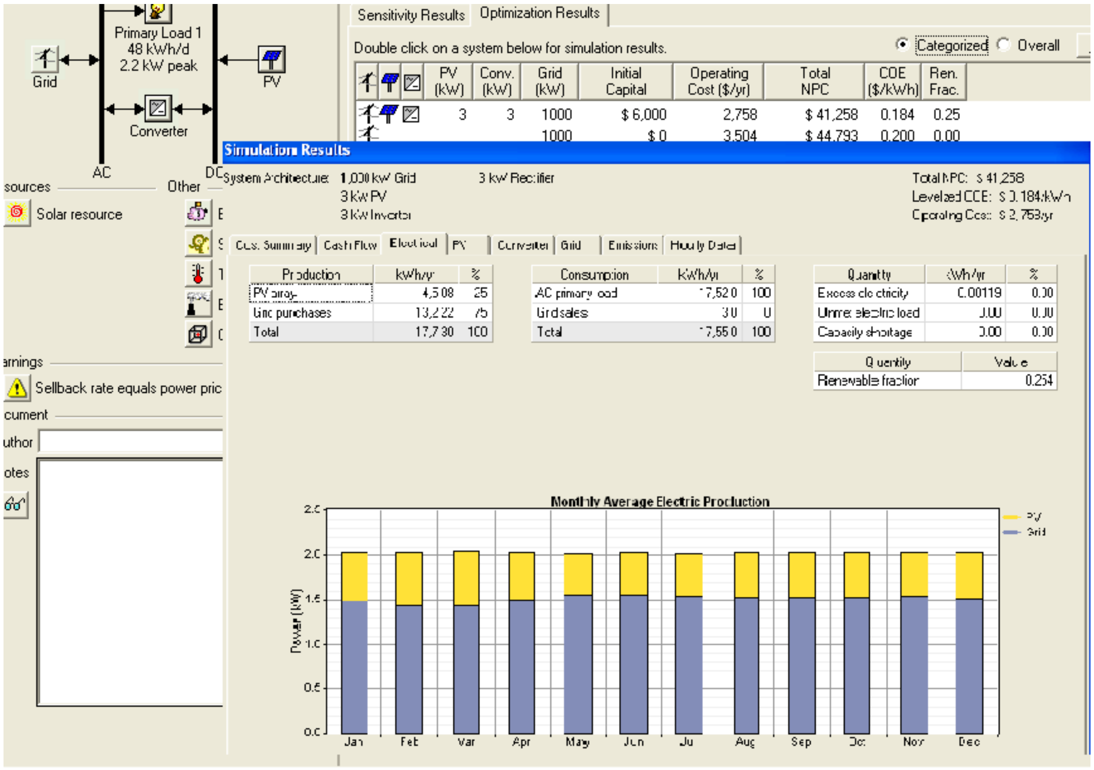


Figure 4.8.3.2- Annual output summary simulated through HOMER software of 3kW Solar PV integration to Grid tie inverter system for Net Metering.

This implies the renewable energy fraction of the design is 25.4% out of total energy consumption.

4.9 Shading Calculations.

Calculation of shading due to tower high and other structures, are essential for the best placements of Solar PV panels to minimize the reductions in output energy due to shading for better energy outputs, though panel wise optimizing technologies are exists, such as Solar PV optimizers or Micro inverter technologies possibility of regaining the benefits of individual Solar PV panel wise controlling against shadings.

4.9.1 Susdesign software for locating Sun positioning.

A software named "Sustainable By Design" shortened in to "Susdesign" is freely available in the web for downloading, developed by Mr. Christopher Gronbeck, a freelance consultant in the renewable energy and green building fields in Seattle, USA.

Sustainable By Design provides a suite of shareware design tools on sustainable energy topics, in here it is interested about "Sun position" where it calculates an array of solar angle data as an altitude and azimuth angles with respect to series of dates and/or times.

- Solar Altitude angle - It describes how high the sun appears in the sky. The angle is measured between an imaginary line between the observer and the sun and the horizontal plane the observer is standing on as shown in Figure 4.9.1.1. Therefore altitude angle is negative when the sun drops below the horizon.

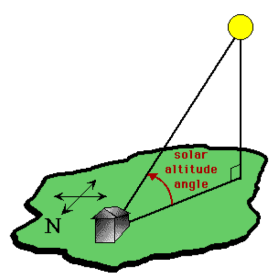


Figure 4.9.1.1 - Solar Altitude angle.

- Solar Azimuth angle - The solar azimuth angle is the angular distance between the zero azimuth (either due South or due North) and the projection of the line of sight to the sun on the ground. The azimuth angle is measured clockwise from the zero azimuth. For example, if you are in the Northern Hemisphere and the zero azimuth is set to South, the azimuth angle value will be negative before solar noon, and positive after solar noon, as shown in Figure 4.9.1.2.

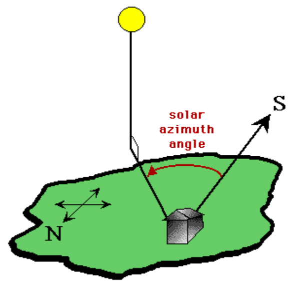


Figure 4.9.1.2 - Solar Azimuth angle.

To calculate the shading on to Solar PV panels from tower or else object, it is needed to consider the Sun's position for all positive altitude angles, same as the Sun above the horizon.

4.9.2 Susdesign software for shading calculations.

For a tower height "h" for an altitude angle (ά) and azimuth angle (β), the instantaneous position of Sun's projection on to the tower is shown below Figure 4.9.2.1.

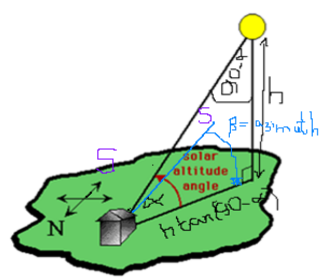


Figure 4.9.2.1- Sun's projection on to the tower.

Therefore shading from tower would be h tan (90- ά) for all positive altitude angles (ά) at the position of azimuth angle (β) in to zero, where it would give maximum shading length since the Sun's projection on to the tower is aligned with the positioning of Solar PV panels on to the direction of South neglecting the panel dimensions with respect to the tower heights. Also there is no shading for an azimuth angle equals to 180 degrees, because of the solar PV panels are positioned between to the Sun and Tower inline.

If panel dimensions are to be considered, it is needed to find respective range of azimuth angles and its corresponding range of altitude angles to find the exact lengths of shading.

As an example, a site located on heart of Colombo with height of 12m at the Latitude 6.54 and Longitude 79.50 is selected.

The Sun position angles of an each hour for every day from the month of January to December for the Latitude 6.54 are calculated by the software and outputs angles are listed down on the Figure 4.9.2.2 below. In here the azimuth angles are measured with respect to the South for clockwise.

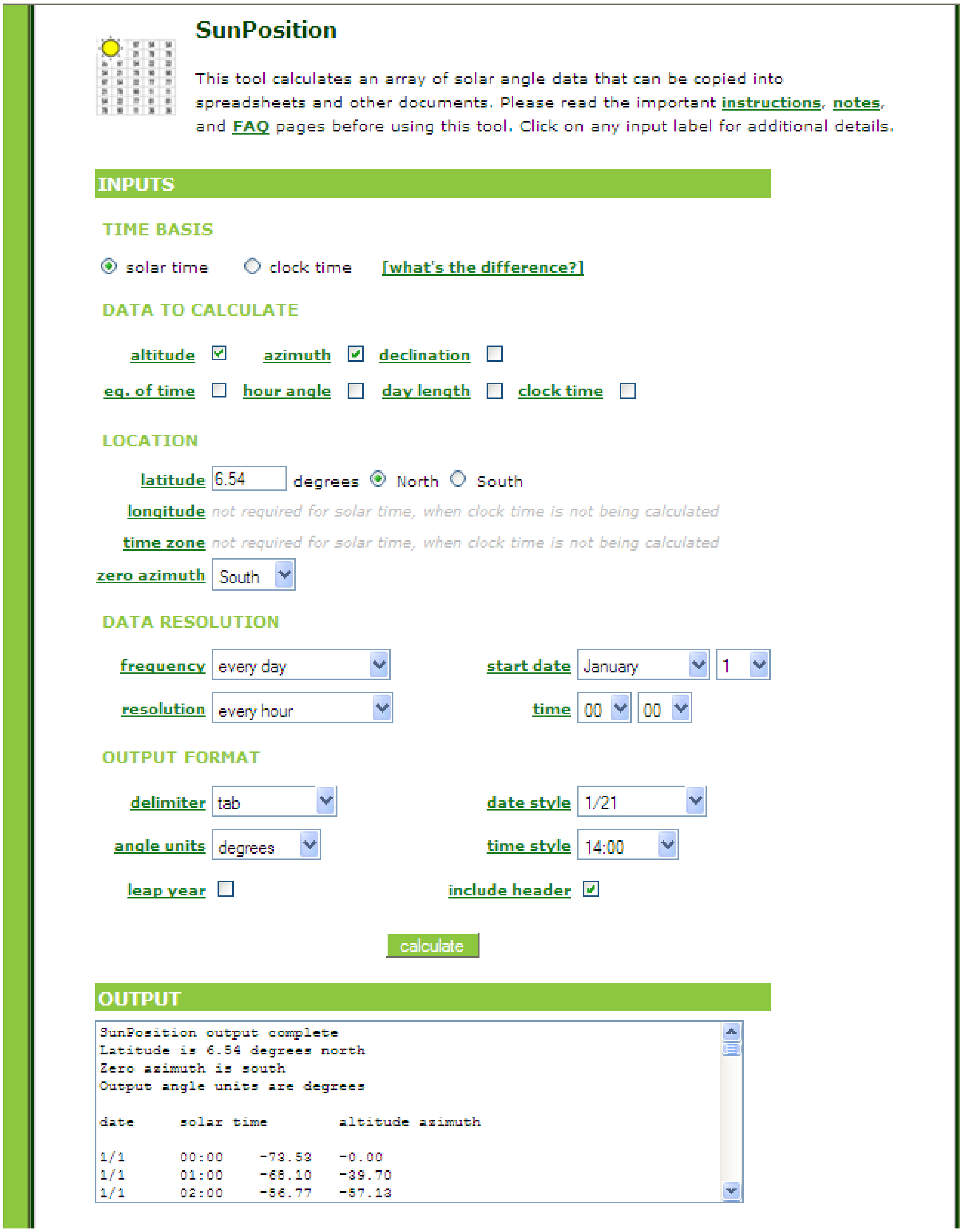


Figure 4.9.2.2 - The Sun position angles of an each hour for every day from the month of January to December for the Latitude 6.54.

The summarized output of shading lengths due to tower are shown in Table 4.9.2.1 below for a typical rooftop tower with height of 12m.

Table 4.9.2.1 - Summarized output of shading lengths due to tower.

date	solar time	altitude angle	azimuth angle (wrt S)	(90- Alti a	Tower Height	Length of Shading
6-Sep	12:00	89.74	0	0.26	12	0.054477
5-Apr	12:00	89.69	0	0.31	12	0.064953
7-Sep	12:00	89.37	0	0.63	12	0.132005
4-Apr	12:00	89.31	0	0.69	12	0.144578
8-Sep	12:00	89	0	1	12	0.209545
3-Apr	12:00	88.93	0	1.07	12	0.224217
9-Sep	12:00	88.62	0	1.38	12	0.289199
2-Apr	12:00	88.55	0	1.45	12	0.303874
10-Sep	12:00	88.24	0	1.76	12	0.368878
17-Dec	12:00	60.09	0	29.91	12	6.906449
25-Dec	12:00	60.08	0	29.92	12	6.909239
18-Dec	12:00	60.06	0	29.94	12	6.91482
24-Dec	12:00	60.05	0	29.95	12	6.917611
19-Dec	12:00	60.04	0	29.96	12	6.920403
20-Dec	12:00	60.03	0	29.97	12	6.923195
23-Dec	12:00	60.03	0	29.97	12	6.923195
21-Dec	12:00	60.02	0	29.98	12	6.925988
22-Dec	12:00	60.02	0	29.98	12	6.925988

This implies, the Solar PV panels are to be kept away 7m away from the tower in line with the directions North & South.

4.10 Payback Analysis for Option 1.

4.10.1 Simple Payback of 1kW Solar PV integration on to a Rectifier System for D1 Tariff rate.

Solar Irradiance in Colombo (Considering monthly average, Pessimistic value) = 4.3 kWh/day/m2.

Average dimension of 250W Solar PV Panel = 1.6m x 1m = 1.6 m2.

Panel Area for 1kW Solar PV Installation = 1.6 m2 x 4 panels = 6.4 m2.

Average Solar PV Module efficiency = 15.1%

Energy output daily = 4.3 kWh/day/m2 x 6.4 m2 x 0.151 = 4.16 kWh/day

Energy output monthly = 4.16 kWh/day x 30days = 124.8 kWh/ month.

Conversion efficiency of 1.5 kW DC/DC Solar PV charger controller = 96.5 %

So energy on to the DC bus = 124.8 kWh/ month x 0.965 = 120 kWh/ month.

Annual Energy on to the DC Bus = 120 kWh/month x 12 months/year = 1440 kWh/annum.

Annual Saving = 1440 kWh/annum x 58 Rs/kWh = 83,520.00 Rs/annum.

Price of 1 kW Solar PV panels = 1000 USD.

Price of 1.5kW Solar PV DC to DC charger controller with MPPT = 750 USD.

No of 1.5kW Solar PV DC to DC charger controller with MPPT required = 1 nos.

Total Investment for 1 kW Solar PV Installation = (1000+750) USD * 130 Rs/ USD = 227,500.00 Rs.

Simple Pay Back = (Total Investment) / (Annual Saving).

= 227,500.00 Rs / 83,520 Rs

= 2.72 years.

Similarly, the simple paybacks of Solar PV integrations on to Rectifier Systems with different capacities of Solar PV array sizing against respective tariff categories are derived and tabulated in Table 4.10.1.1.

Table 4.10.1.1 - Simple Paybacks of Solar PV integrations on to Rectifier System for different tariff categories.

Solar PV integration on to a Rectifier System						
Tariff Category	D1 (58 Rs/kWh)			GP1 (27 Rs/kWh)		
Solar PV Installed Capacity	1kW	2kW	3KW	1kW	2kW	3KW
Solar Irradiance in Colombo (kWh/day/m2)	4.3	4.3	4.3	4.3	4.3	4.3
Panel Area of a 250W Solar PV with average module efficiency 15.1% (m2)	1.6	1.6	1.6	1.6	1.6	1.6
Panel Area required for Solar PV Installation with average module efficiency 15.1% (m2)	6.4	12.8	19.2	6.4	12.8	19.2
Energy output - Daily (kWh/day)	4.16	8.32	12.48	4.16	8.32	12.48
Energy output - Monthly (kWh/month)	124.8	249.6	374.4	127.8	249.6	374.4
Required nos of 1.5 kW DC/DC Solar PV charger controllers with 96.5% efficiency.	1	2	2	1	2	2
Energy on to the DC bus - Monthly (kWh/month)	120	240	360	120	240	360
Energy on to the DC bus - Yearly (kWh/year)	1440	2880	4320	1440	2880	4320
Annual Saving (LKR/year)	83520.00	167040.00	250560.00	38880.00	77760.00	116640.00
Price of 1kW Solar PV Panels (USD)	1000	1000	1000	1000	1000	1000
Price of 1.5kW Solar PV DC to DC charger controller with MPPT	750	750	750	750	750	750
Total Investment (USD)	1750	3500	4500	1750	3500	4500
Total Investment (LKR)	227500.00	455000.00	585000.00	227500.00	455000.00	585000.00
Simple Pay Back = (Total Investment) / (Annual Saving), in years.	2.72	2.72	2.33	5.85	5.85	5.01

Summarized simple payback times for each Solar PV system integrated on to the DC bus are shown in Table 4.10.1.2.

Table 4.10.1.2 - Summarized simple payback times for Solar PV systems integrated on to the DC bus.

Capacity of Solar PV System on to DC Bus	Simple Payback	
	D1 Tariff	GP1 Tariff
1 kW	2.72 years.	5.85 years.
2 kW	2.72 years.	5.85 years.
3 kW	2.33 years.	5.01 years.

4.11 Payback Analysis for Option 2.

4.11.1 Simple Payback of 1kW Solar PV integration in to Grid tie inverter for Net Metering for D1 Tariff rate.

Solar Irradiance in Colombo (Considering monthly average, Pessimistic value) = 4.3 kWh/day/m2.

Average dimension of 250W Solar PV Panel = 1.6m x 1m = 1.6 m2.

Panel Area for 1kW Solar PV Installation = 1.6 m2 x 4 panels = 6.4 m2.

Average Solar PV Module efficiency = 15.1%

Energy output daily = 4.3 kWh/day/m2 x 6.4 m2 x 0.151 = 4.16 kWh/day

Energy output monthly = 4.16 kWh/day x 30days = 124.8 kWh/ month.

DC to A/C Inversion Efficiency of 1kW Grid Tie Inverter = 97%

So energy on to the A/C bus = 124.8 kWh/ month x 0.97 = 120 kWh/ month.

Annual Energy on to the A/C Bus = 120 kWh/month x 12 months/year = 1440 kWh/annum.

Annual Saving = 1440 kWh/annum x 58 Rs/kWh = 83,520.00 Rs/annum.

Price of 1 kW Solar PV panels = 1000 USD.

Price of 1.2 kW DC to A/C Grid tie Inverter with MPPT = 1200 USD.

Total Investment for 1 kW Solar PV Installation = (1000+1200) USD * 130 Rs/ USD = 286,000.00 Rs.

Simple Pay Back = (Total Investment) / (Annual Saving).

= 286,000.00 Rs / 83,520.00 Rs

= 3.42 years.

Similarly, the simple paybacks of Solar PV integration in to Grid tie inverter for Net Metering against different capacities of Solar PV array sizing with respective tariff categories are derived and tabulated in Table 4.10.1.1.

Table 4.11.1.1 - Simple paybacks of Solar PV integration in to Grid tie inverters for Net Metering with different tariff categories.

Solar PV integration in to Grid tie inverter for Net Metering.						
Tariff Category	D1 (58 Rs/kWh)			GP1 (27 Rs/kWh)		
Solar PV Installed Capacity	1kW	2kW	3KW	1kW	2kW	3KW
Solar Irradiance in Colombo (kWh/day/m2)	4.3	4.3	4.3	4.3	4.3	4.3
Panel Area of a 250W Solar PV with average module efficiency 15.1% (m2)	1.6	1.6	1.6	1.6	1.6	1.6
Panel Area required for Solar PV Installation with average module efficiency 15.1% (m2)	6.4	12.8	19.2	6.4	12.8	19.2
Energy output - Daily (kWh/day)	4.16	8.32	12.48	4.16	8.32	12.48
Energy output - Monthly (kWh/month)	124.8	249.6	374.4	127.8	249.6	374.4
Capacity of required DC to A/C Grid Tie Inverter with 97% inversion efficiency (kW)	1	2	3	1	2	3
Energy on to the AC bus - Monthly (kWh/month)	120	240	360	120	240	360
Energy on to the AC bus - Yearly (kWh/year)	1440	2880	4320	1440	2880	4320
Annual Saving (LKR/year)	83520.00	167040.00	250560.00	38880.00	77760.00	116640.00
Price of 1kW Solar PV Panels (USD)	1000	1000	1000	1000	1000	1000
Price of respective capacity of Solar PV DC to A/C Grid Tie Inverter with MPPT.	1200	1600	1900	1200	1600	1900
Total Investment (USD)	2200	3600	4900	2200	3600	4900
Total Investment (LKR)	286000.00	468000.00	637000.00	286000.00	468000.00	637000.00
Simple Pay Back = (Total Investment) / (Annual Saving), in years.	3.42	2.8	2.54	7.36	6.02	5.46

Summarized simple payback times for each Solar PV system integrated in to Grid tie inverter for Net Metering are shown in Table 4.10.1.2.

Table 4.11.1.2 - Summarized simple payback times for Solar PV systems integrated in to Grid tie inverter for Net Metering.

Capacity of Solar PV System in to Grid tie inverter for Net Metering.	Simple Payback	
	D1 Tariff	GP1 Tariff
1 kW	3.42 years.	7.36 years.
2 kW	2.80 years.	6.02 years.
3 kW	2.54 years.	5.46 years.

4.12 Net Present Value (NPV) and Internal Rate of Return (IRR) Analysis.

Net Present Value.

$$NPV = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n}$$

Cn = Cash Flow of the project

n= Period

r = Rate of return (Inflation rate)

- Assume Tariff rates are increased at a rate of 5% per year over the 20 years of period.
- Assume O&M cost remains constant for every year since it is more about Solar PV Panels & Solar PV Charger Controllers.
- Project Loan is obtain for the total project cost, for the period of 6years at interest rate of 12% annum.
- 1 USD is around 130 LKR.

Internal Rate of return is the discount rate (r) where the Net present value (NPV) of the project becomes zero. Therefore, higher the IRR value against present interest rates means a good robust project.

4.12.1 NPV and IRR of 1kW Solar PV integration on to a Rectifier System for D1 Tariff rate.

Annual energy supplied = 4kWh/day x 365days/year = 1460 kWh/year.

Price of 1 kW Solar PV panels = 1000 USD.

Price of 1.5kW Solar PV DC to DC charger controller with MPPT = 750 USD.

No of 1.5kW Solar PV DC to DC charger controller with MPPT required = 1 nos.

Total Investment for 1 kW Solar PV Installation = (1000+750) USD * 130 Rs/ USD = 227,500.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			227500	189583.3	151666.7	113750	75833.33	37916.67
Interest	16% p.a.		36400	30333.33	24266.67	18200	12133.33	6066.67
Loan Capital Repayment			37916.67	37916.67	37916.67	37916.67	37916.67	37916.67
Closing Balance			189583.3	151666.7	113750	75833.33	37916.67	0

Profit and Loss statement with Cash flow.

Year	Energy Supplied (kWh)	Tariff (LKR/kWh)	Revenue, Saving (LKR)	O&M Cost	Loan Interest		NPV (r=10%)	IRR
		5% p.a.					598,405.85	29%
0						-227500.00		
1	1460	50.00	73000	2000	36400	34600.00		
2	1460	52.50	76650	2000	30333.33	44316.67		
3	1460	55.13	80482.5	2000	24266.67	54215.83		
4	1460	57.88	84506.63	2000	18200	64306.63		
5	1460	60.78	88731.96	2000	12133.33	74598.63		
6	1460	63.81	93168.55	2000	6066.67	85101.88		
7	1460	67.00	97826.98	2000		95826.98		
8	1460	70.36	102718.3	2000		100718.33		
9	1460	73.87	107854.2	2000		105854.25		

10	1460	77.57	113247	2000		111246.96
11	1460	81.44	118909.3	2000		116909.31
12	1460	85.52	124854.8	2000		122854.77
13	1460	89.79	131097.5	2000		129097.51
14	1460	94.28	137652.4	2000		135652.39
15	1460	99.00	144535	2000		142535.01
16	1460	103.95	151761.8	2000		149761.76
17	1460	109.14	159349.8	2000		157349.84
18	1460	114.60	167317.3	2000		165317.34
19	1460	120.33	175683.2	2000		173683.20
20	1460	126.35	184467.4	2000		182467.36
21	1460	132.66	193690.7	2000		191690.73
22	1460	139.30	203375.3	2000		201375.27
23	1460	146.26	213544	2000		211544.03
24	1460	153.58	224221.2	2000		222221.23
25	1460	161.25	235432.3	2000		233432.30

4.12.2 NPV and IRR of 2kW Solar PV integration on to a Rectifier System for D1 Tariff rate.

Annual energy supplied = 8kWh/day x 365days/year = 2920kWh/year.

Price of 2 kW Solar PV panels = 2000 USD.

Price of 1.5kW Solar PV DC to DC charger controller with MPPT = 750 USD.

No of 1.5kW Solar PV DC to DC charger controller with MPPT required = 2 nos.

Total Investment for 1 kW Solar PV Installation = (2000+750x2) USD * 130 Rs/ USD = 455,000.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			455000.00	379166.67	303333.33	227500.00	151666.67	75833.33
Interest	16% p.a.		72800.00	60666.67	48533.33	36400.00	24266.67	12133.33
Loan Capital Repayment			75833.33	75833.33	75833.33	75833.33	75833.33	75833.33
Closing Balance			379166.67	303333.33	227500.00	151666.67	75833.33	0.00

Profit and Loss statement with Cash flow.

Year	Energy Supplied (kWh)	Tariff (LKR/kWh)	Revenue, Saving (LKR)	O&M Cost	Loan Interest		NPV (r=10%)	IRR
		5% p.a.					1,213,315.41	29%
0						-455000.00		
1	2920	50.00	146000	2000	72800	71200.00		
2	2920	52.50	153300	2000	60666.67	90633.33		
3	2920	55.13	160965	2000	48533.33	110431.67		
4	2920	57.88	169013.3	2000	36400	130613.25		
5	2920	60.78	177463.9	2000	24266.67	151197.24		
6	2920	63.81	186337.1	2000	12133.33	172203.78		
7	2920	67.00	195654	2000		193653.96		
8	2920	70.36	205436.7	2000		203436.66		
9	2920	73.87	215708.5	2000		213708.49		
10	2920	77.57	226493.9	2000		224493.92		
11	2920	81.44	237818.6	2000		235818.62		
12	2920	85.52	249709.5	2000		247709.55		
13	2920	89.79	262195	2000		260195.02		
14	2920	94.28	275304.8	2000		273304.77		
15	2920	99.00	289070	2000		287070.01		
16	2920	103.95	303523.5	2000		301523.51		
17	2920	109.14	318699.7	2000		316699.69		
18	2920	114.60	334634.7	2000		332634.67		
19	2920	120.33	351366.4	2000		349366.41		
20	2920	126.35	368934.7	2000		366934.73		
21	2920	132.66	387381.5	2000		385381.46		
22	2920	139.30	406750.5	2000		404750.54		
23	2920	146.26	427088.1	2000		425088.07		
24	2920	153.58	448442.5	2000		446442.47		
25	2920	161.25	470864.6	2000		468864.59		

4.12.3 NPV and IRR of 3kW Solar PV integration on to a Rectifier System for D1 Tariff rate.

Annual energy supplied = 12kWh/day x 365days/year = 4380 kWh/year.

Price of 3 kW Solar PV panels = 3000 USD.

Price of 1.5kW Solar PV DC to DC charger controller with MPPT = 750 USD.

No of 1.5kW Solar PV DC to DC charger controller with MPPT required = 2 nos.

Total Investment for 3 kW Solar PV Installation = (3000+750 x 2) USD * 130 Rs/ USD = 585,000.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			585000.00	487500.00	390000.00	292500.00	195000.00	97500.00
Interest	16% p.a.		93600.00	78000.00	62400.00	46800.00	31200.00	15600.00
Loan Capital Repayment			97500.00	97500.00	97500.00	97500.00	97500.00	97500.00
Closing Balance			487500.00	390000.00	292500.00	195000.00	97500.00	0.00

Profit and Loss statement with Cash flow.

Year	Energy Supplied (kWh)	Tariff (LKR/kWh)	Revenue, Saving (LKR)	O&M Cost	Loan Interest		NPV (r=10%)	IRR
		5% p.a.					1,955,736.99	34%
0						-585000.00		
1	4380	50.00	219000	2000	93600	123400.00		
2	4380	52.50	229950	2000	78000	149950.00		
3	4380	55.13	241447.5	2000	62400	177047.50		
4	4380	57.88	253519.9	2000	46800	204719.88		
5	4380	60.78	266195.9	2000	31200	232995.87		
6	4380	63.81	279505.7	2000	15600	261905.66		
7	4380	67.00	293480.9	2000		291480.95		
8	4380	70.36	308155	2000		306154.99		
9	4380	73.87	323562.7	2000		321562.74		
10	4380	77.57	339740.9	2000		337740.88		
11	4380	81.44	356727.9	2000		354727.92		
12	4380	85.52	374564.3	2000		372564.32		
13	4380	89.79	393292.5	2000		391292.54		
14	4380	94.28	412957.2	2000		410957.16		
15	4380	99.00	433605	2000		431605.02		
16	4380	103.95	455285.3	2000		453285.27		
17	4380	109.14	478049.5	2000		476049.53		
18	4380	114.60	501952	2000		499952.01		
19	4380	120.33	527049.6	2000		525049.61		
20	4380	126.35	553402.1	2000		551402.09		
21	4380	132.66	581072.2	2000		579072.20		

22	4380	139.30	610125.8	2000		608125.81
23	4380	146.26	640632.1	2000		638632.10
24	4380	153.58	672663.7	2000		670663.70
25	4380	161.25	706296.9	2000		704296.89

4.12.4 NPV and IRR of 1kW Solar PV integration on to a Rectifier System for GP1 Tariff rate.

Annual energy supplied = 4kWh/day x 365days/year = 1460 kWh/year.

Price of 1 kW Solar PV panels = 1000 USD.

Price of 1.5kW Solar PV DC to DC charger controller with MPPT = 750 USD.

No of 1.5kW Solar PV DC to DC charger controller with MPPT required = 1 nos.

Total Investment for 1 kW Solar PV Installation = (1000+750) USD * 130 Rs/ USD = 227,500.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			227500.00	189583.33	151666.67	113750.00	75833.33	37916.67
Interest	16% p.a.		36400.00	30333.33	24266.67	18200.00	12133.33	6066.67
Loan Capital Repayment			37916.67	37916.67	37916.67	37916.67	37916.67	37916.67
Closing Balance			189583.33	151666.67	113750.00	75833.33	37916.67	0.00

Profit and Loss statement with Cash flow.

Year	Energy Supplied (kWh)	Tariff (LKR/kWh)	Revenue, Saving (LKR)	O&M Cost	Loan Interest		NPV (r=10%)	IRR
		5% p.a.					178,684.55	16%
0						-227500.00		
1	1460	27.00	39420	2000	36400	1020.00		
2	1460	28.35	41391	2000	30333.33	9057.67		
3	1460	29.77	43460.55	2000	24266.67	17193.88		

4	1460	31.26	45633.58	2000	18200	25433.58
5	1460	32.82	47915.26	2000	12133.33	33781.93
6	1460	34.46	50311.02	2000	6066.67	42244.35
7	1460	36.18	52826.57	2000		50826.57
8	1460	37.99	55467.9	2000		53467.90
9	1460	39.89	58241.29	2000		56241.29
10	1460	41.89	61153.36	2000		59153.36
11	1460	43.98	64211.03	2000		62211.03
12	1460	46.18	67421.58	2000		65421.58
13	1460	48.49	70792.66	2000		68792.66
14	1460	50.91	74332.29	2000		72332.29
15	1460	53.46	78048.9	2000		76048.90
16	1460	56.13	81951.35	2000		79951.35
17	1460	58.94	86048.92	2000		84048.92
18	1460	61.88	90351.36	2000		88351.36
19	1460	64.98	94868.93	2000		92868.93
20	1460	68.23	99612.38	2000		97612.38
21	1460	71.64	104593	2000		102593.00
22	1460	75.22	109822.6	2000		107822.65
23	1460	78.98	115313.8	2000		113313.78
24	1460	82.93	121079.5	2000		119079.47
25	1460	87.08	127133.4	2000		125133.44

4.12.5 NPV and IRR of 2kW Solar PV integration on to a Rectifier System for GP1 Tariff rate.

Annual energy supplied = 8kWh/day x 365days/year = 2920kWh/year.

Price of 2 kW Solar PV panels = 2000 USD.

Price of 1.5kW Solar PV DC to DC charger controller with MPPT = 750 USD.

No of 1.5kW Solar PV DC to DC charger controller with MPPT required = 2 nos.

Total Investment for 1 kW Solar PV Installation = (2000+750x2) USD * 130 Rs/ USD = 455,000.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			455000.00	379166.67	303333.33	227500.00	151666.67	75833.33
Interest	16% p.a.		72800.00	60666.67	48533.33	36400.00	24266.67	12133.33
Loan Capital Repayment			75833.33	75833.33	75833.33	75833.33	75833.33	75833.33
Closing Balance			379166.67	303333.33	227500.00	151666.67	75833.33	0.00

Profit and Loss statement with Cash flow.

Year	Energy Supplied (kWh)	Tariff (LKR/kWh)	Revenue, Saving (LKR)	O&M Cost	Loan Interest		NPV (r=10%)	IRR
		5% p.a.					373,872.81	16%
0						-455000.00		
1	2920	27.00	78840	2000	72800	4040.00		
2	2920	28.35	82782	2000	60666.67	20115.33		
3	2920	29.77	86921.1	2000	48533.33	36387.77		
4	2920	31.26	91267.16	2000	36400	52867.16		
5	2920	32.82	95830.51	2000	24266.67	69563.84		
6	2920	34.46	100622	2000	12133.33	86488.71		
7	2920	36.18	105653.1	2000		103653.14		
8	2920	37.99	110935.8	2000		108935.80		
9	2920	39.89	116482.6	2000		114482.59		
10	2920	41.89	122306.7	2000		120306.72		
11	2920	43.98	128422.1	2000		126422.05		
12	2920	46.18	134843.2	2000		132843.15		
13	2920	48.49	141585.3	2000		139585.31		
14	2920	50.91	148664.6	2000		146664.58		
15	2920	53.46	156097.8	2000		154097.81		
16	2920	56.13	163902.7	2000		161902.70		
17	2920	58.94	172097.8	2000		170097.83		
18	2920	61.88	180702.7	2000		178702.72		
19	2920	64.98	189737.9	2000		187737.86		
20	2920	68.23	199224.8	2000		197224.75		
21	2920	71.64	209186	2000		207185.99		
22	2920	75.22	219645.3	2000		217645.29		
23	2920	78.98	230627.6	2000		228627.56		
24	2920	82.93	242158.9	2000		240158.93		
25	2920	87.08	254266.9	2000		252266.88		

4.12.6 NPV and IRR of 3kW Solar PV integration on to a Rectifier System for GP1 Tariff rate.

Annual energy supplied = 12kWh/day x 365days/year = 4380 kWh/year.

Price of 3 kW Solar PV panels = 3000 USD.

Price of 1.5kW Solar PV DC to DC charger controller with MPPT = 750 USD.

No of 1.5kW Solar PV DC to DC charger controller with MPPT required = 2 nos.

Total Investment for 3 kW Solar PV Installation = (3000+750 x 2) USD * 130 Rs/ USD = 585,000.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			585000.00	487500.00	390000.00	292500.00	195000.00	97500.00
Interest	16% p.a.		93600.00	78000.00	62400.00	46800.00	31200.00	15600.00
Loan Capital Repayment			97500.00	97500.00	97500.00	97500.00	97500.00	97500.00
Closing Balance			487500.00	390000.00	292500.00	195000.00	97500.00	0.00

Profit and Loss statement with Cash flow.

Year	Energy Supplied (kWh)	Tariff (LKR/kWh)	Revenue, Saving (LKR)	O&M Cost	Loan Interest		NPV (r=10%)	IRR
		5% p.a.					696,573.09	19%
0						-585000.00		
1	4380	27.00	118260	2000	93600	22660.00		
2	4380	28.35	124173	2000	78000	44173.00		
3	4380	29.77	130381.7	2000	62400	65981.65		
4	4380	31.26	136900.7	2000	46800	88100.73		
5	4380	32.82	143745.8	2000	31200	110545.77		
6	4380	34.46	150933.1	2000	15600	133333.06		
7	4380	36.18	158479.7	2000		156479.71		
8	4380	37.99	166403.7	2000		164403.70		
9	4380	39.89	174723.9	2000		172723.88		

10	4380	41.89	183460.1	2000		181460.07
11	4380	43.98	192633.1	2000		190633.08
12	4380	46.18	202264.7	2000		200264.73
13	4380	48.49	212378	2000		210377.97
14	4380	50.91	222996.9	2000		220996.87
15	4380	53.46	234146.7	2000		232146.71
16	4380	56.13	245854	2000		243854.05
17	4380	58.94	258146.7	2000		256146.75
18	4380	61.88	271054.1	2000		269054.09
19	4380	64.98	284606.8	2000		282606.79
20	4380	68.23	298837.1	2000		296837.13
21	4380	71.64	313779	2000		311778.99
22	4380	75.22	329467.9	2000		327467.94
23	4380	78.98	345941.3	2000		343941.33
24	4380	82.93	363238.4	2000		361238.40
25	4380	87.08	381400.3	2000		379400.32

Summarized NPVs and IRRs according to the D1 and GP1 tariff rates for each Solar PV system integrated on to the DC bus are shown in Table 4.12.6.1.

Table 4.12.6.1- Summarized NPVs and IRRs according to the D1 and GP1 tariff rates for Solar PV systems integrated on to the DC bus.

Capacity of Solar PV System on to DC Bus	D1 Tariff (5% increment p.a.)		GP1 Tariff (5% increment p.a.)	
	NPV in LKR (r=10% p.a.)	IRR	NPV in LKR (r=10% p.a.)	IRR
1 kW	598,405.85	29%	178,684.55	16%
2 kW	1,213,315.41	29%	373,872.81	16%
3 kW	1,955,736.99	34%	696,573.09	19%

4.12.7 NPV and IRR of 1kW Solar PV integration in to Grid tie inverter for Net Metering for D1 Tariff rate.

Annual energy supplied = 4kWh/day x 365days/year = 1460 kWh/year.

Price of 1 kW Solar PV panels = 1000 USD.

Price of 1.2 kW DC to A/C Grid tie Inverter with MPPT = 1200 USD.

Total Investment for 1 kW Solar PV Installation = (1000+1200) USD * 130 Rs/ USD = 286,000.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			286000.00	238333.33	190666.67	143000.00	95333.33	47666.67
Interest	16% p.a.		45760.00	38133.33	30506.67	22880.00	15253.33	7626.67
Loan Capital Repayment			47666.67	47666.67	47666.67	47666.67	47666.67	47666.67
Closing Balance			238333.33	190666.67	143000.00	95333.33	47666.67	0.00

Profit and Loss statement with Cash flow.

Year	Energy Supplied (kWh)	Tariff (LKR/kWh)	Revenue, Saving (LKR)	O&M Cost	Loan Interest		NPV (r=10%)	IRR
		5% p.a.					521,898.64	23%
0						-286000.00		
1	1460	50.00	73000	2000	45760	25240.00		
2	1460	52.50	76650	2000	38133.33	36516.67		
3	1460	55.13	80482.5	2000	30506.67	47975.83		
4	1460	57.88	84506.63	2000	22880	59626.63		
5	1460	60.78	88731.96	2000	15253.33	71478.63		
6	1460	63.81	93168.55	2000	7626.67	83541.88		
7	1460	67.00	97826.98	2000		95826.98		
8	1460	70.36	102718.3	2000		100718.33		
9	1460	73.87	107854.2	2000		105854.25		
10	1460	77.57	113247	2000		111246.96		
11	1460	81.44	118909.3	2000		116909.31		

12	1460	85.52	124854.8	2000		122854.77
13	1460	89.79	131097.5	2000		129097.51
14	1460	94.28	137652.4	2000		135652.39
15	1460	99.00	144535	2000		142535.01
16	1460	103.95	151761.8	2000		149761.76
17	1460	109.14	159349.8	2000		157349.84
18	1460	114.60	167317.3	2000		165317.34
19	1460	120.33	175683.2	2000		173683.20
20	1460	126.35	184467.4	2000		182467.36
21	1460	132.66	193690.7	2000		191690.73
22	1460	139.30	203375.3	2000		201375.27
23	1460	146.26	213544	2000		211544.03
24	1460	153.58	224221.2	2000		222221.23
25	1460	161.25	235432.3	2000		233432.30

4.12.8 NPV and IRR of 2kW Solar PV integration in to Grid tie inverter for Net Metering for D1 Tariff rate.

Annual energy supplied = 8kWh/day x 365days/year = 2920kWh/year.

Price of 2 kW Solar PV panels = 2000 USD.

Price of 2 kW DC to A/C Grid tie Inverter with MPPT = 1600 USD.

Total Investment for 2 kW Solar PV Installation = (2000+1600) USD * 130 Rs/ USD = 468,000.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			468000.00	390000.00	312000.00	234000.00	156000.00	78000.00
Interest	16% p.a.		74880.00	62400.00	49920.00	37440.00	24960.00	12480.00
Loan Capital Repayment			78000.00	78000.00	78000.00	78000.00	78000.00	78000.00
Closing Balance			390000.00	312000.00	234000.00	156000.00	78000.00	0.00

Profit and Loss statement with Cash flow.

Year	Energy Supplied (kWh)	Tariff (LKR/kWh)	Revenue, Saving (LKR)	O&M Cost	Loan Interest		NPV (r=10%)	IRR
		5% p.a.					1,196,313.81	28%
0						-468000.00		
1	2920	50.00	146000	2000	74880	69120.00		
2	2920	52.50	153300	2000	62400	88900.00		
3	2920	55.13	160965	2000	49920	109045.00		
4	2920	57.88	169013.3	2000	37440	129573.25		
5	2920	60.78	177463.9	2000	24960	150503.91		
6	2920	63.81	186337.1	2000	12480	171857.11		
7	2920	67.00	195654	2000		193653.96		
8	2920	70.36	205436.7	2000		203436.66		
9	2920	73.87	215708.5	2000		213708.49		
10	2920	77.57	226493.9	2000		224493.92		
11	2920	81.44	237818.6	2000		235818.62		
12	2920	85.52	249709.5	2000		247709.55		
13	2920	89.79	262195	2000		260195.02		
14	2920	94.28	275304.8	2000		273304.77		
15	2920	99.00	289070	2000		287070.01		
16	2920	103.95	303523.5	2000		301523.51		
17	2920	109.14	318699.7	2000		316699.69		
18	2920	114.60	334634.7	2000		332634.67		
19	2920	120.33	351366.4	2000		349366.41		
20	2920	126.35	368934.7	2000		366934.73		
21	2920	132.66	387381.5	2000		385381.46		
22	2920	139.30	406750.5	2000		404750.54		
23	2920	146.26	427088.1	2000		425088.07		
24	2920	153.58	448442.5	2000		446442.47		
25	2920	161.25	470864.6	2000		468864.59		

4.12.9 NPV and IRR of 3kW Solar PV integration in to Grid tie inverter for Net Metering for D1 Tariff rate.

Annual energy supplied = 12kWh/day x 365days/year = 4380kWh/year .

Price of 3 kW Solar PV panels = 3000 USD.

Price of 3 kW DC to A/C Grid tie Inverter with MPPT = 1900 USD.

Total Investment for 3 kW Solar PV Installation = (3000+1900) USD * 130 Rs/ USD = 637,000.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			637000.00	530833.33	424666.67	318500.00	212333.33	106166.67
Interest	16% p.a.		101920.00	84933.33	67946.67	50960.00	33973.33	16986.67
Loan Capital Repayment			106166.67	106166.67	106166.67	106166.67	106166.67	106166.67
Closing Balance			530833.33	424666.67	318500.00	212333.33	106166.67	0.00

Profit and Loss statement with Cash flow.

Year	Energy Supplied (kWh)	Tariff (LKR/kWh)	Revenue, Saving (LKR)	O&M Cost	Loan Interest		NPV (r=10%)	IRR
		5% p.a.					1,887,730.58	31%
0						-637000.00		
1	4380	50.00	219000	2000	101920	115080.00		
2	4380	52.50	229950	2000	84933.33	143016.67		
3	4380	55.13	241447.5	2000	67946.67	171500.83		
4	4380	57.88	253519.9	2000	50960	200559.88		
5	4380	60.78	266195.9	2000	33973.33	230222.54		
6	4380	63.81	279505.7	2000	16986.67	260518.99		
7	4380	67.00	293480.9	2000		291480.95		
8	4380	70.36	308155	2000		306154.99		
9	4380	73.87	323562.7	2000		321562.74		
10	4380	77.57	339740.9	2000		337740.88		
11	4380	81.44	356727.9	2000		354727.92		
12	4380	85.52	374564.3	2000		372564.32		
13	4380	89.79	393292.5	2000		391292.54		
14	4380	94.28	412957.2	2000		410957.16		
15	4380	99.00	433605	2000		431605.02		
16	4380	103.95	455285.3	2000		453285.27		
17	4380	109.14	478049.5	2000		476049.53		
18	4380	114.60	501952	2000		499952.01		
19	4380	120.33	527049.6	2000		525049.61		
20	4380	126.35	553402.1	2000		551402.09		
21	4380	132.66	581072.2	2000		579072.20		
22	4380	139.30	610125.8	2000		608125.81		
23	4380	146.26	640632.1	2000		638632.10		
24	4380	153.58	672663.7	2000		670663.70		
25	4380	161.25	706296.9	2000		704296.89		

4.12.10 NPV and IRR of 1kW Solar PV integration in to Grid tie inverter for Net Metering for GP-1 Tariff rate.

Annual energy supplied = 4kWh/day x 365days/year = 1460 kWh/year.

Price of 1 kW Solar PV panels = 1000 USD.

Price of 1.2 kW DC to A/C Grid tie Inverter with MPPT = 1200 USD.

Total Investment for 1 kW Solar PV Installation = (1000+1200) USD * 130 Rs/ USD = 286,000.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			286000.00	238333.33	190666.67	143000.00	95333.33	47666.67
Interest	16% p.a.		45760.00	38133.33	30506.67	22880.00	15253.33	7626.67
Loan Capital Repayment			47666.67	47666.67	47666.67	47666.67	47666.67	47666.67
Closing Balance			238333.33	190666.67	143000.00	95333.33	47666.67	0.00

Profit and Loss statement with Cash flow.

Year	Energy Supplied (kWh)	Tariff (LKR/kWh)	Revenue, Saving (LKR)	O&M Cost	Loan Interest		NPV (r=10%)	IRR
		5% p.a.					102,177.34	13%
0						-286000.00		
1	1460	27.00	39420	2000	45760	-8340.00		
2	1460	28.35	41391	2000	38133.33	1257.67		
3	1460	29.77	43460.55	2000	30506.67	10953.88		
4	1460	31.26	45633.58	2000	22880	20753.58		
5	1460	32.82	47915.26	2000	15253.33	30661.93		
6	1460	34.46	50311.02	2000	7626.67	40684.35		
7	1460	36.18	52826.57	2000		50826.57		
8	1460	37.99	55467.9	2000		53467.90		
9	1460	39.89	58241.29	2000		56241.29		
10	1460	41.89	61153.36	2000		59153.36		
11	1460	43.98	64211.03	2000		62211.03		

12	1460	46.18	67421.58	2000		65421.58
13	1460	48.49	70792.66	2000		68792.66
14	1460	50.91	74332.29	2000		72332.29
15	1460	53.46	78048.9	2000		76048.90
16	1460	56.13	81951.35	2000		79951.35
17	1460	58.94	86048.92	2000		84048.92
18	1460	61.88	90351.36	2000		88351.36
19	1460	64.98	94868.93	2000		92868.93
20	1460	68.23	99612.38	2000		97612.38
21	1460	71.64	104593	2000		102593.00
22	1460	75.22	109822.6	2000		107822.65
23	1460	78.98	115313.8	2000		113313.78
24	1460	82.93	121079.5	2000		119079.47
25	1460	87.08	127133.4	2000		125133.44

4.12.11 NPV and IRR of 2kW Solar PV integration in to Grid tie inverter for Net Metering for GP-1 Tariff rate.

Annual energy supplied = 8kWh/day x 365days/year = 2920kWh/year.

Price of 2 kW Solar PV panels = 2000 USD.

Price of 2 kW DC to A/C Grid tie Inverter with MPPT = 1600 USD.

Total Investment for 2 kW Solar PV Installation = (2000+1600) USD * 130 Rs/ USD = 468,000.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			468000.00	390000.00	312000.00	234000.00	156000.00	78000.00
Interest	16% p.a.		74880.00	62400.00	49920.00	37440.00	24960.00	12480.00
Loan Capital Repayment			78000.00	78000.00	78000.00	78000.00	78000.00	78000.00
Closing Balance			390000.00	312000.00	234000.00	156000.00	78000.00	0.00

Profit and Loss statement with Cash flow.

Year	Energy Supplied (kWh)	Tariff (LKR/kWh)	Revenue, Saving (LKR)	O&M Cost	Loan Interest		NPV (r=10%)	IRR
		5% p.a.					356,871.21	16%
0						-468000.00		
1	2920	27.00	78840	2000	74880	1960.00		
2	2920	28.35	82782	2000	62400	18382.00		
3	2920	29.77	86921.1	2000	49920	35001.10		
4	2920	31.26	91267.16	2000	37440	51827.16		
5	2920	32.82	95830.51	2000	24960	68870.51		
6	2920	34.46	100622	2000	12480	86142.04		
7	2920	36.18	105653.1	2000		103653.14		
8	2920	37.99	110935.8	2000		108935.80		
9	2920	39.89	116482.6	2000		114482.59		
10	2920	41.89	122306.7	2000		120306.72		
11	2920	43.98	128422.1	2000		126422.05		
12	2920	46.18	134843.2	2000		132843.15		
13	2920	48.49	141585.3	2000		139585.31		
14	2920	50.91	148664.6	2000		146664.58		
15	2920	53.46	156097.8	2000		154097.81		
16	2920	56.13	163902.7	2000		161902.70		
17	2920	58.94	172097.8	2000		170097.83		
18	2920	61.88	180702.7	2000		178702.72		
19	2920	64.98	189737.9	2000		187737.86		
20	2920	68.23	199224.8	2000		197224.75		
21	2920	71.64	209186	2000		207185.99		
22	2920	75.22	219645.3	2000		217645.29		
23	2920	78.98	230627.6	2000		228627.56		
24	2920	82.93	242158.9	2000		240158.93		
25	2920	87.08	254266.9	2000		252266.88		

4.12.12 NPV and IRR of 3kW Solar PV integration in to Grid tie inverter for Net Metering for GP-1 Tariff rate.

Annual energy supplied = 12kWh/day x 365days/year = 4380kWh/year .

Price of 3 kW Solar PV panels = 3000 USD.

Price of 3 kW DC to A/C Grid tie Inverter with MPPT = 1900 USD.

Total Investment for 3 kW Solar PV Installation = (3000+1900) USD * 130 Rs/ USD = 637,000.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			637000.00	530833.33	424666.67	318500.00	212333.33	106166.67
Interest	16% p.a.		101920.00	84933.33	67946.67	50960.00	33973.33	16986.67
Loan Capital Repayment			106166.67	106166.67	106166.67	106166.67	106166.67	106166.67
Closing Balance			530833.33	424666.67	318500.00	212333.33	106166.67	0.00

Profit and Loss statement with Cash flow.

Year	Energy Supplied (kWh)	Tariff (LKR/kWh)	Revenue, Saving (LKR)	O&M Cost	Loan Interest		NPV (r=10%)	IRR
		5% p.a.					628,566.68	18%
0						-637000.00		
1	4380	27.00	118260	2000	101920	14340.00		
2	4380	28.35	124173	2000	84933.33	37239.67		
3	4380	29.77	130381.7	2000	67946.67	60434.98		
4	4380	31.26	136900.7	2000	50960	83940.73		
5	4380	32.82	143745.8	2000	33973.33	107772.44		
6	4380	34.46	150933.1	2000	16986.67	131946.39		
7	4380	36.18	158479.7	2000		156479.71		
8	4380	37.99	166403.7	2000		164403.70		
9	4380	39.89	174723.9	2000		172723.88		
10	4380	41.89	183460.1	2000		181460.07		
11	4380	43.98	192633.1	2000		190633.08		
12	4380	46.18	202264.7	2000		200264.73		
13	4380	48.49	212378	2000		210377.97		
14	4380	50.91	222996.9	2000		220996.87		
15	4380	53.46	234146.7	2000		232146.71		
16	4380	56.13	245854	2000		243854.05		
17	4380	58.94	258146.7	2000		256146.75		
18	4380	61.88	271054.1	2000		269054.09		
19	4380	64.98	284606.8	2000		282606.79		
20	4380	68.23	298837.1	2000		296837.13		
21	4380	71.64	313779	2000		311778.99		
22	4380	75.22	329467.9	2000		327467.94		
23	4380	78.98	345941.3	2000		343941.33		
24	4380	82.93	363238.4	2000		361238.40		
25	4380	87.08	381400.3	2000		379400.32		

Summarized NPVs and IRRs according to the D1 and GP1 tariff rates for each Solar PV system integrated in to Grid tie inverter for Net Metering are shown in Table 4.12.12.1.

Table 4.12.12.1 - Summarized NPVs and IRRs according to the D1 and GP1 tariff rates for Solar PV systems integrated in to Grid tie inverter for Net Metering.

Capacity of Solar PV System in to Grid tie inverter for Net Metering	D1 Tariff (5% increment p.a.)		GP1 Tariff (5% increment p.a.)	
	NPV in LKR (r=10% p.a.)	IRR	NPV in LKR (r=10% p.a.)	IRR
1 kW	521,898.64	23%	102,177.34	13%
2 kW	1,196,313.81	28%	356,871.21	16%
3 kW	1,887,730.58	31%	628,566.68	18%

4.13 Sensitivity analysis of finding NPV and IRR for varying electricity tariff rates, and reduced life span in practical environmental conditions.

It is considered , 5% increment of tariff per annum for both D1 and GP1 during NPV and IRR calculations for Solar PV integration in to DC bus and Solar PV integrated in to Grid tie inverter for Net Metering.

But Sri Lankan context, electricity tariff rate for GP-1 is reduced by 15% at end of 2014, may be of adding substantial capacity of cheap coal power generation in to the grid against expensive fossil fuel generation. Under new government formed in 2015, it can be expected this electricity tariff remains constant for another 5 years, and 5% increment beyond that.

Due to actual environmental conditions in tropics, it can be assumed that the good quality solar PV panel performs maximum 10 years with acceptable generation against its rated capacity.

Since the applicable electricity tariff rate for telecom service industry for its BTS sites is GP1, it is worthy to calculate NPV and IRR for aforesaid varying electricity tariff rates for the real life span of 10 years for both Solar PV integration into DC bus and Solar PV integrated in to Grid tie inverter for Net Metering.

4.13.1 NPV and IRR of 1kW Solar PV integration on to a Rectifier System for GP-1 Tariff rate (Assume 15% p.a. electricity tariff reduction at initial year, remains constant for 5 years and increment of 5% p.a. beyond for the life span of 10 years*)

Annual energy supplied = 4kWh/day x 365days/year = 1460 kWh/year.

Price of 1 kW Solar PV panels = 1000 USD.

Price of 1.5kW Solar PV DC to DC charger controller with MPPT = 750 USD.

No of 1.5kW Solar PV DC to DC charger controller with MPPT required = 1 nos.

Total Investment for 1 kW Solar PV Installation = (1000+750) USD * 130 Rs/ USD = 227,500.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			227500.00	189583.33	151666.67	113750.00	75833.33	37916.67
Interest	16% p.a.		36400.00	30333.33	24266.67	18200.00	12133.33	6066.67
Loan Capital Repayment			37916.67	37916.67	37916.67	37916.67	37916.67	37916.67
Closing Balance			189583.33	151666.67	113750.00	75833.33	37916.67	0.00

Profit and Loss statement with Cash flow.

Year		0	1	2	3	4	5	6	7	8	9	10
Energy Supplied (kWh/year)			1460	1460	1460	1460	1460	1460	1460	1460	1460	1460
Tariff*(Rs/kWh)			23	23	23	23	23	24	25	27	28	29
Revenue , Energy Saving (Rs/Year)			33507	33507	33507	33507	33507	35182	36941	38789	40728	42764
O&M Cost			2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Interest			36400	30333	24267	18200	12133	6067				
Loan Capital Repayment			37917	37917	37917	37917	37917	37917				
Net Value			-42810	-36743	-30676	-24610	-18543	-10801	34941	36789	38728	40764
NPV (r=10%)	(59,517.44)											
IRR	-1%											

4.13.2 NPV and IRR of 2kW Solar PV integration on to a Rectifier System for GP-1 Tariff rate. (Assume 15% p.a. electricity tariff reduction at initial year, remains constant for 5 years and increment of 5% p.a. beyond for the life span of 10 years*)

Annual energy supplied = 8kWh/day x 365days/year = 2920kWh/year.

Price of 2 kW Solar PV panels = 2000 USD.

Price of 1.5kW Solar PV DC to DC charger controller with MPPT = 750 USD.

No of 1.5kW Solar PV DC to DC charger controller with MPPT required = 2 nos.

Total Investment for 1 kW Solar PV Installation = (2000+750x2) USD * 130 Rs/ USD = 455,000.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			455000.00	379166.67	303333.33	227500.00	151666.67	75833.33
Interest	16% p.a.		72800.00	60666.67	48533.33	36400.00	24266.67	12133.33
Loan Capital Repayment			75833.33	75833.33	75833.33	75833.33	75833.33	75833.33
Closing Balance			379166.67	303333.33	227500.00	151666.67	75833.33	0.00

Profit and Loss statement with Cash flow.

Year		0	1	2	3	4	5	6	7	8	9	10
Energy Supplied (kWh/year)			2920	2920	2920	2920	2920	2920	2920	2920	2920	2920
Tariff*(Rs/kWh)			23	23	23	23	23	24	25	27	28	29
Revenue , Energy Saving (Rs/Year)			67014	67014	67014	67014	67014	70365	73883	77577	81456	85529
O&M Cost			2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Interest			72800	60667	48533	36400	24267	12133				
Loan Capital Repayment			75833	75833	75833	75833	75833	75833				
Net Value			-83619	-71486	-59353	-47219	-35086	-19602	71883	75577	79456	83529
NPV (r=10%)	(106,745.74)											
IRR	0%											

4.13.3 NPV and IRR of 3kW Solar PV integration on to a Rectifier System for GP-1 Tariff rate. (Assume 15% p.a. electricity tariff reduction at initial year, remains constant for 5 years and increment of 5% p.a. beyond for the life span of 10 years*)

Annual energy supplied = 12kWh/day x 365days/year = 4380 kWh/year.

Price of 3 kW Solar PV panels = 3000 USD.

Price of 1.5kW Solar PV DC to DC charger controller with MPPT = 750 USD.

No of 1.5kW Solar PV DC to DC charger controller with MPPT required = 2 nos.

Total Investment for 3 kW Solar PV Installation = (3000+750 x 2) USD * 130 Rs/ USD = 585,000.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			585000.00	487500.00	390000.00	292500.00	195000.00	97500.00
Interest	16% p.a.		93600.00	78000.00	62400.00	46800.00	31200.00	15600.00
Loan Capital Repayment			97500.00	97500.00	97500.00	97500.00	97500.00	97500.00
Closing Balance			487500.00	390000.00	292500.00	195000.00	97500.00	0.00

Profit and Loss statement with Cash flow.

Year		0	1	2	3	4	5	6	7	8	9	10
Energy Supplied (kWh/year)			4380	4380	4380	4380	4380	4380	4380	4380	4380	4380
Tariff*(Rs/kWh)			23	23	23	23	23	24	25	27	28	29
Revenue , Energy Saving (Rs/Year)			100521	100521	100521	100521	100521	105547	110824	116366	122184	128293
O&M Cost			2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Interest			93600	78000	62400	46800	31200	15600				
Loan Capital Repayment			97500	97500	97500	97500	97500	97500				
Net Value			-92579	-76979	-61379	-45779	-30179	-9553	108824	114366	120184	126293
NPV (r=10%)	(40,437.84)											
IRR	7%											

4.13.4 NPV and IRR of 1kW Solar PV integration in to Grid tie inverter for Net Metering for GP-1 Tariff rate. (Assume 15% p.a. electricity tariff reduction at initial year, remains constant for 5 years and increment of 5% p.a. beyond for the life span of 10 years*)

Annual energy supplied = 4kWh/day x 365days/year = 1460 kWh/year.

Price of 1 kW Solar PV panels = 1000 USD.

Price of 1.2 kW DC to A/C Grid tie Inverter with MPPT = 1200 USD.

Total Investment for 1 kW Solar PV Installation = (1000+1200) USD * 130 Rs/ USD = 286,000.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			286000.00	238333.33	190666.67	143000.00	95333.33	47666.67
Interest	16% p.a.		45760.00	38133.33	30506.67	22880.00	15253.33	7626.67
Loan Capital Repayment			47666.67	47666.67	47666.67	47666.67	47666.67	47666.67
Closing Balance			238333.33	190666.67	143000.00	95333.33	47666.67	0.00

Profit and Loss statement with Cash flow.

Year		0	1	2	3	4	5	6	7	8	9	10
Energy Supplied (kWh/year)			1460	1460	1460	1460	1460	1460	1460	1460	1460	1460
Tariff*(Rs/kWh)			23	23	23	23	23	24	25	27	28	29
Revenue , Energy Saving (Rs/Year)			33507	33507	33507	33507	33507	35182	36941	38789	40728	42764
O&M Cost			2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Interest			45760	38133	30507	22880	15253	7627				
Loan Capital Repayment			47667	47667	47667	47667	47667	47667				
Net Value			-61920	-54293	-46666	-39040	-31413	-22111	34941	36789	38728	40764
NPV (r=10%)	(127,639.16)											
IRR	-9%											

4.13.5 NPV and IRR of 2kW Solar PV integration in to Grid tie inverter for Net Metering for GP-1 Tariff rate. (Assume 15% p.a. electricity tariff reduction at initial year, remains constant for 5 years and increment of 5% p.a. beyond for the life span of 10 years*)

Annual energy supplied = 8kWh/day x 365days/year = 2920kWh/year.

Price of 2 kW Solar PV panels = 2000 USD.

Price of 2 kW DC to A/C Grid tie Inverter with MPPT = 1600 USD.

Total Investment for 2 kW Solar PV Installation = (2000+1600) USD * 130 Rs/ USD = 468,000.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			468000.00	390000.00	312000.00	234000.00	156000.00	78000.00
Interest	16% p.a.		74880.00	62400.00	49920.00	37440.00	24960.00	12480.00
Loan Capital Repayment			78000.00	78000.00	78000.00	78000.00	78000.00	78000.00
Closing Balance			390000.00	312000.00	234000.00	156000.00	78000.00	0.00

Profit and Loss statement with Cash flow.

Year		0	1	2	3	4	5	6	7	8	9	10
Energy Supplied (kWh/year)			2920	2920	2920	2920	2920	2920	2920	2920	2920	2920
Tariff*(Rs/kWh)			23	23	23	23	23	24	25	27	28	29
Revenue , Energy Saving (Rs/Year)			67014	67014	67014	67014	67014	70365	73883	77577	81456	85529
O&M Cost			2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Interest			74880	62400	49920	37440	24960	12480				
Loan Capital Repayment			78000	78000	78000	78000	78000	78000				
Net Value			-87866	-75386	-62906	-50426	-37946	-22115	71883	75577	79456	83529
NPV (r=10%)	(121,883.90)											
IRR	-1%											

14.13.6 NPV and IRR of 3kW Solar PV integration in to Grid tie inverter for Net Metering for GP-1 Tariff rate. (Assume 15% p.a. electricity tariff reduction at initial year, remains constant for 5 years and increment of 5% p.a. beyond for the life span of 10 years*)

Annual energy supplied = 12kWh/day x 365days/year = 4380kWh/year .

Price of 3 kW Solar PV panels = 3000 USD.

Price of 3 kW DC to A/C Grid tie Inverter with MPPT = 1900 USD.

Total Investment for 3 kW Solar PV Installation = (3000+1900) USD * 130 Rs/ USD = 637,000.00 Rs.

Loan Schedule.

Year		0	1	2	3	4	5	6
Opening Balance			637000.00	530833.33	424666.67	318500.00	212333.33	106166.67
Interest	16% p.a.		101920.00	84933.33	67946.67	50960.00	33973.33	16986.67
Loan Capital Repayment			106166.67	106166.67	106166.67	106166.67	106166.67	106166.67
Closing Balance			530833.33	424666.67	318500.00	212333.33	106166.67	0.00

Profit and Loss statement with Cash flow.

Year		0	1	2	3	4	5	6	7	8	9	10
Energy Supplied (kWh/year)			4380	4380	4380	4380	4380	4380	4380	4380	4380	4380
Tariff*(Rs/kWh)			23	23	23	23	23	24	25	27	28	29
Revenue , Energy Saving (Rs/Year)			100521	100521	100521	100521	100521	105547	110824	116366	122184	128293
O&M Cost			2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Interest			101920	84933	67947	50960	33973	16987				
Loan Capital Repayment			106167	106167	106167	106167	106167	106167				
Net Value			-109566	-92579	-75592	-58606	-41619	-19606	108824	114366	120184	126293
NPV (r=10%)	(100,990.48)											
IRR	3%											

Summarized NPV and IRR for aforesaid varying electricity tariff rates for the real life span of 10 years for both Solar PV integration into DC bus and Solar PV integrated in to Grid tie inverter for Net Metering. (Assume 15% p.a. electricity tariff reduction at initial year, remains constant for 5 years and increment of 5% p.a. beyond for the life span of 10 years*) are shown in Table 4.13.6.1.

Table 4.13.6.1 - Summarized NPVs and IRRs according to the varying electricity tariff rates for the real life span of 10 years for both Solar PV integration into DC bus and Solar PV integrated in to Grid tie inverter for Net Metering.

Capacity of Solar PV System in to new GP1 Tariff* with 10 years of lifespan.	Solar PV integration into DC bus		Solar PV integrated in to Grid tie inverter for Net Metering	
	NPV in LKR (r=10% p.a.)	IRR	NPV in LKR (r=10% p.a.)	IRR
1 kW	(59,517.44)	-1%	(127,639.16)	-9%
2 kW	(106,745.74)	0%	(121,883.90)	-1%
3 kW	(40,437.84)	7%	(100,990.48)	3%

4.14 Methodology for implementation, both Solar PV integration on to the DC bus & for Net Metering.

Summarized flow chart for both Solar PV integration on to the DC bus & for Net Metering is show in Figure 4.14.1 below.

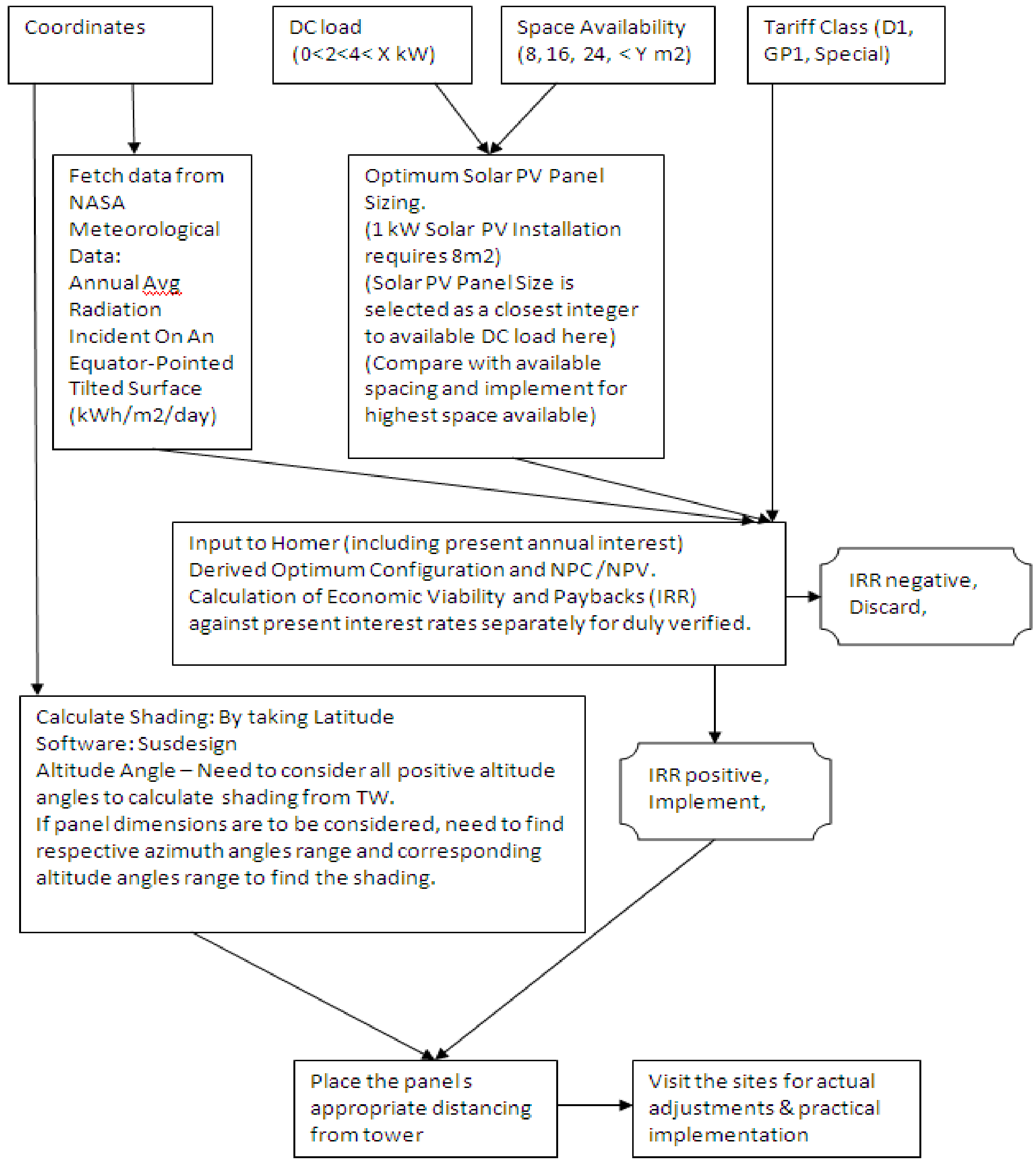


Figure 4.14.1- Flow chart for both Solar PV integration on to the DC bus & for Net Metering.

4.15 Benchmark the tariff rates which paybacks within acceptable time under different tariff structures.

4.15.1 The tariff rate which makes 3 years of payback for 1kW Solar PV integration on to a Rectifier System.

Solar Irradiance in Colombo (Considering monthly average, Pessimistic value) = 4.3 kWh/day/m2.

Average dimension of 250W Solar PV Panel = 1.6m x 1m = 1.6 m2.

Panel Area for 1kW Solar PV Installation = 1.6 m2 x 4 panels = 6.4 m2.

Average Solar PV Module efficiency = 15.1%

Energy output daily = 4.3 kWh/day/m2 x 6.4 m2 x 0.151 = 4.16 kWh/day

Energy output monthly = 4.16 kWh/day x 30days = 124.8 kWh/ month.

Conversion efficiency of 1.5 kW DC/DC Solar PV charger controller = 96.5 %

So energy on to the DC bus = 124.8 kWh/ month x 0.965 = 120 kWh/ month.

Annual Energy on to the DC Bus = 120 kWh/month x 12 months/year = 1440 kWh/annum.

Assume respective tariff rate = X Rs/kWh.

Annual Saving = 1440 kWh/annum x X Rs/kWh = 1440 x X Rs/annum.

Price of 1 kW Solar PV panels = 1000 USD.

Price of 1.5kW Solar PV DC to DC charger controller with MPPT = 750 USD.

No of 1.5kW Solar PV DC to DC charger controller with MPPT required = 1 nos.

Total Investment for 1 kW Solar PV Installation = (1000+750) USD * 130 Rs/ USD = 227,500.00 Rs.

Simple Pay Back = (Total Investment) / (Annual Saving).

3 = 227,500.00 Rs / 1440 x X Rs

X = 52.66

The tariff rate which makes 3 years of payback for 1kW Solar PV integration on to a Rectifier System = 52.66 Rs/kWh.

Similarly, expected tariff rates which makes 3 years of payback for Solar PV integrations on to Rectifier Systems with different capacities of Solar PV array sizing are derived and tabulated in Table 4.15.1.1.

Table 4.15.1.1- Expected tariff rates which makes 3 years of payback for Solar PV integrations on to Rectifier Systems with different capacities of array sizing.

Solar PV Installed Capacity	1kW	2kW	3kW
Solar Irradiance in Colombo (kWh/day/m2)	4.3	4.3	4.3
Panel Area of a 250W Solar PV with average module efficiency 15.1% (m2)	1.6	1.6	1.6
Panel Area required for Solar PV Installation with average module efficiency 15.1% (m2)	6.4	12.8	19.2
Energy output - Daily (kWh/day)	4.16	8.32	12.48
Energy output - Monthly (kWh/month)	124.8	249.6	374.4
Required nos of 1.5 kW DC/DC Solar PV charger controllers with 96.5% efficiency.	1	2	2
Energy on to the DC bus - Monthly (kWh/month)	120	240	360
Energy on to the DC bus - Yearly (kWh/year)	1440	2880	4320
Price of 1kW Solar PV Panels (USD)	1000	1000	1000
Price of 1.5kW Solar PV DC to DC charger controller with MPPT	750	750	750
Total Investment (USD)	1750	3500	4500
Total Investment (LKR)	227500	455000	585000
Expected Simple Pay Back = (Total Investment) / (Annual Saving), in years.	3	3	3
Expected Annual Saving (LKR/year)	75833.33	151666.70	195000.00
The derived tariff rate which makes 3 years of payback (Rs/kWh)	52.66	52.66	45.14

4.15.2 The tariff rate which makes 3 years of payback for 1kW Solar PV integration in to Grid tie inverter for Net Metering.

Solar Irradiance in Colombo (Considering monthly average, Pessimistic value) = 4.3 kWh/day/m2.

Average dimension of 250W Solar PV Panel = 1.6m x 1m = 1.6 m2.

Panel Area for 1kW Solar PV Installation = 1.6 m2 x 4 panels = 6.4 m2.

Average Solar PV Module efficiency = 15.1%

Energy output daily = 4.3 kWh/day/m2 x 6.4 m2 x 0.151 = 4.16 kWh/day

Energy output monthly = 4.16 kWh/day x 30days = 124.8 kWh/ month.

DC to A/C Inversion Efficiency of 1kW Grid Tie Inverter = 97%

So energy on to the A/C bus = 124.8 kWh/ month x 0.97 = 120 kWh/ month.

Annual Energy on to the A/C Bus = 120 kWh/month x 12 months/year = 1440 kWh/annum.

Assume respective tariff rate = X Rs/kWh.

Annual Saving = 1440 kWh/annum x X Rs/kWh = 1440 x X Rs/annum.

Price of 1 kW Solar PV panels = 1000 USD.

Price of 1.2 kW DC to A/C Grid tie Inverter with MPPT = 1200 USD.

Total Investment for 1 kW Solar PV Installation = (1000+1200) USD * 130 Rs/ USD = 286,000.00 Rs.

Simple Pay Back = (Total Investment) / (Annual Saving).

3 = 286,000.00 Rs / 1440 x X Rs

X = 66.20

The tariff rate which makes 3 years of payback for 1kW Solar PV integration in to Grid tie inverter for Net Metering = 66.20 Rs/kWh.

Similarly, expected tariff rates which makes 3 years of payback for Solar PV integration in to Grid tie inverter for Net Metering with different capacities of Solar PV array sizing are derived and tabulated in Table 4.15.2.1.

Table 4.15.2.1- Expected tariff rates which makes 3 years of payback for Solar PV integration in to Grid tie inverter for Net Metering with different capacities of arrays.

Solar PV Installed Capacity	1kW	2kW	3kW
Solar Irradiance in Colombo (kWh/day/m2)	4.3	4.3	4.3
Panel Area of a 250W Solar PV with average module efficiency 15.1% (m2)	1.6	1.6	1.6
Panel Area required for Solar PV Installation with average module efficiency 15.1% (m2)	6.4	12.8	19.2
Energy output - Daily (kWh/day)	4.16	8.32	12.48
Energy output - Monthly (kWh/month)	124.8	249.6	374.4
Capacity of required DC to A/C Grid Tie Inverter with 97% inversion efficiency (kW)	1	2	3
Energy on to the AC bus - Monthly (kWh/month)	120	240	360
Energy on to the AC bus - Yearly (kWh/year)	1440	2880	4320
Price of 1kW Solar PV Panels (USD)	1000	1000	1000
Price of respective capacity of Solar PV DC to A/C Grid Tie Inverter with MPPT.	1200	1600	1900
Total Investment (USD)	2200	3600	4900
Total Investment (LKR)	286000.00	468000.00	637000.00
Expected Simple Pay Back = (Total Investment) / (Annual Saving), in years.	3	3	3
Expected Annual Saving (LKR/year)	95333.33	156000.00	212333.33
The derived tariff rate which makes 3 years of payback (Rs/kWh)	66.2	54.17	49.15

Benchmarked tariff rates payback in 3 years for each Solar PV system integrated on to the DC bus vs. Grid tie inverter for Net Metering are shown for ease of comparisons in Table 4.15.2.2.

Table 4.15.2.2 - Benchmarked tariff rates payback in 3 years for each Solar PV system integrated on to the DC bus vs. Grid tie inverter for Net Metering.

Solar PV System Capacity	Tariff rate paybacks in 3 years.	
	Solar PV System on to DC Bus	Solar PV System in to Grid tie inverter for A/C Bus
1 kW	52.66 Rs/kWh	66.2 Rs/kWh
2 kW	52.66 Rs/kWh	54.17 Rs/kWh
3 kW	45.14 Rs/kWh	49.15 Rs/kWh

4.16 Implementation of Pilot Scale site for Solar PV integration on to a Rectifier System for GP1 Tariff rate.

Selected site Name: Port Access Road (Latitude 6.54 / Longitude 79.5) – 4 story RT with mono poles.

Site DC load (Demand) = 54 V x 28 A = 1.512 kW.

Cabin Dimensions (L x W x H) = 2.5m x 2.5m x 3m.

Roof Area = 2.5m x 2.5m = 6.25m2.

Solar Irradiance in Colombo (Considering monthly average, Pessimistic value) = 4.3 kWh/day/m2

Panel Area required for 1.5 kW = 1.6 m2 x 6 panels = 9.6 m2

Module efficiency = 15.1% (By proposed REC Solar PV data sheet)

Energy output daily = 4.3 x 9.6 x 0.151 = 6.23 kWh/day

Energy output monthly = 6.234 kWh/day x 30days = 187 kWh/ month.

Conversion efficiency of 1.5 kW DC/DC Solar PV charger controller = 96.5 % (By proposed Eltek Solar PV DC/DC Charger controller data sheet)

So energy on to the DC bus = 180 kWh/ month.

Quoted Price for 1.5kW total Solar PV system with installation = LKR 315,000.00

Payback = (Investment)/ (Saving) = (LKR 315,000 .00) / [(180 kWh x 12 x 27 Rs/kWh)] = 5.40 years.

NPV and IRR calculated according to the GP1 tariff rates for Solar PV installation at Port Access Road.

Loan Schedule:

Year		0	1	2	3	4	5	6
Opening Balance			315000.00	262500.00	210000.00	157500.00	105000.00	52500.00
Interest	16% p.a.		50400.00	42000.00	33600.00	25200.00	16800.00	8400.00
Loan Capital Repayment			52500.00	52500.00	52500.00	52500.00	52500.00	52500.00
Closing Balance			262500.00	210000.00	157500.00	105000.00	52500.00	0.00

Profit and Loss statement with Cash flow.

Year	Energy Supplied (kWh)	Tariff (LKR/kWh)	Revenue, Saving (LKR)	O&M Cost	Loan Interest		NPV (r=10%)	IRR
		5% p.a.					310,608.84	18%
0						-315000.00		
1	2190	27.00	59130	2000	50400	6730.00		
2	2190	28.35	62086.5	2000	42000	18086.50		
3	2190	29.77	65190.83	2000	33600	29590.83		
4	2190	31.26	68450.37	2000	25200	41250.37		
5	2190	32.82	71872.88	2000	16800	53072.88		
6	2190	34.46	75466.53	2000	8400	65066.53		
7	2190	36.18	79239.86	2000		77239.86		
8	2190	37.99	83201.85	2000		81201.85		
9	2190	39.89	87361.94	2000		85361.94		
10	2190	41.89	91730.04	2000		89730.04		
11	2190	43.98	96316.54	2000		94316.54		
12	2190	46.18	101132.4	2000		99132.37		
13	2190	48.49	106189	2000		104188.98		
14	2190	50.91	111498.4	2000		109498.43		
15	2190	53.46	117073.4	2000		115073.36		
16	2190	56.13	122927	2000		120927.02		

17	2190	58.94	129073.4	2000		127073.37
18	2190	61.88	135527	2000		133527.04
19	2190	64.98	142303.4	2000		140303.40
20	2190	68.23	149418.6	2000		147418.57
21	2190	71.64	156889.5	2000		154889.49
22	2190	75.22	164734	2000		162733.97
23	2190	78.98	172970.7	2000		170970.67
24	2190	82.93	181619.2	2000		179619.20
25	2190	87.08	190700.2	2000		188700.16

Panel placements on rooftop and no shading due to tower structure comprised of poles only. Figure 4.16.1 shows the first On Grid Solar PV integrated site directly on to the DC bus of rectifier (To the Hybrid controller) on 14/10/2013.

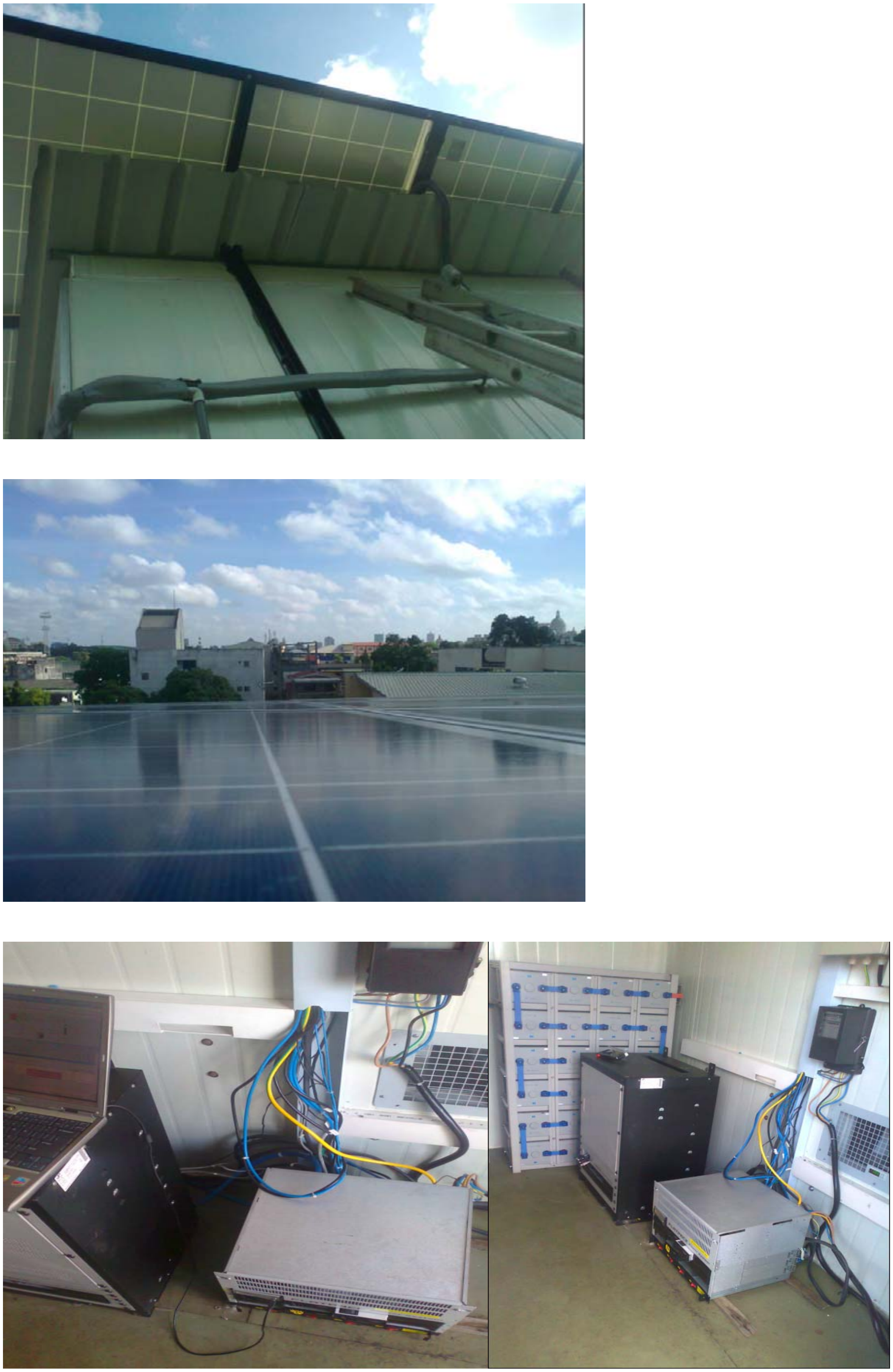


Figure 4.16.1 First On Grid Solar PV integrated site directly on to the DC bus of rectifier (To the Hybrid controller) on 14/10/2013.

4.17 Evaluation outputs of Pilot Scale site – Port Access Road did Solar PV integration on to a Rectifier System for GP1 Tariff rate.

Power consumption prior to Solar PV Installation during 11 days according to the energy meter reading = 394 kWh. (During between 3/11/2013 to 14/11/2013)

Consumption per day prior to Solar PV Installation = 394kWh/11days = 36 kWh /day.

Site Demand = 36 kWh/24 hr = 1.5 kW.

Confirms with site load = 28 A x 54 V = 1.512 kW.

Energy meter reading obtained after stabilizing the site on 15/10/2013 at 1 p.m = 423 kWh.

Energy meter reading obtained at 16/10/2013 at 3.00 p.m (after 26 hrs) = 455 kWh.

So energy consumed through commercial power line = 455 – 423 = 32 kWh per 26 hrs.

Energy received through Solar PV = 1.5 kW x 26h – 32 kWh (for 26hrs)

= 39 kWh – 32kWh

= 7kWh per 26 hrs

= 6.5 kWh per day. => for 1.5 kW Installation.

It can be seen that performances of installation Solar PV Integration on to the DC bus, are exceeded our pessimistic values in a day of non sunny October.

Also actual savings from the billing proof of Port Access Road RBS are shown in Table 4.17.1

Table 4.17.1: Actual savings from the billing proof of Port Access Road RBS

Month	Units	Amount	Cheque No	Date
December	930	25233.75	1645	28/01/2014
November	930	25233.75	57952	24/12/2013
October	1092	29587.5	57533	
September	1154	31253.75	57159	
August	1201	32516.88	56911	
July	1189	32194.38	56656	

Since the system is implemented on Month of November 2013 onwards, it is proof that bill reduction in LKR 6000.00 Rs/ Month, more than the units corresponds to 1.5kW typical Solar PV installation. (i.e. 180 units saving per month x 30 days per month x 30 Rs per KWh = 5400 Rs /LKR)

Figure 4.17.1 shows the current drawn from the Solar PV DC/DC charger controller module & the rectifier to the load at 3.02 p.m. on 14/10/2013 where 13A and 13A accordingly.

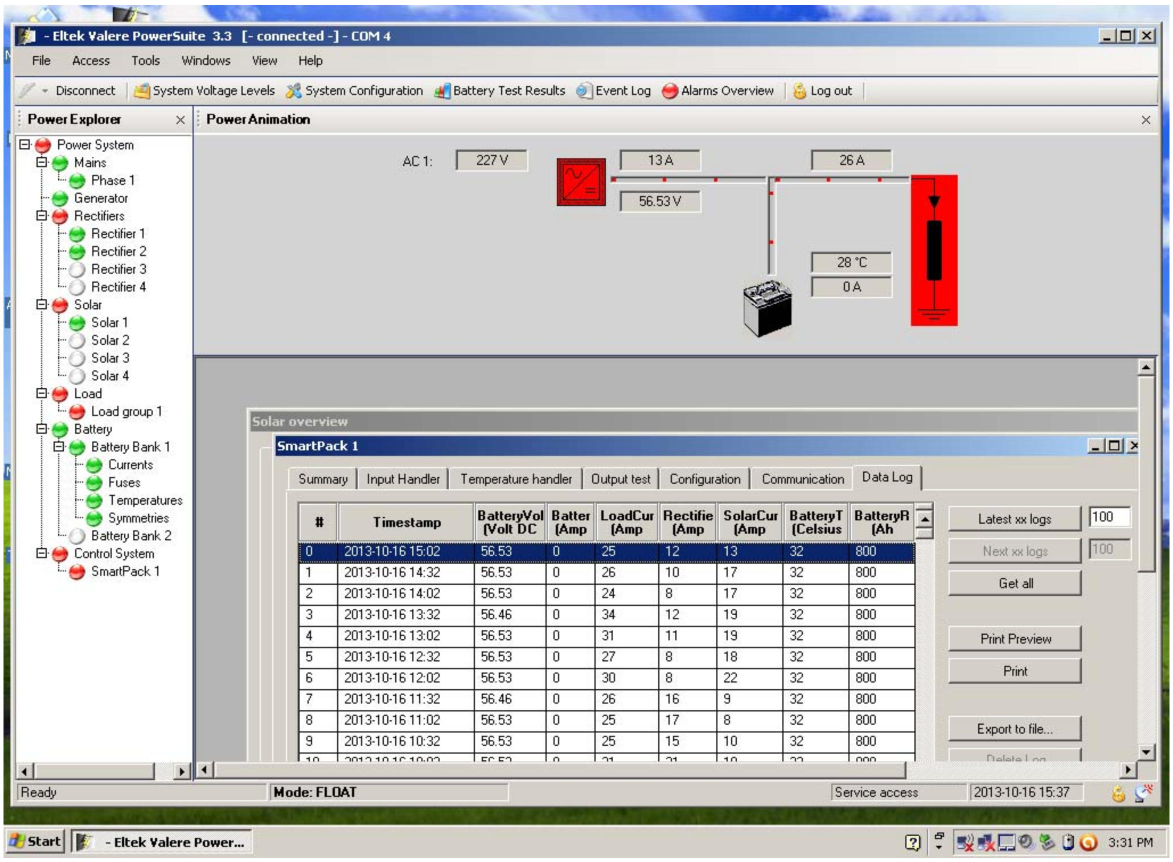
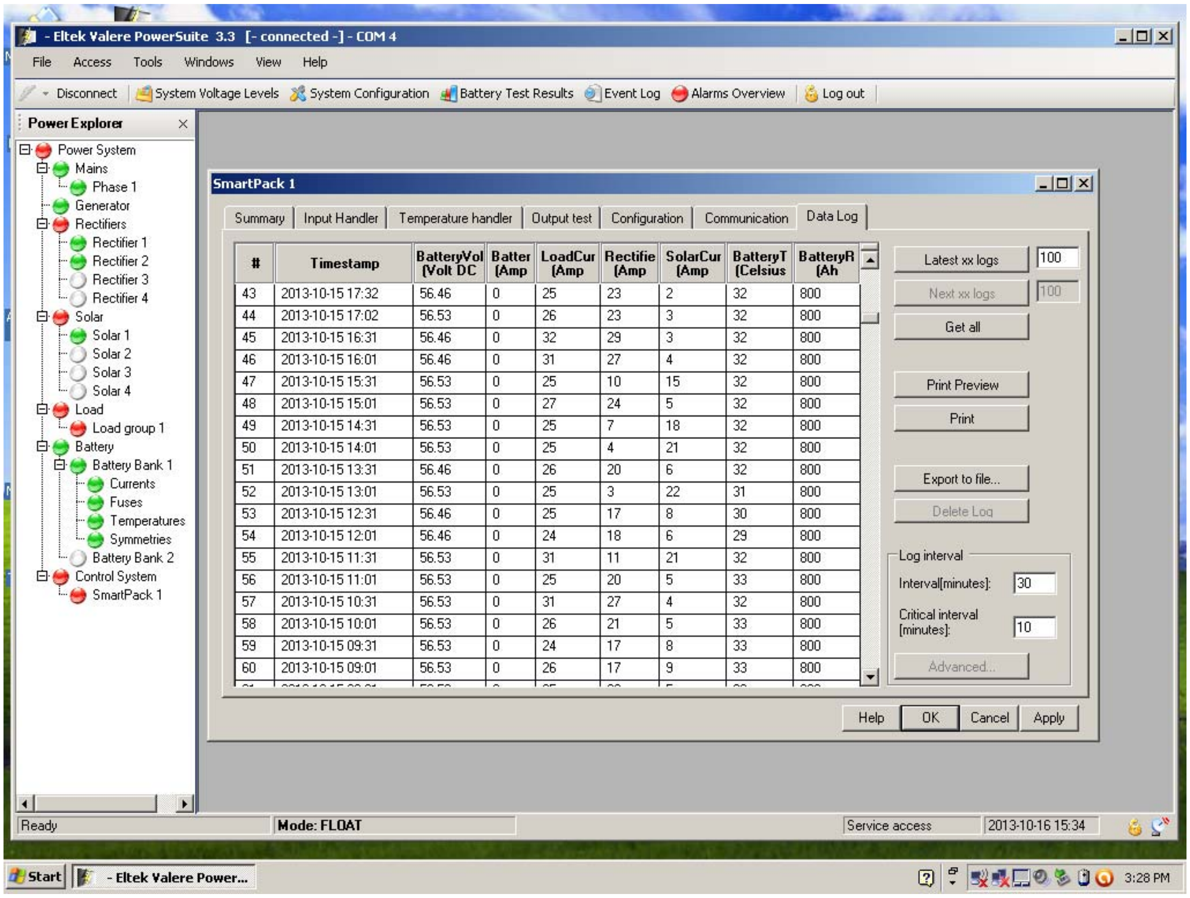


Figure 4.17.1. Current drawn from the Solar PV DC/DC charger controller module & the rectifier to the load at 3.02 p.m. on 14/10/2013.

Also it is worthy check the panel performances at low light intensities to ensure the DC/DC charger controller have sufficient input voltage in operation. Figure 4.17.3 shows the 2A current output of Solar PV DC/DC charger controller during low light intensities at 17.32 p.m. on 14/10/2013.



#	Timestamp	BatteryVol (Volt DC	Batter (Amp	LoadCur (Amp	Rectifie (Amp	SolarCur (Amp	BatteryT (Celsius	BatteryR (Ah
43	2013-10-15 17:32	56.46	0	25	23	2	32	800
44	2013-10-15 17:02	56.53	0	26	23	3	32	800
45	2013-10-15 16:31	56.46	0	32	29	3	32	800
46	2013-10-15 16:01	56.46	0	31	27	4	32	800
47	2013-10-15 15:31	56.53	0	25	10	15	32	800
48	2013-10-15 15:01	56.53	0	27	24	5	32	800
49	2013-10-15 14:31	56.53	0	25	7	18	32	800
50	2013-10-15 14:01	56.53	0	25	4	21	32	800
51	2013-10-15 13:31	56.46	0	26	20	6	32	800
52	2013-10-15 13:01	56.53	0	25	3	22	31	800
53	2013-10-15 12:31	56.46	0	25	17	8	30	800
54	2013-10-15 12:01	56.46	0	24	18	6	29	800
55	2013-10-15 11:31	56.53	0	31	11	21	32	800
56	2013-10-15 11:01	56.53	0	25	20	5	33	800
57	2013-10-15 10:31	56.53	0	31	27	4	32	800
58	2013-10-15 10:01	56.53	0	26	21	5	33	800
59	2013-10-15 09:31	56.53	0	24	17	8	33	800
60	2013-10-15 09:01	56.53	0	26	17	9	33	800

Figure 4.17.3 Current output of Solar PV DC/DC charger controller during range of light intensities during between at 9 a.m. to 6 p.m. on 14/10/2013

Chapter 5

5.0 Conclusion.

5.1 Comparison between Solar PV integration in to On-Grid Base Station, directly on to the DC bus Vs net metering system.

Grid tied inverters connected to solar arrays with contracts of utility power provider can cut down the energy bills to greater levels.

For some applications such as office buildings, residences, where almost all the equipment are using A/C power, grid tied solar systems are very useful. Even with these applications, grid connect inverter cannot provide any power during a grid power failure. It is not even possible to contribute power to the generator during grid power failure (There are special equipment to connect with generators, to avoid reverse current, but these are very complicated and expensive, not recommended for small systems).

In telecom applications, other than air conditioners, almost all other equipment are working with DC power.

In this situation, the most efficient way of integration Solar PV energy would be directly on the form of DC power.

The reason is, when using solar array to generate power with grid connect inverter, the power output from solar panels will be DC, and it will be converted to A/C power with the grid connect Inverter. During this process, there will be a power loss of 7.5% to 15% depending on the efficiency and technology of the inverter.

Then the AC power output of the inverter is back again converted to DC to power incurring a power loss, to power the telecom equipment. In this whole process, the total power loss can be as high as 20% or more. Which means, it is needed a 20% bigger solar array compared with direct DC power supply from solar array to have the same benefit.

In technical point of view, it can be seen that Solar PV energy DC output integration directly on to the DC bus is much more efficient than integrating it in to A/C bus through Grid tie inverter for Net Metering due to DC power requirement in telecom applications.

Summarized simple payback times for each Solar PV system integrated on to the DC bus vs. Grid tie inverter for Net Metering are shown for ease of comparisons in Table 5.1.1.

Table 5.1.1 - Summarized simple payback times for each Solar PV system capacity integrated on to the DC bus vs. Grid tie inverter for Net Metering.

Solar PV System Capacity	Simple Payback			
	Solar PV System on to DC Bus		Solar PV System in to Grid tie inverter for A/C Bus	
	D1 Tariff	GP1 Tariff	D1 Tariff	GP1 Tariff
1 kW	2.72 years.	5.85 years.	3.42 years.	7.36 years.
2 kW	2.72 years.	5.85 years.	2.80 years.	6.02 years.
3 kW	2.33 years.	5.01 years.	2.54 years.	5.46 years.

Summarized NPVs and IRRs according to the D1 and GP1 tariff rates for each Solar PV system integrated in to Grid tie inverter for Net Metering are shown in Table 5.1.2.

Table 5.1.2 - Summarized NPVs and IRRs according to the D1 and GP1 tariff rates for each Solar PV system capacity integrated on to the DC bus vs. Grid tie inverter for Net Metering.

Solar PV System Capacity	Solar PV System on to DC Bus				Solar PV System in to Grid tie inverter for A/C Bus			
	D1 Tariff		GP1 Tariff (5% increment p.a.)		D1 Tariff		GP1 Tariff (5% increment p.a.)	
	NPV in LKR (r=10% p.a.)	IRR	NPV in LKR (r=10% p.a.)	IRR	NPV in LKR (r=10% p.a.)	IRR	NPV in LKR (r=10% p.a.)	IRR
1 kW	598,405.85	29%	178,684.55	16%	521,898.64	23%	102,177.34	13%
2 kW	1,213,315.41	29%	373,872.81	16%	1,196,313.81	28%	356,871.21	16%
3 kW	1,955,736.99	34%	696,573.09	19%	1,887,730.58	31%	628,566.68	18%

Note: It is taken the Price of 1.2 kW DC to A/C Grid tie Inverter with MPPT = 1200 USD, 2 kW = 1600 USD, 3 kW = 1900 USD. Price of 1.5kW Solar PV DC to DC charger controller with MPPT = 750 USD, 3 kW = 1500 USD. Solar PV panel pricing = 1$/1W.

It can be seen that, systems having Solar PV energy DC output directly integrated on to the DC bus, have lesser paybacks than integrating it in to A/C bus through Grid tie inverter for Net Metering for both D1 and GP-1 tariff rates. It can also be seen that, higher the renewable energy fraction gives lesser the payback time, and installation for D1 tariff paybacks almost half of the time earlier corresponds to the GP-1 tariff rate.

For systems having Solar PV energy directly integrated on to the DC bus have positive NPVs under rate of depreciation 10% p.a. for all 1,2 & 3kW installations under both D1 and GP-1, but better for tariff rate D1. Further, higher the renewable energy fraction gives higher NPV values with high IRRs. For systems having Solar PV energy integrating in to A/C bus through Grid tie inverter for Net Metering have similar results but lesser than corresponding Solar PV installations comes under D1 tariff rate.

For systems having Solar PV energy integrating in to A/C bus through Grid tie inverter for Net Metering comes under tariff rate GP-1, still have positive NPVs, and acceptable IRRs under rate of depreciation 10% p.a., is the lowest among all comparisons.

The both types of Solar PV integration methods come under tariff rate D1, have high IRRs, almost twice than the same capacity of Solar PV installations fallen under the tariff category of GP-1. Also this rate is much higher than present loan interest rates, as well as depreciation rates, implies much more robust good projects for D1 tariff category. (Due to Project IRR > Present Loan Interest > Inflation rate).

In Financial point of view too, it can be seen that Solar PV energy integration directly on to the DC bus is much more financially beneficial than integrating it in to A/C bus through Grid tie inverter for Net Metering for telecom applications.

It can be recommended to go for Solar PV integration on to DC bus rather than integrating for A/C bus for Net Metering. Further more it is identified that higher capacity Solar PV systems will pay back much faster than lower capacity Solar PV installations. Because cost of appropriate converter or inverter systems don't linearly increase against its capacity, rather according to reduced rate.

During Sensitivity analysis of finding NPV and IRR for varying electricity tariff rates, and reduced life span in practical environmental conditions by Assuming 15% p.a. electricity tariff reduction at initial year, remains constant for 5 years and increment of 5% p.a. beyond for the life span of 10 years for both Solar PV integration into DC bus and Solar PV integrated in to Grid tie inverter for Net Metering, derived NPV and IRR values cannot be financially accepted. Hence, it is recommended to apply these models when the actual tariff rates reach the benched marked figures to have effective Return On Investments.

Considering the aforesaid, it is recommended to have DC Solar System for Rectifier DC bus against Grid Connect Solar system for Net metering, for most telecom applications, due to reasons discussed summarized in Table 5.1.3 below.

Table 5.1.3 – Comparison of Grid Connect Solar system for Net metering against DC Solar System for Rectifier DC Bus.

	Features.	Grid Connect Solar system for Net metering.	DC Solar System for Rectifier DC Bus.
1	Overall Efficiency	75-85% at the equipment level	96% or more.
2	Ability to provide power during a grid power failure.	Grid connect inverter system will shut down during a power failure, with no use of solar array	Will provide power uninterruptedly at full capacity.
3	Equipment required.	Solar arrays (20% bigger capacity than DC system), Special surge protection equipment (Since these inverters are very sensitive, basic surge protection used in residential applications cannot be used for telecom applications), Grid Connect Inverter, Solar Optimizing equipment, Net Metering system.	Existing Eltek rectifier system can control the total system, just by plugging in solar charge modules to the solar slots of the rectifier system. (each solar charge module can take up to 1.5 kW, 3kW of solar power). With the built in Prioritizing system, Solar system will provide 100% of its generation, and only the balance required power will be used from the grid.
4	Reliability.	Since this is full time connected to the grid, any over Voltages Surges in the grid may effect the system.	Totally independent system, and irregular grid voltages or surges will not effect the system.
5	Backup power.	Cannot used for backup power.	Can be used as an backup power source even during a power failure.
6	Other benefits.		Reduces generator run time during power failures. Facility to intelligent operation of generator, cabin cooling system, air conditioners, generator fuel monitoring etc.
7	ROI	Over 6 years	Around 5 years.

5.2 Advancements of Solar PV integration in to Telecom RBSes.

The Solar PV directly on to the DC Bus (Option 1) is a totally independent system (i.e. irregular grid voltages or surges will not affect the system plus can be used as an backup power source even during a power failure) , high conversion efficiencies with lesser in paybacks, it is recommended Option 1 for long run to modify telecom power setup accordingly.

Also there are other possibilities where it doesn't make any burden in to our utility peak demand as our proposed systems. It can be used Solar PV as Backup System, by cutting off commercial power at night during system peak by time of day timer and letting batteries to discharged as CDC, good way of avoiding burden on to the peak demand, is a way of promoting of its corporate social responsibility to the society. Also there is a possibility of replacing the conventional standby diesel generator set by Solar PV backup with adequate DC battery backup. (i.e. VRLA OPzV series, which is specifically designed for cyclic power applications.)

Some of world leading Solar PV manufacturers offer project financing schemes to integrate renewable energy sources in to typical RBSes with the cost of operation are being paid to them for the limited period of time provided meeting their base line budget. As an example a world leading Norwegian Solar PV manufacturer, REC Solar and Eltek offer these types of schemes as part of their corporate social responsibility to the society.

It is worthy to point out that, typical AC to DC converting rectifiers in telecom RBSes can be easily replaced by introducing DC generators (Hybrid Generators) in combine with renewable energy sources like Solar PV panels plus Solar PV charger controllers, for Off Grid systems.

It is figure out most of the possible combinations of energy sources integration to have possible configurations according to the site conditions, will be thought provoking in to many other research possibilities for analyzing their techno economical viabilities for sustainable deployments discussed in below.

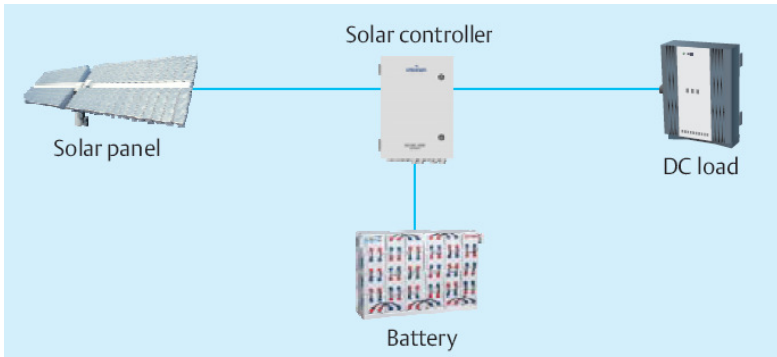


Figure 5.2.1- Configuration of Pure Solar Power System.

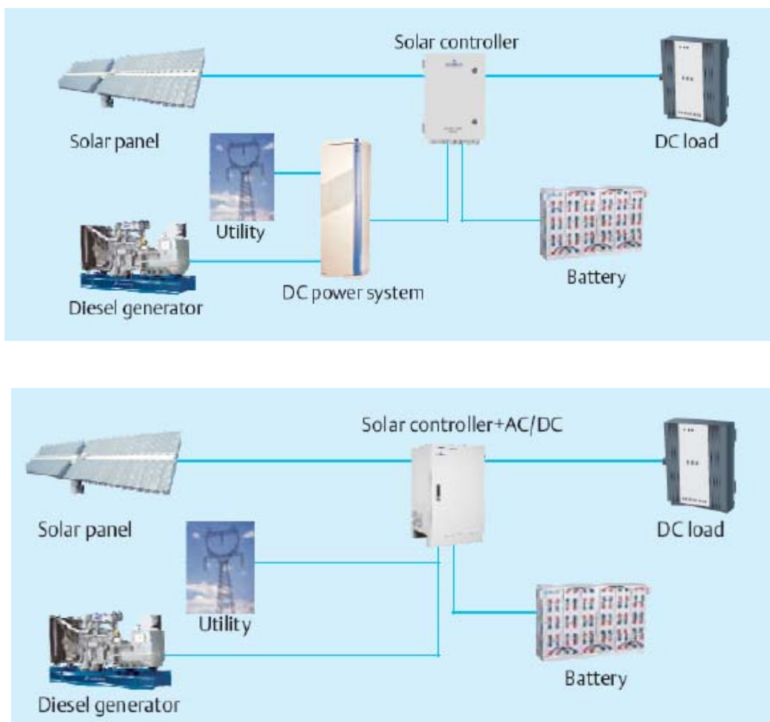


Figure 5.2.2 - Configuration of Solar Utility (with Gen Set) for DC and DC/AC System.

Figure 5.2.3 - Configuration of Solar Power & Wind Power System with Horizontal and/or Vertical axis Wind Generators.

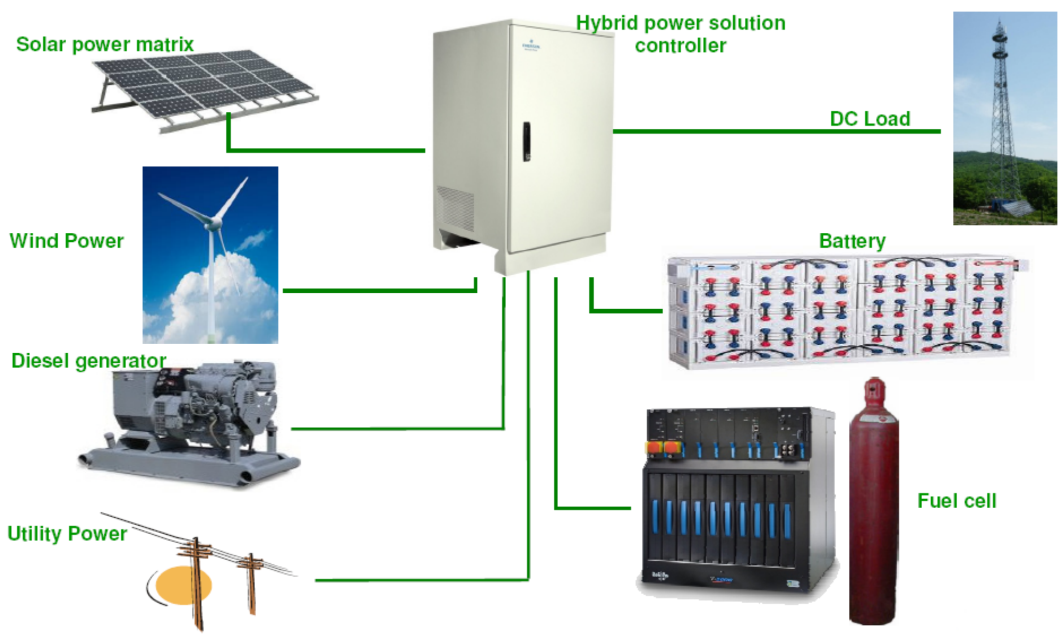


Figure 5.2.4 - Configuration of Hybrid Solar, Wind, Utility(Gen Set), Fuel Cells Integrated Power System.

Reference:

[1] https://eosweb.larc.nasa.gov "A renewable energy resource web site developed by NASA" about Surface meteorology and Solar energy resource. (release 6.0)

[2] http://www.pucsl.gov.lk/english/wp-content/uploads/2013/03/Electricity-Tariff-2013-Proposal-by-CEB-Main-tables.pdf "A Retail Tariff Proposal for 2013 Ceylon Electricity Board March" published by Public Utility Commission Sri Lanka.

[3] www.homerenergy.com Hybrid Optimization Modeling Software for micro grid and distributed generation power system design and renewable energy integration

[4] http://homerenergy.com/HOMER_2.html HOMER 2 is the current commercial version of HOMER developed by National Renewable Energy Laboratory with new power system components.

[5] http://www.retscreen.net RETScreen is a Clean Energy Project Analysis Software developed and maintained by the Government of Canada through Natural Resources Canada's CanmetENERGY research centre.

[6] http://www.pvsyst.com PVSyst is a photovotic PVsyst software is a tool that allows its user to accurately analyze different configurations and to evaluate the results and identify the best solution.

APPENDIX A

Solar Energy

Using solar power as an energy source started as early as 7th century B.C. as magnifying glasses were started to use for concentrating sun's rays to make fire and for burning ants. In 3rd century B.C., Greeks and Romans used burning mirrors to light torches for religious purposes. In 1839, French scientist Edmond Becquerel discovered the photovoltaic effect while experimenting with an electrolytic cell made up of two metal electrodes placed in an electricity-conducting solution. The electricity generation of this system increased when exposed to light. In 1883, the first solar cell was built by Charles Fritt, by coating the semiconductor selenium with an extremely thin layer of gold to form junctions which are around 1% efficient. In 1954, Daryl Chapin, Calvin Fuller, and Gerald Pearson developed the silicon photovoltaic (PV) cell at Bell Telephone Laboratories with 4% efficiency and later achieved 11% efficiency [16].

Efficiencies around 40% is developed by some solar PV array manufacturers, and National Renewable Energy Laboratory (NREL) accepted that the 40.8% is the maximum tested efficiency for a solar PV panel [13]. Manufacturing those high efficiency solar photovoltaic modules in industrial level for mass applications is not economically viable and generally, at industrial level, 10% to 19% efficiency ranges are more popular.

There are three types of solar PV cell depending on the crystal type used to manufacture the cell, namely, mono crystalline, polycrystalline and amorphous.

Physics

PV cells can be modeled as a current source in parallel with a diode [14]. When there is no light present to generate any current, the PV cell behaves like a diode. As the intensity of incident light increases, current is generated by the PV cell, as illustrated in below figure.

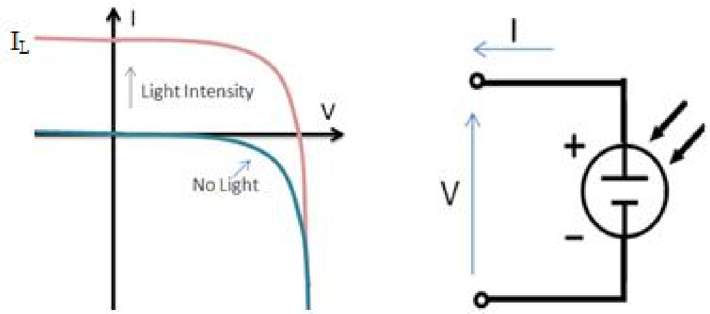


Figure 4: I-V curve of a PV cell and equivalent electrical diagram

In an ideal cell, the total current I is equal to the current I_ℓ generated by the photoelectric effect minus the diode current I_D, according to the equation:

$$I = I_l - I_D = I_l - I_0\left(e^{\frac{qV}{kT}} - 1\right)$$

Where,

I_0 - Saturation current of the diode

q - Elementary charge 1.6×10^{-19} Coulombs

k - Constant of value 1.38×10^{-23} J/K

T - Cell temperature in Kelvin

V - Measured cell voltage that is either produced (power quadrant) or applied (voltage bias).

By expanding the equation, circuit model shown in Figure 3.6 and the following associated equation can be obtained.

$$I = I_l - I_0\left(e^{\frac{q(V+IR_s)}{nkT}} - 1\right) - \frac{V + IR_s}{R_{SH}}$$

Where,

n - Diode ideality factor (typically between 1 and 2)

R_S - series resistances.

R_{SH} - Shunt resistance

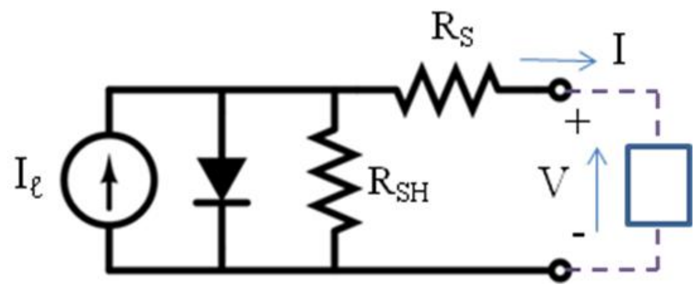


Figure 5: Simplified Equivalent Circuit Model for a Photovoltaic Cell

I-V curve of an illuminated PV cell has the shape shown in Figure 3.7, as the voltage across the measuring load is swept from zero to V_{OC}, and many performance parameters for the cell can be determined from this data.

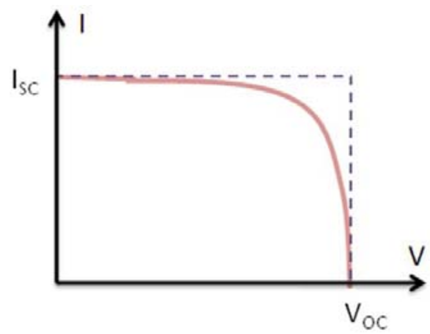


Figure 6: Illuminated I-V Sweep Curve

Important electrical characteristics of a solar PV panel are given below.

- Nominal power (P_{MAX} measured in Watts), Maximum power point voltage (V_{MPP}), Maximum power point current (I_{MPP}) - The power produced by the cell in Watts can be easily calculated along the I-V sweep by the equation P=IV. At the I_{SC} and V_{OC} points, the power will be zero and the maximum value for power will occur between the two. The voltage and current at this maximum power point are denoted as V_{MP} and I_{MP} respectively.

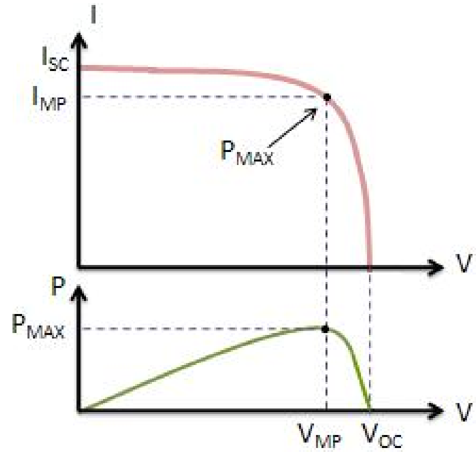


Figure 7: Maximum Power for an I-V Sweep

- Open circuit voltage (V_{OC} measured in Volts) - The open circuit voltage (V_{OC}) occurs when there is no current passing through the cell.

$$V \text{ (at } I=0) = V_{OC}$$

  V_{OC} is also the maximum voltage difference across the cell for a forward-bias sweep in the power quadrant.

$$V_{OC} = V_{MAX} \text{ for forward-bias power quadrant}$$

- Short circuit current (I_{SC} measured in Ampere) - The short circuit current I_{SC} corresponds to the short circuit condition when the impedance is low and is calculated when the voltage equals 0.

$$I \text{ (at } V=0) = I_{SC}$$

  I_{SC} occurs at the beginning of the forward-bias sweep and is the maximum current value in the power quadrant. For an ideal cell, this maximum current value is the total current produced in the solar cell by photon excitation.

$$I_{SC} = I_{MAX} = I_{\ell} \text{ for forward-bias power quadrant}$$

- Module efficiency (%) - Efficiency is the ratio of the electrical power output P_{out}, compared to the solar power input, P_{in}, into the PV cell. P_{out} can be taken to be P_{MAX} since the solar cell can be operated up to its maximum power output to get the maximum efficiency.

$$\eta = \frac{P_{out}}{P_{in}}$$

Solar PV module performance is generally rated under standard test conditions, which are given below.

- Solar Irradiance of 1000 W/m^2
- Sun angle
- Module temperature of 25^{0}C
- I-V Operating (load matching for maximum power)

The crystals used to make PV cells, like all semiconductors, are sensitive to temperature. Figure 3.9 depicts the effect of temperature on an I-V curve. When a PV cell is exposed to higher temperatures, I_{SC} increases slightly, while V_{OC} decreases more significantly.

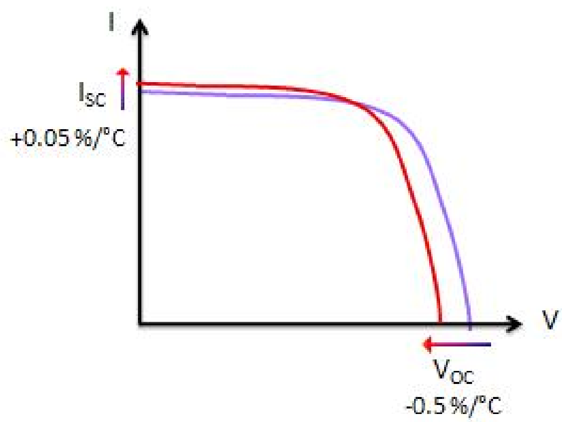


Figure 8: Temperature Effect on I-V Curve

For a specified set of ambient conditions, higher temperatures result in a decrease in the maximum power output P_{MAX}.

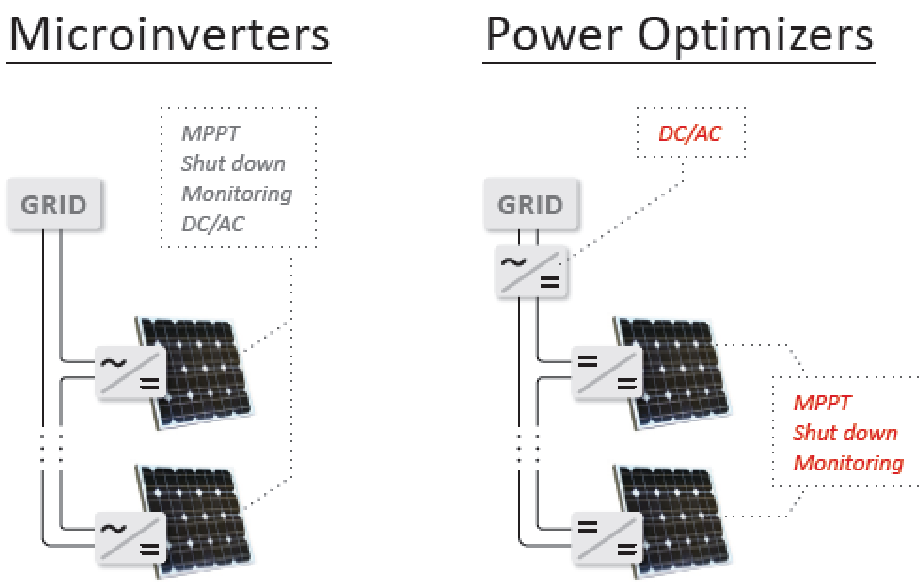
Shading on solar panels results uneven current flows through the circuits and diodes are included to avoid overheating of cells in case of partial shading. Since cell heating reduces the operating efficiency it is desirable to minimize the heating. Very few modules incorporate any design features to decrease temperature, and it is a good practice to provide good ventilation behind the module.

APPENDIX B

A comparison of Micro inverters & Power Optimizers

Module level electronics overcome the shortcomings of traditional inverters and enable maximum power, module level monitoring, flexible design and enhanced safety.

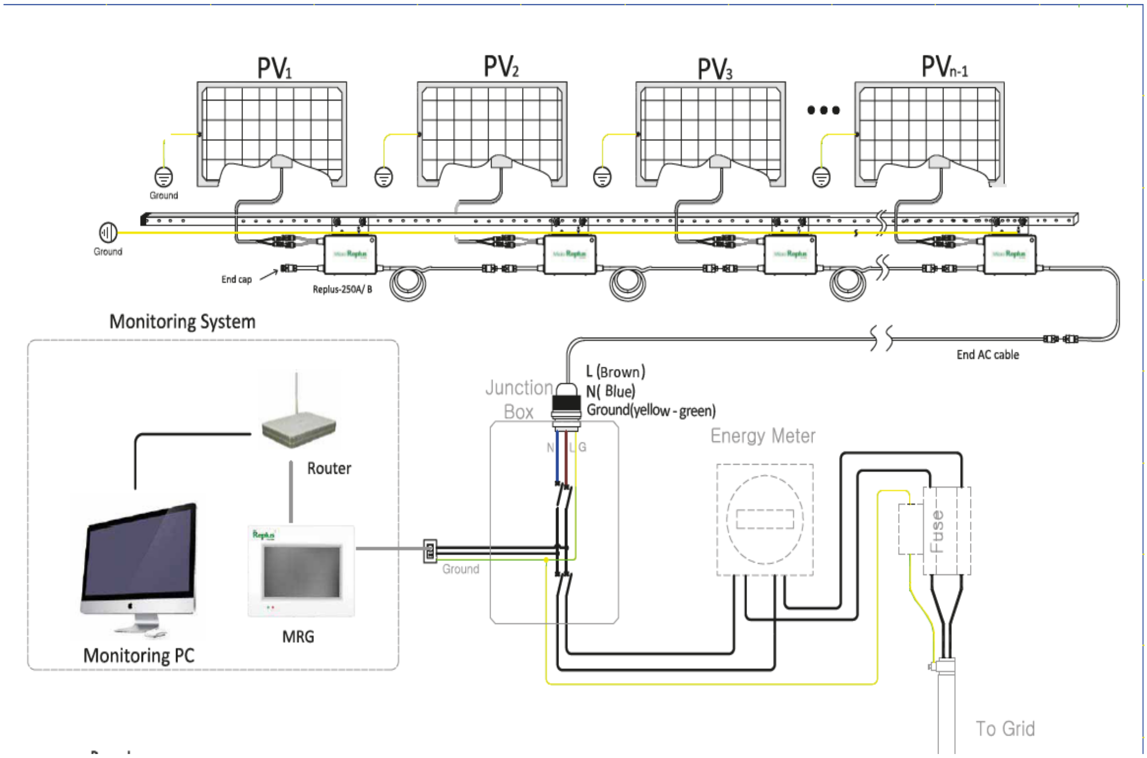
However, there is no need to add an inverter to every module if DC power optimizers can achieve all these benefits at lower cost, higher efficiency and higher reliability.



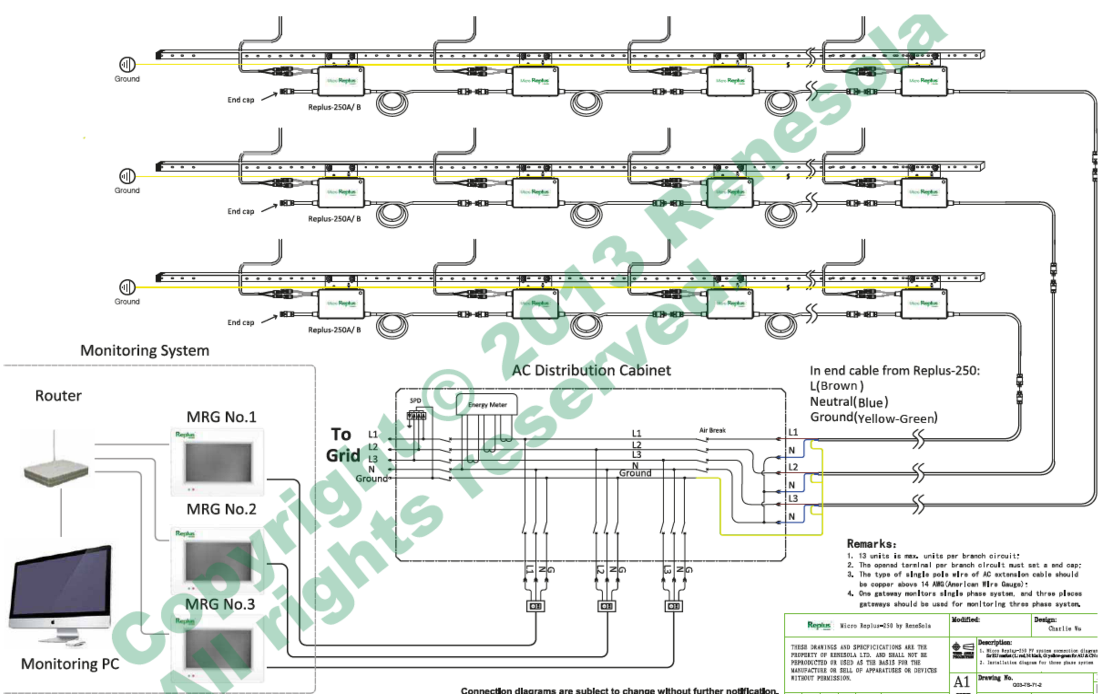
The comparision with respect to Micro Inverters Vs Solar Edge Power Optimizers are discusse below with respect to the Israel manufacture Solar Edge.

Benefits	Micro inverters	Power Optimizers	Details
Cost per Watt	Higher	Lower - 20-50% cheaper	Micro inverters cost includes trunk cables and gateways. Solar Edge system cost includes inverter, built-in module-level monitoring and 25 year warranty for inverters and power optimizers.
Scalability	Not scalable	Scalable	The cost/watt of a Solar Edge system decreases as installation size increases
Added Energy	Lower	Higher	Power optimizers have higher efficiency (99.5%) than micro inverters. Reduced efficiency of micro inverters increases heat dissipation. which enhances module degradation. Micro inverters have a higher minimum voltage than power optimizers: Less shading tolerance Late wake up leading to fewer production hour
Compatibility	Limited	Broad	Micro inverters have a limited AC output power (e.g. no support for 72-cell modules) When connected to higher capacity modules, the excess DC power is lost. E.g. in a 6kW installation of 260W modules, only 5kW AC power will be produced
Reliability	Lower	Higher	Micro inverters have much higher part count leading to increased failure rate. Some micro inverters work with electrolytic capacitors which have short life time. Micro inverters create higher temperatures

A connection diagram of single phase Grid tie micro inverter system for Net Metering is shown below.

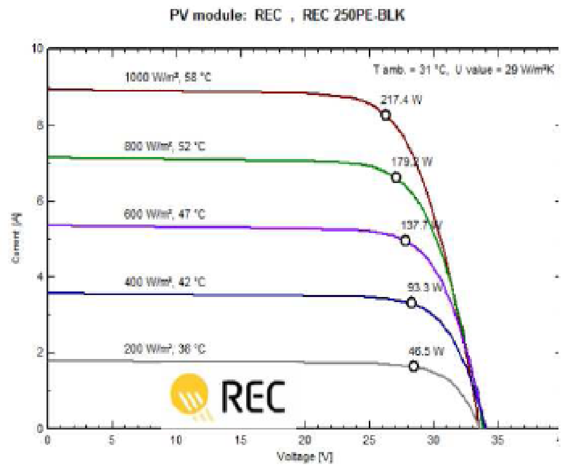


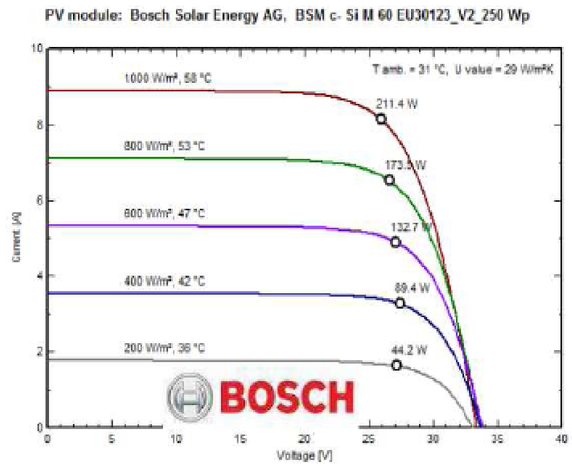
A connection diagram of three phase Grid tie micro inverter system for Net Metering is shown below.

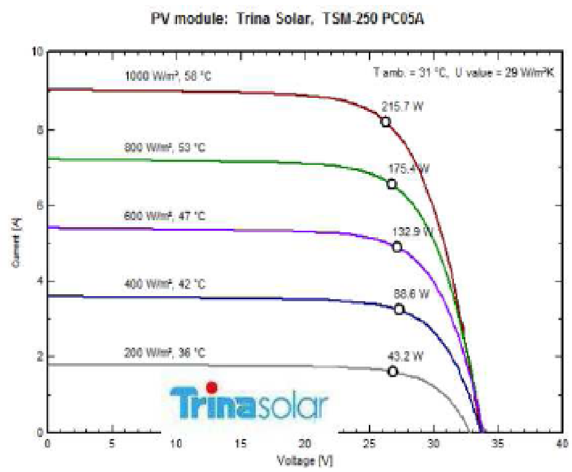


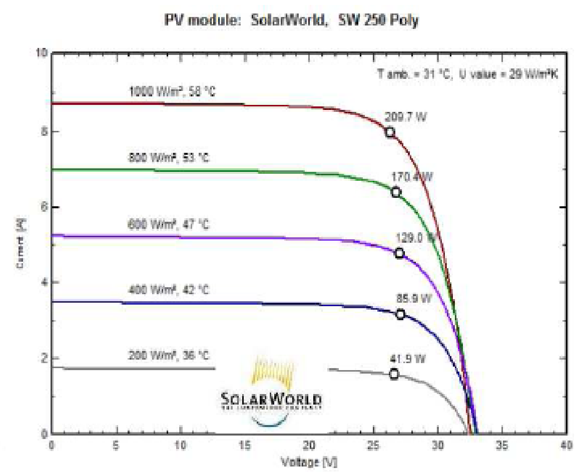
Comparison of characteristics of some leading solar modules.

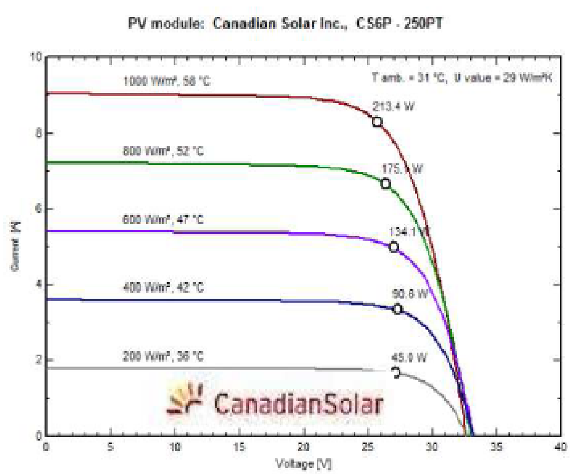
Source : Data Sheet & PVSyst PAN File.

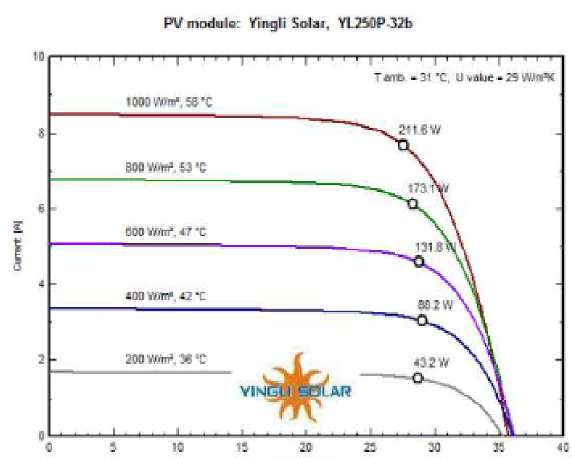






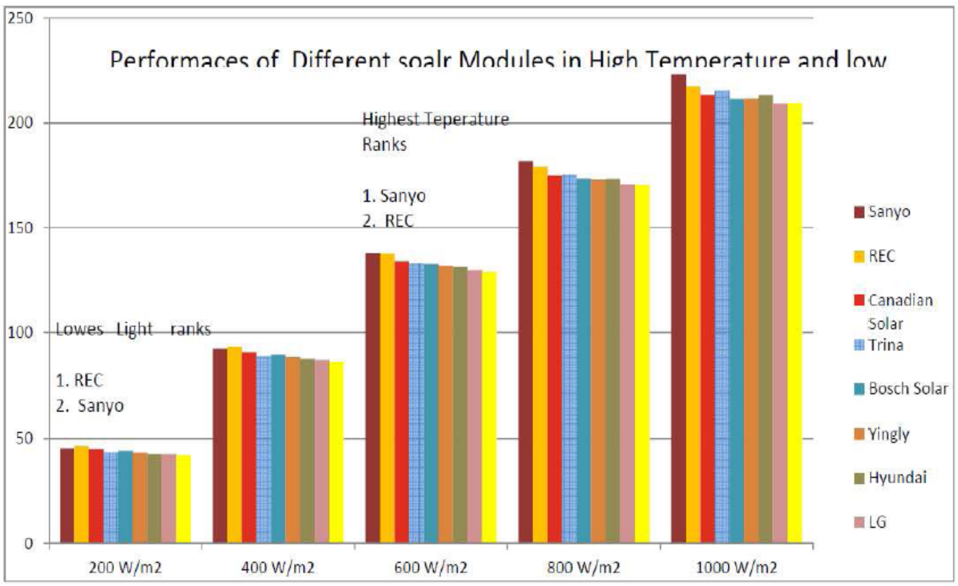






Output power in Watts at different environmental conditions

	1000 W/m2	800 W/m2	600 W/m2	400 W/m2	200 W/m2
Sanyo	223.1	181.7	138	92.3	45.4
REC	217.4	179.2	137.7	93.3	46.5
Canadian Solar	213.4	175.1	134.1	90.6	45
Trina	215.7	175.4	132.9	88.6	43.2
Bosch Solar	211.4	173.5	132.7	89.4	44.2
Yingly	211.6	173.1	131.8	88.2	43.2
Hyundai	213.3	173.3	131.2	87.4	42.6
LG	209.3	170.8	129.9	87	42.6
Solarworld	209.7	170.4	129	85.9	41.9

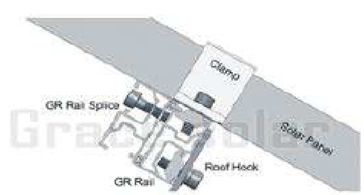


Source: PV syst- world's leading PV analysis software

Solar PV Mounting Systems.

- Standard Mounting system provides
    - Better ventilation gap and cooling effect →up to 5% more energy yield
    - Nice aesthetic appearance
    - Quick assembling and dissembling for easy maintenance
    - Low weight – less burden on structure.

Four Steps to put the tilt-in module into rail easily



Assembly drawing