OPTIMUM SELECTION OF SOLAR SYSTEMS FOR NET METERED CONSUMERS A CASE STUDY : COLOMBO CITY

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Degree of Master of Science

Department of Electrical Engineering

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Dissertation submitted in partial fulfillment of the requirements for the degree

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DECLARATION

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Abstract

This paper presents the optimum selection criteria of a PV solar system for net metered consumers. This was done as a case study in Colombo City with optimization of five parameters which directly affect the output of PV solar system. Five parameters are tilt angle, azimuth angle, shadow possibilities, array size, and inverter capacity.

Geography and the climate in Sri Lanka justify the capability of harnessing the solar energy under net metering concept. Extreme motivation and guidance for this research came due to direct involvement in implementing net metering scheme in Colombo south area in CEB.

Highest solar insolation level in Colombo City reaches 5.09 kWh/m^2/day in March. If the monthly electricity consumption is between 360-510 kWh, optimum benefits could be achieved by consumers who have installed 3 kW systems in domestic tariff (D1) category. A domestic consumer with average consumption of 225 kWh can achieve a 10 year payback. The analytical model developed with weighted marking scheme will assist a designer to select the best combination of inverter and solar panel for a particular location.

Best tilt angle in Colombo city is 6^o, 7^o and 8^o. Tilt of tile roof is 30^o which is the most common in domestics. Maximum 6.13% energy is lost due to use of tile roofs for solar PV even with the best azimuth angle (5^o to 15^o away from south toward east direction). If the Shadow Free percentage is less than 60%, the PV solar system should not be installed though the effectiveness factor is 80%. Peak point of the benefits can be reached through selecting an optimum rated power of the inverter to be 77%-91% to that of the solar panel capacity.

Investing in a net metering PV solar system is more beneficial compared to an investment with the return of even 12% interest rate. Domestic tariff (D1) provides highest benefits to a net metering consumer.

Key words: Net Metering, Insolation, Tilt Angle, Azimuth Angle

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LIST OF ABBREVIATIONS

Abbreviation	Description
CEB	Ceylon Electricity Board
PV	Photo Voltaic
C-Si	Single crystal silicon
mc-Si	multi crystal silicon
GaAs	Gallium arsenide
a-Si	Amorphous silicon
CuInSe2	Copper Indium Deselienide
CIGS	Copper Indium Gallium Deselenide
CdTe	Cadmium telluride
NASA	National Aeronautics and Space Administration
ASDC	Atmospheric Science Data Center
EOS	Earth Observing System
DAAC	Distributed Active Archive Center
EOSDIS	Earth Observing System Data and Information System
SPP	Simple Payback Period

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Chapter 01

INTRODUCTION

1.1 Background

Sri Lanka possesses renewable energy potential in the form of wind, solar, hydro and biomass. Absorption of some of them such as mini hydro does not make any substantial impact on the Sri Lanka power system, owing to their dispatch issues. Sri Lanka's wind potential along its north western and northern coasts is estimated to be about 3,000 MW. Solar potential of Sri Lanka is also estimated to be about 6,000MW. Solar and wind are the two major renewable energy sources which are vastly available in Sri Lanka. Sri Lanka is a tropical country and daylight is freely available from 6.00 am to 6.00 pm over 365 days due to the location of the country. Therefore, proper utilization of this resource would be beneficial both economically and environmentally.

It is not amazing that a country like Sri Lanka is moving towards more renewable energy sources such as solar energy to full fill the country's electricity requirement. Currently there is a 1 MW solar power plant operating in Sri Lanka at Sooriyawewa, Hambantota. In near future there will be several more solar power plants around the country which are to be connected to the national grid.

Sri Lanka was targeting to reach 10% minimum level energy generation using non-conventional renewable energy compared to total energy generation by the year 2015 through national energy policy which was introduced in 2006. [02]. The data in the Section 1.3 shows that Sri Lanka has reached 6.24% energy generation through non-conventional energy sources in 2012. At the end of 2011, total installed solar capacity in Sri Lanka was 1.38 MW which is very small capacity compared to the total installed capacity [02]. Therefore, it can be seen that solar energy is rarely used to generate electricity even though this source of energy is available in abundance. That appears to be mainly due to the high capital cost and high payback period in earlier times.

But, today solar panels have been become as a global product. There is tremendous variation in the cost of PV solar panels based on the type and efficiency of the PV solar panels. However, the type of panels used for residential solar installations is quite standard and the costs are basically set globally.

The production of electricity from PV solar system is still expensive when compared to conventional production methods. These facts necessitate the careful selection of each individual part of a grid connected PV solar system is essential to obtain maximum energetic and economic performance.

1.2 Geography and Climate in Sri Lanka

Sri Lanka is an island with total area of 65,610 km^2 and lie within the equatorial belt. It is located in the Indian Ocean, to the southwest of the Bay of Bengal, between latitudes 5°55’ and 9°51’N, and longitudes 79°42’ and 81°63’E [03]. Sri Lanka is separated from the subcontinent by the Gulf of Mannar and the Palk Strait.

Climate in Sri Lanka varies with altitude relative to the latitude. The mean monthly temperature fluctuates with two factors, namely seasonal movement of the sun and the rainfall. Highlands have cooler and more temperate climate with an annual average temperature around 16-20ºC while coastal areas are warmer with annual average temperature around 27ºC. In coastal areas, the March to June period experiences slightly higher temperatures with maximum up to 33ºC to 35ºC, while temperatures in November to January experiences a little lower around 27ºC. Still weather in the shores is more relaxed by cooling sea breezes. The temperature of the surrounding sea remains fairly constant around 27ºC continuously throughout the year [04].

Humidity typically depends on the seasonal pattern of rainfall. In Colombo humidity stays above 70% throughout the year and it rises up to 90% in the monsoon rainy season in June [05]. Since, Sri Lanka is located close to the equator, it receives constant high solar radiation and gets high daylight illumination throughout the year. The annual solar energy which is received across Sri Lanka ranges from 4.2 to 5.6 kWh/m^2/day [06].

1.3 Electricity Statistics

Sri Lanka inherits several high potential sustainable energy sources such as hydro power, solar power, wind power etc though Sri Lanka does not possess any fossil fuels. Statistics of electricity installed capacity, demand, generation and usage recorded in 2012 is as follows [01]

Total installed capacity	:	3312	MW
Maximum demand	:	2146	MW
Total generation	:	11801	GWh

Gross Electricity Generation by Source

Hydro	:	2727	GWh
Hydro – small	:	565	GWh
Thermal (Oil & coal)	:	8338	GWh
New renewable	:	171	GWh

Electricity Consumption by User (Total 9268 GWh in 2012)

Domestic	:	44.0 %
Religious	:	0.6 %
Commercial	:	21.2%
Hotel	:	1.5 %
Industrial	:	31.5 %
Street Lighting	:	1.1 %

It can be seen that in 2012, 28% of the electricity requirement in the island was generated by hydro power while the contribution of the new renewable sources such as wind and solar energy was very less.

1.4 Motivation

Majority of high end domestic (D1 tariff category) consumers are residing in Colombo city. Their monthly bill is somewhat high. Awareness and willingness of the green energy concept and availability of Net metering concept in CEB has prompted them to install PV solar systems in their households.

The cost of the solar panels fallen tremendously within the past few years and they are now about half the price they were in 2008, and about 100 times lower than they were in 1977. Due to the increase of demand for PV solar systems, lot of solar companies were formed to provide this service. Then wide range of quality levels of equipments are appeared in the market.

Under the net metering scheme within short period of time (2010 – 2013) around 500 consumers installed PV solar systems in Colombo city. As an electrical engineer (Maintenance), Colombo south area I was entrusted with a task of inspecting and approving the grid connected solar PV installations to be in lined with the required safety and protections of CEB for the purpose of grid connection.

Due to low electricity generation by PV solar system compared to their expectation, majority of consumers raised their concern to CEB. In addition raised a whole and heap of questions like,

- What is the roof top PV solar system?
- What is the Net Metering Concept?
- How do I install a PV solar system?
- How can I get benefits with PV solar systems?
- How do I select a good installer?
- How do I select a system capacity with the consumption?
- How much does it cost to go for solar?
- How much will I save? etc.

In addition my own collides of CEB from different parts of the country also wanted to get more details regarding grid connected PV solar systems.

These reasons prompted me to further study and investigation grid connection performance related to PV solar systems.

Due to easy access to all the information of Colombo city was selected for the case study in this dissertation.

1.5 Objective of the Study

Propose a selection algorithm of PV solar system for Net Metered consumers by optimization of following parameters

- Tilt Angle
- Azimuth Angle
- Shadow Possibilities
- Array Size
- Inverter Capacity

Chapter 2

LITERATURE REVIEW

There are many immediate and long term effects from burning fossil fuels to the environment such as emission of greenhouse gases, other pollutants, global climate change, global weather pattern changes etc. These harmful long and short term effects can be reduced by conserving electricity and generating electricity using renewable energy source.

The earth receives 174×10^{15} Watt of incoming solar radiation at the upper atmosphere. Approximately 30% is reflected back to the space while the rest is received by the earth and absorbed by the clouds, oceans and landmasses. The total solar energy receives by the earth is 3.85×10^{24} J per year. This is 10,000 times more than the total energy consumption in the world. The potential for solar energy along is 1.6×10^{21} joules per year. The amount of solar energy reaching the surface of the earth in one year is about twice as much as will ever be obtained from all of the Earth's non-renewable resources of coal, oil, natural gas, and mined uranium [7].

2.1 Net Metering

Use of a system with batteries coupled with inverters for energy storage is prohibitively expensive for micro-scale producers of electricity using renewable energy readily available in their premises. This limitation has retarded the use of renewable energy source based electricity generating facilities in areas where the grid is available. Therefore, CEB has decided to offer the “Energy Banking Facility” for such micro scale generating facilities, commonly known as the “Net Energy Metering Facility” by the electricity utilities. This scheme allows electricity consumers connected to CEB distribution network to install a renewable energy based electricity generating facility up to maximum of 1,000 kVA provided its generating facility shall not exceed the contract demand at any time. The electricity network connection scheme shall be approved by CEB.

It also can say “Net Metering” is an energy incentive policy for the customers those who generate electricity by means of renewable energy sources such as photovoltaic, wind power etc. This policy allows customers to export excess electricity generated to the grid and import and use the same amount of energy at free of charge at any other time when the customer demand exceed the local generation. In this system, the grid acts as infinite energy storage to the customer and omits the capital cost for the batteries. Battery maintenance cost is a considerable amount of total cost.

2.2 Energy Metering and Billing

The utility energy meter will be replaced with an Import/Export meter. The electrical energy consumed from the grid is considered as import energy and electrical energy generated and supplied to the grid is considered as export energy.

At the end of each billing period (typically one month), CEB will read the consumer's export energy meter reading and the import meter reading. The electricity bill will be prepared giving credit to the export, and charging the consumer for the difference between the import and the export. If the export is more than the import in any billing period, the Consumer will receive an export credit, and will be credited towards his next month's consumption. Such credits may be carried-over to subsequent months, as long as there is no change in the legal consumer for the premises.

For a multi-tier tariff consumer, the energy balancing is carried out within each tariff-tier and credit, if any, is given in the same tier. Credit in one tier is not transferable to another tier.

The key factor in this process is that there will be no financial compensation for the excess energy exported by the consumer. All exports will be set-off against the consumer's own consumption, either in the current billing period or future billing periods, in relevant tariff-tier. Accordingly, consumers will be compelled to select the capacity of the renewable energy equipment to reasonably match their requirements.

2.3 Colombo City

Electrification Level in Year 2013 : 99%

Land Area : 37 km^2

Population : 740,000

Peak Power Demand : 252 MW (Day Peak)

Energy Demand : 1220 GWh/Yr

Colombo City is located within the equatorial belt where substantial and constant solar energy resource is available throughout the year. There are no seasonal changes due to very less cloud coverage. Un-obstructed direct solar radiation is available on the top of almost any building during daytime which is constant throughout the year from 6.00am 6.00pm. Therefore constant and stable amount of solar radiation energy is available for many of the solar related applications such as day lighting, solar water heating, solar electricity etc. The annual solar energy receives across Sri Lanka ranges from 4.2 to 5.6 kWh/m^2/day [8]. Due to high solar radiation and other weather and climatic influences, the average temperature of the Colombo City varies from 28ºC to 31ºC.

2.3.1 Colombo City Consumer Mix

Table 2.1 - Consume Mix in Colombo City

Area	Number of Consumers		
	Retail	Bulk	Total
North	46,260	204	46,464
East	38,502	299	38,801
South	40,285	453	40,738
West	30,471	701	31,172
Total	**155,518**	**1,657**	**157,175**

2.4 Main Components of PV Solar System

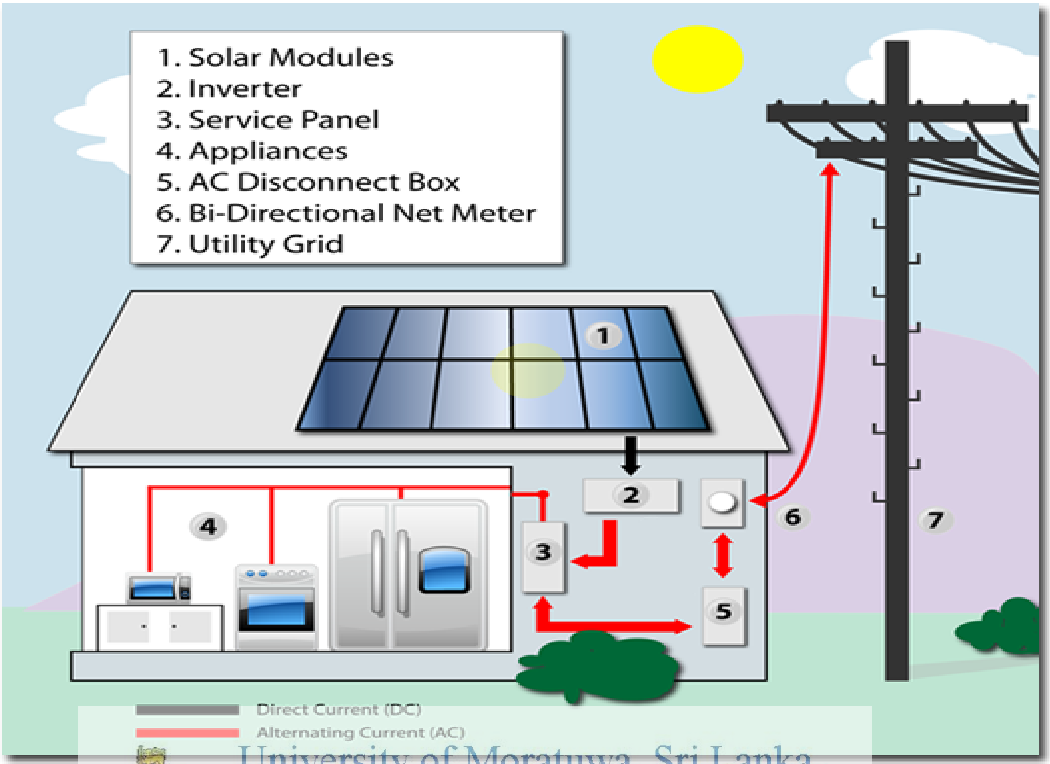

Figure 2.1 – Main Components of PV Solar System

2.5 History of Photovoltaic

Solar energy, radiant heat and light from the sun have been harnessed by human since ancient times. Solar photovoltaic energy is the direct conversion of solar radiation into electricity which is the most useful and flexible form of energy.

Photovoltaic cells are entirely made out of Silicon which the most abundant element in the earth's crust. Since photocells do not contain any moving parts, theoretically the life time of photocells should be indefinite [9]. However, the lifetime of the photocells could be reduced due to heat and radiation, by changing the property of Silicon.

The name "Photovoltaic" came from combination of two Latin words "Photo" and "Volt", where the meaning of "Photo" is light and "Volt" is the name of the units of electro motive force. The photovoltaic is discovered by the French physicist Edmond

Becquerel in 1839. He found that battery voltage of wet cell batteries are increased when silver plates of the batteries are exposed to sunlight [9].

The photovoltaic effect in a solid substance was first discovered in 1877 by two Cambridge scientists, W.G. Adams and R. E. Day. They found electrical properties in Selenium when exposed to light [9].

Solar cell with similar form to Silica cell of present was first constructed by Charles Edgar Fritts, a New York electrician in1883. Those photocells consisted with thin wafer of Selenium covered with grid of thin gold wired and a protective glass sheet. The efficiency of these was less than 1% and the production cost too was very high. Due to these reasons, the production of these were not seen much until mid of twentieth century [9].

The development of modern type photocells with doped semiconductors was invented by Darryl Chapin, Calvin Fuller and Gerald Pearson at Bell Telephone Laboratories in New Jersey in 1950. In 1954, they were able to increase the efficiency of the photocells to 6 % and in 1958, photocells were used to power a small radio transmitter in the second space satellite, Vanguard [9].

Rapid increase in the efficiencies of the photocells was able to achieve in the last decade and efficiency has reached to 24% at laboratory test conditions by single junction Silicon solar cells making the cost of photocells is considerably less [9].

2.6 Photovoltaic Technologies

Three generations of photocells have been contributed to the development of the photovoltaic industry. The first generation is based on silicon wafers and occupies about 90% of the market volume. The second generation of solar cells are based on cheap semiconductor thin films deposited on low cost substrates to produce devices of slightly low efficiency and occupies about 6% of the market volume. New advanced nanotechnologies technologies such as photonics, optical metamaterials, plasmonics and semiconducting polymer sciences will use to produce high efficient third generation photocells. Cost reduction in production of photocells can be expected while moving from 1st generation to 3rd generation and can expect fully cost competitive 3rd generation photocells will be in the market in 10 to15 years.

2.6.1 1st generation photocells

Different types of 1st generation photocells technologies are available in the market. Single junction solar cells which are based on silicon wafers dominate the market. Single crystal silicon (C-Si) and multi crystal silicon (mc-Si) both are single junction silicon wafer photocells. Majority of the 1st generation photocell technologies were developed with the development of screen print based integrated circuit industry.

2.6.1.1. Monocrystalline Silicon Cells

Until recently, majority of photocells were produced using monocrystalline technology in which extremely pure monocrystalline silicon is used. Monocrystalline silicon has single continuous crystal lattice structure with no defects or impurities. Sophisticated and expensive and Czochralski Process initially developed for the electronics industry is used to produce monocrystalline silicon. A small seed of crystal is slowly pulled out from polycrystalline silicon and monocrystalline silicons grown. The extremely pure monocrystalline silicon is used to produce single junction photovoltaic modules. This is a very slow process and requires highly skilled labour hence the process is labour and energy intensive. These are the most efficient photovoltaic cells available in the market.

2.6.1.2. Polycrystalline PV Materials

Monocrystalline silicon requires extremely pure electronic grade silicon. Photovoltaic cells can be produced using slightly less pure solar grade silicon and with slightly less efficient polycrystalline PV materials. Polycrystalline PV materials such as polycrystalline silicon, gallium arsenide can be grown as ribbons or as sheets.

2.6.1.2.1. Polycrystalline Silicon

Polycrystalline silicon consists of small grains of monocrystalline silicons. There are different ways of manufacturing polycrystalline silicon. Polycrystalline silicon can be controlled casting into cube shaped ingots which then cut into thin square wafers using fine wire saws and then fabricated into complete photocells.

2.6.1.2.2. Silicon Ribbons and Sheets

The main process is called edge defined film fed growth and was developed by US company Mobil Solar. Multicrystalline silicon from a silicon melt is drawn into sheets or ribbons and then doped, processed and produced single junction silicon ribbons/ sheet cells.

2.6.1.3. Gallium Arsenide

Gallium arsenide (GaAs) is called as compound semiconductor material and this has a crystal structure similar to silicon. Since GaAs has higher light absorption coefficient, this is highly suitable for photovoltaic applications. Due to the high light absorption coefficient, only a thin layer of material is required and due to the wider band gap than silicon, GaAs absorb more energy in the terrestrial solar spectrum.

The light absorption efficiency of GaAs cells are more stable with the temperature rise compared to silicon cells. The production process has not been well developed yet and Gallium and Arsenic are not abundant material as Silicon, the production cost of GaAs cells is substantially higher than silicon cells. GaAs cells are the preferred option when the efficiency is the main concern regardless the cost.

2.6.2 2nd Generation Photocells

2.6.2.1. Thin Film Photovoltaic

2.6.2.1.1. Amorphous Silicon

Amorphous silicon (a-Si) cells have a different form of junction between p-type and n-type material and this junction is called p-i-n junction. The sandwich of a- Si cell consist of extremely thin layer of p-type silicon on the top, a thicker intrinsic undoped Si j layer in the middle and very thin n-type silicon layer in the bottom.

Very thin films of a-Si can be used due better lighting absorption quality. The production cost of a-Si is much lesser than crystalline silicon as much lower manufacturing temperature, less material cost and easy production process. However the efficiency of a-Si is currently is less than monocrystalline or multicrystalline solar cells.

2.6.2.1.2. Other thin Film Technologies

Most of the thin film technologies are based on compound semiconductors such as copper Indium deselienide (CuInSe2), copper indium gallium deselenide (CIGS), cadmium telluride (CdTe) etc. Highest 17% laboratory efficiency of thin film photocells was recorded by CIGS at laboratory test conditions.

2.6.3 3rd Generation Photocells

3rd generation photocells are based on nanotechnologies which aims to manipulate molecules and atoms at extremely small scales. Crystals of such small scale are called nanocrystals. Solar cells contain with nanocrystals contain wide range of electronic band gap which can absorb energy of solar spectrum and ideal for a solar collector. The technology of this is very young and developing very rapidly.

2.7 Photovoltaic Cell and Module Production

Photovoltaic manufactures have been increasing their cell and module production steadily and strongly. According to the data provided by Earth Policy Institute by GTM Research confirms that Chinese manufacturers leads global market in 2010 for seventh consecutive year with approximate 11,000 MW production while Taiwan produced 3,600 MW occupying the second position in global market. Japan 2,200 MW, Germany 2000MW and Unites State1,100MW manufactured in 2010 and were the top five global manufacturers [10].

Considering the installed solar capacities, Germany leads with 17,200MW installed capacity while Spain was the number two with 3,800MW installed capacity in 2010. Phototoltaic installed capacity in Japan is nearly 1,000MW in 2010 ranking 3rd position and their national target to achieve 28,000 MW installation by 2010 as Japan weighs more for alternative renewable energies after March 2011 nuclear disaster [10].

The main usage of photovoltaic in the developing countries are installation of small systems typically from 200W to 500W for houses and installation of typically 500W to 2500W systems for village power schemes, healthcare centres, schools, water pumping stations and telecommunication stations.

2.8 World Annual Solar Photovoltaic Production

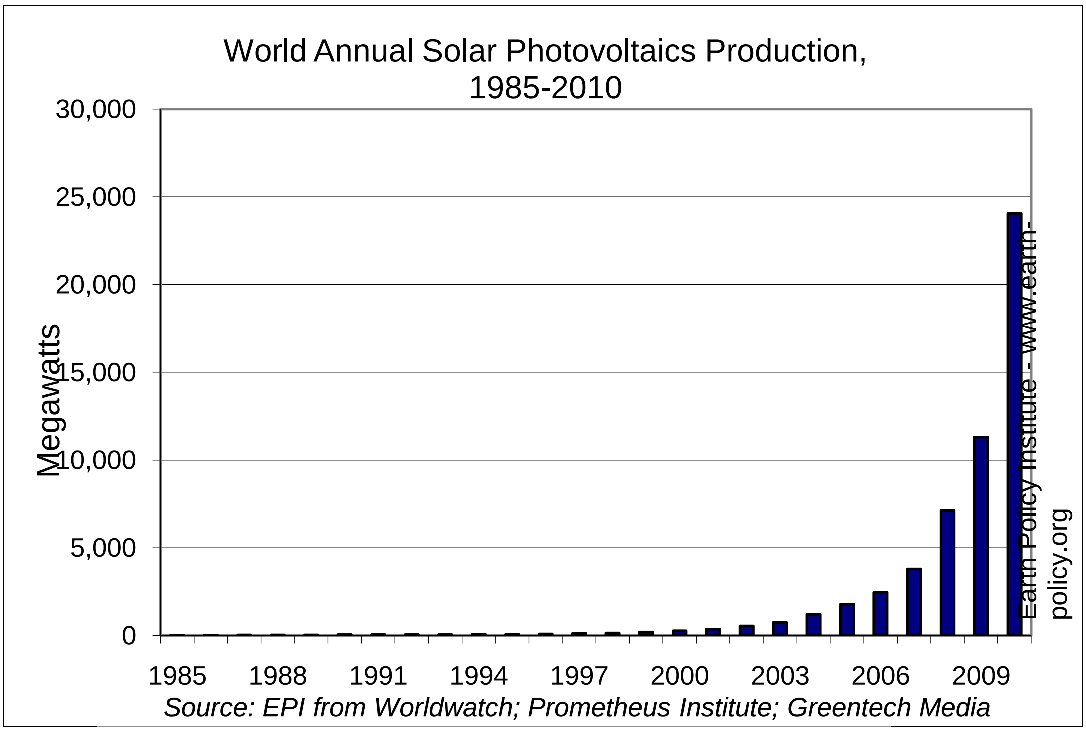

Figure 2.2 - World annual solar photovoltaic production 1985 -2010

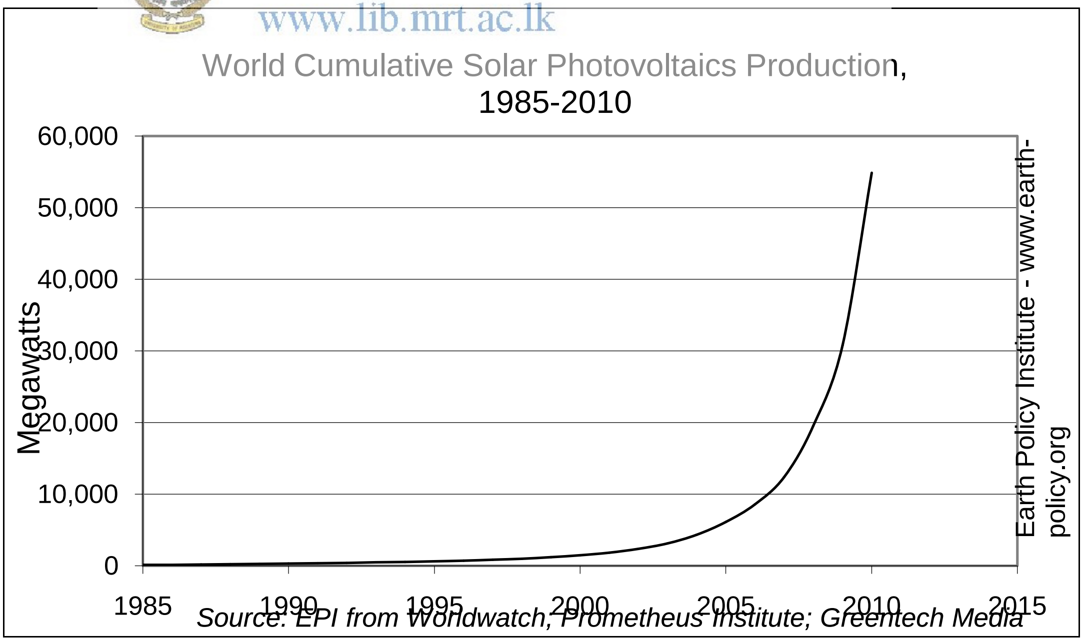

Figure 2.3 - World cumulative solar photovoltaic production 1985 -2010

Load Profile with Relevant Solar System

Consumption (kWh)	Solar System (kW)	Unit Generation From Solar System (kWh)
30	1	125
60	1	125
90	1	125
120	1	125
150	1	125
180	1	125
210	1	125
240	2	210
270	2	210
300	2	210
330	2	210
360	2	210
390	2	210
420	3	330
450	3	330
480	3	330
510	3	330
540	4	450
570	4	450
600	4	450
630	4	450
660	5	600
720	5	600
750	5	600
810	5	600
870	6	750
930	6	750
960	6	750
1020	6	750
1080	8	960
1140	8	960
1200	8	960
1260	8	960
1320	10	1200

1380	10	1200
1450	10	1200
1480	10	1200
1570	12	1450
1630	12	1450
1690	12	1450
1750	12	1450
1800	12	1450
1890	15	1800
1920	15	1800
1950	15	1800
1980	15	1800

Chapter 4

PARAMETER OPTIMIZATION

This Chapter presents the optimization process of a grid connected PV solar system. The optimization method is based on maximizing the utilization of the array output energy and at the same time optimizing the electricity power delivered to grid. Because of the international competition, along with years of experience in manufacturing and research & development, efficiency improved photovoltaic modules are available in the market. But the cost of entire system still remains relatively high compare with traditional power generation technology. This high cost necessitates that the following design parameters should be optimized.

- Tilt Angle
- Azimuth Angle (Orientation)
- Shadow Possibilities
- Array Size
- Inverter Size

4.1 Tilt Angle Optimization

The angle between the horizontal plane and the solar panel is called the tilt angle (β).

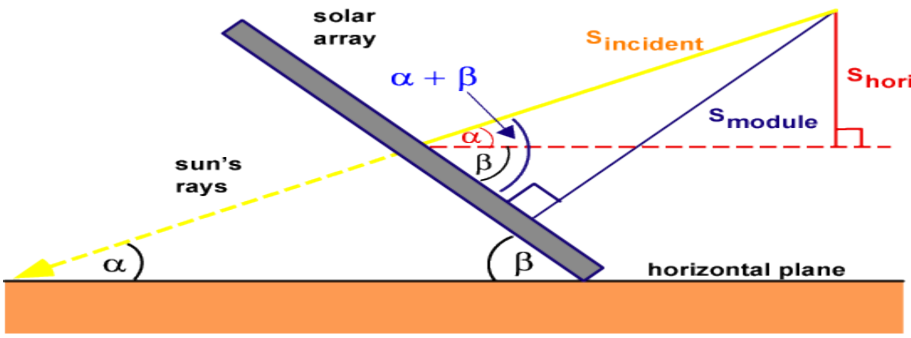

Figure 4.1 – Solar Radiation on Tilted Surface

α- Elevation Angle,

β- Tilt Angle

The sun moves across the sky from east to west. Solar panels are most effective when they are positioned facing the sun at a perpendicular angle at noon. Solar panels are usually placed on a roof or a frame and have a fixed position and cannot follow the movement of the sun along the sky. Therefore they will not face the sun with an optimal (90 degrees) angle all day, and then the amount of energy that could be captured by a solar panel would be maximized by pointing the device.

The radiation received by a PV array on earth can be divided into three categories:

- Direct (Direct radiation strikes array surface from only one angle)
- Diffuse (the diffuse radiation approaches array surface from all unobstructed angle)
- Reflected

According to Mathew (Buresh, 1983) the optimal tilt angle for a surface equals the site's latitude (This surface would receive optimum amount of direct-beam solar radiation over the entire year) [11]

However, for PV solar systems this angle may not be the best because the efficiency of PV solar modules increases when the ambient temperature decrease. In addition, the diffuse and reflected components of solar radiation were neglected in the above analysis.

According to the above analysis array surface tilt angle for Colombo City is,

Colombo, Coordinates - 6.9167° N, 79.8333° E

Then, Optimal Tilt Angle = 7^o

4.1.1 Simulation Model

This Simulation was done by PVSYST and SMA SUNNY DESIGN simulation software.

Table 4.1 – Simulation Model for Tilt Angle Simulation

Solar System	4.4 kW
Location	Colombo
PV Module Type	REC 245 PE
No of PV Modules	18
Inverter Type	SB 4000 TL - 20
Azimuth Angle (Orientation)	0 (South)
Shadow Possibilities	Shadow Free > 90%

4.1.2 PV Output (kWh) for Different Tilt Angle

PV output for different tilt angles was simulated and results are as follows,

Table 4.2 – PV Output for Different Tilt Angle

	Azimuth Angle - South											
Tilt Angle	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
0	496	552	600	569	513	502	504	519	493	476	458	456
2	497	554	602	571	515	504	506	521	495	478	460	458
4	498	555	603	573	516	505	507	522	496	479	461	459
6	499	556	604	573	517	506	508	522	497	480	461	459
7	499	556	604	573	517	506	508	523	497	480	461	459
8	499	556	604	573	517	506	508	523	497	480	461	459
10	499	555	603	573	516	505	507	522	496	479	461	459
12	498	554	602	572	515	504	506	521	495	478	460	458
14	496	553	600	570	514	503	505	520	494	477	459	457
16	495	551	598	568	512	501	503	518	492	475	457	455
18	492	548	595	565	510	499	501	515	490	473	455	453
20	489	545	592	562	507	496	498	512	487	470	452	450
22	486	541	588	558	503	493	494	509	484	467	449	447
24	482	537	583	554	499	489	491	505	480	464	446	444
26	478	532	578	549	495	485	486	501	476	460	442	440
28	474	527	573	544	490	480	482	496	471	455	438	436
30	469	522	567	538	485	475	477	491	466	450	433	431
32	463	515	560	532	479	469	471	485	461	445	428	426

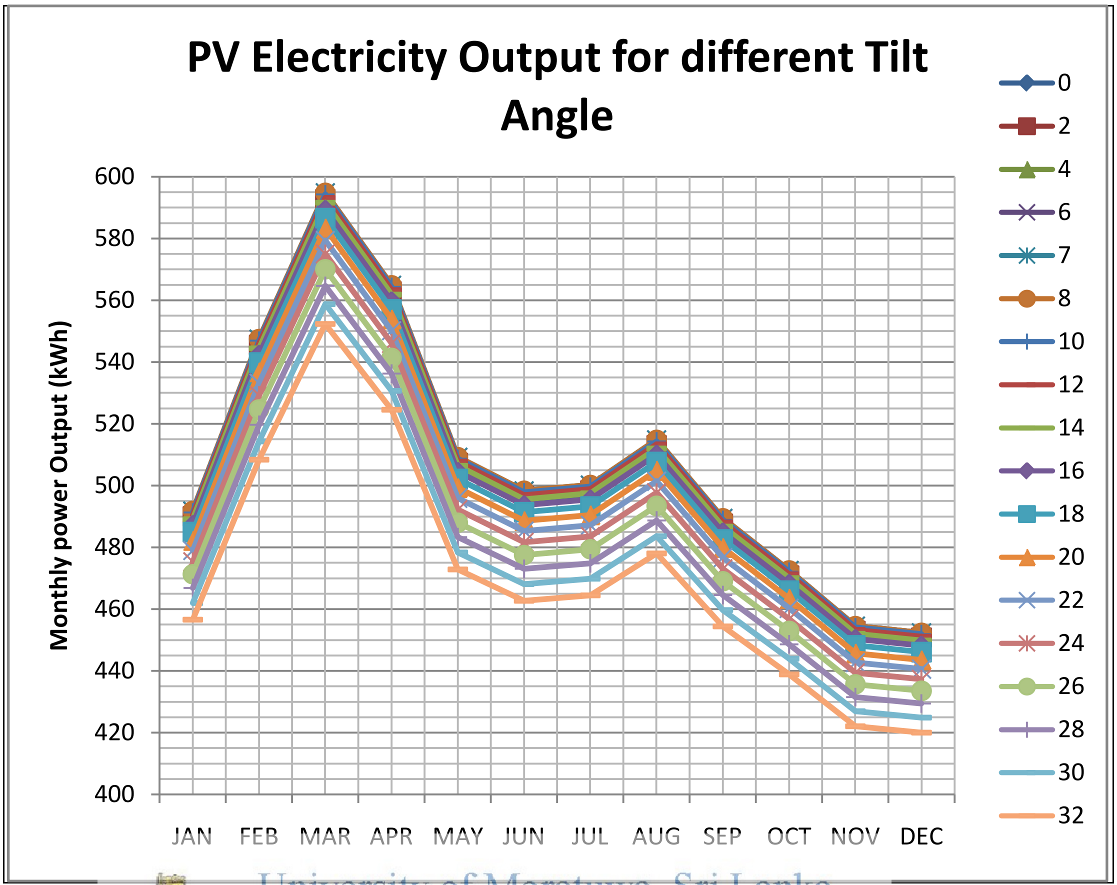

Figure 4.2 - PV Electricity Output for different Tilt Angle

This graph shows monthly PV solar output for different tilt angles.

The PV solar output increases dramatically from January and reached a peak in March. Then PV solar output started to decrease and dropped drastically from March to May and it continued and fell slightly in June.

The PV solar Output increases again from June to August and started to decrease gradually from August to December.

The PV solar output fluctuates from January to December and the graph reached its highest point in March. Then it showed a downward trend till December.

4.1.3 Annual PV Output (kWh) for Different Tilt Angle

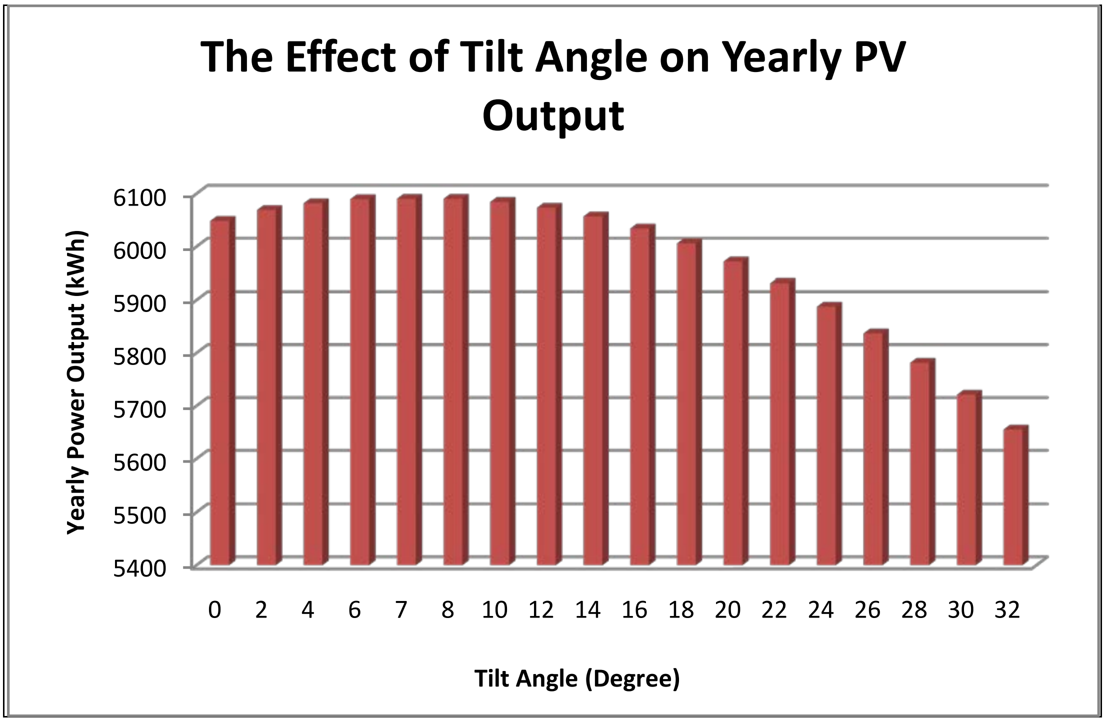

Figure 4.3 – Annual PV Output (kWh) for different Tilt Angle

The graph shows that the most common available roof angles in Sri Lanka (Described in 4.1.4) are not the best surface tilt angles for PV solar systems in Colombo City.

Best Tilt angle according to Mathew (Buresh, 1983) [11] in Colombo city is about 7^o. But the same yearly output available for tilt angle 6^o and 8^o too.

The output of a solar PV array increases from tilt angle $0^o$and reached a peak at tilt angle 6^o. Then the PV solar output remains till tilt angle 8^o. Then output of the solar PV array started to decrease gradually and it continues up to December.

4.1.4 Differential Energy Savings

There are three common types of roofs available in Sri Lanka. They are listed with relevant roof angle below,

- Tiles – 30^o
- Asbestos – 20^o
- Trapezoidal Sheets (Amano Sheets) – 12^o

Though solar panels should be installed at a tilt angle equal to the latitude to get the maximum benefits, common practice is install PV solar panels with available roofs due to high cost of mounting structure which help to improve the tilt angle. By taking the solar PV output of existing roof angle as reference, a series of energy savings was determined. It helps to analyze the deviation of the solar PV output from the different tilt angles that can be installed PV solar panels.

Table 4.3 – PV Output with reference Tilt Angle

Tilt Angle	**Saving Percentage (%)**		
	Roof type Tiles (30^o)	**Roof type Asbestos (20^o)**	**Roof type Amano Sheets (12^o)**
0	5.48	1.29	-0.42
2	5.79	1.62	-0.08
4	6.00	1.84	0.14
6	6.12	1.96	0.26
7	6.13	1.97	0.28
8	6.13	1.97	0.28
10	6.05	1.89	0.19
12	5.87	1.70	0.00
14	5.61	1.43	-0.28
16	5.25	1.06	-0.65
18	4.79	0.57	-1.15
20	4.24	0.00	-1.73
22	3.60	-0.67	-2.41
24	2.86	-1.44	-3.20
26	2.02	-2.32	-4.09
28	1.06	-3.32	-5.11
30	0.00	-4.43	-6.23
32	-1.19	-5.67	-7.50

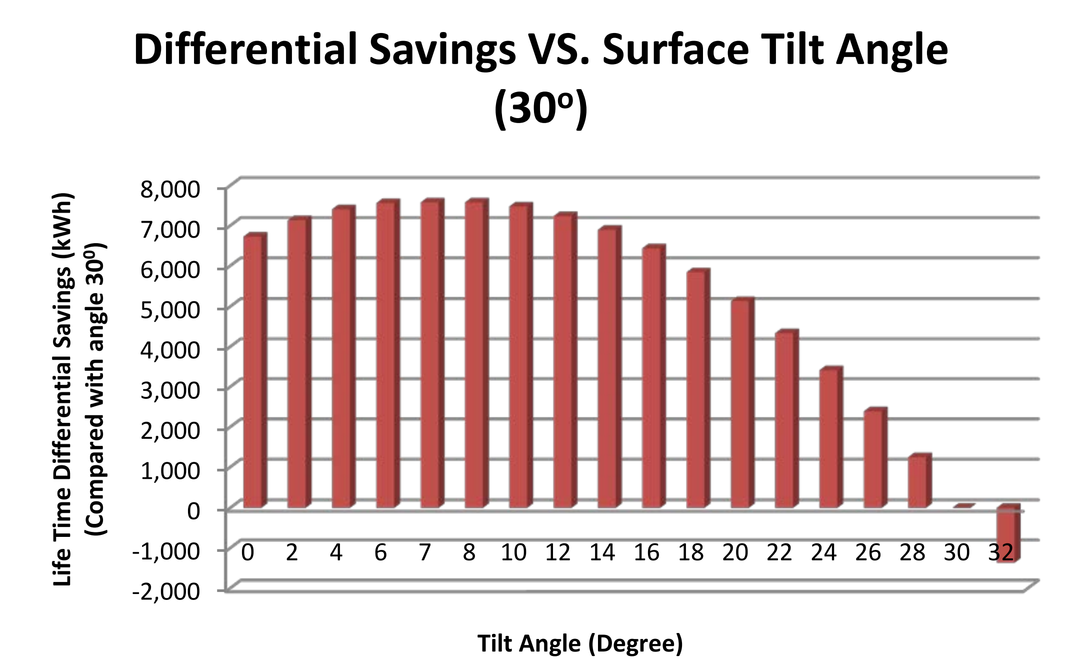

Figure 4.4 – Energy Savings with reference Tilt Angle (30°)

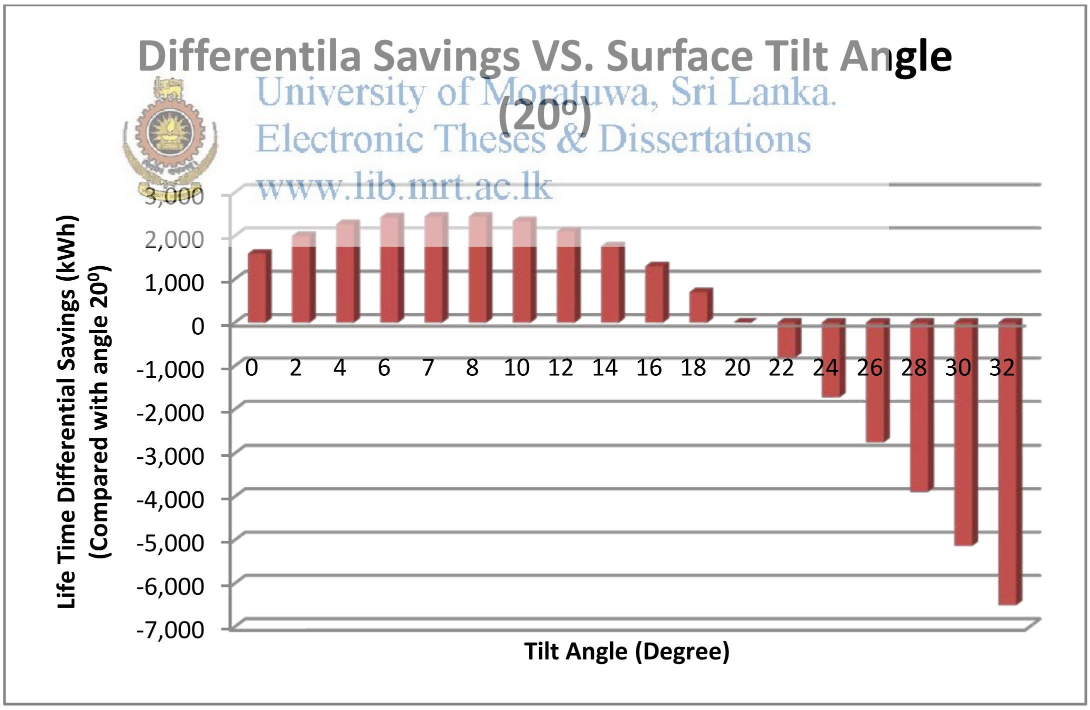

Figure 4.5 – Energy Savings with reference Tilt Angle (20°)

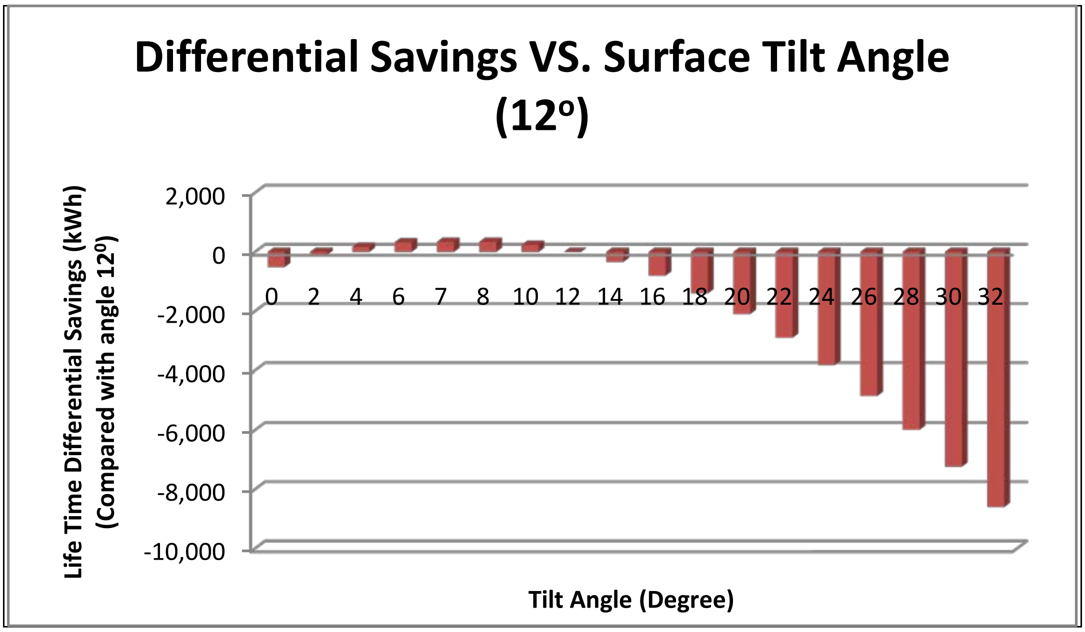

Figure 4.6 – Energy Savings with reference Tilt Angle (12°)

4.1.4.1 Summary of Energy Saving

Table 4.4 – Summary of Energy Savings with reference Tilt Angle

Roof type	Annual Loss Percentage Reference to the Best Tilt Angle (%)
Tiles (30°)	6.13
Asbestos (20°)	1.97
Trapezoidal Sheets (Amano Sheets) (12°)	0.28

4.2 Azimuth Angle Optimization

Azimuth angle denotes how the surface is located relative to the true north-south and east-west coordinates. There are several conventions for the solar azimuth. However it is traditionally defined as the angle between a line due south and the shadow cast by a vertical rod on Earth. This convention states the angle is positive if the line is east of south and negative if it is west of south. For example due east would be -90°

and due west would be 90°.(South represents an azimuth angle of 0° and East is (-90°), North is 180° and West is 90°)

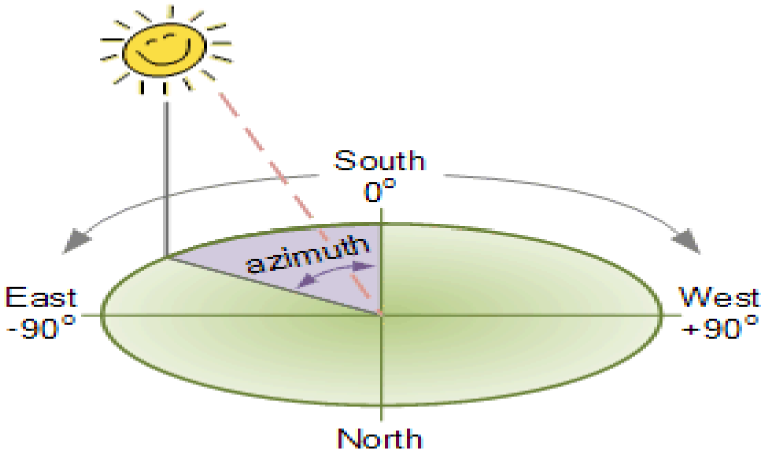

Figure 4.7 – Azimuth Angle

This section determines the optimal azimuth angle for PV solar panels and this was investigated with specific references in Colombo city.

4.2.1 Simulation Model

This Simulation was done by PVSYST and SMA SUNNY DESIGN simulation software.

Table 4.5 – Simulation Model for Azimuth Angle simulation

Solar System	4.4 kW
Location	Colombo
PV Module Type	REC 245 PE
No of PV Modules	18
Inverter Type	SB 4000 TL - 20
Tilt Angle	7°
Shadow Possibilities	Shadow Free > 90%

4.2.2 PV Output (kWh) for Different Azimuth Angle

PV output for different azimuth angles was simulated and results are shown in Annex C.

4.2.3 Summary of PV Output for Main Directions

Simulated solar PV output for cardinal directions is as follows,

Table 4.6 – Summary of PV Output (kWh) for Main Directions

Azimuth Angle	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
(-180) - North	479	534	580	551	496	486	488	502	477	461	443	441
-135	482	537	583	554	499	489	491	505	480	464	446	444
(-90)-East	487	542	589	560	504	494	496	510	485	468	450	448
-45	491	547	594	564	508	497	499	514	489	472	454	452
0 - South	492	547	595	565	509	498	500	515	489	473	455	452
45	490	545	592	563	507	496	498	513	487	471	453	450
90 -West	486	541	588	558	503	492	494	508	483	467	449	447
135	481	536	582	553	498	488	489	504	479	462	445	443
180 - North	479	534	580	551	496	486	488	502	477	461	443	441

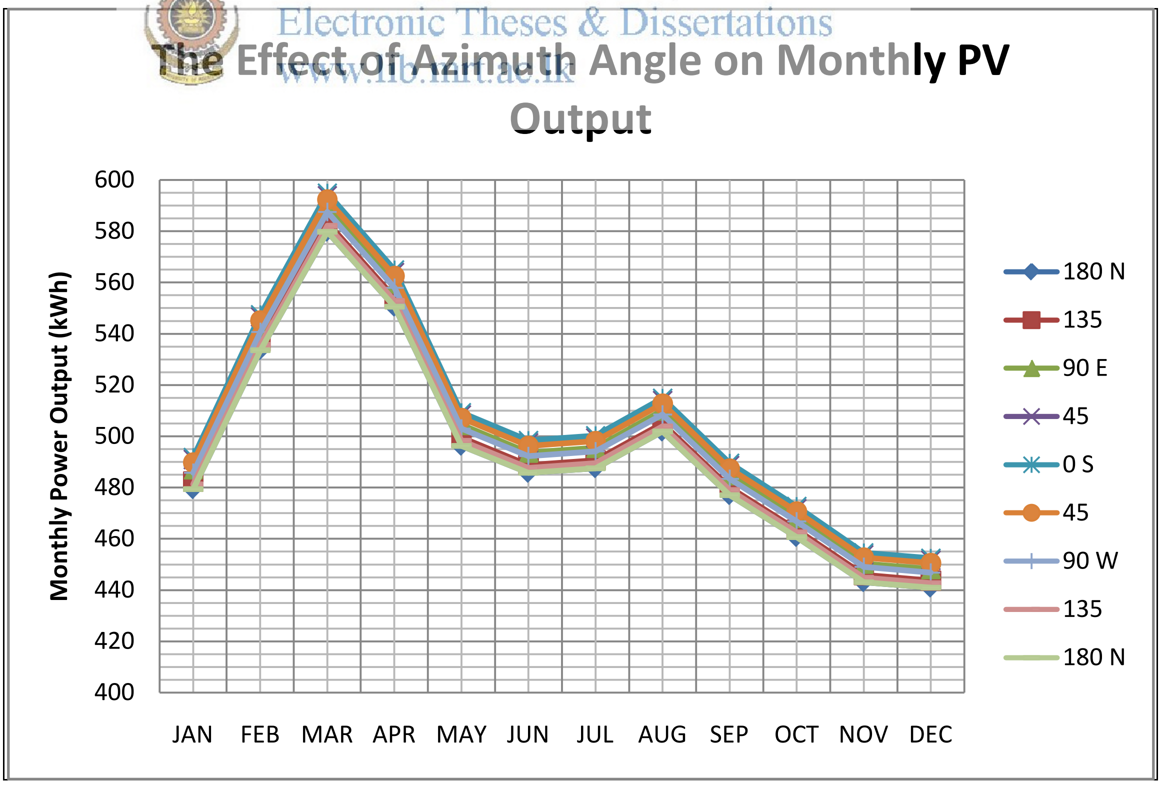

Figure 4.8 – The Effect of Azimuth Angle on Monthly PV Output for Main Directions

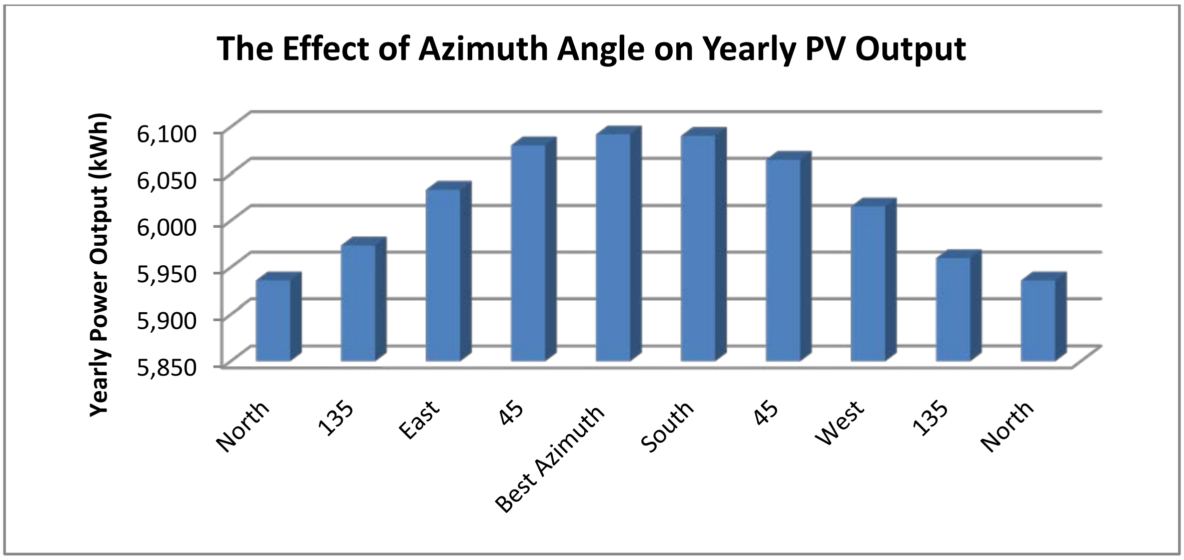

Figure 4.9 – The Effect of Azimuth Angle on Annual PV Output for Main Directions

It can be seen that south toward south east direction performs than south toward south west direction. The output is decreased to the direction from east towards north as well as from west toward north. East direction performs than west direction and the worst case is for north direction

4.2.4 Best Azimuth Angle

Table 4.7 – Summary of PV Output (kWh) for best azimuth angle

Azimuth	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
-45	491	547	594	564	508	497	499	514	489	472	454	452	6,080
-20	492	548	595	565	509	498	500	515	489	473	455	452	6,091
-18	492	548	595	565	509	498	500	515	489	473	455	452	6,091
-16	492	548	595	565	509	498	500	515	489	473	455	452	6,091
-15	492	548	595	565	509	498	500	515	490	473	455	453	6,092
-14	492	548	595	565	509	498	500	515	490	473	455	453	6,092
-12	492	548	595	565	509	498	500	515	490	473	455	453	6,092
-10	492	548	595	565	509	498	500	515	490	473	455	453	6,092
-8	492	548	595	565	509	498	500	515	490	473	455	453	6,092
-6	492	548	595	565	509	498	500	515	490	473	455	453	6,092
-5	492	548	595	565	509	498	500	515	490	473	455	453	6,092
-4	492	548	595	565	509	498	500	515	489	473	455	452	6,091
-2	492	548	595	565	509	498	500	515	489	473	455	452	6,091
0 - South	492	547	595	565	509	498	500	515	489	473	455	452	6,090

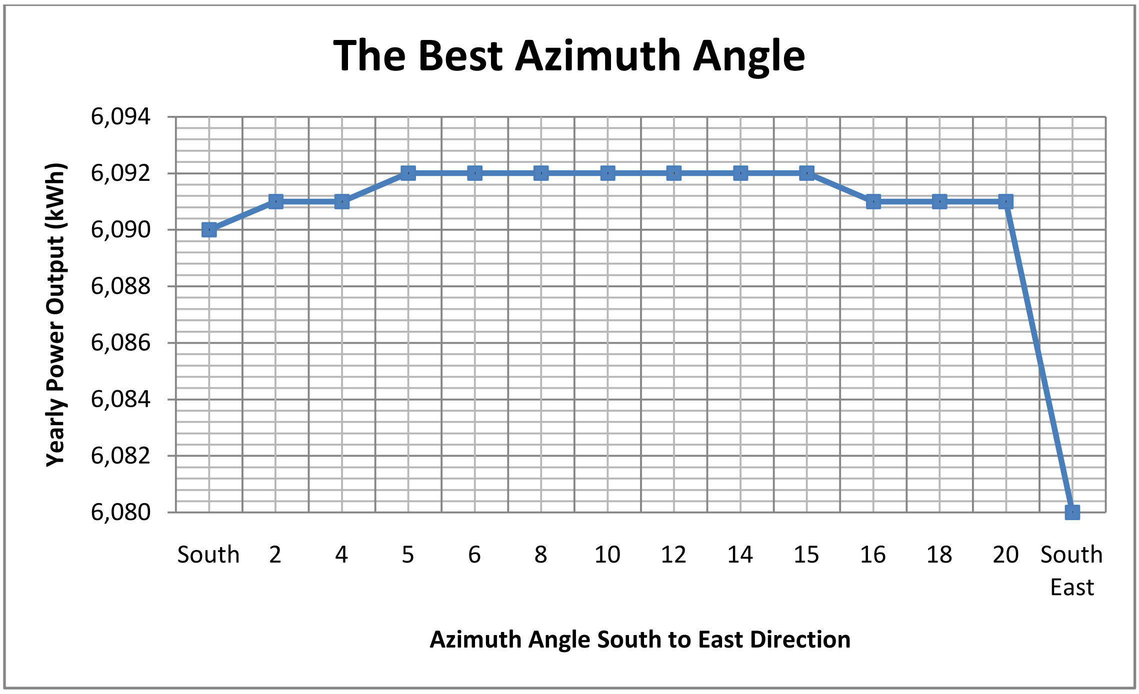

Figure 4.10 – The Effect of Azimuth Angle on Annual PV Output including best azimuth angle

- The best Azimuth angle reaches from south toward east direction
- The same highest PV output can be obtained 5^{0} to 15^{0} away from south direction toward east direction

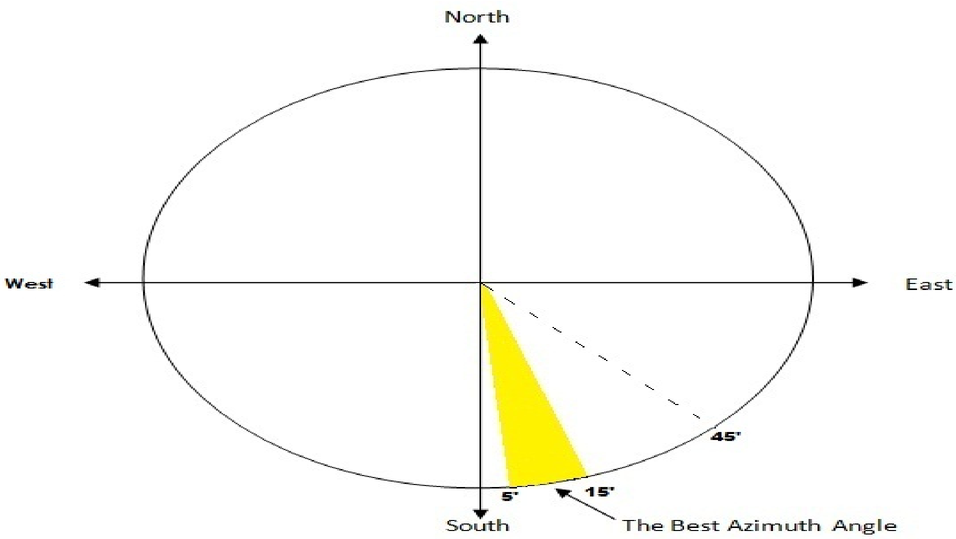

Figure 4.11 – Best Azimuth Angle

4.2.5 Differential Energy Savings

Azimuth angle is an important parameter of a PV solar system and it needs to be optimized before designing a PV solar system. By taking the solar PV output of cardinal directions as reference, a series of energy savings was determined. It helps to analyze the deviation of the solar PV output from the different azimuth angles that can be installed PV solar panels.

Table 4.8 – Energy Savings with reference Azimuth Angle

Azimuth Angle	Annual Saving Percentage (%)			
	Azimuth Angle South	Azimuth Angle East	Azimuth Angle West	Azimuth Angle North
North	-2.60	-1.64	-1.34	0.00
North-East	-1.96	-1.00	-0.70	0.63
East	-0.95	0.00	0.30	1.61
South East	-0.17	0.77	1.07	2.37
Best Angle	0.03	0.97	1.26	2.56
South	0.00	0.94	1.23	2.54
South West	-0.42	0.52	0.82	2.12
West	-1.25	-0.30	0.00	1.32
North West	-2.19	-1.23	-0.93	0.40
North	-2.60	-1.64	-1.34	0.00

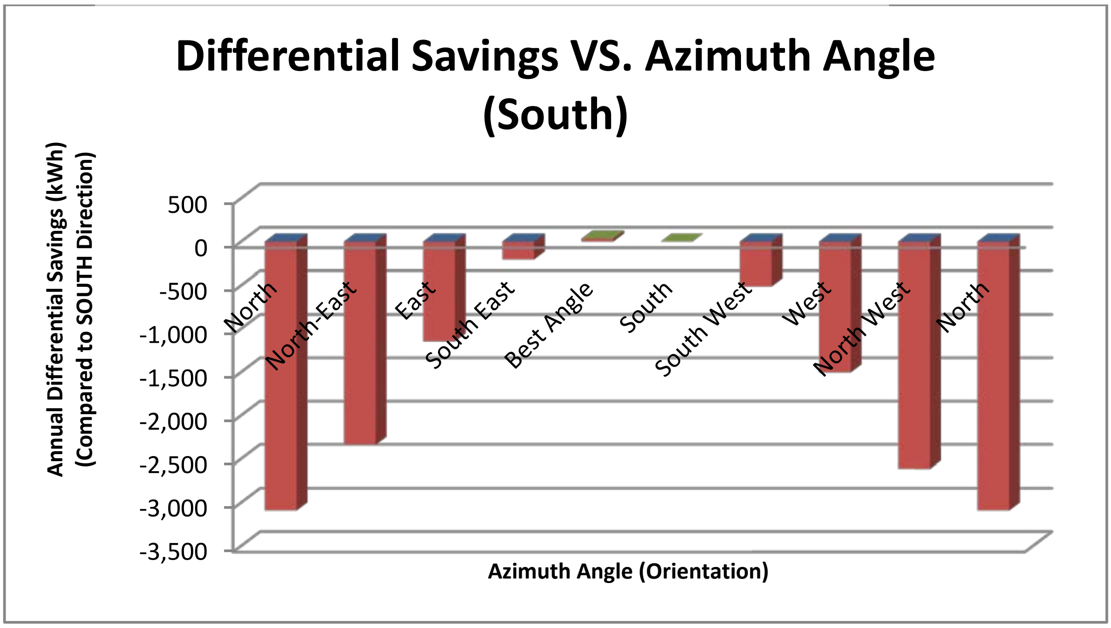

Figure 4.12 – Energy Savings with reference Azimuth Angle (SOUTH)

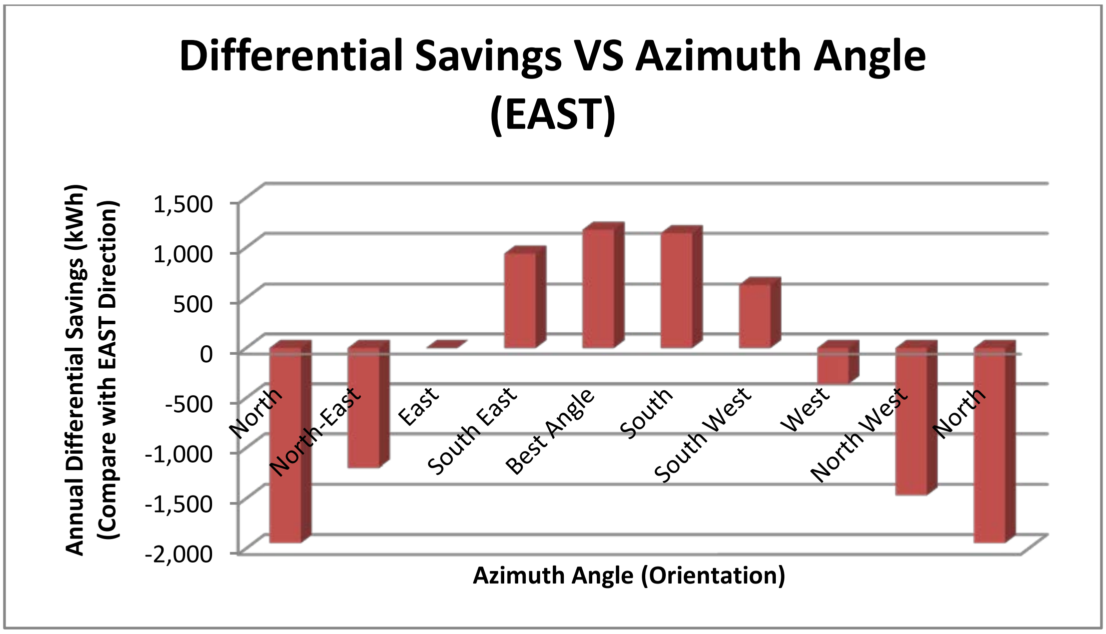

Figure 4.13 – Energy Savings with reference Azimuth Angle (EAST)

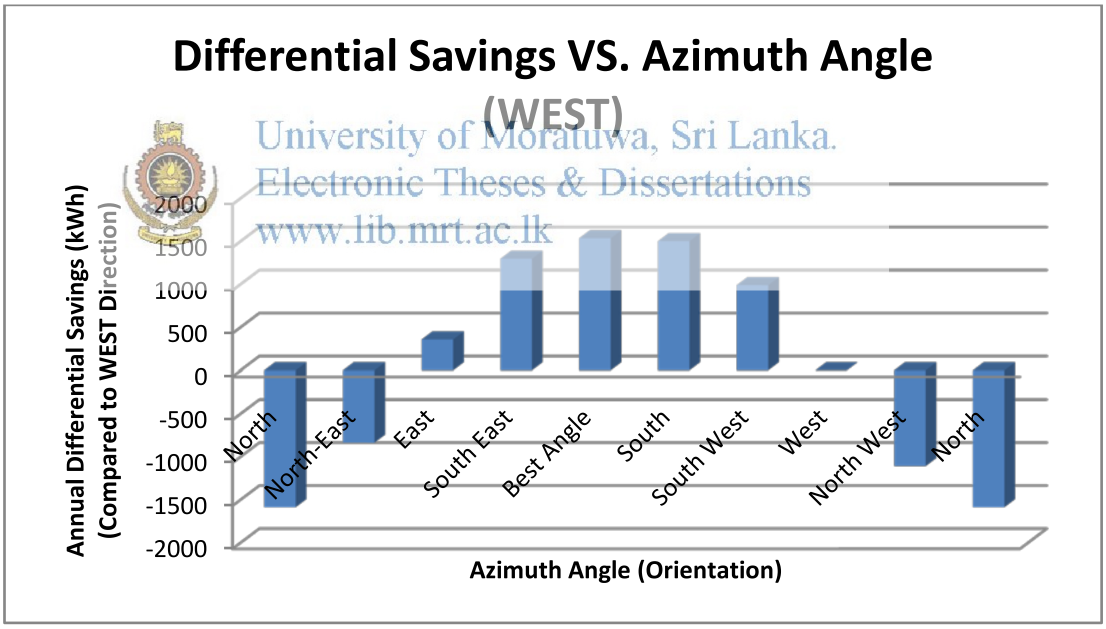

Figure 4.14 – Energy Savings with reference Azimuth Angle (WEST)

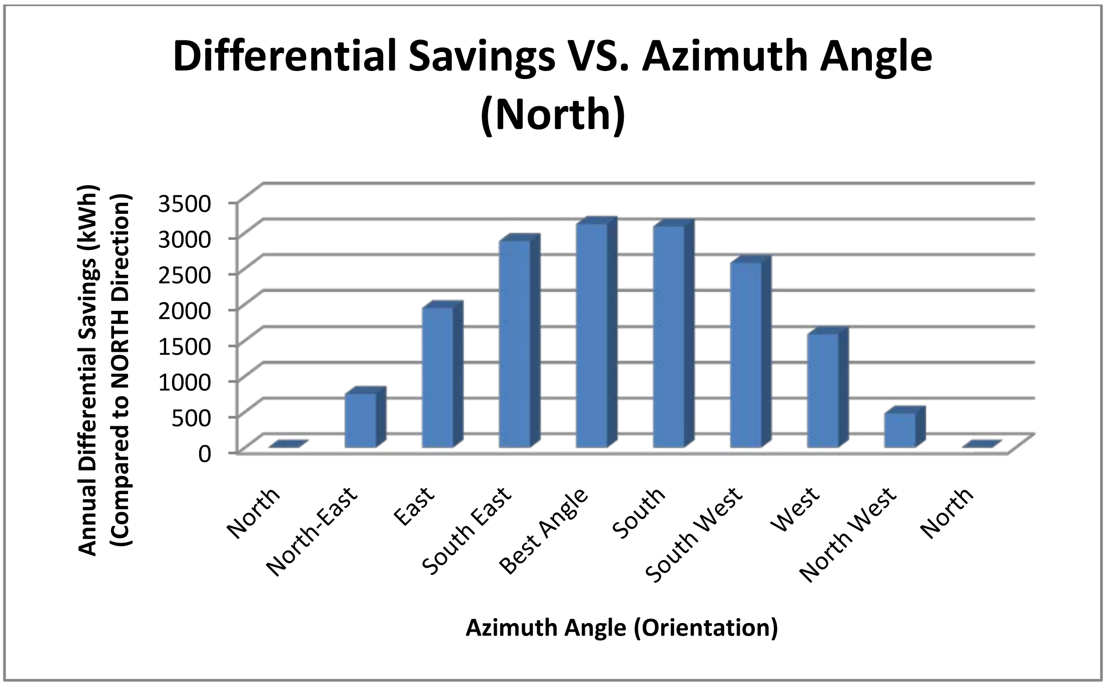

Figure 4.15 – Energy Savings with reference Azimuth Angle (NORTH)

4.2.5.1 Summary of Energy Saving

Table 4.9 – Summary of Energy Savings with reference Azimuth Angle

Orientation	Annual Loss PercentageReference To Best Azimuth Angle (%)
South	0.03
East	0.94
West	1.23
North	2.54

4.3 Combined Optimization of Tilt and Azimuth Angles

Traditional practice is tilting PV solar panels at an angle equal to the latitude with an azimuth of south in an area of maximum annual solar radiation. This conventional wisdom has been accepted for promoting purpose. When the temporal and location value of electricity enters to the calculations, decisions about orientation and location may differ. Purpose of this section is to determine the optimal combination of tilt and azimuth to install solar PV panels.

4.3.1 Annual PV Output (kWh) for Different Tilt Angle VS Azimuth Angle

Table 4.10 – The PV output (kWh) of Tilt angle VS Azimuth angle

Tilt	**180 (North)**	**135 (North/ West)**	**90 (West)**	**45(South /West)**	**0 (South)**	**(-45) (South/ East)**	**(-90) (East)**	**(-135) (North/ East)**	**(-180) (North)**
0	7,195	7,195	7,195	7,195	7,195	7,195	7,195	7,195	7,195
2	7,164	7,171	7,189	7,208	7,219	7,216	7,199	7,178	7,164
4	7,128	7,143	7,180	7,215	7,235	7,229	7,195	7,153	7,128
6	7,084	7,108	7,165	7,216	7,244	7,234	7,184	7,122	7,084
7	7,059	7,088	7,156	7,215	7,245	7,233	7,176	7,104	7,059
8	7,033	7,066	7,145	7,212	7,245	7,231	7,167	7,085	7,033
10	6,976	7,019	7,119	7,200	7,239	7,221	7,146	7,041	6,976
12	6,911	6,965	7,087	7,183	7,225	7,205	7,120	6,992	6,911
14	6,840	6,906	7,049	7,159	7,205	7,183	7,088	6,937	6,840
16	6,763	6,841	7,006	7,129	7,178	7,156	7,050	6,876	6,763
18	6,680	6,771	6,958	7,091	7,143	7,122	7,006	6,809	6,680
20	6,590	6,697	6,907	7,048	7,102	7,082	6,956	6,736	6,590
22	6,495	6,617	6,853	6,999	7,055	7,035	6,902	6,659	6,495
24	6,394	6,532	6,795	6,945	7,001	6,983	6,844	6,578	6,394
26	6,287	6,443	6,731	6,886	6,941	6,924	6,784	6,492	6,287
28	6,175	6,348	6,663	6,822	6,874	6,860	6,721	6,402	6,175
30	6,058	6,250	6,587	6,752	6,801	6,792	6,653	6,306	6,058
32	5,936	6,150	6,510	6,677	6,721	6,719	6,580	6,207	5,936

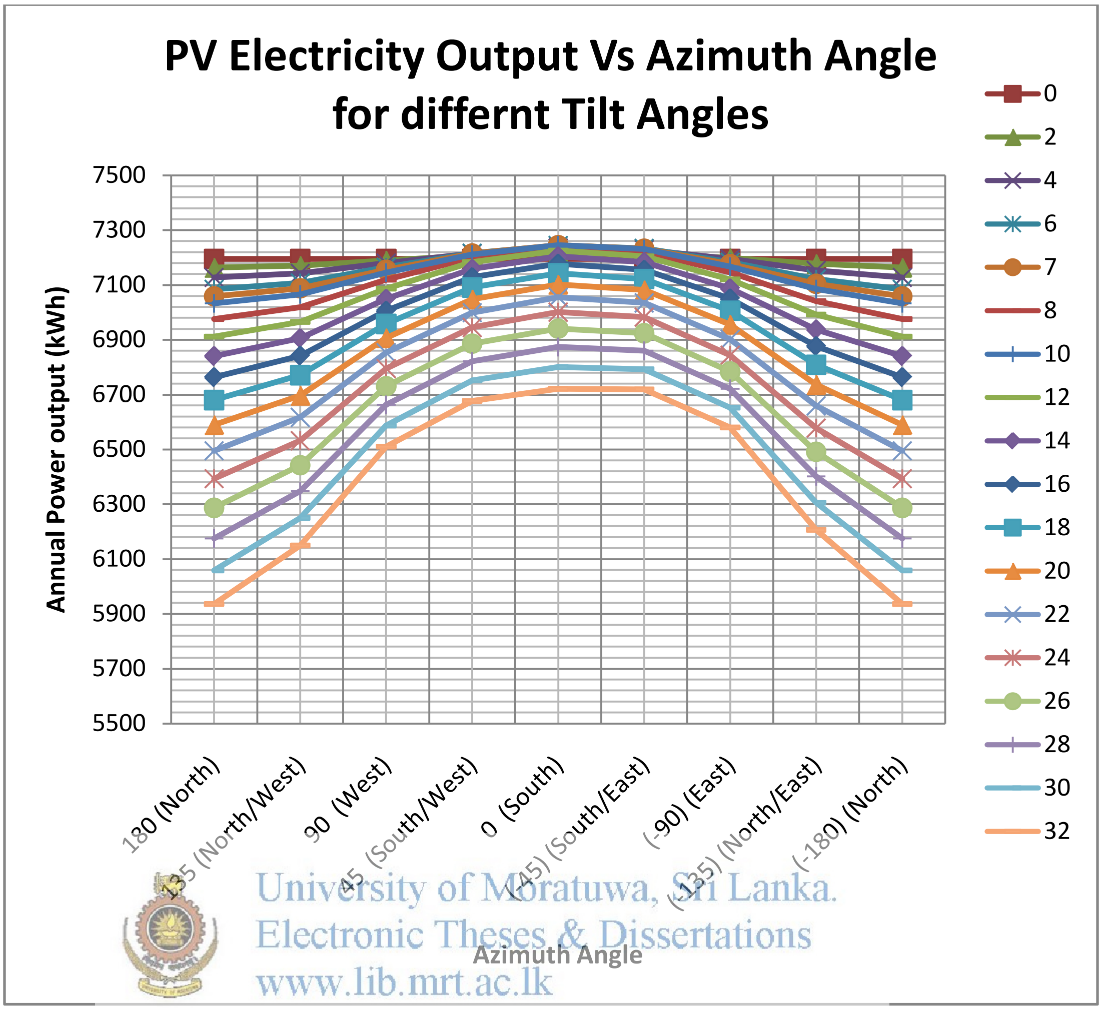

Figure 4.16 – Annual PV Output (kWh) Vs Azimuth Angle for different Tilt Angles

4.3.2 Tilt Azimuth Analysis Model for the Optimum Selection

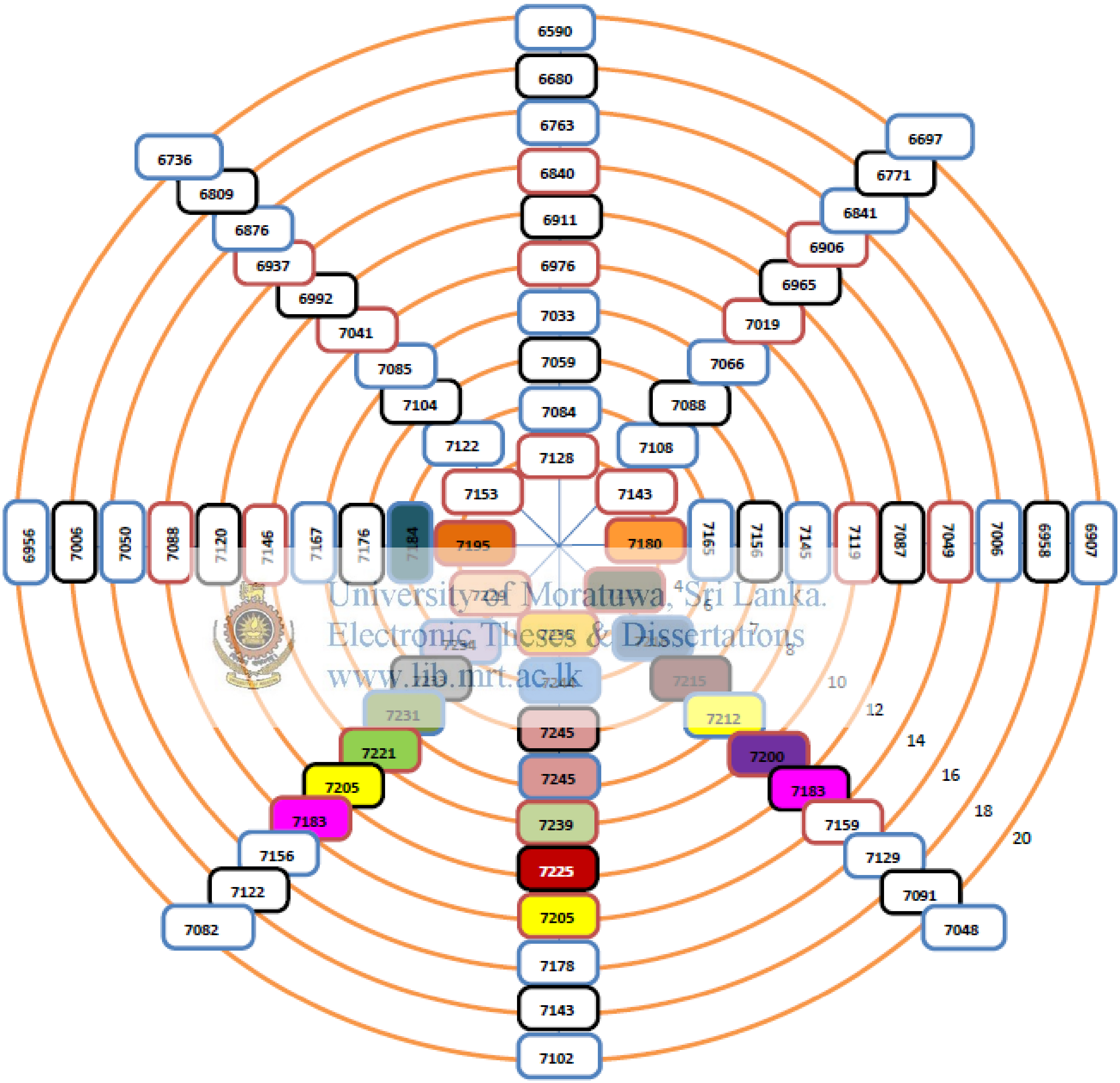

Figure 4.17 - Tilt Azimuth Analysis Model

Results of the simulation are shown in the following table.

Table 4.11 – Color code for Tilt Azimuth Model

Maximum Range	Value	Colour	Tilt Angle	Azimuth Angle
1	7245		7 & 8	South
2	7244		6	South
3	7239		10	South
4	7235		4	South
5	7234		6	South/East
6	7233		7	South/East
7	7231		8	South/East
8	7229		4	South/East
9	7225		12	South
10	7221		10	South/East
11	7216		6	South/West
12	7215		4	South/West
13	7215		7	South/West
14	7212		8	South/West
15	7205		12	South/East
16	7200		10	South/West
17	7195		4	East
18	7184		6	East
19	7183		12 14	South/West South/East
20	7180		4	West

4.4 Optimization of Shadow Possibilities

There are two different forms of shade, which were classified as “hard” and “soft” shade. Hard shade occurs when a solid object or obstacle is placed in front of the array, blocking the sunlight in a clear and definable shape. Soft shade occurs when the overall intensity of the light is reduced, such as haze or smog in the atmosphere above. Shading effect severely affects for output of PV solar systems. A shadow cast on even just part of one solar panel in solar PV array can potentially compromise the output of the whole system.

4.4.1 Simulation Model

This Simulation was done by PVSYST and SMA SUNNY DESIGN simulation software.

Table 4.12 – Simulation model for the Shadowing effect simulation

Solar System	4.4 kW
Location	Colombo
PV Module Type	REC 245 PE
No of PV Modules	18
Inverter Type	SB 4000 TL - 20
Tilt Angle	7^o
Azimuth Angle (Orientation)	0 (South)
Simulation by	Solmetric PV Designer

4.4.2 PV Output (kWh) for Different Shadow Possibilities

Table 4.13 – PV Output (kWh) for Different Shadow Possibilities

Shadows	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
Shadow Free > 90%	492	547	595	565	509	498	500	515	489	473	455	452	6,090
90% > Shadow Free > 80%	344	383	416	395	356	349	350	360	343	331	318	317	4,263
80% > Shadow Free > 70%	246	274	297	282	255	249	250	257	245	236	227	226	3,045
Shadow Free < 60%	98	109	119	113	102	100	100	103	98	95	91	90	1,218

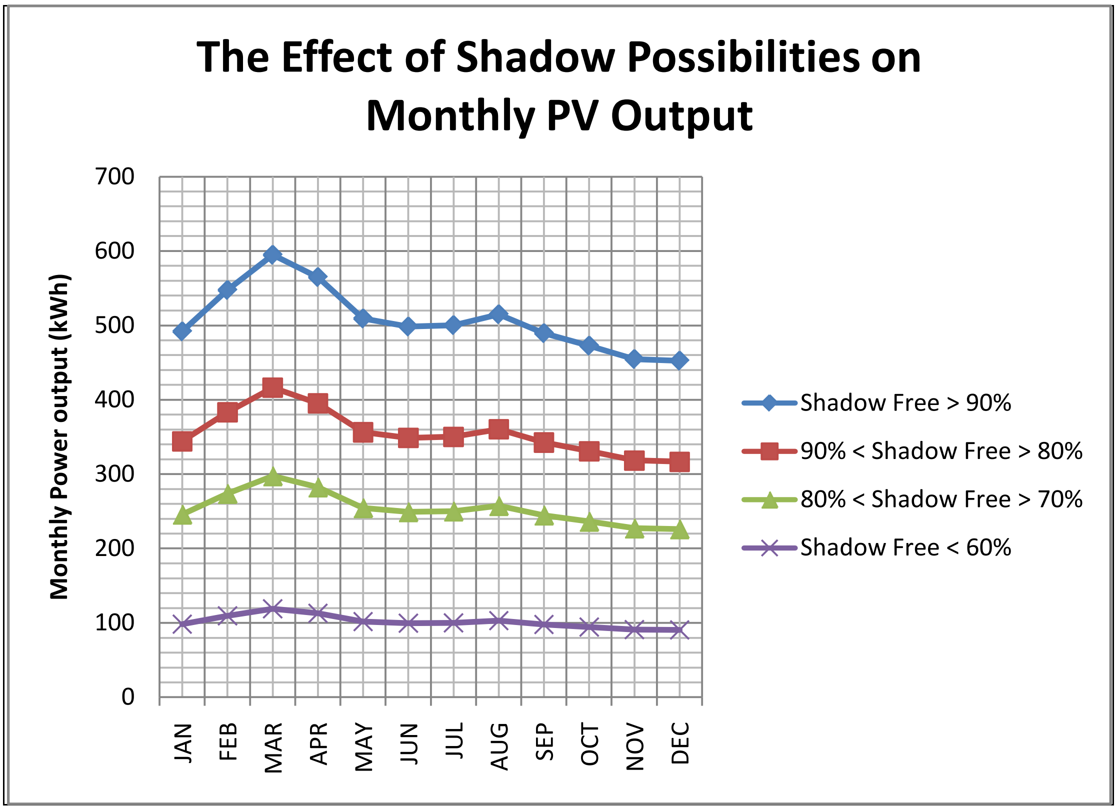

Figure 4.18 – The Effect of Shadow Possibilities on Monthly PV Output

4.4.3 The Effect of Shadow Possibilities for Yearly PV Output (kWh)

Table 4.14 – The Effect of Shadow Possibilities on Yearly PV Output

Shadows	The Effect of Shadow Possibilities on Yearly PV Output
SF > 90%	6,090
90% > SF > 80%	4,263
80% > SF > 70%	3,045
SF < 60%	1,218

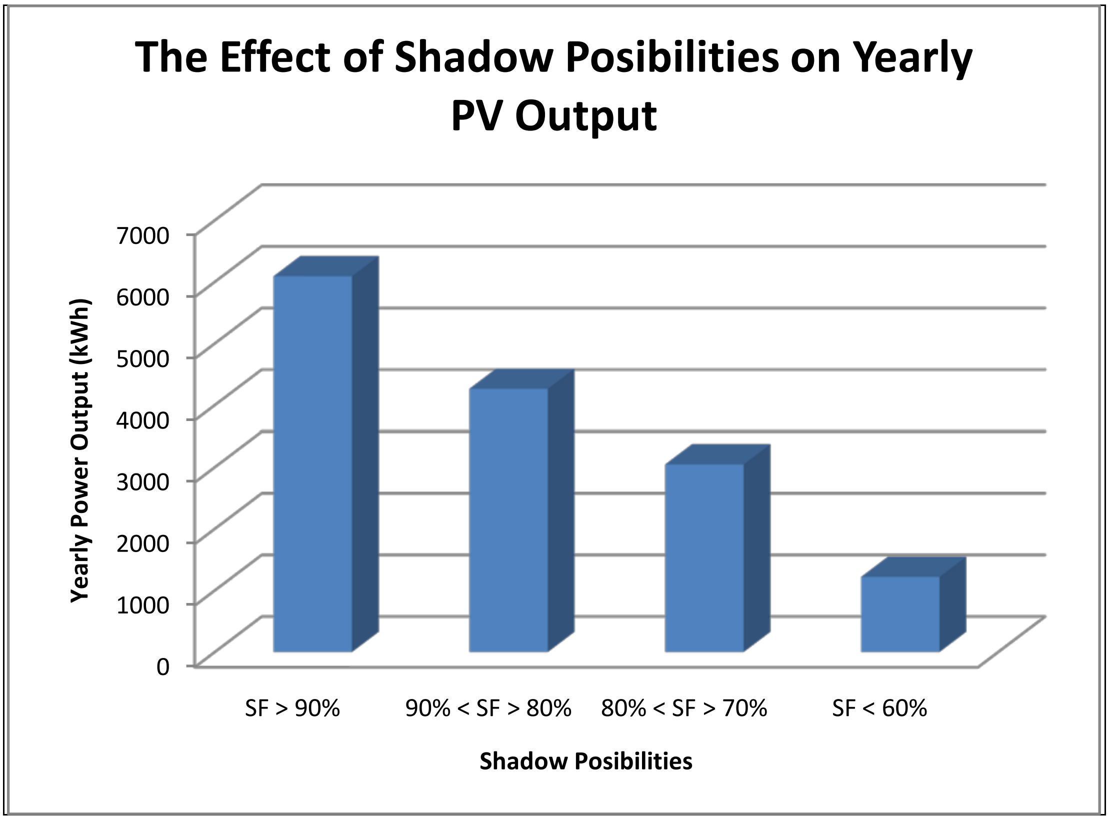

Figure 4.19 – The Effect of Shadow Possibilities on Yearly PV Output

4.4.4 Differential Energy Savings

When a PV solar panel is blocked by a shadow (either by a cloud, a chimney, or tree branch, etc) it reduces the performance of the PV solar system dramatically. Then knowledge and experience about shadow effects helps to choose the best area of the roof to install PV solar panels. it may avoid certain areas due to constant shade obstructions but it is important to keep in mind that some shadows may affect a panel in the morning however may not affect the same panel the rest of the day, then resulting in overall good performance. Then it is very important to do following analysis to obtain the optimum solar system.

Table 4.15 – The Effect of Shadow Possibilities on Energy Savings

Shadow Effect	**Saving Percentage (%)**		
	90% > SF > 80%	**80% > SF > 70%**	**SF < 60%**
SF > 90%	30.00	50.00	80.00
90% > SF > 80%	0.00	28.57	71.43
80% > SF > 70%	-40.00	0.00	60.00
SF < 60%	-250.00	-150.00	0.00

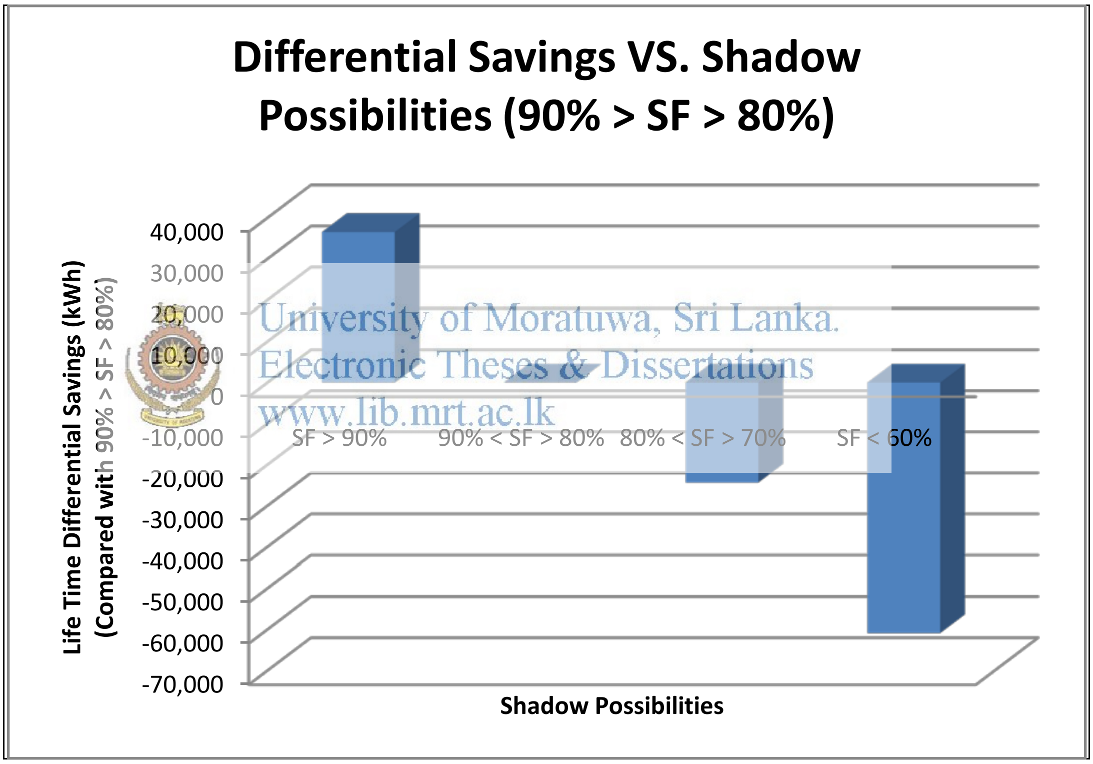

Figure 4.20 –The Effect of Shadow Possibilities on (90% > SF > 80%)

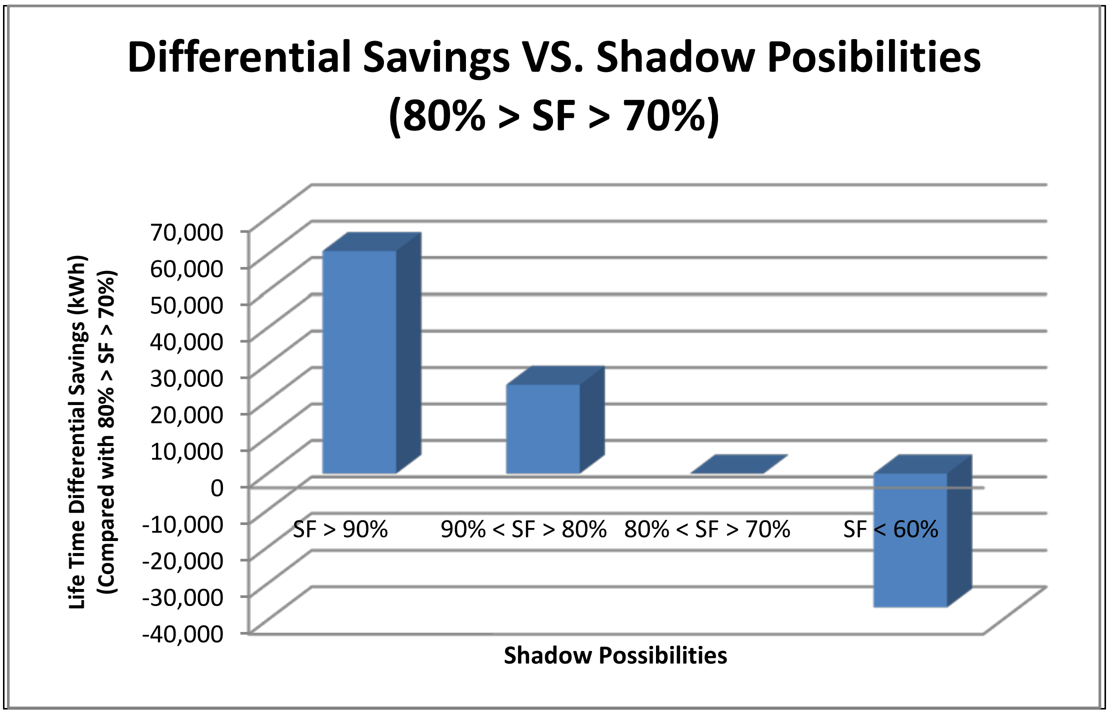

Figure 4.21 –The Effect of Shadow Possibilities on (80% > SF > 70%)

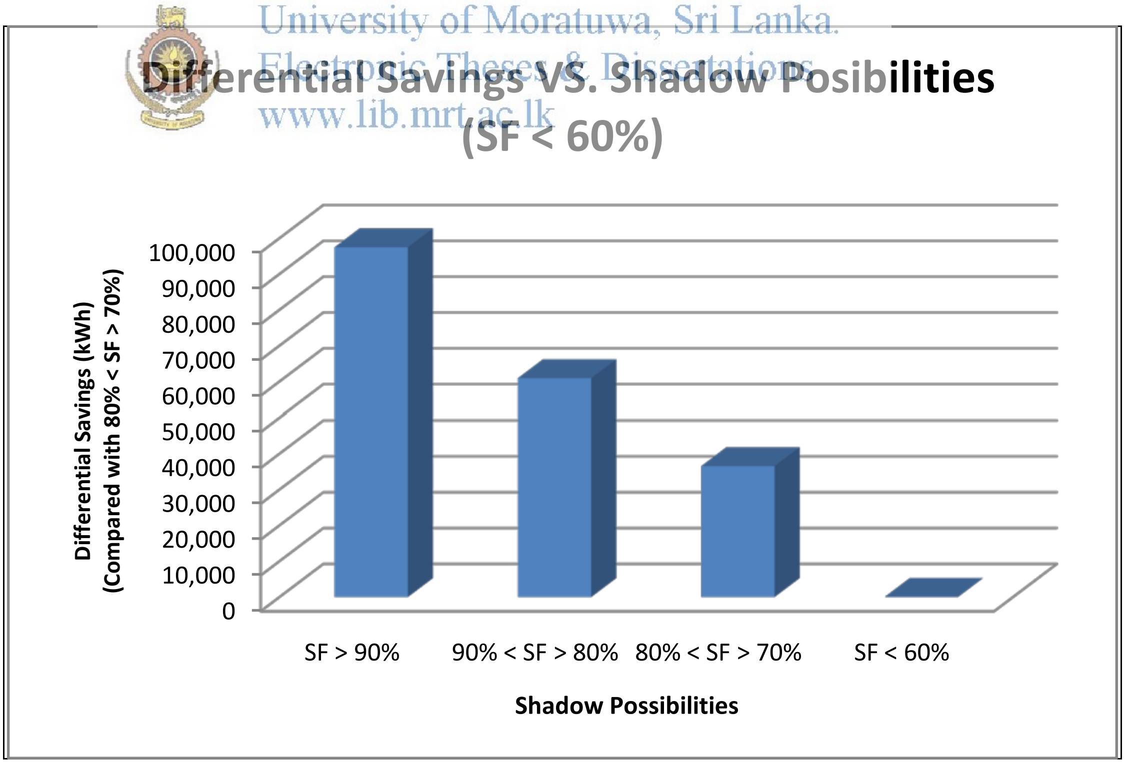

Figure 4.22– The Effect of Shadow Possibilities on (SF < 60%)

4.4.4.1 Summary for Shadow Possibilities

Table 4.16 – Summary of the Effect of Shadow Possibilities

Shadow Possibilities	Loss Percentage Reference To the Best Shadow Free System (Sf > 90%) - %
90% > SF > 80%	30
80% >SF > 70%	50
SF < 60%	80

If the Location is SF < 60%, the system should not be installed and better to go for another location

4.5 Optimization of Array Size

Solar PV array output surpasses the building electric load, the surplus electricity can be fed to grid. The electricity delivered to the grid can be taken as credit. When array output is less than building electric load, the grid can supply the makeup electricity (Net Metering Concept).

The Optimal PV System is one where the array output matches the electricity loads very well and surplus electricity delivered to the grid is optimized. The load profile of the building and power output of proposed PV array should always be analyzed as combination to obtain the optimum array size. Relevant PV solar system capacities with different consumption levels (load profile) are shown in Appendix D.

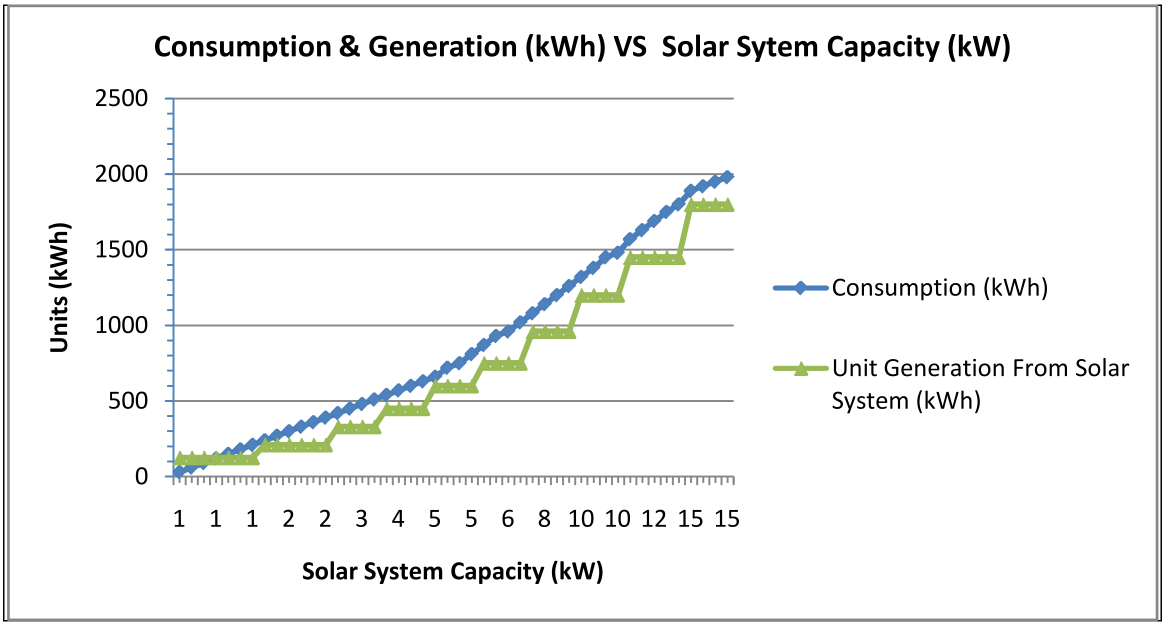

Figure 4.23 – Load Profile with Relevant Solar System

4.5.1 Simulation - Array Size Optimization

This simulation was done with details of following consumer who was randomly selected from Colombo City.

Table 4.17 – Consumer Details for Array Size Optimization

Account No	794361110 82/3 A Ward Place Colombo 07
Connection	3p 30 A - Domestic

4.5.2 Consumption Pattern of the Consumer

Table 4.18 – Consumption of the Consumer for Array Size Optimization

Month	Consumption (kWh) -2012	Consumption (kWh) -2013
Jan	540	559
Feb	429	463
Mar	471	397
Apr	570	474
May	483	515
Jun	472	567
Jul	457	655
Aug	440	695
Sep	395	613
Oct	459	643
Nov	464	573
Dec	406	503

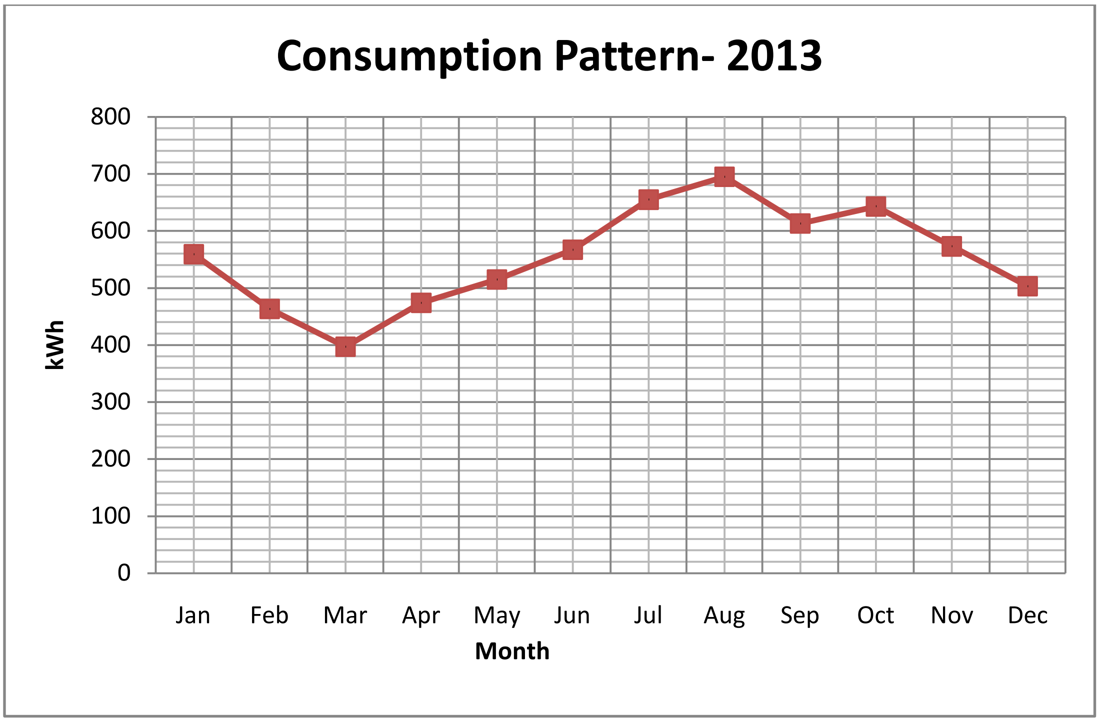

Figure 4.24 – Consumption Pattern

4.5.3 Effectiveness Factor

- Effectiveness factor is defined for Study the utilization fraction of PV System.
- Effectiveness factor is equal to array output that is utilized by the building over total PV array output.
- A Lower effectiveness factor means a longer payback time and lower usable fraction of PV array to enhance the investment benefit.
- Effectiveness Factor should be 80% to get the Optimum Output [12]

$$\text{Effectiveness Factor} = \frac{\text{Yearly PV Output (kWh)} - \text{Electricity Delivered to the Grid (kWh)}}{\text{Yearly PV Output (kWh)}}$$

Figure 4.25 – Definition of Effectiveness Factor

4.5.4 Effectiveness Factor for Different Array Areas

It is important to analyse the Effectiveness Factor for different array areas to match the load profile of the relevant building and the power output profile of proposed PV solar system.

4.5.4.1 Simulation Model

Table 4.19 – Simulation Model for Array Size Optimization

Location	Colombo
PV Module Type	REC 245 PE
Inverter Type	SB 4000 TL - 20
Tilt Angle	7^o
Azimuth Angle (Orientation)	0 (South)
Shadow Possibilities	Shadow Free > 90%

4.5.4.2 Effectiveness Factor VS Array Size

Table 4.20 – Effectiveness Factor Relevant to Array Area

Area (m^2)	Output (kWh)	Consumption (kWh)	Buy (kWh)	Sell (kWh)	Effectiveness Factor
17	3,912	6,657	2,745	0	1.00
20	4,738	6,657	1,919	0	1.00
23	5,567	6,657	1,090	0	1.00
27	6,247	6,657	410	0	1.00
30	7,060	6,657	0	403	0.94
33	7,995	6,657	0	1,338	0.83
37	8,752	6,657	0	2,095	0.76
40	9,520	6,657	0	2,863	0.70
43	10,234	6,657	0	3,577	0.65
46	10,855	6,657	0	4,198	0.61
50	11,394	6,657	0	4,737	0.58

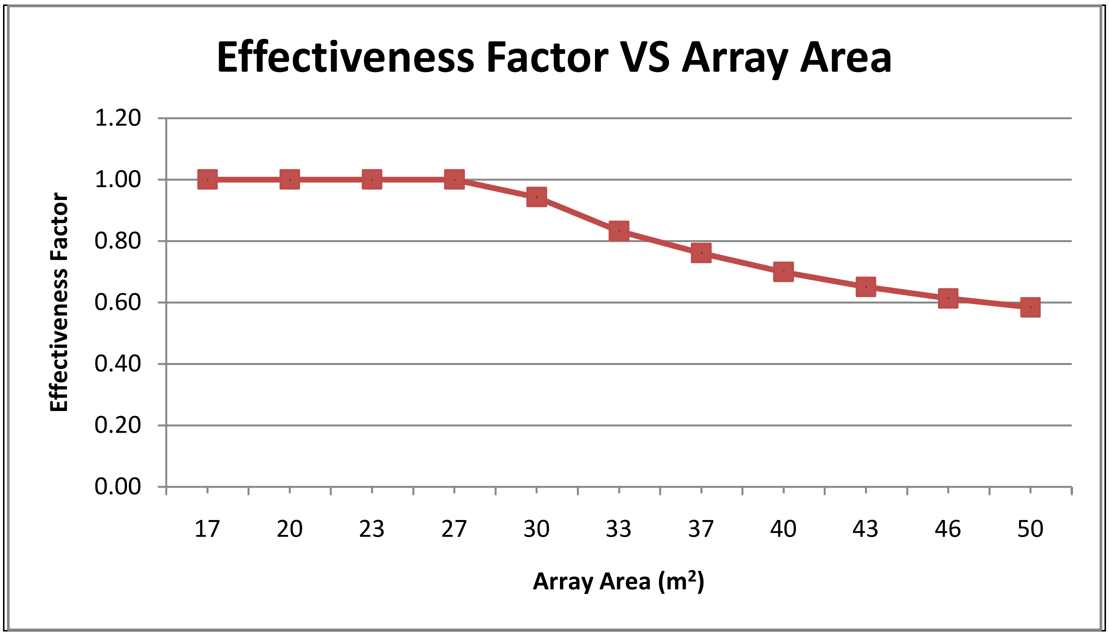

Figure 4.26 – Effectiveness Factor VS Array Area

- Output of PV array increases with the array Area
- The effectiveness factor becomes lower when array area increases.
- The Electricity delivered to the Grid begins to increase when array is larger than 27m^2
- The Design Should equal to 35m^2 (Array Size)(If the Effectiveness Factor is 80%)

Comparison between actual and optimum selection is as follows,

Table 4.21 – Comparison with the Actual Condition

Parameter	**Actual (82/3 A, Ward Place, Colombo 07)**	**Optimum Selection**
Array Area	36 m^2	35 m^2
Solar Module	Trinasolar (TSM-190 DC/DA01A)	REC (REC245PE)
Inverter	Solar edge (SE5000)	SMA (SMC4600A–11)
Tilt Angle	12^o	7^o
Azimuth Angle	0 (South)	0 (South)
Shadow	SF > 90%	SF > 90%
Average Units Per Month	**625 kWh**	**660 kWh**

4.5.5 Monthly Summary

Monthly Summary of the PV solar system with relevant optimum selection is as follows,

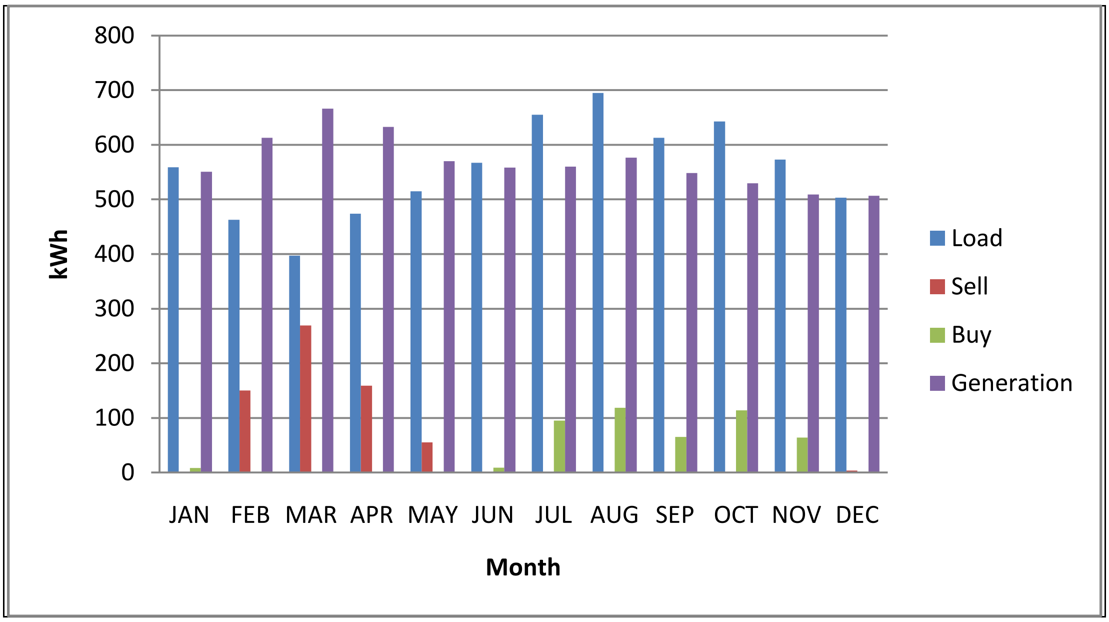

Figure 4.27 – Monthly Summary of optimum PV Solar System

4.6 Inverter Size Optimization

The Common Practice among many design engineers is to select the rated power of the inverter equal to the total nominal power of the PV array. But this is not the Optimum selection due to following reasons,

- The Nominal Power of the installed PV modules is achieved only under their Standard Testing Condition (STC), which are very unlikely to happen in real condition
- The solar Irradiance varies, during the day, from zero up to a maximum point which depends on the time of the year and the geographical location of the PV installation
- The efficiency of any inverter is not constant over its operating range but drops significantly when the inverter operates at or below 10-20% of its rated power

It has been shown that the optimum rated inverter power is **0.77-0.91** of the rated power of the PV plant. [13]

It has been shown that the optimum rated power of the inverter for **Kasel, Germany** is **0.825** of the rated power of the PV plant [14].

Table 4.22 – Verifying Model of the Inverter Size Optimization

STC (Standard Test Condition)	
Air Mass	AM 1.5
Irradiance	1000 W/m^2
Cell Temperature	25 ^oC
NOCT (Nominal Cell Operating Temperature)	
Irradiance	800 W/m^2
Air Mass	AM 1.5
Windspeed	1 m/S
Ambient Temperature	20 ^oC
Negative Temperature Coefficient(Average Value)	**(-)0.45% /^oC**
Cell Temperature (STC)	25 ^oC
Cell Temperature (Actual)	**60 ^oC - 70 ^oC**
Cell Temperature (Calculation)	**65 ^oC**
Temperature Difference (Calculation - STC)	**40 ^oC**
Nominal Power Deduction of the Solar Panel	**40 * 0.45%**
	18%
REC 245 PE Panel	
Nominal Power (Wp)	**245 W**
Actual Power (Wp)	**245 -245 * 18 %**
	200.9
Factor	**0.82**

According to the above analysis, it was verified that the optimum rated inverter power is **0.77-0.91** of the rated power of the PV plant.

Chapter 5

FINANCIAL OVER VIEW

5.1 Net Metering Concept

Net Energy Metering means the measurement of the difference between electrical energy supplied through the electricity distribution network of CEB to the Producer and the amount of electrical energy generated by the Producer's Generating Facility delivered to the electricity distribution network of CEB.

During any Billing Period, if the electrical energy supplied by CEB exceeds the electricity exported by the Consumer plus any energy credits carried-over from the previous Billing Period, the charges for the net energy (kWh) consumed will be calculated using the Producer's applicable tariff. The fixed charge and/or the minimum charge applicable for the installation will also be applicable

During any Billing Period, if the electricity exported by the Producer plus any energy credits carried-over from the previous Billing Period exceeds the electrical energy supplied by CEB, the Producer shall be billed only for the applicable fixed charge and/or the minimum charge, and the balance of the electricity generated shall be carried over to the next Billing Period and appear as an energy credit, stated in kilowatt hours.

Energy credits may be carried over from one Billing Period to another, for so long as the Consumer has a legal contract for the supply of electricity by CEB, and during the Term of this Agreement.

5.2 Comparison Benefits with Deposit Money in the Bank

The cost of the entire PV solar system still remains relatively high compared with traditional power generation technologies. Then the cost of the PV solar system could be deposited in the bank as a fixed deposit of which interest is paid on monthly basis. Then monthly electricity bill could be paid by the interest of the deposit. Here amount of interest which is paid on monthly basis was calculated with different categories of interest rates.

Table 5.1 – Monthly Saving Comparison

System Capacity	Selling Price (LKR)	Units per month	5 Years FD - Monthly Interest (6%)	5 Years FD - Monthly Interest (8%)	5 Years FD - Monthly Interest (10%)	5 Years FD - Monthly Interest (12%)	5 Years FD - Monthly Interest (15%)	Domestic Tariff	GP 1 Tariff
1.0 kW	600,000	125	3,000.00	4,000.00	5,000.00	6,000.00	7,500.00	2,243.50	2,861.63
2.0 kW	740,000	210	3,700.00	4,933.33	6,166.67	7,400.00	9,250.00	5,413.50	4,635.83
3.0 kW	1,000,000	330	5,000.00	6,666.67	8,333.33	10,000.00	12,500.00	10,813.50	8,356.08
4.0 kW	1,250,000	450	6,250.00	8,333.33	10,416.67	12,500.00	15,625.00	16,213.50	11,307.38
5.0 kW	1,500,000	600	7,500.00	10,000.00	12,500.00	15,000.00	18,750.00	22,963.50	14,996.51
6.0 kW	1,800,000	750	9,000.00	12,000.00	15,000.00	18,000.00	22,500.00	29,713.50	18,685.63
8.0 kW	2,200,000	960	11,000.00	14,666.67	18,333.33	22,000.00	27,500.00	39,163.50	23,850.41
10.0 kW	2,700,000	1200	13,500.00	18,000.00	22,500.00	27,000.00	33,750.00	49,963.50	29,753.01
12.0 kW	3,200,000	1450	16,000.00	21,333.33	26,666.67	32,000.00	40,000.00	61,213.50	35,904.23
15.0 kW	3,900,000	1800	19,500.00	26,000.00	32,500.00	39,000.00	48,750.00	76,963.50	44,509.51

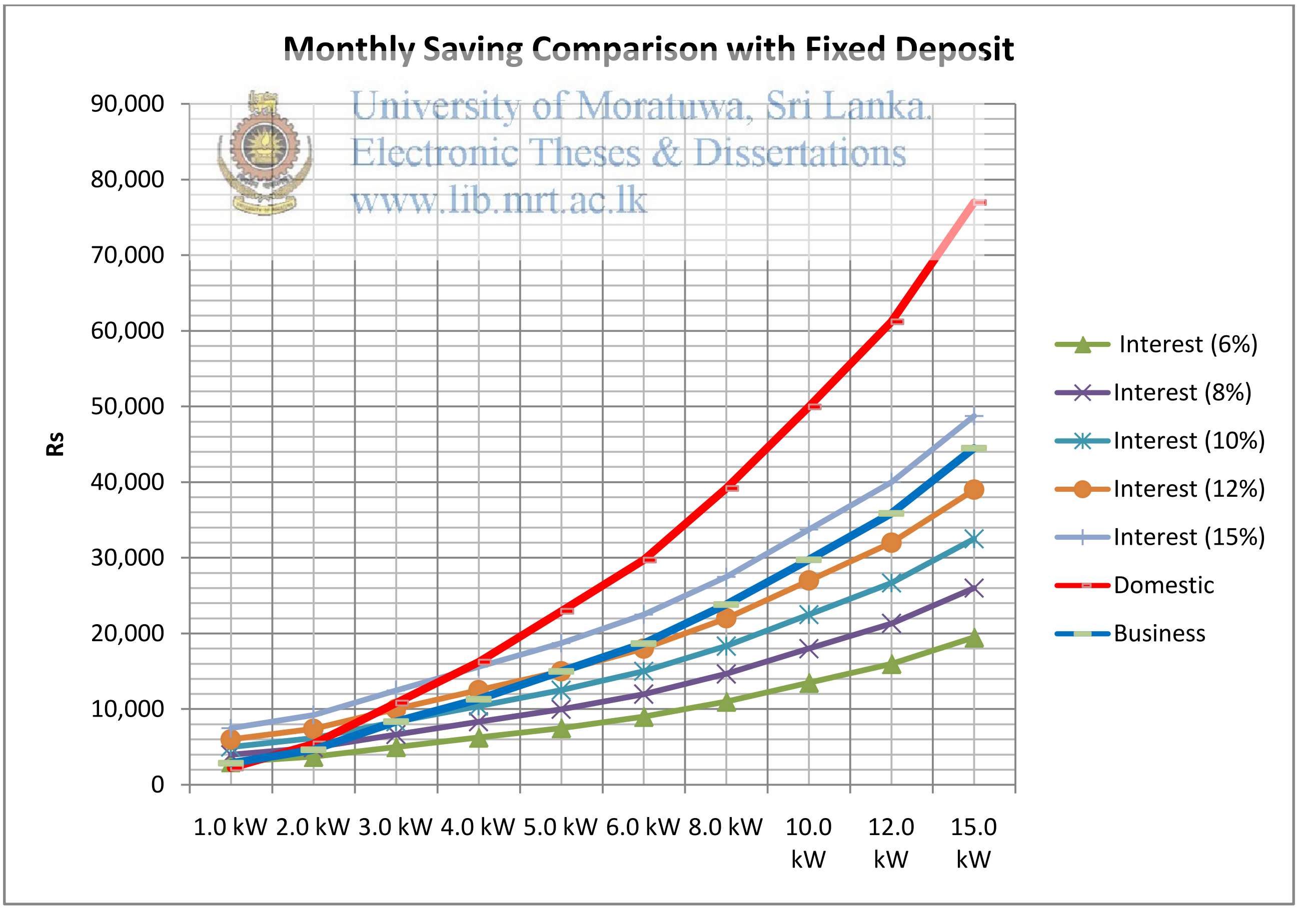

Figure 5.1 - Monthly Saving Comparison

The graph shows that more financial benefits could be experienced than depositing money in the bank for both of consumer categories except interest rate is 15% for General Purpose Tariff(GP1) Category. More benefits could be enjoyed by domestic tariff(D1) consumers than General Purpose tariff (GP1) consumers.

5.3 Install a solar system through bank loan

A Personal loan can be obtained from a commercial bank to install a PV solar system. If the monthly installment of the bank loan could be paid by the savings of monthly electricity bill by PV solar system, bank loan could be settled within the periods mentioned in the following table. This was analyzed under 10.5% Interest rate of the personal loan.

5.3.1 Domestic Tariff Consumers

Table 5.2 - Loan Recovery Period for Domestic Tariff Consumers

System Capacity	Selling Price (Rs)	Units per month	Domestic (Monthly Saving) (Rs)	Loan Recovery Period (Years)
1.0 kW	600,000.00	125	2,243.50	More than 20 Years
2.0 kW	740,000.00	210	5,413.50	More than 20 Years
3.0 kW	1,000,000.00	330	10,813.50	More than 20 Years
4.0 kW	1,250,000.00	450	16,213.50	14
5.0 kW	1,500,000.00	600	22,963.50	10
6.0 kW	1,800,000.00	750	29,713.50	9
8.0 kW	2,200,000.00	960	39,163.50	7.5
10.0 kW	2,700,000.00	1200	49,963.50	7
12.0 kW	3,200,000.00	1450	61,213.50	6.5
15.0 kW	3,900,000.00	1800	76,963.50	6.5

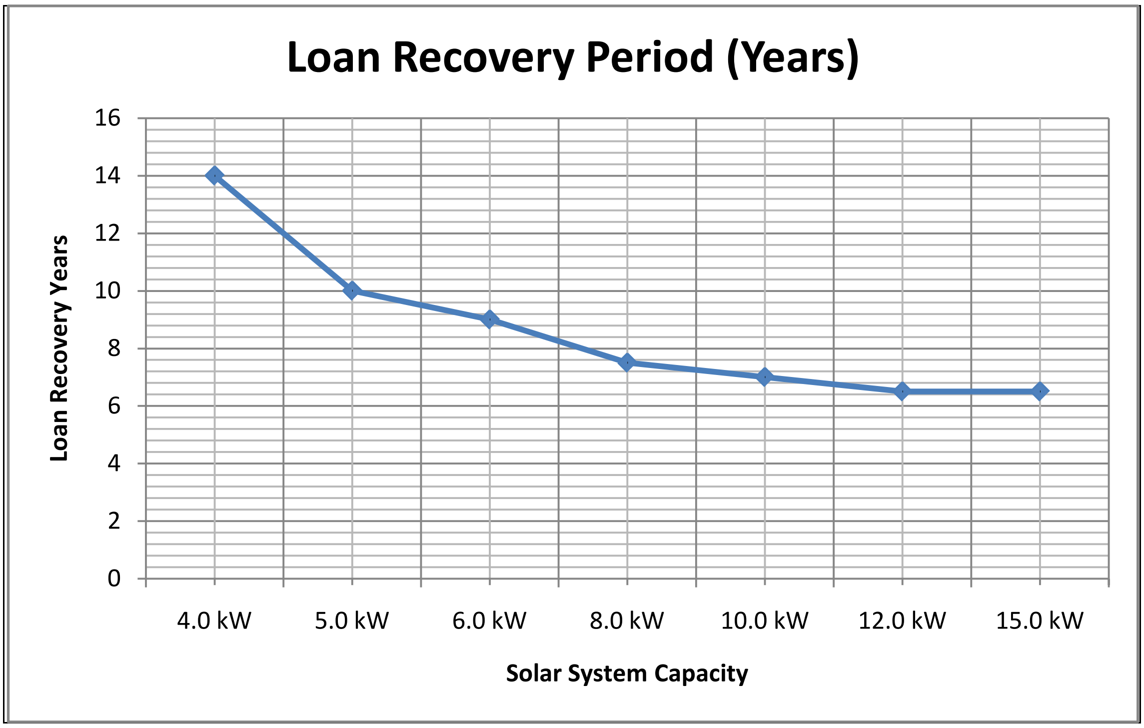

Figure 5.2 - Loan Recovery Period for Domestic Tariff Consumers

5.3.2 General Purpose Tariff (GP 1) Consumers

Table 5.3 - Loan Recovery Period for Business Tariff Consumers

System Capacity	Selling Price (Rs)	Units per month	Business (Monthly Saving) (Rs)	Loan Recovery Period (Years)
1.0 kW	600,000.00	125	2,861.63	More than 20 Years
2.0 kW	740,000.00	210	4,635.83	More than 20 Years
3.0 kW	1,000,000.00	330	8,356.08	More than 20 Years
4.0 kW	1,250,000.00	450	11,307.38	More than 20 Years
5.0 kW	1,500,000.00	600	14,996.51	More than 20 Years
6.0 kW	1,800,000.00	750	18,685.63	More than 20 Years
8.0 kW	2,200,000.00	960	23,850.41	More than 20 Years
10.0 kW	2,700,000.00	1200	29,753.01	More than 20 Years
12.0 kW	3,200,000.00	1450	35,904.23	More than 20 Years
15.0 kW	3,900,000.00	1800	44,509.51	More than 20 Years

No benefits are gained from a bank loan for business tariff (GP 1) consumers since loan recovery period is more than 20 years.

Chapter 6

CONCLUSION AND RECOMMENDATION

This dissertation describes and proposes an algorithm for selecting optimum PV solar systems for Net Metered consumers by optimization of following parameters. The accuracy of the algorithm has been verified with data taken from already installed PV solar systems in Colombo city as a case study.

- Tilt Angle
- Azimuth Angle
- Shadow Possibilities
- Array Size
- Inverter Capacity

The lowest and highest solar insolation level (kWh/m^2/day) in Colombo City are 3.47kWh/m^2/day in December and 5.09kWh/m^2/day in March respectively. Monthly Insolation level is presented in table 3.4.

For a domestic tariff consumer (D1) with average monthly consumption of 210-360 kWh, a 2kW PV solar system would give the maximum benefits. Similarly for a general purpose tariff consumer (GP1) with average monthly consumption of 300-420 kWh, a 3kW PV solar system would give the maximum benefits. Required PV solar system capacity to optimize the benefits for domestic (D1) and general purpose (GP1) tariff category consumers are presented in tables 3.7 and 3.9 respectively.

It is shown that the payback periods are 5 years and 10 years respectively if the monthly average consumptions are 645kWh and 225kWh for domestic tariff (D1) consumers. Similarly the payback periods are 10 years and 15 years respectively if the monthly average consumptions are 375kWh and 205kWh for general purpose tariff (GP1) consumers.

An analytical model was developed for comparing different inverters and PV solar panels for a particular location. Weighing factors were assigned to different attributes of the solar panel and inverter. Another factor termed “important factor” was introduced to each attribute. The analytical method presented in chapter 3 can be a valuable tool to design engineers for comparing different inverters and solar panels without having multiple simulations.

Three best tilt angles were derived for Colombo city area and they are 6°, 7° and 8°. Same yearly output can be obtained for these angles. Annual loss percentage due to use of available roof types of Tiles (30^{o}), Asbestos (20^{o}) and Trapezoidal Sheets (Amano Sheets) (12^{o}) are 6.13%, 1.97% and 0.28% respectively with reference to above mentioned best tilt angles.

The best Azimuth angle was reached in the direction from south to east and it was 5^{o} to 15^{o} away from south towards east direction. The same highest PV output can be obtained from these angles. Annual loss percentage of cardinal directions of South, East, West and North are 0.03%, 0.94%, 1.23% and2.54% respectively with reference to above mentioned best azimuth angles.

Annual loss percentage of shadow possibilities of 90% > SF > 80%, 80% > SF > 70%, and SF < 60% are 30%, 50% and 80% respectively with reference to shadow free system.

Shadow free analysis is essential and highly recommended to every site where PV solar systems are to be introduced. If shadow Free (SF) percentage of the location is less than 60% (SF < 60%), the system should not be installed.

To enhance economic benefits of the PV solar system, the array output should match the electric load of the building. An effectiveness factor was introduced and it should be 80% to get the Optimum Output. Array size should be decided according to the available roof area and the effectiveness factor. Sample array size optimization is presented in table 4.20.

A proper size of the inverter enables the stable and reliable operation of the PV system. It is shown that the optimum rated inverter power is **0.77-0.91** of the rated power of the PV plant.

More financial benefits could be achieved by installing a PV solar system than depositing money in the bank for both of consumer categories. i.e. Domestic tariff (D1) and Business tariff (GP1) except interest rate is 15% for General Purpose Tariff Category. More benefits could be enjoyed by domestic tariff (D1) consumers than general purpose tariff (GP1) consumers.

A Personal loan can be obtained from a commercial bank to install a PV solar system. If the monthly installment of the bank loan could be paid by the savings of monthly electricity bill by PV solar system, bank loan could be settled within the period of 7 and 9 years for consumers in domestic tariff (D1) category if the system capacities are 10 kW and 6kW respectively. Different loan recovery periods are calculated up to 15kW and presented in table 5.2.

No benefits are gained from a bank loan for general purpose tariff (GP 1) consumers since loan recovery period is more than 20 years.

Proposed solar systems which could give maximum benefits are as follows,

Table 6.1 – Proposed Solar Systems for Colombo City

System Capacity (kW)	Selling Price (Rs)	Units per month (Actual-kWh)	Solar Panels REC245PE	Actual Size (kWp)	Area (m^2)	Inverter	Unite Per Month (Simulation - kWh)
1.0 kW	**600,000**	125	5	1.23	8.30	SB 1200	160
2.0 kW	**740,000**	210	8	1.96	13.28	SB 2000 HF -30	260
3.0 kW	**1,000,000**	330	12	2.94	19.92	SB 3000 TL - 20	400
			13	3.19	21.58		430
4.0 kW	**1,250,000**	450	16	3.92	26.56	SB 4000 TL - 20	527
			17	4.17	28.22		560
5.0 kW	**1,500,000**	600	20	4.90	33.20	SMC 4600 A - 11	650
			22	5.39	36.52		660
6.0 kW	**1,800,000**	750	24	5.88	39.84	SMC 6000 A	790
			26	6.37	43.16		850
8.0 kW	**2,200,000**	960	32	7.84	53.12	SMC 8000 TL	1070
			34	8.33	56.44		1140
10.0 kW	**2,900,000**	1200	40	9.80	66.40	STP 10000 TL -10	1350
			42	10.29	69.72		1420
12.0 kW	**3,300,000**	1450	48	11.76	79.68	STP 12000 TL -10	1620
			50	12.25	83.00		1690
15.0 kW	**4,000,000**	1800	60	14.70	99.60	STP 15000 TL- 10	2010
			62	15.19	102.92		2090

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Monthly Consumption with Solar System for Domestic Tariff Consumers

Domestic								
Consumption	**Solar System**	**Unit Generation**	**Billing Units**	**Previous Bill (LKR)**	**Present Bill (LKR)**	**Savings per Month (LKR)**	**System Cost (LKR)**	**SPP (Years)**
30	1 kW	125	0	105.00	30.00	75.00	600,000.00	666.67
60		125	0	280.50	30.00	250.50	600,000.00	199.60
90		125	0	861.00	30.00	831.00	600,000.00	60.17
120		125	0	2,083.50	30.00	2,053.50	600,000.00	24.35
150		125	25	3,043.50	92.50	2,951.00	600,000.00	16.94
180		125	55	4,003.50	256.25	3,747.25	600,000.00	13.34
210		125	85	5,413.50	811.00	4,602.50	600,000.00	10.86
240		125	115	6,763.50	1,944.75	4,818.75	600,000.00	10.38
210	2 kW	210	0	5,413.50	30.00	5,383.50	740,000.00	11.45
240		210	30	6,763.50	105.00	6,658.50	740,000.00	9.26
270		210	60	8,113.50	280.50	7,833.00	740,000.00	7.87
300		210	90	9,463.50	861.00	8,602.50	740,000.00	7.17
330		210	120	10,813.50	2,083.50	8,730.00	740,000.00	7.06
360		210	150	12,163.50	3,043.50	9,120.00	740,000.00	6.76
390		210	180	13,513.50	4,003.50	9,510.00	740,000.00	6.48
420		210	210	14,863.50	5,413.50	9,450.00	740,000.00	6.53
330	3 kW	330	0	10,813.50	30.00	10,783.50	1,000,000.00	7.73
360		330	30	12,163.50	105.00	12,058.50	1,000,000.00	6.91
390		330	60	13,513.50	280.50	13,233.00	1,000,000.00	6.30
420		330	90	14,863.50	861.00	14,002.50	1,000,000.00	5.95
450		330	120	16,213.50	2,083.50	14,130.00	1,000,000.00	5.90
480		330	150	17,563.50	3,043.50	14,520.00	1,000,000.00	5.74
510		330	180	18,913.50	4,003.50	14,910.00	1,000,000.00	5.59
540		330	210	20,263.50	5,413.50	14,850.00	1,000,000.00	5.61
450	4 kw	450	0	16,213.50	30.00	16,183.50	1,250,000.00	6.44
480		450	30	17,563.50	105.00	17,458.50	1,250,000.00	5.97
510		450	60	18,913.50	280.50	18,633.00	1,250,000.00	5.59
540		450	90	20,263.50	861.00	19,402.50	1,250,000.00	5.37
570		450	120	21,613.50	2,083.50	19,530.00	1,250,000.00	5.33
600		450	150	22,963.50	3,043.50	19,920.00	1,250,000.00	5.23
630		450	180	24,313.50	4,003.50	20,310.00	1,250,000.00	5.13

660		450	210	25,663.50	5,413.50	20,250.00	1,250,000.00	5.14
600	5 kW	600	0	22,963.50	30.00	22,933.50	1,500,000.00	5.45
630		600	30	24,313.50	105.00	24,208.50	1,500,000.00	5.16
660		600	60	25,663.50	280.50	25,383.00	1,500,000.00	4.92
690		600	90	27,013.50	861.00	26,152.50	1,500,000.00	4.78
720		600	120	28,363.50	2,083.50	26,280.00	1,500,000.00	4.76
750		600	150	29,713.50	3,043.50	26,670.00	1,500,000.00	4.69
810		600	210	32,413.50	5,413.50	27,000.00	1,500,000.00	4.63
870		600	270	35,113.50	8,113.50	27,000.00	1,500,000.00	4.63
750	6 kW	750	0	29,713.50	30.00	29,683.50	1,800,000.00	5.05
810		750	60	32,413.50	280.50	32,133.00	1,800,000.00	4.67
870		750	120	35,113.50	2,083.50	33,030.00	1,800,000.00	4.54
930		750	180	37,813.50	4,003.50	33,810.00	1,800,000.00	4.44
960		750	210	39,163.50	5,413.50	33,750.00	1,800,000.00	4.44
1020		750	270	41,863.50	8,113.50	33,750.00	1,800,000.00	4.44
1080		750	330	44,563.50	10,813.50	33,750.00	1,800,000.00	4.44
960	8 kW	960	0	39,163.50	30.00	39,133.50	2,200,000.00	4.68
1020		960	60	41,863.50	280.50	41,583.00	2,200,000.00	4.41
1080		960	120	44,563.50	2,083.50	42,480.00	2,200,000.00	4.32
1140		960	180	47,263.50	4,003.50	43,260.00	2,200,000.00	4.24
1200		960	240	49,963.50	6,763.50	43,200.00	2,200,000.00	4.24
1260		960	300	52,663.50	9,463.50	43,200.00	2,200,000.00	4.24
1320		960	360	55,363.50	12,163.50	43,200.00	2,200,000.00	4.24
1200	10 kW	1200	0	49,963.50	30.00	49,933.50	2,700,000.00	4.51
1260		1200	60	52,663.50	280.50	52,383.00	2,700,000.00	4.30
1320		1200	120	55,363.50	2,083.50	53,280.00	2,700,000.00	4.22
1380		1200	180	58,063.50	4,003.50	54,060.00	2,700,000.00	4.16
1450		1200	250	61,213.50	7,213.50	54,000.00	2,700,000.00	4.17
1480		1200	280	62,563.50	8,563.50	54,000.00	2,700,000.00	4.17
1570		1200	370	66,613.50	12,613.50	54,000.00	2,700,000.00	4.17
1450	12 kW	1450	0	61,243.50	30.00	61,213.50	3,200,000.00	4.36
1480		1450	30	62,563.50	105.00	62,458.50	3,200,000.00	4.27
1510		1450	60	63,913.50	280.50	63,633.00	3,200,000.00	4.19
1570		1450	120	66,613.50	2,083.50	64,530.00	3,200,000.00	4.13
1630		1450	180	69,313.50	4,003.50	65,310.00	3,200,000.00	4.08
1690		1450	240	72,013.50	6,763.50	65,250.00	3,200,000.00	4.09
1750		1450	300	74,713.50	9,463.50	65,250.00	3,200,000.00	4.09
1800		1450	350	76,963.50	11,713.50	65,250.00	3,200,000.00	4.09
1890		1450	440	81,013.50	15,763.50	65,250.00	3,200,000.00	4.09
1800	15 kW	1800	0	76,963.50	30.00	76,933.50	3,900,000.00	4.22
1860		1800	60	79,663.50	280.50	79,383.00	3,900,000.00	4.09

1890		1800	90	81,013.50	861.00	80,152.50	3,900,000.00	4.05
1920		1800	120	82,363.50	2,083.50	80,280.00	3,900,000.00	4.05
1950		1800	150	83,713.50	3,043.50	80,670.00	3,900,000.00	4.03
1980		1800	180	85,063.50	4,003.50	81,060.00	3,900,000.00	4.01

Monthly Consumption with Solar System for General Purpose Tariff Consumers

General Purpose Tariff (GP 1)								
Consumption	**Solar System**	**Unit Generation**	**Billing Units**	**Previous Bill (LKR)**	**Present Bill (LKR)**	**Savings per Month (LKR)**	**System Cost (LKR)**	**SPP (Years)**
30	1 kW	125	0	867.98	240.00	627.98	600,000	79.62
60		125	0	1,495.95	240.00	1,255.95	600,000	39.81
90		125	0	2,123.93	240.00	1,883.93	600,000	26.54
120		125	0	2,751.90	240.00	2,511.90	600,000	19.91
150		125	25	3,379.88	764.33	2,615.55	600,000	19.12
180		125	55	4,007.85	1,392.30	2,615.55	600,000	19.12
210		125	85	4,635.83	2,020.28	2,615.55	600,000	19.12
240		125	115	5,523.81	2,648.25	2,875.56	600,000	17.39
210	2 kW	210	0	4,635.83	240.00	4,395.83	740,000	14.03
240		210	30	5,523.81	867.98	4,655.83	740,000	13.25
270		210	60	6,184.28	1,495.95	4,688.33	740,000	13.15
300		210	90	6,844.76	2,123.93	4,720.83	740,000	13.06
330		210	120	8,356.08	2,751.90	5,604.18	740,000	11.00
360		210	150	9,093.91	3,379.88	5,714.03	740,000	10.79
330	3 kW	330	0	8,356.08	240.00	8,116.08	1,000,000	10.27
360		330	30	9,093.91	867.98	8,225.93	1,000,000	10.13
390		330	60	9,831.73	1,495.95	8,335.78	1,000,000	10.00
420		330	90	10,569.56	2,123.93	8,445.63	1,000,000	9.87
450		330	120	11,307.38	2,751.90	8,555.48	1,000,000	9.74
480		330	150	12,045.21	3,379.88	8,665.33	1,000,000	9.62
510		330	180	12,783.03	4,007.85	8,775.18	1,000,000	9.50
450	4 kw	450	0	11,307.38	240.00	11,067.38	1,250,000	9.41
510		450	60	12,783.03	1,495.95	11,287.08	1,250,000	9.23
540		450	90	13,520.86	2,123.93	11,396.93	1,250,000	9.14
570		450	120	14,258.68	2,751.90	11,506.78	1,250,000	9.05
600		450	150	14,996.51	3,379.88	11,616.63	1,250,000	8.97
600		600	0	14,996.51	240.00	14,756.51	1,500,000	8.47
660	5 kW	600	60	16,472.16	1,495.95	14,976.21	1,500,000	8.35
720		600	120	17,947.81	2,751.90	15,195.91	1,500,000	8.23
750		600	150	18,685.63	3,379.88	15,305.75	1,500,000	8.17
750	6 kW	750	0	18,685.63	240.00	18,445.63	1,800,000	8.13
810		750	60	20,161.28	1,495.95	18,665.33	1,800,000	8.04
870		750	120	21,636.93	2,751.60	18,885.33	1,800,000	7.94

930		750	180	23,112.58	4,007.85	19,104.73	1,800,000	7.85
960		750	210	23,850.41	4,635.83	19,214.58	1,800,000	7.81
960	8 kW	960	0	23,850.41	240.00	23,610.41	2,200,000	7.76
1020		960	60	25,326.06	1,495.95	23,830.11	2,200,000	7.69
1080		960	120	26,801.71	2,751.90	24,049.81	2,200,000	7.62
1140		960	180	28,277.36	4,007.85	24,269.51	2,200,000	7.55
1200		960	240	29,753.01	5,523.81	24,229.20	2,200,000	7.57
1200	10 kW	1200	0	29,753.01	240.00	29,513.01	2,700,000	7.62
1260		1200	60	31,228.66	1,495.95	29,732.71	2,700,000	7.57
1320		1200	120	32,704.31	2,751.90	29,952.41	2,700,000	7.51
1380		1200	180	34,179.96	4,007.85	30,172.11	2,700,000	7.46
1450		1200	250	35,904.23	5,749.68	30,154.55	2,700,000	7.46
1450	12 kW	1450	0	35,904.23	240.00	35,664.23	3,200,000	7.48
1510		1450	60	37,379.88	1,495.95	35,883.93	3,200,000	7.43
1570		1450	120	38,855.53	2,751.90	36,103.63	3,200,000	7.39
1630		1450	180	40,331.18	4,007.85	36,323.33	3,200,000	7.34
1690		1450	240	41,806.83	5,523.81	36,283.02	3,200,000	7.35
1750		1450	300	43,282.48	6,844.76	36,437.72	3,200,000	7.32
1800		1450	350	44,509.51	8,849.31	35,660.20	3,200,000	7.48
1800	15 kW	1800	0	44,509.51	240.00	44,269.51	3,900,000	7.34

PV Output (kWh) for Different Azimuth Angle

Tilt Angle - 7^0													
Azimuth	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**TOTAL**
(-180) - North	479	534	580	551	496	486	488	502	477	461	443	441	5,936
-170	480	534	580	551	496	486	488	502	477	461	443	441	5,939
-160	480	534	581	552	497	487	488	503	478	461	444	442	5,946
-150	481	535	582	552	498	487	489	503	479	462	444	442	5,956
-140	482	536	583	553	499	488	490	504	479	463	445	443	5,967
-135	482	537	583	554	499	489	491	505	480	464	446	444	5,974
-130	483	537	584	555	500	489	491	505	481	464	446	444	5,980
-120	484	539	585	556	501	490	492	507	482	465	447	445	5,993
-110	485	540	587	557	502	491	493	508	483	466	448	446	6,006
-100	486	541	588	558	503	493	494	509	484	467	449	447	6,020
(-90)-East	487	542	589	560	504	494	496	510	485	468	450	448	6,033
-80	488	543	590	561	505	495	496	511	486	469	451	449	6,045
-70	489	544	592	562	506	496	497	512	487	470	452	450	6,057
-60	490	545	593	563	507	496	498	513	488	471	453	451	6,067
-50	491	546	593	564	508	497	499	514	488	471	453	451	6,076
-45	491	547	594	564	508	497	499	514	489	472	454	452	6,080
-40	491	547	594	564	509	498	500	514	489	472	454	452	6,084
-30	492	547	595	565	509	498	500	515	489	472	454	452	6,089
-20	492	548	595	565	509	498	500	515	489	473	455	452	6,091
-18	492	548	595	565	509	498	500	515	489	473	455	452	6,091
-16	492	548	595	565	509	498	500	515	489	473	455	452	6,091
-15	492	548	595	565	509	498	500	515	490	473	455	453	6,092
-14	492	548	595	565	509	498	500	515	490	473	455	453	6,092
-12	492	548	595	565	509	498	500	515	490	473	455	453	6,092
-10	492	548	595	565	509	498	500	515	490	473	455	453	6,092
-8	492	548	595	565	509	498	500	515	490	473	455	453	6,092
-6	492	548	595	565	509	498	500	515	490	473	455	453	6,092
-5	492	548	595	565	509	498	500	515	490	473	455	453	6,092
-4	492	548	595	565	509	498	500	515	489	473	455	452	6,091
-2	492	548	595	565	509	498	500	515	489	473	455	452	6,091
0 - South	492	547	595	565	509	498	500	515	489	473	455	452	6,090
10	491	547	594	564	509	498	500	514	489	472	454	452	6,086
20	491	547	594	564	508	497	499	514	489	472	454	452	6,080
30	491	546	593	563	508	497	499	514	488	471	453	451	6,075

40	490	545	593	563	507	496	498	513	488	471	453	451	6,068
45	490	545	592	563	507	496	498	513	487	471	453	450	6,065
50	489	545	592	562	507	496	498	512	487	470	452	450	6,061
60	489	544	591	561	506	495	497	512	486	470	452	449	6,051
70	488	543	590	560	505	494	496	511	485	469	451	449	6,040
80	487	542	589	559	504	493	495	510	484	468	450	448	6,029
90 -West	486	541	588	558	503	492	494	508	483	467	449	447	6,015
100	485	540	586	557	502	491	493	507	482	466	448	446	6,003
110	484	538	585	556	501	490	492	506	481	465	447	445	5,990
120	483	537	584	554	500	489	491	505	480	464	446	444	5,977
130	482	536	583	553	499	488	490	504	479	463	445	443	5,965
135	481	536	582	553	498	488	489	504	479	462	445	443	5,960
140	481	535	582	552	498	487	489	503	479	462	444	442	5,956
150	480	535	581	552	497	487	488	503	478	461	444	442	5,947
160	480	534	580	551	497	486	488	502	477	461	443	441	5,941
170	479	534	580	551	496	486	488	502	477	461	443	441	5,937
180	479	534	580	551	496	486	488	502	477	461	443	441	5,936

Appendix - D

Load Profile with Relevant Solar System

Consumption (kWh)	Solar System (kW)	Unit Generation From Solar System (kWh)
30	1	125
60	1	125
90	1	125
120	1	125
150	1	125
180	1	125
210	1	125
240	2	210
270	2	210
300	2	210
330	2	210
360	2	210
390	2	210
420	3	330
450	3	330
480	3	330
510	3	330
540	4	450
570	4	450
600	4	450
630	4	450
660	5	600
720	5	600
750	5	600
810	5	600
870	6	750
930	6	750
960	6	750
1020	6	750
1080	8	960
1140	8	960
1200	8	960
1260	8	960
1320	10	1200

1380	10	1200
1450	10	1200
1480	10	1200
1570	12	1450
1630	12	1450
1690	12	1450
1750	12	1450
1800	12	1450
1890	15	1800
1920	15	1800
1950	15	1800
1980	15	1800