NEAR EAST UNIVERSITY

INSTITUTE OF GRADUATE STUDIES

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

6MW ELECTRIC POWER GENERATION IN NIGERIA USING PHOTOVOLTAIC SYSTEM AND HIGH VOLTAGE GAIN CONVERTERS

MSc. THESIS

Salim Tsowa MOHAMMED

Nicosia

November, 2022

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Supervisor

Asst. Prof. Dr. Samuel Nii Tackie

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Approval

We certify that we have read the thesis submitted by Salim Tsowa Mohammed titled "6MW Electric Power Generation in Nigeria Using Photovoltaic System and High Voltage Gain Converters" and that in our combined opinion it is fully adequate, in the scope and in quality, as a thesis for the degree of Master of Educational Sciences.

Examining Committee Name-Surname Signature

Head of the Committee:Assist. Prof. Dr. Lida Ebrahimi Vafaei ....

Committee Member:Assoc. Prof. Dr. Kamil Dimililer ....

Supervisor: Asst. Prof. Dr. Samuel Nii Tackie..................

Approved by the Head of the Department

29/12/2022

Prof. Dr. Bülent Bilgehan

Head of Department

Approved by the Institute of Graduate Studies

13/1/23

Prof. Dr. Kemal Hüsnü Can Başer

Head of the Institute

Declaration

I hereby declare that all information, documents, analysis and results in this thesis have been collected and presented according to the academic rules and ethical guidelines of Institute of Graduate Studies, Near East University. I also declare that as required by these rules and conduct, I have fully cited and referenced information and data that are not original to this study.

Salim Tsowa Mohammed

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Salim Tsowa Mohammed

Abstract

6MW Electric Power Generation in Nigeria Using Photovoltaic System and High Voltage Gain Converters

Mohammed, Salim Tsowa

Asst. Prof. Dr. Samuel Nii Tackie

M.Sc., Department of Electrical and Electronic Engineering

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Electric power is an essential commodity required for the socio-economic transformation of developing countries like Nigeria. As 2019, the world bank report puts access to electric power in Nigeria at 55.4%. Having abundant renewable energy sources and being a major exporter of crude oil, this statistic shows the lack of investments and policy directions in the electric power sector.

This research proposes two electric power generating systems based on photovoltaic system. The two systems are to provide electric power for residential and grid-connected commercial applications. The grid-tied system generates 6MW of electricity while the residential system generates electric power based on the needs assessment. Both systems are sited in Doko in the Niger state of Nigeria.

The viability of the proposed systems is determined by two highly rated, industry and academia accepted PV system software known as PVsyst and HelioScope. Both software uses real-time plant location to determine the expected daily, monthly and yearly electric energy output of the proposed plants. One DC-DC converter and one multilevel inverter are presented to properly boost and condition the generated electric power for grid applications.

Key words: Photovoltaic system, Stand-alone, PVsyst, Grid-connected, HelioScope, Power Electronic Converters.

Özet

Nijerya'da Fotovoltaik Sistem ve Yüksek Gerilim Kazanç Dönüştürücüleri Kullanarak 6MW Elektrik Enerjisi ÜretimiLiberya'daki Gençler Arasında

Mohammed, Salim Tsowa

Asst. Prof. Dr. Samuel Nii Tackie

Yüksek Lisans, Elektrik-Elektronik Mühendisliği Bölümü

Kasım 2022, 115 sayfa

Elektrik enerjisi, Nijerya gibi gelişmekte olan ülkelerin sosyo-ekonomik dönüşümü için gerekli olan temel bir metadır. 2019 olarak, dünya bankası raporu Nijerya'da elektrik enerjisine erişimin %55,4 olduğunu belirtiyor. Bol miktarda yenilenebilir enerji kaynaklarına sahip olması ve önemli bir ham petrol ihracatçısı olması, bu istatistik, elektrik enerjisi sektöründe yatırımların ve politika yönelimlerinin eksikliğini göstermektedir.

Bu araştırma, fotovoltaik sisteme dayalı iki elektrik enerjisi üretim sistemi önermektedir. İki sistem, konut ve şebekeye bağlı ticari uygulamalar için elektrik gücü sağlayacak. Şebekeye bağlı sistem 6MW elektrik üretirken konut sistemi ihtiyaç değerlendirmesine göre elektrik enerjisi üretir. Her iki sistem de Nijerya'nın Nijer eyaletindeki Doko'da bulunuyor.

Önerilen sistemlerin uygulanabilirliği, PVsyst ve HelioScope olarak bilinen, endüstri ve akademi tarafından kabul edilen iki yüksek dereceli PV sistem yazılımı tarafından belirlenir. Her iki yazılım da önerilen santrallerin beklenen günlük, aylık ve yıllık elektrik enerjisi çıkışını belirlemek için gerçek zamanlı tesis konumunu kullanır. Şebeke uygulamaları için üretilen elektrik gücünü uygun şekilde artırmak ve koşullandırmak için bir DC-DC dönüştürücü ve bir çok seviyeli invertör sunulmuştur.

Anahtar kelimeler: Fotovoltaik sistem, Bağımsız, PVsyst, Şebeke bağlantılı, HelioScope, Güç Elektroniği Dönüştürücüleri.

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List of Abbreviations

AC:	Alternating Current
CCM:	Continuous Conduction Mode
C_{ener}:	Annual Energy income
$C_{0\&M}$:	Yearly operation and maintenance cost
CSI:	Current Source Inverter
C_{CAPA}:	Annual capacity income or savings
C_{RE}:	Annual renewable energy(RE)
C_{GHG}:	The GHG is reduction income
DC:	Direct Current
DCM:	Discontinuous Conduction Mode
EMI:	Electromagnetic Interference
E_Grid:	Energy injected into grid
EArray:	Effective energy at array output
EffSysA:	Effic. Eout system/rough area
EffArrA:	Effic. Eout array/rough area
HF:	Harmonic Factor
HVDC:	High Voltage Direct Current
GlobHor:	Horizontal global irradiation
GlobInc:	Global incident in coll. Plane
GlobEff:	Effective global corr. For IAM and shading
IGBTs:	Insulated-Gate Bipolar Transistors
I_G:	Incenttives and grants
KVL:	Kirchhoff's Voltage Law
MATLAB:	Matrix Laboratory
MISO:	Multi Input Single Output
MPWM:	Multiple Pulse Width Modulation
MSPWM:	Modified Sinusoidal Pulse Width Modulation
PSCAD:	Power System Computer Aided Design
PV:	Photovoltaic
PWM:	Pulse Width Modulation
qZS:	quasi-Z-source

RMS:	Root Mean Square
SC:	Switched Capacitor
SEPIC:	Single Ended Primary Inductor Converter
SL:	Switched Inductor
SLCN:	Switched Inductor Capacitor Network
SL-qZS:	Switched Inductor quasi-Z-source
SLSC:	Switched Inductor Capacitor
SL-ZS:	Switched Inductor Z-source
SPWM:	Single Pulse Width Modulation
T Amb:	Ambient Temperature
THD:	Total Harmonic Distortion
VSI:	Voltage Source Inverter
ZS:	Z-source

CHAPTER 1
Introduction

1.1 Overview

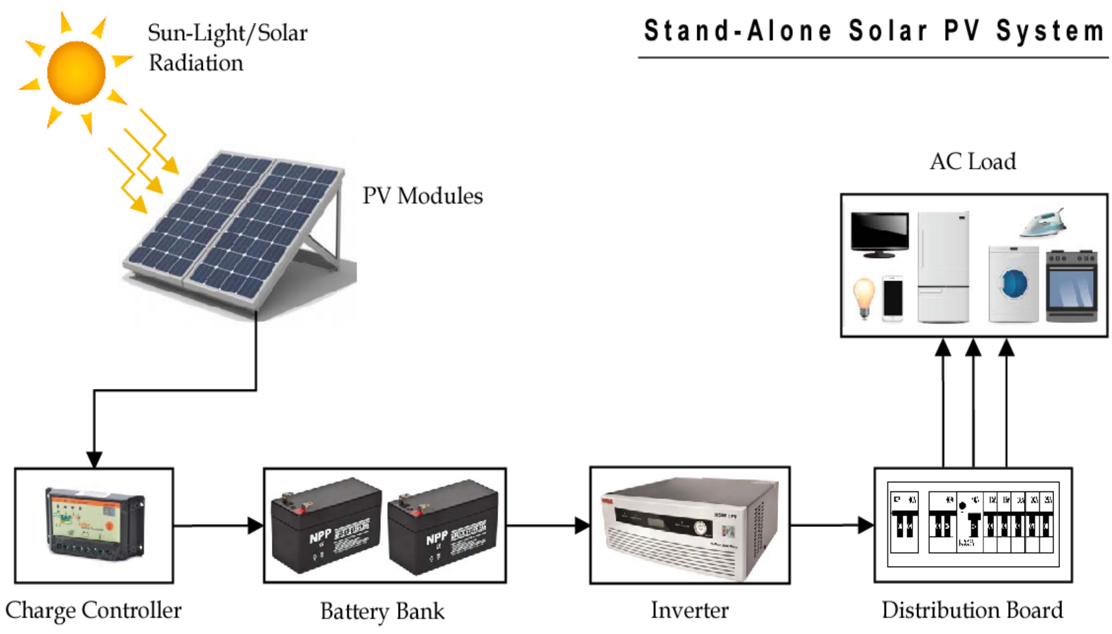
Nigeria is located in the sub Saharan region of West Africa, along the coast of Gulf of Guinea. Unlike other African countries, Nigeria is a federal republic with 36 (thirty-six) states. The current population of Nigeria is about 195 million with annual average growth of 2%. Nigerian economy is highly dependent on crude oil exports which grow annually at a rate of 6%. Price fluctuations of crude oil affect budgeting. Nigeria is blessed with other mineral resources that its yet to fully harness for economic development. Electric power generation and penetration in Nigeria is the not best for a country with the biggest economy in West Africa. Nigeria is blessed with multiple resources for electric power generation. From thermal resources such as gas and oil, and from renewable resources such as wind, hydro and solar, these combined sources can generate close to 12.522GW of electric power if properly planned. Lack of investment and poor maintenance are hugely responsible for stunted growth of the electric power sector in Nigeria. 4000MW of electric power is the biggest magnitude of power Nigeria dispatches on most days.

Even though Nigeria has abundant reserves of crude oil, price fluctuations in world crude prices poses adverse effects on the pricing of electric power generated from crude oil, also negative effects of fossil fuels on the environment has brought to the fore the use of renewable energy sources for electric power generation. Hydro, wind and solar resources are the major renewable energy resources heavily available in Nigeria. Hydro and wind requires huge monetary investments and are mostly suitable for largescale electric power generation. Other forms of solar energy such as CSP (concentrated solar power) also requires huge monetary investments and also suitable for largescale power generation. Photovoltaic systems on the other hand require relatively small monetary investments for small or individual systems and small to medium monetary investment for large scale electric power generation. Comparing PV systems to Hydro and Wind, PV installations does not require specialized land conditions for installation, PVs can be installed on roof tops or on the ground and they will adequately produce rated power provided they are not affected by shading. Hydro dam installation requires special land features which can support the building of the dam to retain water all year round and also provide the needed kinetic motion required for rotor blade rotation. Hydro dams cannot be sited close to consumers unless the water resource is close to the consumer hence huge financial investments are required for transmission lines. Long transmission lines cause loss of electric power.

Photovoltaic systems also popularly known as PV systems are means by which electric power is generated. Photovoltaic systems are best defined as the use of one or multiple solar panels (two or more modules), power electronic converter and other auxiliary components for electric power generation using solar energy. PV electric power generation is based on the use of PV modules placed directly in the path of solar irradiance. The module or panels convert photons (packets of solar energy) into DC (direct current) electric voltage. Power electronic converters are used in conditioning the generated voltage to the required type (ac or dc) and magnitude for utilization by electric loads. With respect to voltage magnitude, PV systems are classified as stand-alone or commercial PV systems. Stand-alone PV systems are mostly used in residential facilities or facilities that require low to medium voltages and are mostly not tied to the national grid.

Figure 1

Standalone PV System (Ali, W, et, al. 2018)



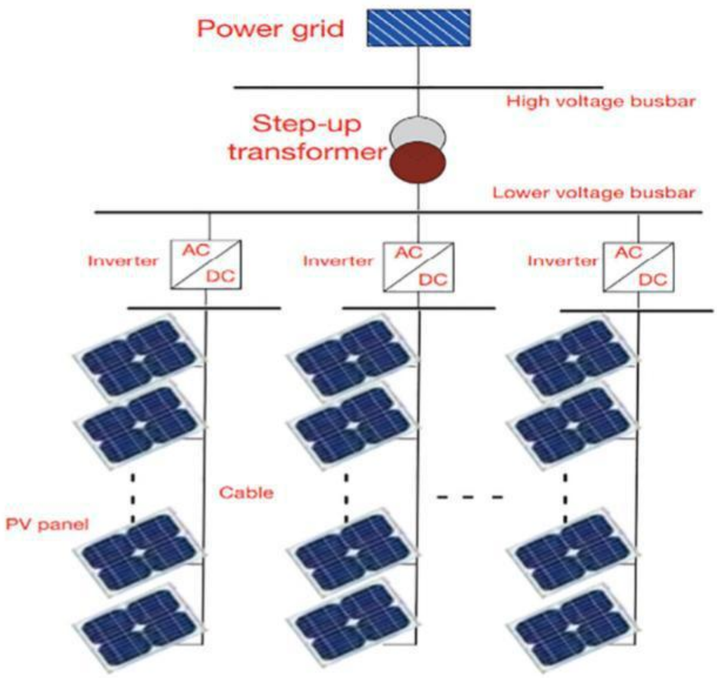
The generated voltages are stored by energy saving systems such string of batteries. Most developed countries such as Germany and USA now provide grid integration of Standalone systems i.e. when batteries are fully charged, excess power produced are transferred to the grid via a metering system, the producer is then paid for the generated power. The other type of PV systems is the commercial or grid tied PV systems where power is produced in medium to high voltages using over thousands of solar panels.

Figure 2

Solar Panels for Grid Connected PV Systems

Figure 3

Generalized Grid Connected PV Systems (Nwaigwe KN, et, al. 2019)



The generalized structure of standalone PV systems is illustrated by Fig. 1. As shown the Fig. 1, the device responsible for conditioning the produced voltage for ac voltage loads is the inverter. Fig. 2. shows thousands of solar panels which are used in producing voltage of high magnitude for grid connection. The generalized structure of grid connected PV system is shown by Fig. 3. Also, inverters are required to change DC voltages to ac voltage for ac grids, however in the case HVDC, DC-DC converter are required for proper voltage conditioning.

As indicated by the two types of photovoltaic systems (Standalone and grid-tied), power electronic converters are required to appropriately change the characteristics of the generated voltage for usage by electric loads or for onward transmission. Two of these power electronic converters required for PV systems are Inverters and DC-DC converters which are also popularly known as DC Choppers. Inverter are required to alter the waveform characteristics of dc voltages to ac voltage. Multilevel inverters are regarded as the pioneer inverters. They were first introduced in 1980s. Multilevel inverters (MLI) are defined as a circuit composed of power electronic components made from semiconductors, these circuits utilize one or more voltage sources of low magnitudes to generate various levels or stepped output voltages which can be considered as sine voltages. Three categories of multilevel inverters constitute the traditional topologies; these are cascaded H-bridge MLI, Diode-clamped MLI and Flying Capacitor MLI.

Unlike DC-DC converters, inverters are generally required to alter the waveform characteristics by changing from DC to AC and also change the magnitude of the voltage. For high voltage applications, high gain inverters with impedance networks (Z source) are sometimes used. DC-DC converters on the other hand do not change the waveform characteristics but providing buck or boost features. They either reduce the output voltage to less than the input voltage (buck feature) or increase the output voltage to be greater than the input voltage (Boost feature). The conventional DC-DC converters are buck converter, boost converter and buck-boost converter. Other topologies of DC-DC converters have been introduced after these conventional topologies. Fig. 4 shows a single-phase H-bridge inverter; this inverter is a 3-level inverter which followed the 2-level inverter. Fig. 5 to Fig. 7 shows dc choppers which are considered to be buck, boost and buck-boost topologies respectfully.

Figure 4

H-Bridge Inverter.

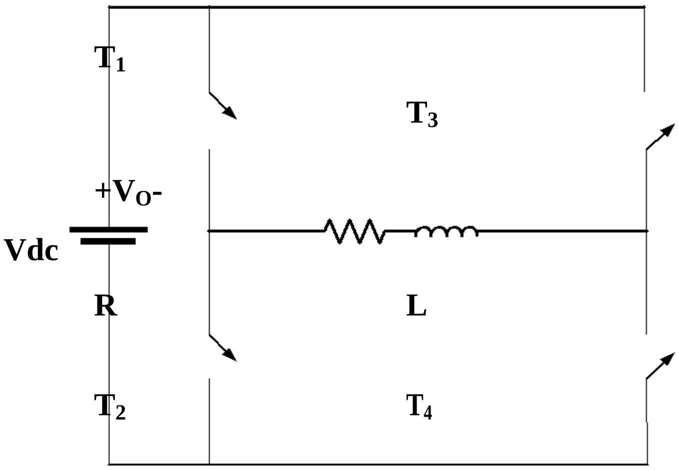


Figure 5

Buck DC-DC Converter (MK Kazimierczuk, 2015)

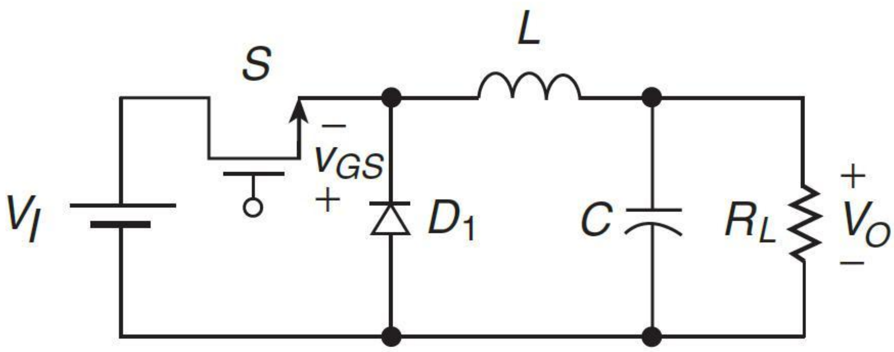


Figure 6

Boost DC-DC Converter (MK Kazimierczuk, 2015)

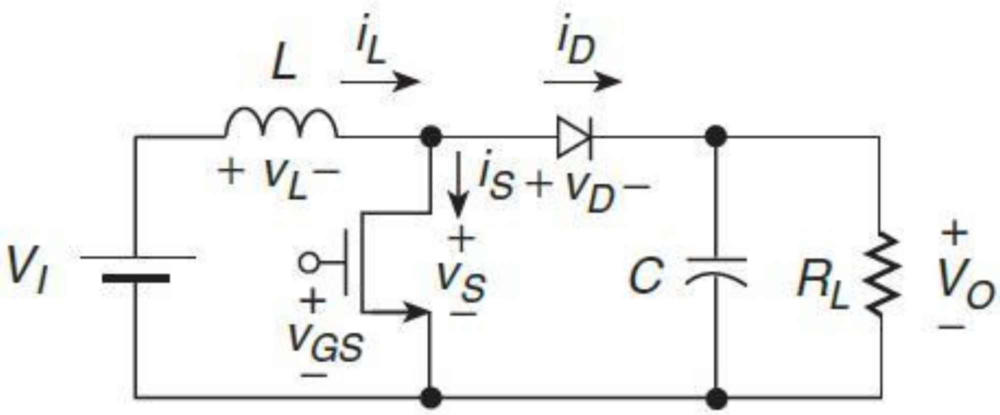
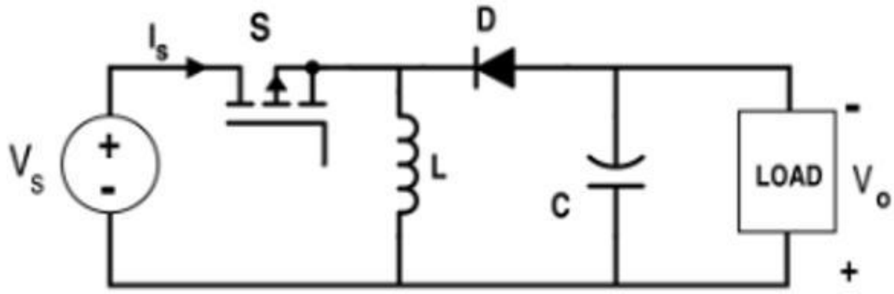


Figure 7

Boost DC-DC Converter (MK Kazimierczuk, 2015)



1.2 Statement of the Problem

It is an undeniable factor that electric power is an essential commodity required for any nation to transition from a developing country to a developed country. Electric power should be constantly available and affordable for consumers to use. The current state of electric power generation and distribution in Nigeria is not at an acceptable level considering the population of the country. As 2019, the world bank report puts access to electric power in Nigeria at 55.4%, which means that over 50 million Nigerians to not have access to grid connected electricity. Most of these people really on generators; these generators are noisy and costly.The challenges of electric power generation, transmission and distribution in Nigeria will continue to exist in the medium to long term period unless adequate solutions are provided to resolve these challenges. The challenges are broadly categorised into sectors namely: illiquidity, inadequate transmission and distribution infrastructure and lack of gas supply. Consumers who have the resources to provide electric powermostly rely on generator sets. These generator sets as stated above are noisy hence cause noise pollution and really on fossil fuels for combustion. As we all know, fossil fuels are being replaced by clean energy sources such as PV systems from renewable energy sources.

1.3 Purpose of Study

The aim of this research is to investigate the prospects of generating electric power by means of photovoltaic systems for Doko Township in Niger State of Nigeria. Commercially grid-tied and standalone PV systems are designed and simulated. The electric power generated requires appropriate voltage conditioning, therefore, two power electronic converters i.e. an inverter and DC-DC converter are presented. The design stage of the PV is executed as: the commercially grid-tied photovoltaic system is the first to be designed followed by stand-alone PV system using real satellite meteorological data in Nigeria. The siting of both PV systems will be in Doko Township in Niger State region of Nigeria. The aim of the standalone PV systems is to provide reliable electric power for families of not more than 5 members. The aim of the grid-tied PV systems is to have a centralised electric power generation for communities that do not have access to grid electricity. Two reliable and industry accepted software's are used in the simulation of the proposed PV systems. The software are PVsyst and HelioScope. Finally, two high voltage gain converters (inverter and dc choppers) are presented, these converters are analysed and simulation results produced by using PSCAD software to exhibit their high voltage gain or boosting characteristics.

1.4 Significance of Study

The importance of this research is to show the potential of PV systems for electric power generation in Nigeria for both standalone and grid connected systems. Also, high voltage boosting capabilities are exhibited by the proposed two power electronic converters. Using PV systems for electric power generation eliminates the negative effects of generator sets such as noise pollution and environmental air pollution (release of CO_2). Also, the cost of PV generated electric power is considerably cheap compared to generator sets and grid tied electric power because no fuel cost is required. With appropriate battery sizing, consumers can have electric power all year round without having to worry about grid electric power. When lowvoltages are generated by the solar panels due to weather conditions, the high voltage boosting capabilities of the converters will provide the required magnitude of output voltage.

1.5 Limitations

This research is entirely conducted by depending on the software's for the photovoltaic system simulation and power electronic simulation. However, it has been proven that simulations result from the utilized software's (PSCAD, PVsyst, and HelioScope) have little deviations from experimental prototypes. This is because actual system parameters and real data are used in these software's. Also, due to COVID travelling restrictions and financial constraints, we could not build experimental prototype for this research. Apart from the above listed limitation, the research was generally a success.

1.6 Overview of the Thesis

This research or thesis is categorized into the following body of chapters:

Chapter 1: Introduction, Statement of Problem, Aims, The importance's, and Overview of the Thesis

Chapter 2: Literature Review of PV Systems and Power Electronic Converters

Chapter 3: System Design and Simulation Results

Chapter 4: Conclusion and Future Works

CHAPTER 2

Literature Review

2.1 INTRODUCTION

Electricity is supplied by a power grid to end customers, who utilize it in their homes and places of work. Any electrically powered equipment is referred to as a load in power networks. Examples of these loads in household electric systems include air conditioning, lights, televisions, refrigerators, washing machines, and dishwashers. Induction motors make up the majority of industrial loads, which are composite loads. The main commercial loads include lights, workstation computers, copier machines, laser printers, and communication equipment. At nominal rated voltages, all electrical loads are supplied. For each to operate safely, the manufacturer specifies the nominal rated voltage. This chapter offers a survey of the literature on the Nigerian electric power industry, solar systems, and power electronic converters, with an emphasis on inverters and DC-DC converters with high voltage boosting characteristics. Since it is impossible to discuss photovoltaic systems without also discussing solar energy, a quick overview of solar energy is given before turning attention to photovoltaic systems.

2.2 Overview of Power Sector in Nigeria

In 1898, the Nigerian electrical grid was established. The Electricity Corporation of Nigeria (ECN) was established in 1951. The Niger Dam Authority was also founded in 1962 for the development of hydroelectric power. It joined with ECN to become NEPA, the National Electric Power Authority. NEPA maintained a little market in the delivery of power to the public, but it could not fulfill demand (IEA, 2020). Upon discovering that NEPA was failing, it was subsequently transformed to PHCN (Hagumimana,et al.,2021). Through Reform Ast 2005, PHCN was split into 18 separate businesses: six generation companies, one transmission company, and eleven distribution firms (SolarGis, 2022). This investment was made in privatization in order help bring about the much-needed reform in the area. National Electric Power Policy (NEPP) also joined in 2001, and Independent Power Plants (IPPs) became a vital element of the Nigeria government's initiative to enhance producing power (N.E.A, 2021). The Nigerian power industry is composed of three primary subsectors: generating (NESI), transmission (TCN), and distribution(DISCOS).

2.2.1.Generation

The current capacity of Nigerian power plants is 10,396 MW, however as of December 2020, fewer than 6056 MW of capacity was accessible. There are 23 producing states, seven of which are more than tweenty years old, Its daily average power output is smaller than the current maximum projection. Existing power plants have a cumulative installed power of 10,396 megawatt.; however, as of December 2013, the usable capacity was less than 6056 MW. The average daily power production is lower than the peak expected for the present existing facilities, and seven of the twenty-three producing states are over twenty years old. The present level of electricity generating in Nigeria faces a variety of challenges, including insufficient generation, obsolete equipment and tools, and delayed facility maintenance.

2.2.2 Transmission

The Transmission Company of Nigeria (TCN) was created as the successor to the Power Holding Company of Nigeria (PHCN). It was partitioned into KV lines (9). This could be split into two parts: the System Operator and the Market Operator. There are about 5523.8 km of 330KV lines and 6801.49 km of 132KV lines in the transmission system.

2.2.3 Distribution & Marketing

Distribution is the third subsector of the electricity sector in Nigeria. There are eleven energy distribution enterprises in this sector (DISCOS).

The firms listed below provide distribution services:

- ABUJA, BENIN, EKO, ENUGU, IBADAN, IKEJA, JOS, KADUNA. KANO, PORT HARCOURT, and YOLA companies.

Some areas in Nigeria have very limited distribution networks and a low population profile, resulting in correct billing.

As distribution departments interface directly with the public, it is impossible to emphasize the significance of implementing proper network coverage, providing high-quality utility supplies, and delivering successful marketing and customer service. Among the identified obstacles are insufficient or inappropriate able to connect, overburdened transporters and poor distribution system, sub - standard distribution system, an inadequate payment system, impolite staff behavior toward electricity clients, inadequate technological infrastructure including company cars and inadequate communication facilities.

2.2.4 Distributed Generation

DG typically refers to relatively small-scale generation. Smart grid would enable distributed generation technologies for the goal of addressing difficulties with generation as it now exists and providing supplementary services. Micro turbines, fuel cells, and reciprocating engines are some of the DG technologies that are now being used to increase overall efficiency. As possible DG sources, solar, wind, and other kinds of renewable energy might be used. By aiding in the lowering of peak demands, distributed generation (DG) systems may provide a more cost-effective alternative to peaking plants. By lowering the production and supply of energy, both electrically and thermally based energy storage systems may improve the problem of dispatch ability and controllability of these resources at the distribution level and on a small scale in commercial or residential structures. Smart grids will help balance supply and demand by automating generation and demand management (in addition to other forms of demand response). Batteries and flywheels are two popular storage methods. This helps postpone the need for infrastructure with increased capacity.

2.2.5 Transmission and Enhancement Technology

Watch gear, High-rupture capacity (HRC) reactors, air-cooled shielded reactors, lighting accelerators, circuit breakers, power transformers, isolators, and bunkers are the most common types of equipment found in PHCN installations, in addition to the power lines, wires, electrical systems, switch, transformer, big capacitors, rigid steel towers, steel tube poles, hardwood poles, and grounding system.

In Nigeria, the traditional grid, or transmission power system, would necessitate maximizing the use of existing transportation infrastructure rather than constructing costly and time-consuming new power plants and transportation lines. The System for Variable Alternating Current.

To overcome the aforementioned challenges, power systems may include high voltage DC (HVDC) controller transmission technology and FACTS systems.

FACTS makes it possible to adjust the amount of a bus's voltage, and active and reactive power flows across the power line of a power system help to better control and transmission efficiency. HVDC is more efficient for long-distance transmission, but it also offers a platform for transporting offshore wind and solar farms to load centers. Numerous ideas and systems are made possible by the smart grid, which ultimately results in its actualization. These concepts serve as the intellectual qualities of the grid and may include a range of technologies to allow it to attain its maximum intelligence. Using line sensors in Dynamic line rating (DLR), Monitoring network conditions in real time is feasible without causing overloads. High-temperature superconductors (HTS) have the potential to significantly decrease power loss and allow cost-effective, high-performance fault current restriction, although the technology's practical practicality is contested.

2.2.6. Distribution Grid Management

Utilizing sensors and automation for distribution and substation, smart grid technologies may speed up asset management, decrease outage and repair times, and maintain voltage levels. For fault identification, feeder automation reconfiguration, voltage and reactive power optimization, advanced distribution automation analyzes sensor-meter data in real time.Demand-side management and dispersed generating integration

2.3 Solar Energy

Solar energy, which is comprised of heat and radiant light, has been used by mankind from the beginning of time. It has provided energy for plant growth, light for illumination, drying, processing and preservation of food etc. Solar energy has been found to be a clean source of generating electricity hence classified as a renewable energy source. Solar energy as it’s know today is usedin generating electric power, used in solar architecture and thermal energy applications. 885 million TWh of solar energy is received on the earth surface yearly (IEA, 2020). With respect to electric power generation, several techniques such as concentrated solar power (SCP) and PV systems are used. Fig. 8 shows the concept of solar concentrated power while Fig. 9 shows CSP flow diagram (Hagumimana, et al.,2021).

Figure 8

CSP Concept(Hagumimana, et al. 2021)

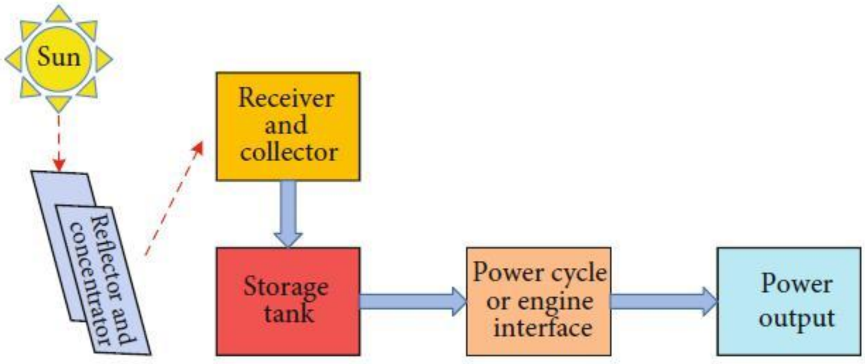
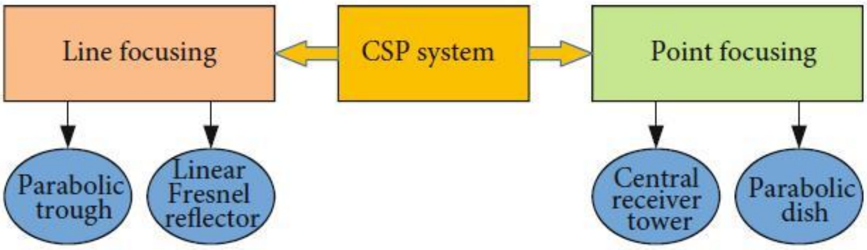


Figure 9

CSP Flow Diagram(Hagumimana, et al. 2021)



2.4 Photovoltaic System

Photovoltaic systems which are also popularly known asPV system or solar array, photovoltaic power systems or solar PV systems (Palma,2020).Photovoltaic system is a technology which directly converts solar energy into electric power by the use of solar panels or modules. Photovoltaic word is a combination of two words where photo and voltaic means light and voltage accordingly. The primary component of photovoltaic systems is the photovoltaic cell. Basically, solar cells (photovoltaic cell) use photoelectric characteristics (also known as photovoltaic effect) to generate or convert solar energy into electric power without applying anytype of generator or engine. When solar energy (irradiance) falls on the surface of solar cells, separation of negative and positive charge carriers occurs due to electric field produced in the cell. Photons cause the breakaway of electrons thus cause electron flow which is known as electric current. Fig. 10 shows electric current generation from a solar cell. Higher number of photons causes the current flow to be huge and therefore higher magnitude of electric current is generated.

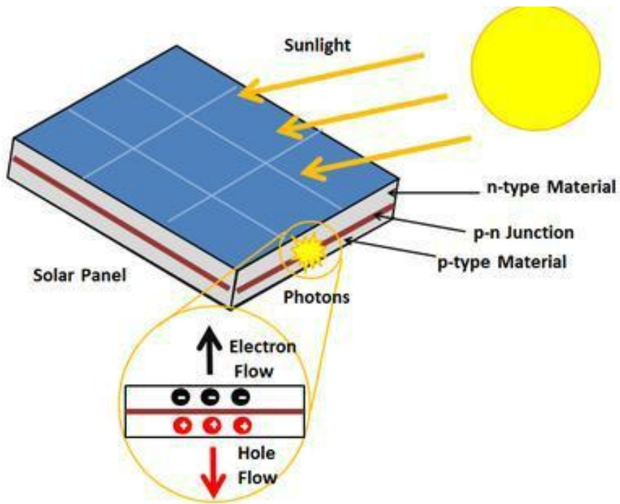
2.4.1 Photovoltaic Cell

Photovoltaic cells also known as solar cells are mostly designed from semiconductor materials such as silicon (Si). Various technologies have given rise to different types of solar cells. Below are some of the commonly used technologies:

- Bar-crystalline silicon
- Thin-film technology
- Monocrystalline
- Polycrystalline

Figure 10

Photovoltaic Cell. (G. Boyle 2004)



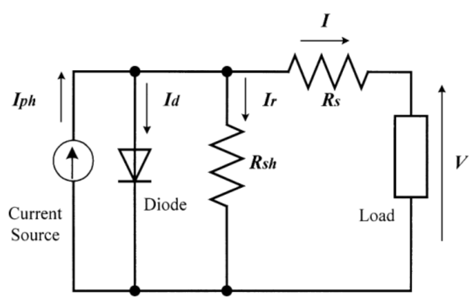
2.4.2. Equivalent Circuit of Solar Cell

Fig. 11 illustrates equivalent circuit or model of a solar cell. A hypothetical current source is linked in parallel to a genuine diode to form the circuit. The current source produces current directly proportional to the magnitude of irradiance received. The parallel current source-diode network is connected in seriesto a series resistance. The equivalent circuit is illustrated by Fig. 11. Short circuit current (I_{sc}) and open circuit voltage (V_{oc}) are two important features of the equivalent and real solar cell.

- $I_{ph}: solar\ cell\ current(A)$
- $I: PV\ output\ current(A)$
- $V: PV\ output\ voltage(V)$
- $R_s: series\ resistance(\Omega)$
- $R_p: parallel\ resistance(\Omega)$
- $T: cell\ temperature\ (K)$
- G_a: irradiance from the sunlight (W/m^2)
- I_d: diode current (A)

Figure 11

Solar Cell Equivalent Circuit (T. Ikegami, et. al, 2001)



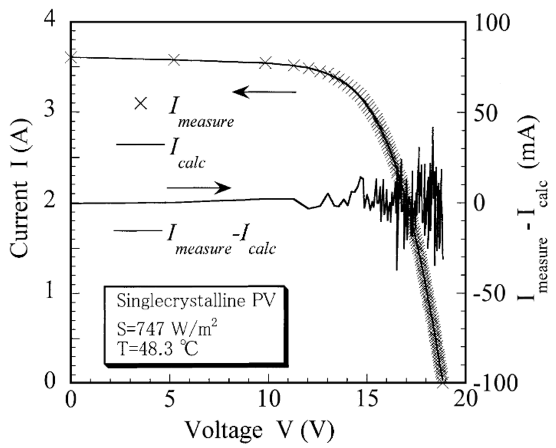
2.4.3 PV I-V Characteristics

The I-V parameter curve of a photovoltaic cell determines or depicts the solar cell's different operating points. It illustrates the link between solar cell voltage and cure. As illustrated in Fig. 12, when the magnitude of the load voltage is altered, the I-V characteristic curve varies proportionally. The short circuit current and open circuit voltage indicate the maximum power point of the solar cell. It also influences the solar cell's total output power. Increasing the voltage and current numbers raises the solar cell's maximum power point and output power. Standard test condition (STC) offers the system parameters necessary to assess the I-V properties of a solar cell. These STC requirements are:

- $Irradiance\ (G) = 100w/m^2$
- $Air\ Mass\ (AM) = 1.5$
- $Temperature\ (T) = 25°\mathrm{C}$

Figure 12

P-V and I-V Characteristic Curve (T. Ikegami, et. al, 2001)

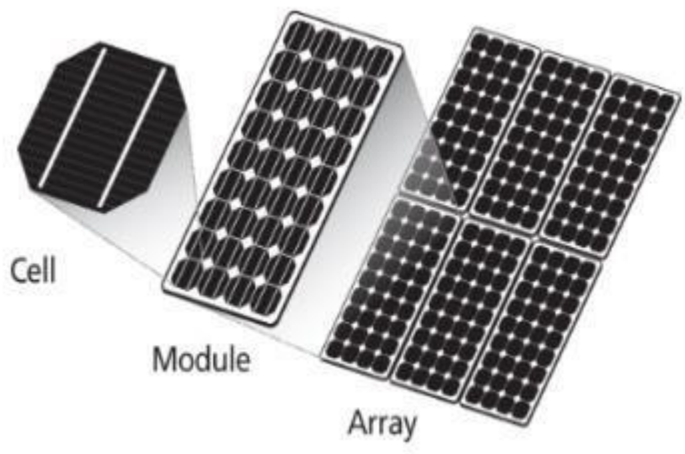


2.4.4 Solar cell/ Modules/ Panels/ Array

Solar cells constitute the building block of photovoltaic systems. The size of solar cells has been increasing since the year 2012 where the average size of a cell was 156mm *156mm. New solar cells introduced in the year 2020 have 210mm * 210mm dimension. A number of cells are connected in series/parallel arrangement to produce solar modules. Again, parallel/series connection of modules produce solar panels. An array of photovoltaic system is composed of solar panels connected in series or parallel or both to derive specific voltage current magnitude. These arrangements are illustrated by Fig. 13.

Figure 13

Solar Cell Arrangements.(Salman, Adil 2014)



2.5 Types of Photovoltaic System

With respect to grid connections, photovoltaic systems are classified as standalone or grid-tied PV systems. There's the third type which is a hybrid system where other forms of energy generating sources such as diesel or wind power are used to augment the required power systems. However, with the current advances in battery technology, large units of battery systems can provide solar power during periods of redundancy of solar panels i.e. during the night, cloudy and rainy days.

Standalone systems are mostly designed for residential and small business establishments. The power produced in standalone systems are either immediately used or stored in energy saving systems such as batteries. Grid-tied or connected PV systems are usually of commercial size and generates high voltages for three-phase distribution or transmission lines. With appropriate safety devices and metering systems, excess power from standalone systems are connected to the grid in advanced countries.

2.6 Photovoltaic Systems in Nigeria

In other to properly determine photovoltaic power potential in Nigerian or site photovoltaic power plants, its necessary to determine the solar irradiance magnitude across the various states. This is can be done by various methods such as using solar data from NASSA website or using the solar map of Fig. 14. As illustrated by Fig. 14, the northern regions of Nigeria have the highest PV output potential compared to the southern parts. It's also evident that any location within the country can generate average magnitudes electric power using photovoltaic systems, however, the northern regions provide optimal locations for efficient PV systems applications.The current generation mix in Nigeria is mainly composed of gas, coal and oil which all put together contributes about 85% of the generation capacity. Solar energy contributes less 1% which is the least of renewable energy sources in the generation mix (N.E.A, 2021). Fig. 15 shows the current (2021) generation mix in Nigeria.

Figure 14

PV Potential Map of Nigeria (SolarGis, 2022)

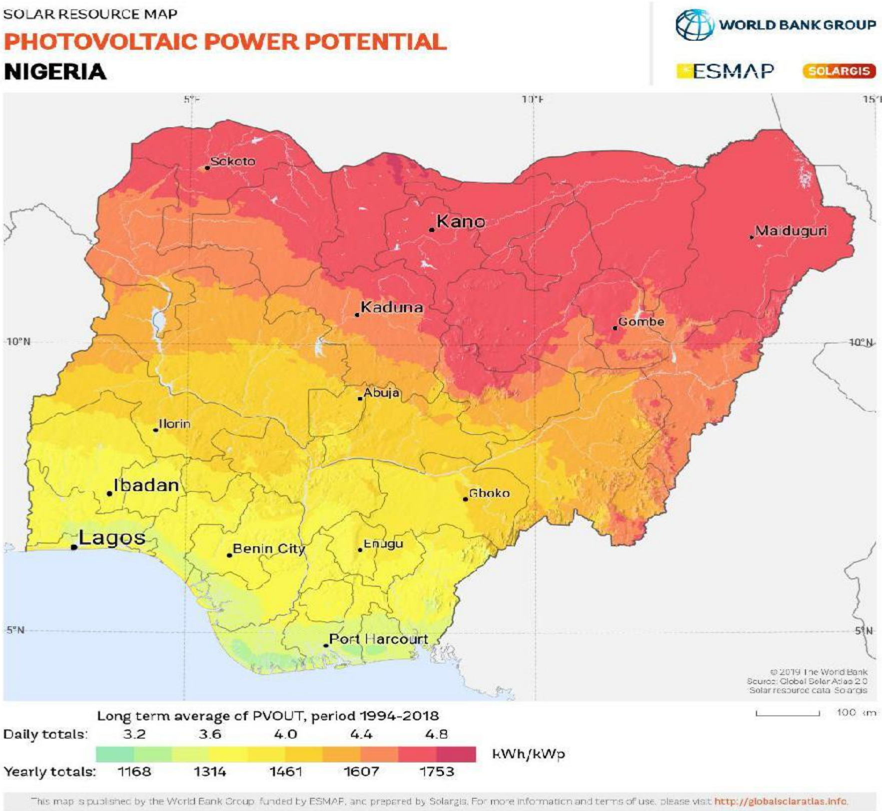
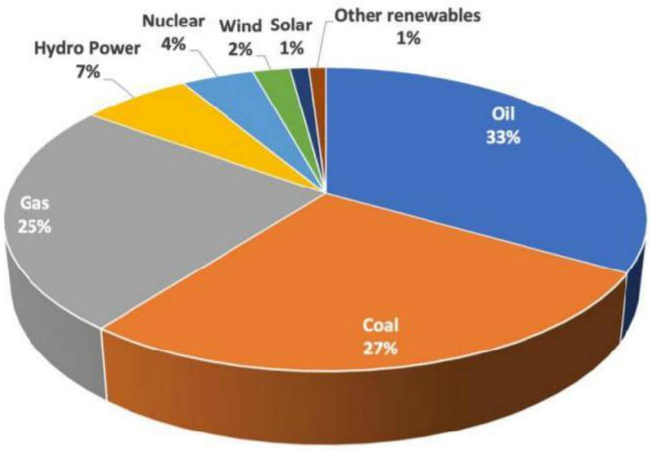


Figure 15

Electric Power Generation Mix in Nigeria



Due to the limited electric power generation in Nigeria, majority homes really on other sources such as PV systems to provide electric power for homes and off grid applications. An average of 6 hours of 19.8 MJm^2/day average solar radiation hits Nigeria annually. This is fairly good to provide unlimited electric power via PV systems. According to research by Heinrich Boll Stiftung, $10 billion annual off grid and mini grid solar market exist in Nigeria where consumers can averagely save $6 billion annually. Between 2018 to 2019, a total $150 million worth of PV system devices were imported (N.E.A, 2021).

Below are some commissioned solar PV plants currently in operation in Nigeria. Ashama Solar Power Station is a 200MW plant which will be commissioned in 2023. When commissioned it will be the largest PV plant in West Africa.

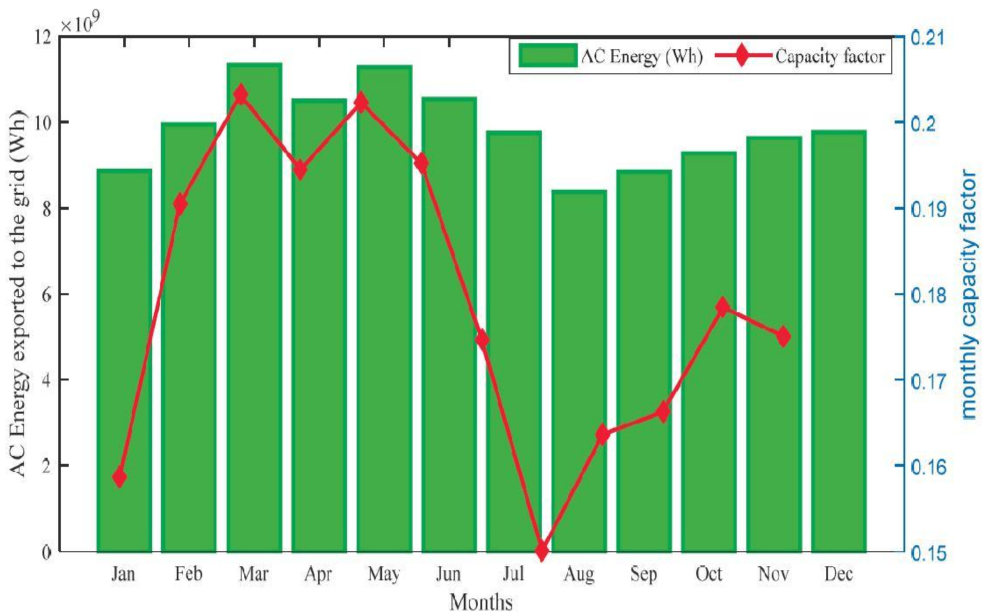
- Makurdi 3.5 MW, Federal University of Agriculture
- Kano 3.5 MW, Bayero University
- Ijebu Mushin 2.35 MW, Tulip Cocoa Processing Ltd.
- Awka 2MW, NnamdiAzikiwe University
- Sokoto 2MW, UsmanuDanfodiyo University
- Abuja 1.52 MW, FMPWH Secretariat
- Abuja 1.2 MW, Usman Dam Water Treatment Plant
- Ndufu Alike-Ikwo 1.155 MW, Alex Ekwueme Federal University
- Ibadan 0.663 MW, Nigerian Breweries Plc.
- Abuja 0.610 MW, Jabi Lake Mall

The authors in (Enongene, et al., 2019) investigated residential photovoltaic systems in Lagos city in Nigeria. They established that PV systems are location specific and therefore affected by factors such as local system cost, solar radiation and required energy. The results of the research showed that PV residential systems provide the best cost benefit investment when compared to other sources of electric power generation such as generator sets. In (Johnson and Ogunseye, 2017), the authors evaluated 148.5kWp grid connected PV systems for use by the Local government of Nigeria. The grid connected system has energy saving components.

To analyse the system performance, PV*SOL software was used. The result of the evaluation shows that the output energy of the system matches the output energy of the software. 70% of the generated power is exported or sold to the national gridsince the secretariat requires only 30% of the produced power. Off grid comparative analysis and feasibility studies for rural electrification was presented by (Oladigbolu, et al., 2020). This paper establishes that the fact that decentralized electric power generation for rural application can improve the quality of life substantially at a reduced cost and environmentally friendly manner. Renewable energy sources such as wind, hydro and PV systems and diesel generators as standby systems provide means of electric power generation for rural off-grid applications. Fig. 16 shows the magnitude of voltage exported to the grid for a proposed 75MW photovoltaic power system in Nigeria (Olarewaju, et al., 2020). The proposed PV system is investigated by the authors to establish its suitable for the proposed location of Kankia which is located in the Nigerian state of Katsina. Using NASA based meteorological data, the proposed PV systems delivers electric power of about 8374.4MWh to 11336MWh yearly with yearly average efficiency of 74.5%.

Figure 16

Grid Supplied Electric Power (Olarewaju, et al., 2020)



2.7 Power Electronic Converters

Power electronic converters comprising inverters, rectifiers, cycloconverters and choppers or DC-DC converters have become very important devices in the supply chain of electric power, from electric power generation, transmission to distribution. Currently, it's virtually impossible to design or develop any power system without applying power electronic converters. Most advanced power supply systems indeveloped countries are gradually replacing conventional transformer with PET (power electronic transformer). Renewable energy sources cannot be efficiently harnessed for electric power generation without the use of power electric converters. This is mainly due to transient nature of power generated from renewable sources. Power electronic converters are required to appropriately change or alter the characteristics of the generated voltage for usage by electric loads or for onward transmission. Two of these power electronic converters required for PV systems applications are inverters and DC-DC converters which are also popularly known as DC Choppers.

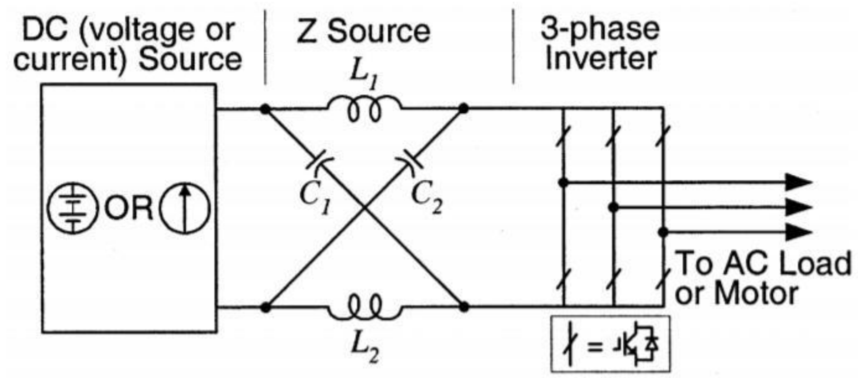
2.7. Inverters

Inverters are power conditioning devices used to change DC voltage waveform to AC voltage waveforms. Multilevel inverters are the most popular types of inverters in industry and academia. Multilevel inverters (MLI) are categories of converters which utilizes one or multiple low level voltages to generate staircase like output voltage. Basically the output voltage of multilevel inverters mimics sinusoidal waveforms in the staircase form. Three categories of multilevel inverters constitute the traditional topologies; these topologies are cascaded H-bridge MLI, Diode-clamped MLI and Flying Capacitor MLI. The above three conventional topologies have their respect advantages and disadvantages. The latter two topologies (Diode clamp and Flying capacitor) suffer from high number of component quantities and are not suitable for applications which require high levels of output voltages. These disadvantages are primarily because complex structure and difficult control techniques for higher levels of output voltages. Cascaded H-bridge which derived by cascading multiples of H-bridges also requires higher number of switches and DC voltage source. However, they are suitable for low or higher levels of output voltage applications because they are simple to control and the structure is less complicated because of its modularity feature.

Conventionally, multilevel inverters did not have high voltage gain capabilities or boosting features until the introduction of Z-Source or impedance based networks and other forms of boosting networks. Z-Source network based MLI have voltage boosting feature and also resolve the disadvantages of VSI (voltage source inverter) or CSI (current source inverter) (Fang, 2003). Conventional Z-source network which placed between the input voltage and power switches iscomposed of two capacitors and two inductors arranged in an X shaped pattern as illustrated in Fig. 17. The main advantage of Z-Source networks are buck-boost capabilities and protection of semiconductor switches, single stage power conversion, higher efficiency reduced volume and cost compared to other converters. There are two operating states or modes of Z-Source topologies. The first is the shoot-through state (ST) and the second is the non-shoot through. Voltage boosting period occurs during ST state.

Figure 17

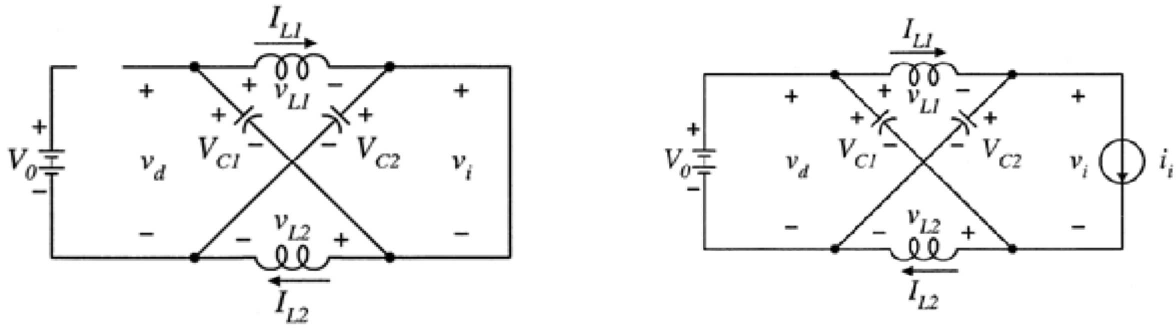
Conventional Z-Source Topology(Fang, 2003)



Brief mathematical analysis of the Z-Source topology during the two operating states are presented below. Fig. 18a and Fig. 18b illustrates ST state and non-ST state respectively.

Figure 18

Equivalent Circuit for Operating Modes(Fang, 2003)



a **b**

Because the capacitors have equivalent capacitance and inductors also have equivalent inductance, therefore symmetric feature of the component are developed. Equation (2.1) shows this analysis:

$$\begin{cases} v_L = v_{L1} = v_{L2} \\ V_C = V_{C1} = V_{C2} \end{cases} \quad (2.1)$$

During ST state, all switches are short circuited, inductor and capacitor voltages are equal, source voltage is zero and the open circuit voltage is twice the capacitor voltage.

$$v_{in} = 0 \quad (2.2)$$

$$V_C = v_L \quad (2.3)$$

$$v_d = 2V_C \quad (2.4)$$

The following expressions are computed during non-ST state. This is state active state where the required switching patterns are implemented to generate the desired output voltage magnitude.

$$v_L = V_0 - V_C \quad (2.5)$$

$$v_d = V_0 \quad (2.6)$$

$$v_i = 2V_C - V_0 \qquad (2.7)$$

The relationship between the output voltages (ac), boost factor (B) and modulation index (M) is expressed by:

$$V_{ac} = \frac{V_0 * B * M}{2} \qquad (2.8)$$

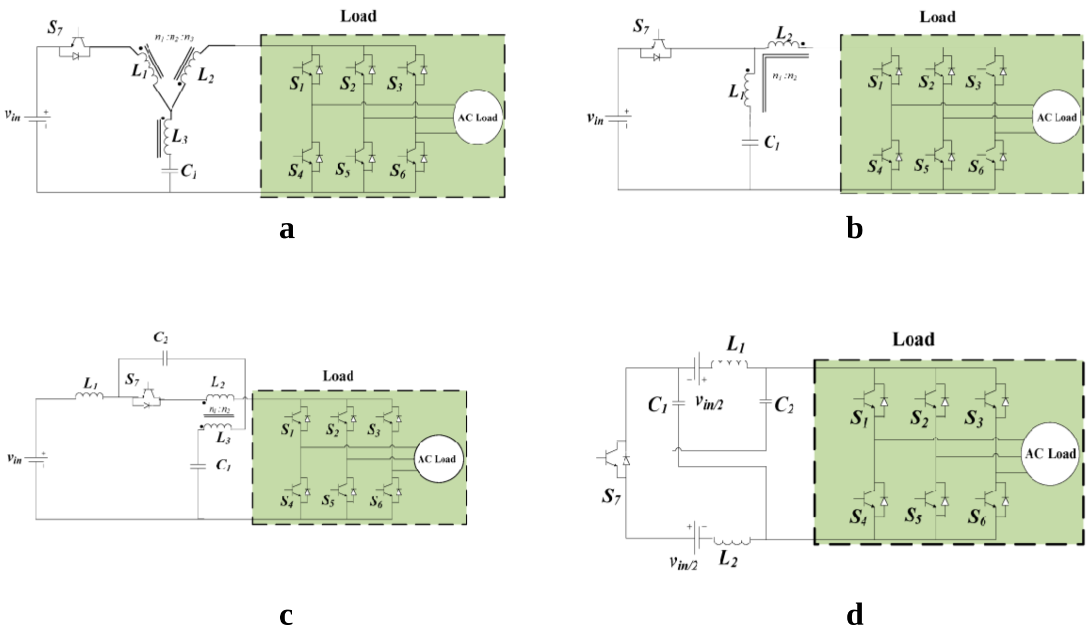
Several topologies of impedance based networks have been implemented since the conventional Z-Source was introduced. This is because Z-Source networks have few drawbacks, they are not suitable for all forms of electric power system applications. For example, quasi Z-Source networks are suitable for PV system applications because of wide range voltage gain. Also, it inherits all advantages of Z-Source networks. Examples of these topologies are:

- Quasi Z-Source
- T-Source
- Trans Z-Source
- TZ-Source
- Switched Z-Source
- Y-source
- Switch Boost

All these various topologies based on Z-Source networks have individual advantages and disadvantages. The common denominator amongst them is the improvement of the boost factor. Later topologies tend to have higher boost factor than preceding topologies. Fig. 19 shows circuit structures of some converters based on Z-Source network. Fig. 19a is the Y-Source converter which offers two advantages that other topologies cannot offer. Higher modulation and higher boosting capabilities are enabled by this topology. Fig. 19b shows Γ Z-Source converter which derived from the Trans topology. This topology produce higher voltage gain with less turns ratio. Fig. 19c and Fig. 19d shows LCCT converter and embedded bidirectional converter respectively (Mande, et al., 2020).

Figure 19

Converters Based Z-Source(Mande, et al., 2020)

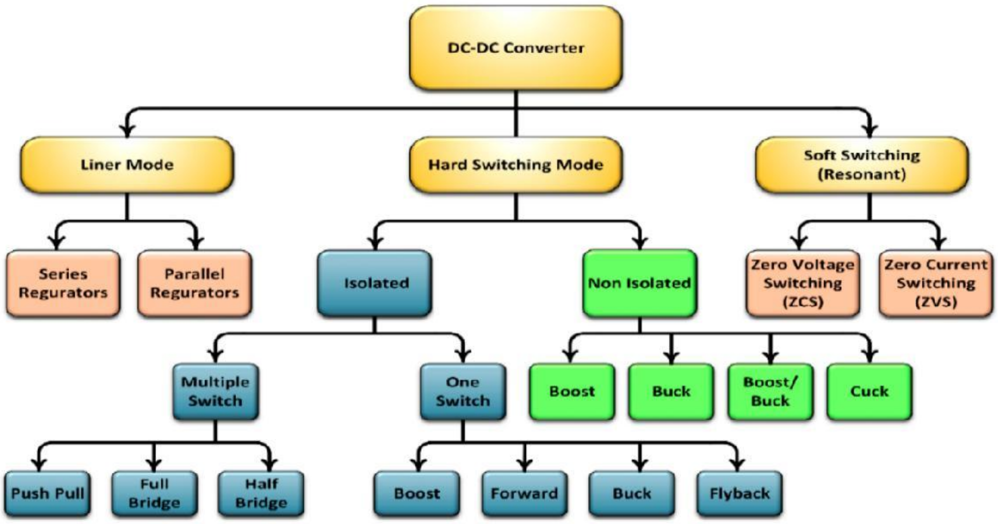


2.7.2 DC-DC Converters

DC-DC converters are gradually gaining popularity in industry and academia because of the significant application of renewable energy sources, most especially photovoltaic systems. Also, proliferation of dc loads such as electric vehicles and HVDC systems has caused a surge in the use and research of DC-DC converters. DC-DC converters are categorized into various groups with respect to the following linear, hard and soft switching modes. Fig. 20 shows the various types of DC-DC converters based on this classification.

Figure 20

Classification of DC-DC Converters (MK Kazimierczuk, 2015)



Buck and Boost DC-DC converters are the most popular and commonly used DC converters. The definition of a DC-DC converter is a that the input and output voltages of these converters have DC voltage characteristics. Basically, these converters provide stepup, stepdown and ripple corrections of DC voltages.

The power semiconductor switches in most DC-DC converters like the buck, boots and buck-boost topologies is only one (1). Therefore, there are only two states of operating mode for these converters with respect to the switch state i.e. ***on*** and ***off*** states of the power switches.

The most common components found in these topologies are inductors, diodes, capacitors and power switch. Based on the inductor current waveforms, DC-DC converters are operated in CCM or DCM modes. Fig. 21 and Fig. 22 shows the circuit structure of classical buck and boost topologies respectively. The component type and count are equivalent in these topologies but the position inductor varies.

Figure 21

Buck DC-DC Converter (MK Kazimierczuk, 2015)

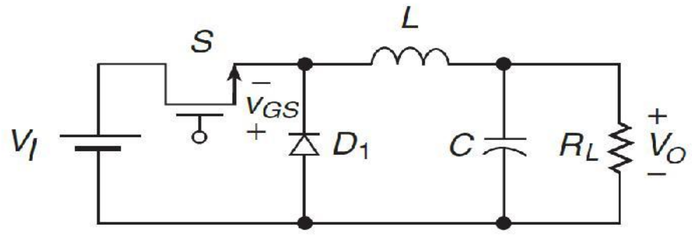
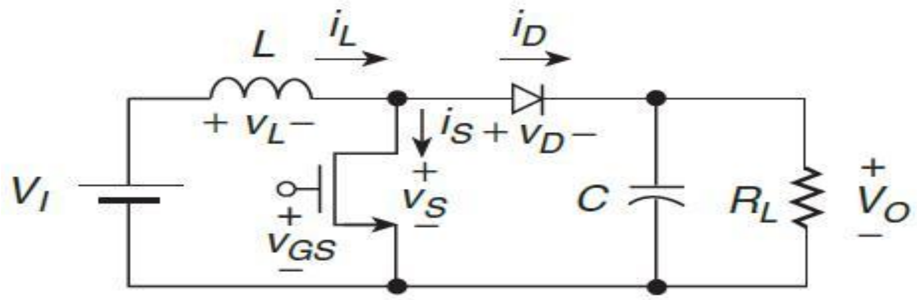


Figure 22

Boost DC-DC Converter (MK Kazimierczuk, 2015)



The boost topology of Fig. 2.15 is used to illustrate the operating modes of the DC-DC converter. CCM or DCM modes of operation are applicable to the boost DC-DC converter. The difference between CCM and DCM is that, the inductor current in CCM mode does fall to zero magnitude. It rises exponentially from a minimum value which is not zero to maximum value, it decreases from the maximum point to minimum again. This mode is repeated continuously, however for the DCM, inductor current rises exponentially from zero magnitude (minimum) to a maximum point and falls back to zero point. Fig. 23 and Fig. 24 shows the power circuit of the boost converter when the power switch is closed and open respectively.

Figure 23

Equivalent Circuit when Switch is Closed (MK Kazimierczuk, 2015)

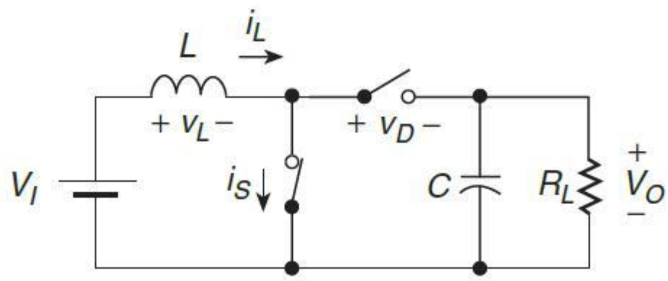
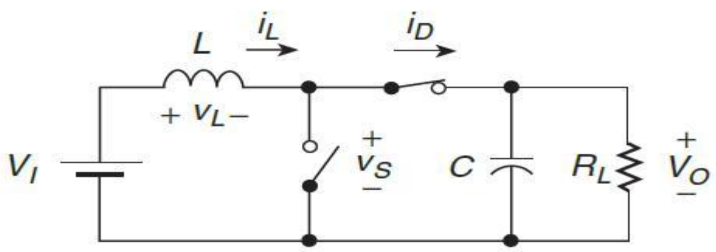


Figure 24

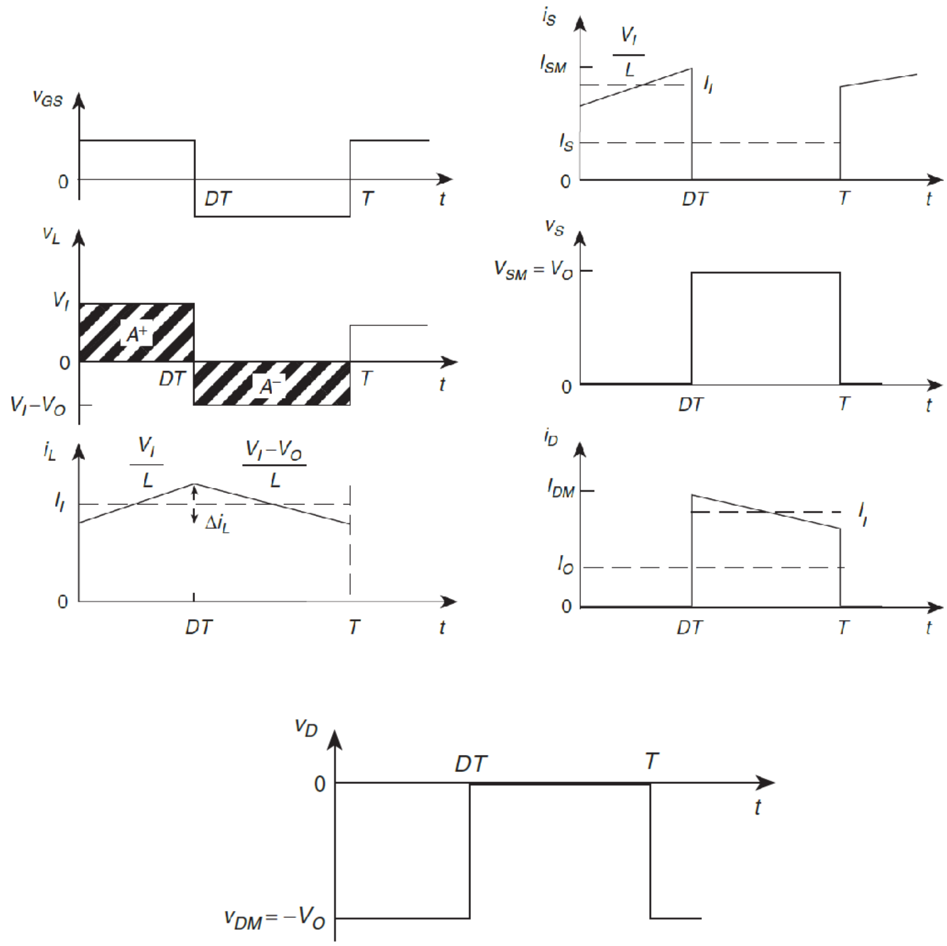
Equivalent Circuit when Switch is Open (MK Kazimierczuk, 2015)



Analysing the above boost converter during CCM, the following equations are developed. Two periods of switch states exist. These states are conduction state (switch closed) which occurs during the time interval $0 \leq t \leq DT$ and non-conduction state (switch is open) when occurs during the intervals $DT \leq t \leq T$.

Figure 25

Output Waveforms During CCM



During $0 \leq t \leq DT$ interval, the following equations are developed. The switch is closed in this state but the diode is reverse biased.

$$v_D = -V_O \quad (2.9)$$

$$v_L = V_i \quad (2.10)$$

$$v_L = L\frac{di_L}{dt} \quad (2.11)$$

$$i_L(slope) = \frac{V_i}{L} \quad (2.12)$$

$$i_s = i_L + \frac{V_i}{L} \quad (2.13)$$

During $DT \leq t \leq T$ interval, the following equations are developed. During this mode, the switch is open and the diode is forward biased.

$$v_D = 0 \quad (2.14)$$

$$i_s = 0 \quad (2.15)$$

$$v_L = V_i - V_o \quad (2.16)$$

$$i_D = i_L(DT) + (t - DT)\frac{V_i - V_o}{L} \quad (2.17)$$

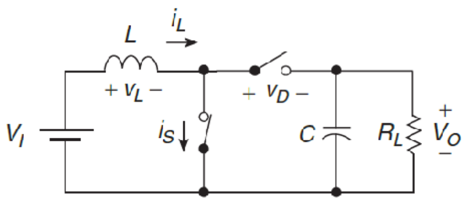
$$v_s = V_o \quad (2.18)$$

$$v_s = V_{SM} \quad (2.19)$$

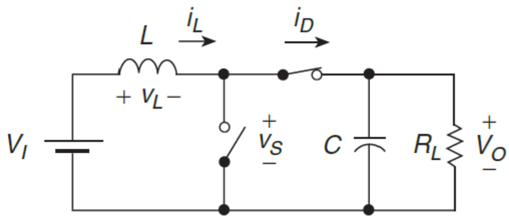
There are three state of operation of the same converter (Boost DC-DC). These operating states are illustrated by Fig. 26a to Fig.26c. In the first state, the switch is closed, diode is reverse biased, in the second state the switch is open, diode is forward biased, in the third state, the switch and diode are all open.

Figure 26

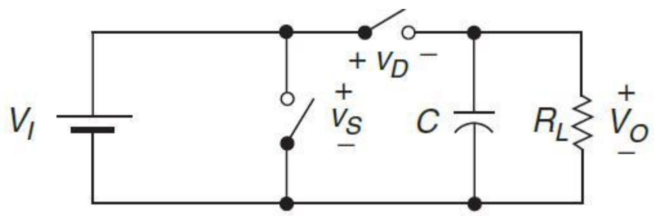
DCM Operating States (MK Kazimierczuk, 2015)



(a) DCM first state



(b) DCM second state



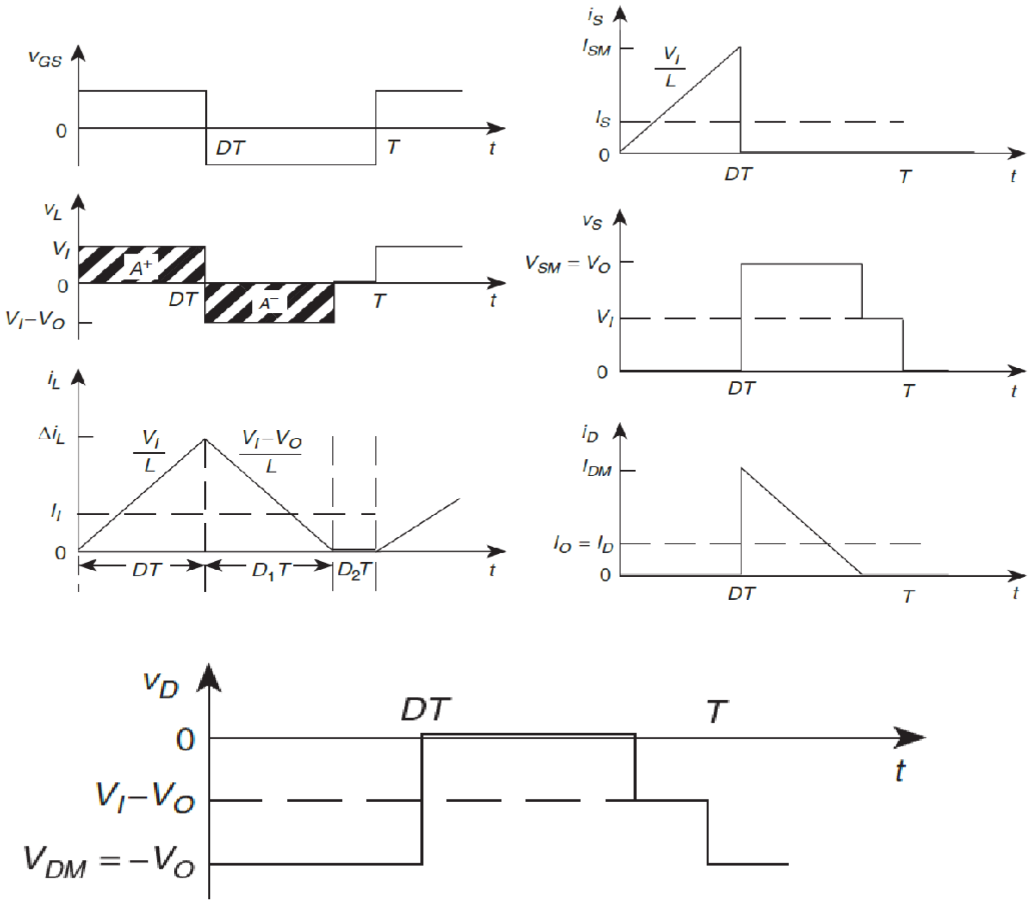
(c) third state

Fig. 27 show the component output waveforms during DCM operation of the boost DC-DC converter. The three states of operation of the converter are:

- $0 < t \leq DT,$
- $DT < t \leq (D+_1)T.$
- $(D + D_1)T < + \leq T$

Figure 27

DCM Boost Converter Output Waveforms (MK Kazimierczuk, 2015)



During $0 < t \leq DT$ time interval, the following equations are developed:

$$v_L = V_i \quad (2.20)$$

$$V_i = L\frac{di_L}{dt} \quad (2.21)$$

$$i_s = \frac{V_i}{L}t \quad (2.22)$$

$$I_{SM} = \frac{DV_i}{Lf_s} \quad (2.23)$$

During $DT < t \leq (D + D_1)T$ time interval, the following equations are developed:

$$v_s = V_o \tag{2.24}$$

Maximum diode current:

$$I_{DM} = \frac{D_1(V_0 - V_i)}{Lf_s} \tag{2.25}$$

$$v_i = V_i - V_o \tag{2.26}$$

$$i_D = \frac{V_i DT}{L} + (t - DT)\frac{V_i - V_o}{L} \tag{2.27}$$

During $(D + D_1) < t \leq T$ time interval, the following equations are developed:

$$v_s = V_o \tag{2.28}$$

$$v_D = V_i - V_o \tag{2.29}$$

2.8 Selected Power Electronic Topologies

This section reviews selected published power electronic converters on MLI with impedance networks and DC-DC converter. These two topologies were chosen because of the suitability for photovoltaic applications and voltage boosting capabilities. Also, they are frequently used because of robustness and high efficiencies. DC-DC converters are mostly required in photovoltaic systems for voltage conditioning. This is mainly because of the wide range variations in the output voltage of photovoltaic systems. This can be attributed to shadowing and variations in irradiance. Comparative investigation of two impedance based DC-DC converters was presented by the authors in (Palma,2020).The presented two topologies are quasi Y-source and quasi Z-source DC-DC converters. Fig. 28a and Fig. 28b shows the two topologies respectively. Quasi Y and Z source networks provide better efficiency for power conversion, high power density and high voltage gains. Detailed analysis of the presented topologies with respect to the two modes of operation below are expressed in the paper.

- Shoot-through
- Non-shoot-through

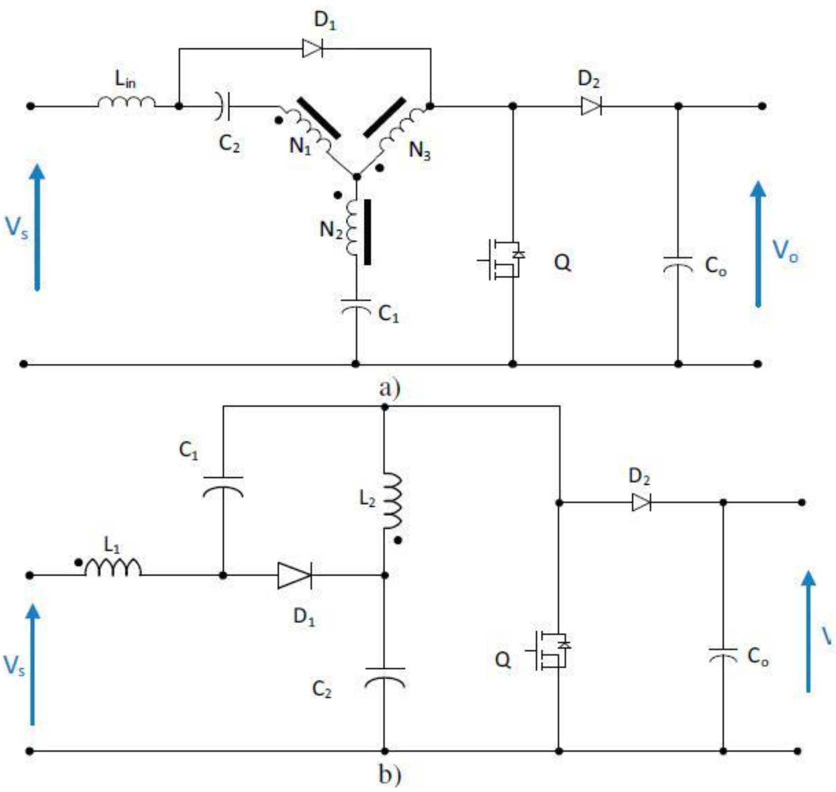
For example, the voltage gain of the quasi Z-source converter is expressed as:

$G_{VQZS} = \frac{1}{-2D+1}$ (2.30)

- Where:
- $G_{VQZS}$is the voltage gain and D is the duty cycle

Figure 28

Impedance Based Converters: A) Quasi Y-Source B) Quasi Z-Source(Palma, 2020)



The voltage gain of the quasi Y-source is expressed by:

$G_{VQYS} = \frac{1}{-\delta D+1}$ (2.31)

Where:

- $G_{VQYS}$is the voltage gain
- δ *is the boost factor*
- D *is the duty cycle*

The boost factor δ is determined by :

$\delta = \frac{N_1+N_2}{-N_3+N_2}$ (2.31) non-isolated DC-DC with buck-boost characteristics was presented by in (Babazadeh,et al., 2019).The presented topology utilizes wide range variations of source voltages to deliver required output voltages. The buck-boost feature is attained by varying the duty cycle. The input and output sections of the converter share same ground and have same polarity of voltages. Also the presented topology has high voltage gain when compared to topologies with the same family. Fig. 29 shows the power circuit of the presented topology.

Figure 29

High Gain Buck-Boost Converter.(Babazadeh,et al., 2019)

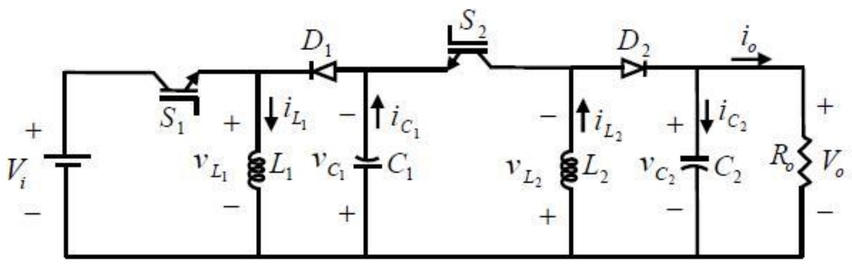
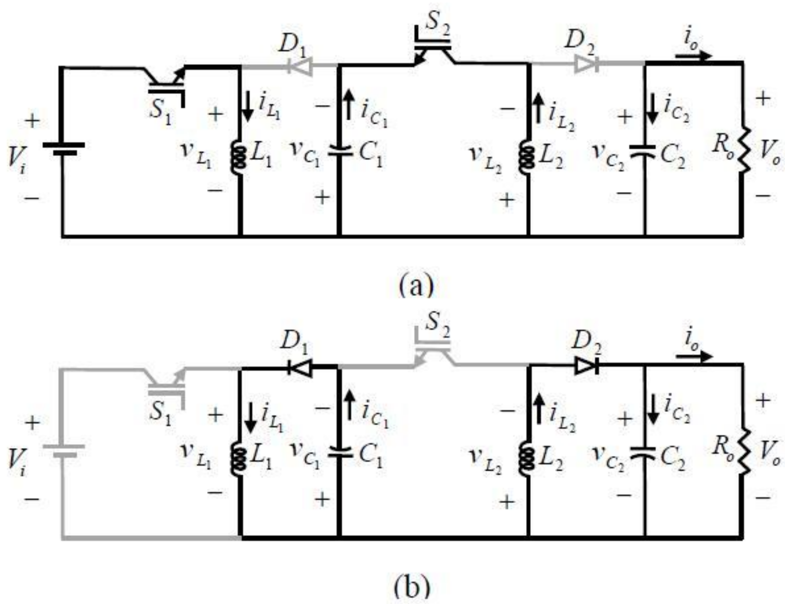


Figure 30

Operating States: A) State 1 *B) State 2*.(Babazadeh,et al., 2019)



The two switches conduct concurrently, therefore there are two states of operation of the presented converter, i.e. when the switches are on and when they are off. Fig. 30a and Fig. 30b illustrates these states. The voltage gain of the presented converter is expressed by:

$$V_0 * \frac{1}{V_i} = \left(\frac{D}{-D+1}\right)^2 \tag{2.32}$$

The maximum current through the switches are expressed by:

$$\begin{cases} DT_s \frac{V_i}{2L_1} + \frac{DI_0}{(-D+1)^2} \\ D^2 T_s \frac{V_i}{2(-D+1)} + \frac{I_0}{-D+1} \end{cases} \tag{2.33}$$

A single power switch DC-DC converter also having buck-boost characteristics was presented by (FernãoPires, et al., 2018). The presented has voltage gain of wide range characteristics. Fig. 31 shows the circuit of the presented topology. Some equations governing the presented topology are presented below.

The output voltage$V_0$is determined by:

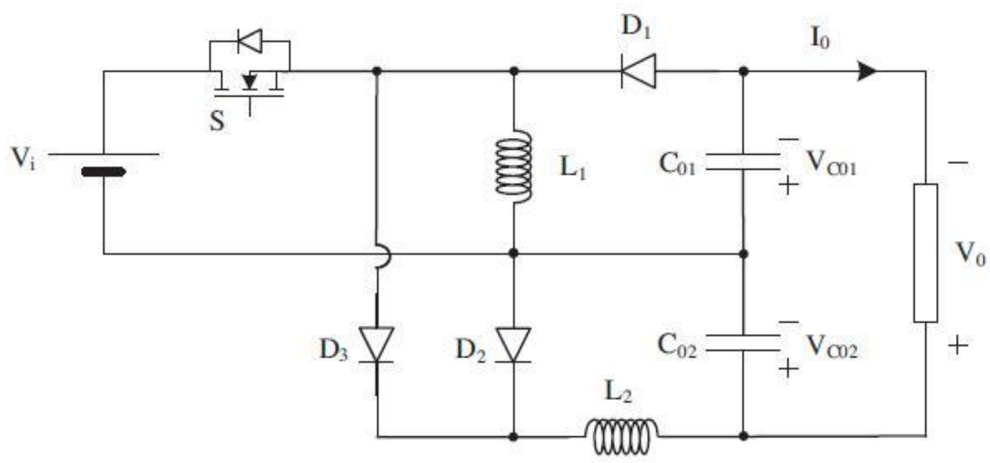
$$V_0 = \frac{V_i \delta}{1-\delta} \tag{2.34}$$

$$V_0 = \frac{V_i}{(1+\delta)+\left(\frac{1}{1-\delta}\right)\left(\frac{r_L}{R_0}\right)} \tag{2.35}$$

$$V_0 = \frac{V_i(2\delta-\delta^2)}{1-\delta} \tag{2.36}$$

Figure 31

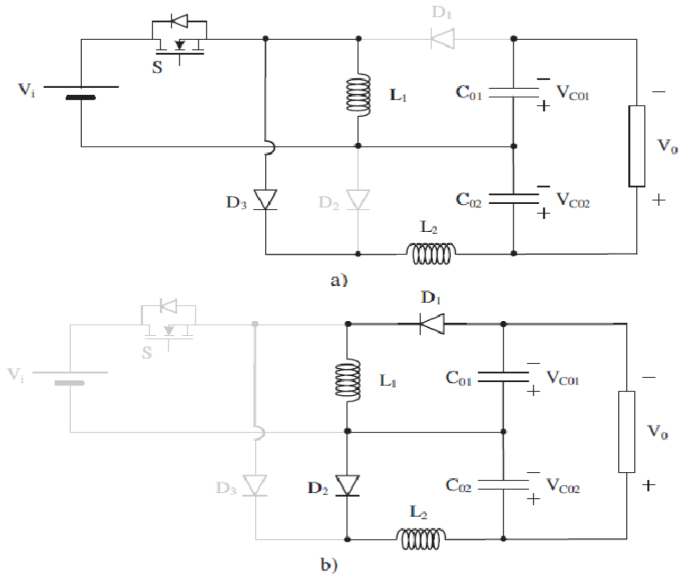
Wide Range Buck-Boost Converter(FernãoPires, et al., 2018)



The switching states or operating modes of the presented converter is illustrated by Fig. 32a and Fig. 32b respectively. In mode one, shown by Fig. 32a, the switch conducts while all the diodes are reverse biased. In the second mode, shown by Fig. 32b, all diodes conduct while the switch is off.

Figure 32

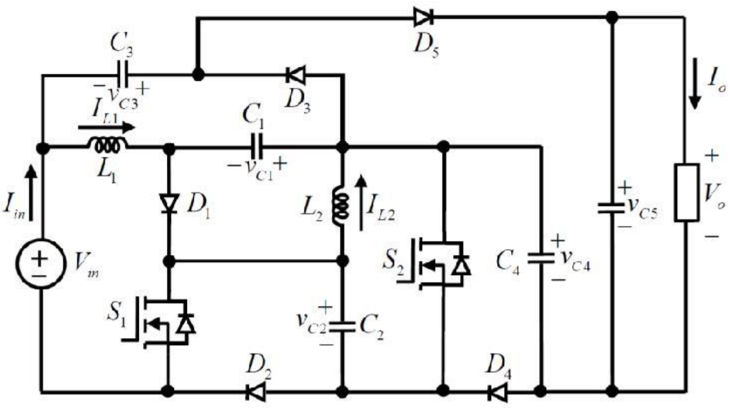
Modes of Operation of BBConverter(FernãoPires, et al., 2018)



Non-isolated two switch high gain DC-DC converter was presented by the authors in (Meinagh, et al., 2020). The presented converter is derived from switched capacitor and quasi switched boost networks. The component count is less therefore the size and cost is reduced. Voltage stress on the switches is less, high gain is achieved with less duty cycle. Fig. 33 shows the power circuit of the presented converter.

Figure 33

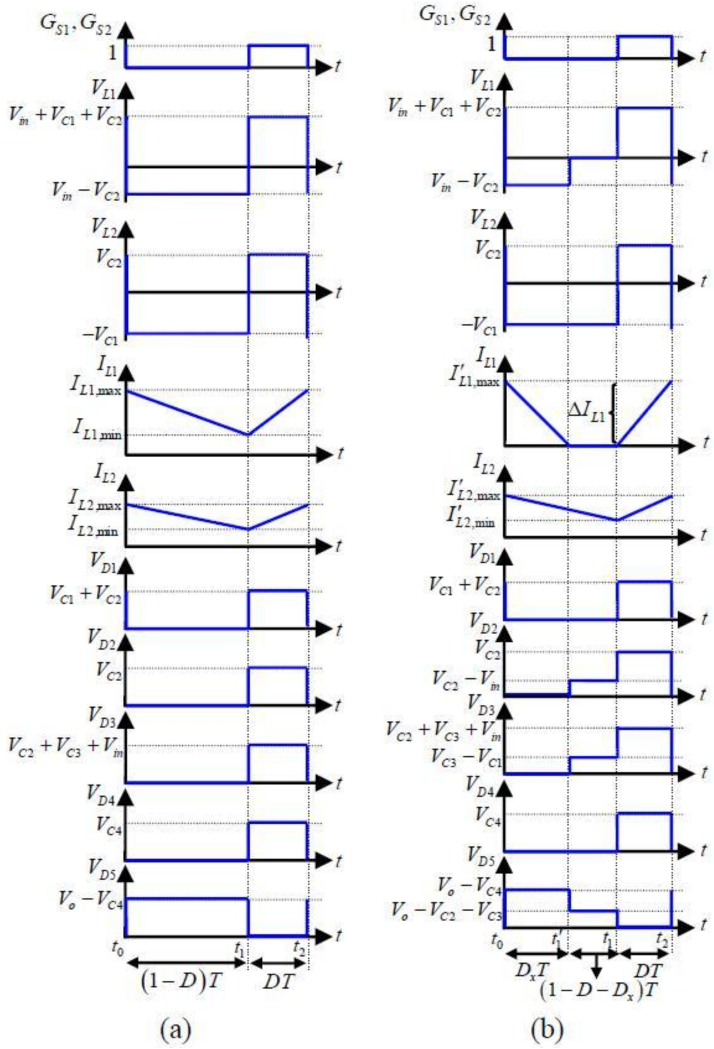
Two Switch High Gain DC-DC Converter(Meinagh, et al., 2020)



The theoretical waveform expected from the presented converter is shown by Fig. 34. The converter was operated in CCM and DCM modes. As shown by the conductor currentI_{L1} , the output waveform for CCM and DCM are different. The latter waveform falls to zero, however, the waveform in CCM does not fall to zero.

Figure 34

Converter Output Waveform: A) CC Mode B) DC Mode(Meinagh, et al., 2020)



A grid tied quasi-Z-source MLI was presented by (Liang, et al., 2021)for photovoltaic system applications, its suitable for night and day applications. The qausi network is coupled to cascaded H-bridge inverter. The presented topology is used for reactive and active compensations/achievement. Fig. 35 shows the circuit arrangement of the presented topology. Fig. 36 and Fig. 37 shows the operating modes of the MLI for day and night times respectively.

Figure 35

Cascaded Quasi-Z-Source MLI(Liang, et al., 2021)

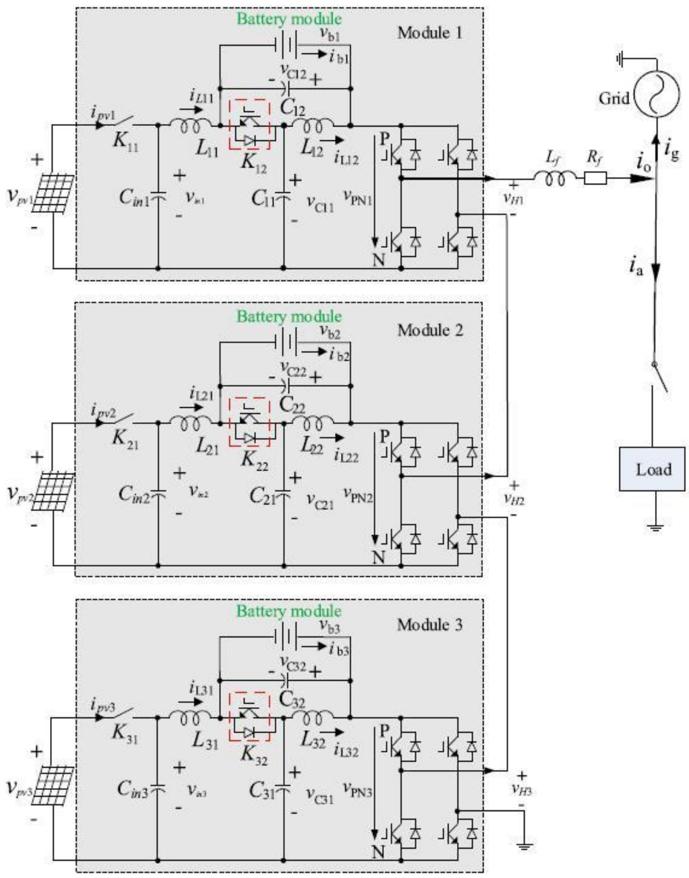


Figure 36

Day-Time Operation: A) ST Mode *B) Non-ST Mode*(Liang, et al., 2021)

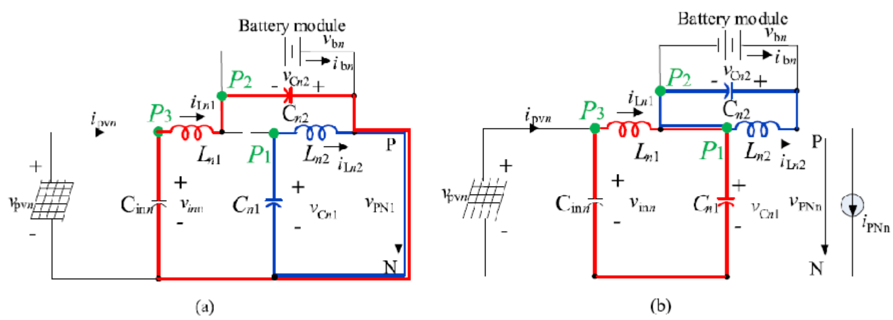
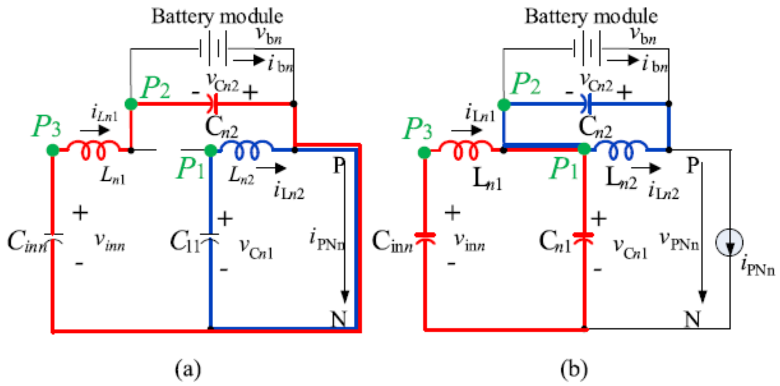


Figure 37

Night-Time Operation: A) ST Mode   B) Non-ST Mode(Liang, et al., 2021)



The boost factor of the presented converter for night and day times operation is calculated by:

$B = \frac{1}{-2D_n+1}$ (Day-time operation) (2.37)

$B = \frac{1}{D_n}$ (Night-time operation) (2.38)

Fundamental frequency of the output voltage is computed by:

$$V = MV_P$$

Where

- M is the modulation index.
- V_P is the peak voltage of the dc-link.

Space vector controlled quasi-Z-source buck-boost MLI for PV system applications was presented by (Manoj, et al., 2021). The presented topology is a three-phase cascaded structure derived from three H-bridge structures and three quasi-Z-source networks, the output voltage is a four level sine-wavelike. With a boosting capability of 50%, minimum voltage stress on the power switches and less component quantities, the presented topology provides superior advantages when compared to similar structures. The presented topology is suitable for both grid tied systems or standalone systems in photovoltaic applications. The boost factor and output voltage of the presented topology are computed from equations (2.39) and (2.40) respectively. The modes of operation of the MLI are illustrated by Fig. 39.

$B = \frac{1}{-3D+1}$ (2.39)

$V_0 = \frac{V_{in}*B*M}{\sqrt{3}}$ (2.40)

Figure 38

Three-Phase Quasi-Z-Source Network(Manoj, et al., 2021)

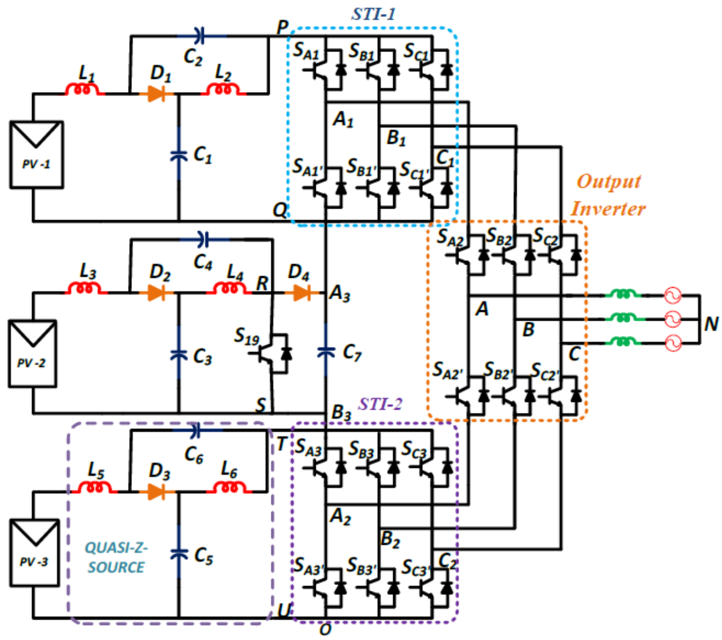
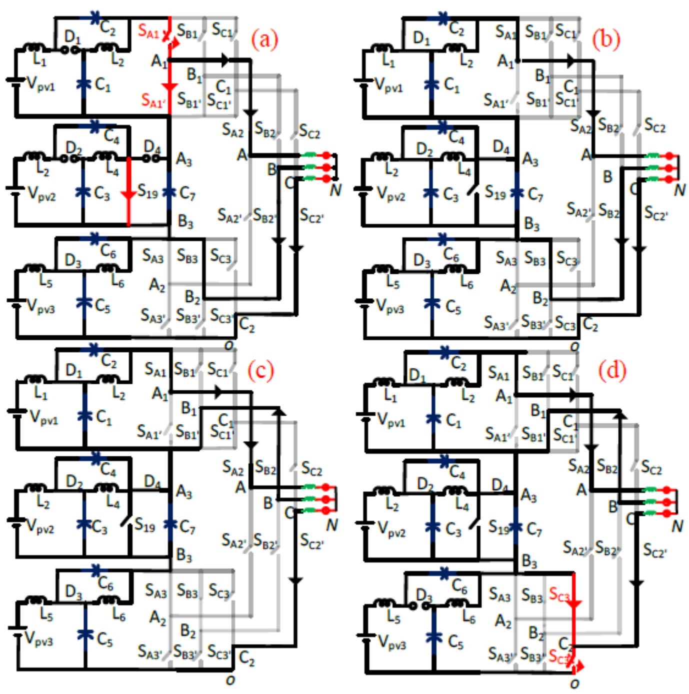


Figure 39

Modes of Operation Of The MLI(Manoj, et al., 2021)



CHAPTER 3
System Design and Simulation Results

3.0 Introduction

This section provides detailed analysis of the proposed system; simulation results are generated to confirm its working principles. This chapter is segmented into two sections. In the first section, standalone and grid connected photovoltaic systems are designed for Doko Township in Niger state in Nigeria. In the second section, two power electronic converters are investigated by means of simulation. These power electronic converters are classified under DC-DC and DC-AC topology. Power from photovoltaic systems and other renewable energy sources require conditioning devices to provide power (voltage and current) at desired waveform characteristics. Therefore, it's important to present these converters.

3.1 Photovoltaic System Design

Two photovoltaic systems are designed in this section using two industry accepted software and guidelines; PVsyst and HelioScope. The first system is a grid-connected PV system with the capacity to generate 6MW of electric power for Doko Township. The second system is a standalone PV system with single-phase 240V ac voltage supply for domestic or small business applications. Fig. 40 shows Doko township in Nigeria, the map of Doko Township and the whole of Niger State are illustrated by Fig. 41.

Figure 40

*Doko Township in Nigeria*52

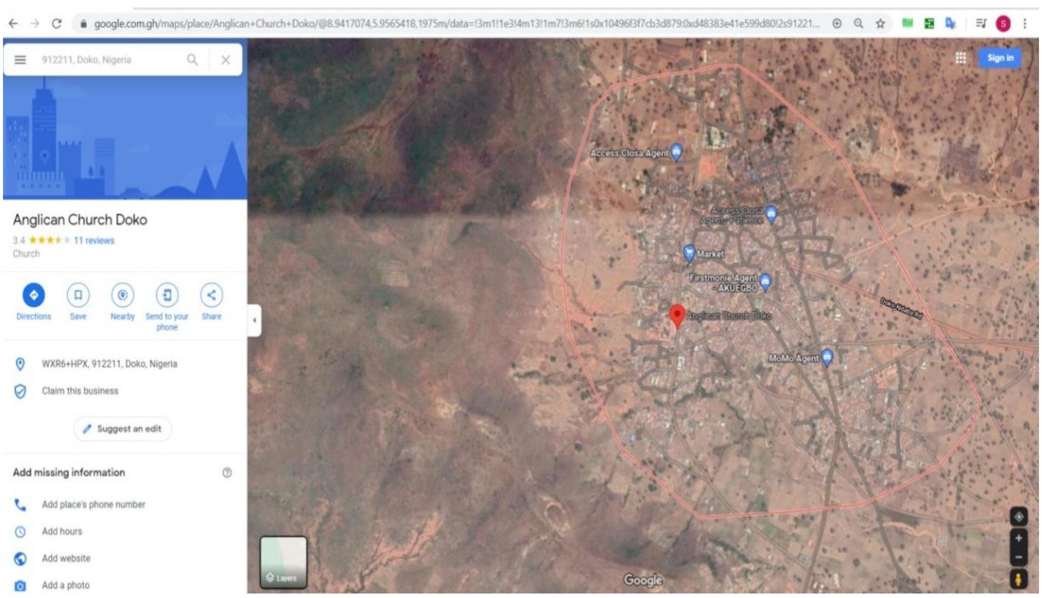
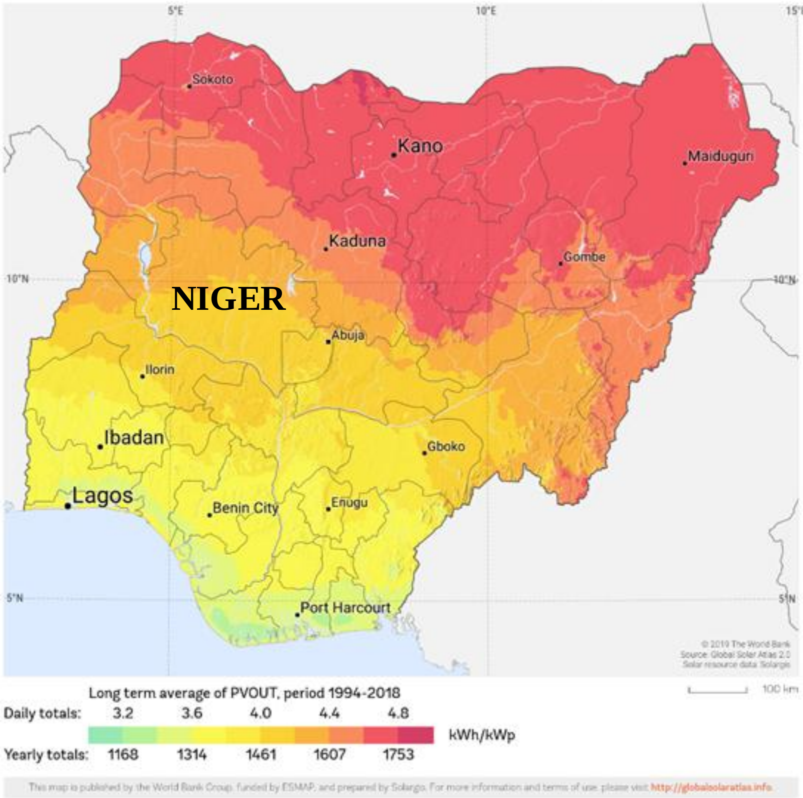


Figure 41

Photovoltaic Power Potential for Niger State.



According Fig. 41, the location of Doko township will generate daily and yearly average PV power of 4.2kWh/kWp and 1534kWh/kWp respectively. This possible due to the solar irradiance of the site. Solar irradiance or irradiation is defined as the received quantity of sun power measured for a unit area inelectromagnetic radiation. Basically, it is the quantity of sun power detectable by measuringinstruments. Table 1 shows the average monthly solar insulation for Doko Township.

Table 1. Average monthly solar insolation in Doko

Month	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**
GlobHor kWh/m^2	177.9	165.5	186.3	173.4	168.3	147.6
Month	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
GlobHor kWh/m^2	137.6	132.1	136.5	158.7	171.6	175.8

The diagram of Fig. 41 shows that the photovoltaic power plant to be sited in Doko township will have high output power characteristics and therefore can provide electric power to all residents. With proper investments, PV systems alone can generate the required electric power for the town.

3.1.1 Doko PV Power Plant Design Using PVsyst

Power plants in general are electrical installation that provide medium to high voltages for grid applications. Mostly these power plants rely on generators of various magnitudes (kW or MW) to generate electric power. PV power plant fits into this description but does not utilize generators for electric power production. Rather, several hundred or thousands of solar panels are connected in strings and arrays for specific magnitude of power generation. PV power plants utilizes solar cells to generate electric power by converting photons (solar energy) into dc voltage. Based of the number, solar cells in module. Short and open circuit provide the capacity or rating of the modules.

Because PV power plants depends on several components and factors such as weather condition at the plant location, the type of PV module and inverter and their specific efficiency, the total output power can vary when the weather is not favourable for photovoltaic applications. STC (standard test condition) provides a standardized criterion for evaluating the power output and efficiency of all PV modules, this data is available on the nameplates of all PV modules.

Doko is a medium size community located in Niger state in Nigeria with population of 7075 and an average of 5 people in each family. The geographical location of Doko is best determined by the longitudinal and latitudinal values of $5^{0}58'0''$ E and $8^{0}57'0''$ N accordingly. Previous electric power data NEPA (national electric power authority) shows that an average of 4kWh of electric power is consumed for each family and therefore the chosen PV power plant magnitude of 6MW is large enough for the community and excess power will be exported to the grid.The PV plants were design to accommodate the required energy at Doko PV power plant during the period when the sun is out. There we can say the PV energy inputted into the power grid (E_{inj}) shall be greater > than the amount of electricity procured by the grid system (E_{abs}) as mathematically given in the below expression.

$$E_{inj} > E_{abs}.$$

For a PV system sizing, the grid-connected PV system is made up of modules (PV), inverter, distribution controller and load. From past research making use to reduced energy consumption and losses that impact the utility distribution networks capacity are made possible by grid-connected PV systems. Therefore, the propose system does not require battery type usage. Is can be viewed as a financial advantage for system reduction budget.This gives rise to the maximum power (P_{max}) of the system plant using mathematical formula:

$$P_{max} = \frac{E_{AC}P_i}{G_{SR}f_{PV}\eta_{ino}} \qquad (3.1)$$

Where $P_i is = solar\ radiation\ at\ STC\ in\ KW/m^2$

G_{SR} is the global solar radiation $(Kwh/m^2/d)$

$$Fpv = PV\ derating\ factor$$

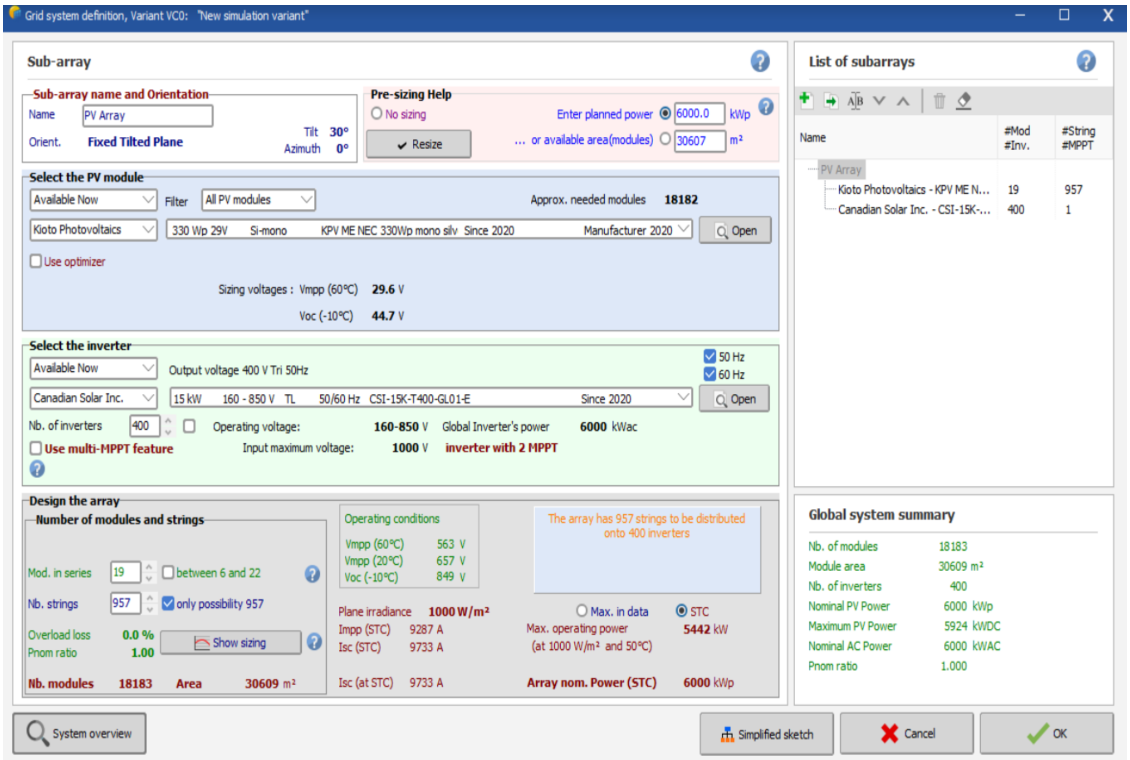
$$E_{AC} = daily\ power\ consumption\ in\ KWh/d$$

η_{inv}= inverter yield.

3.1.2 Doko PV Power Plant Field Details

Figure 42

Doko PV Power System Details



The proposed PV power plant to be situated in Doko will occupy an area of 30609m^2 for the solar panels/modules only. More spacing will be required to demarcate the area and also provide space for mini-substation to appropriately condition the electric power for onward transmission. 18183Kioto photovoltaic modules are required to generate 6MW of electric power.

$$\frac{PV\ module\ capacity*module\ efficiency}{module\ price*frams\ area\ of\ the\ module} = Panel\ Selection (3.13)$$

The module arrangement is such that 19 modules are connected in series and 957 modules constitute a string. Each module has open circuit voltage 44.7V at -10^{0}C and maximum powerpoint voltage of 29.6 V at 60^{0}C. Fig. 42. shows the system details for the proposed Doko PV power plant. The peak power of module is 330Wp. 15kW 160-850 V 50Hz Canadian solar inverter was selected to provide ac voltage for grid tying or connection. The selected solar inverter has 126number of MPPT (maximum power point tracking) inputs therefore there's a total of 945kw of inputs. 400 of these inverters are required for the power plant. The modules are at a fixed orientation with plane tilt and azimuth angles of 30^0 and 0^0 respectively. The module orientation details are illustrated by Fig. 43. Details of the chosen module from the data sheet has been attached to the thesis in the appendix section.

Figure 43

Module Orientation

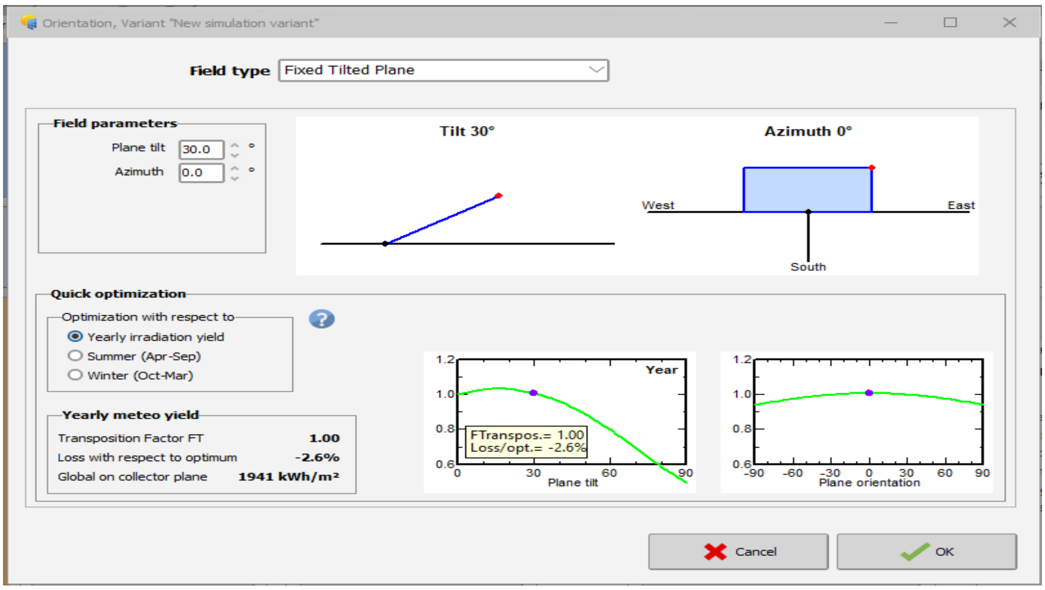


Figure 44

Module Losses Graph

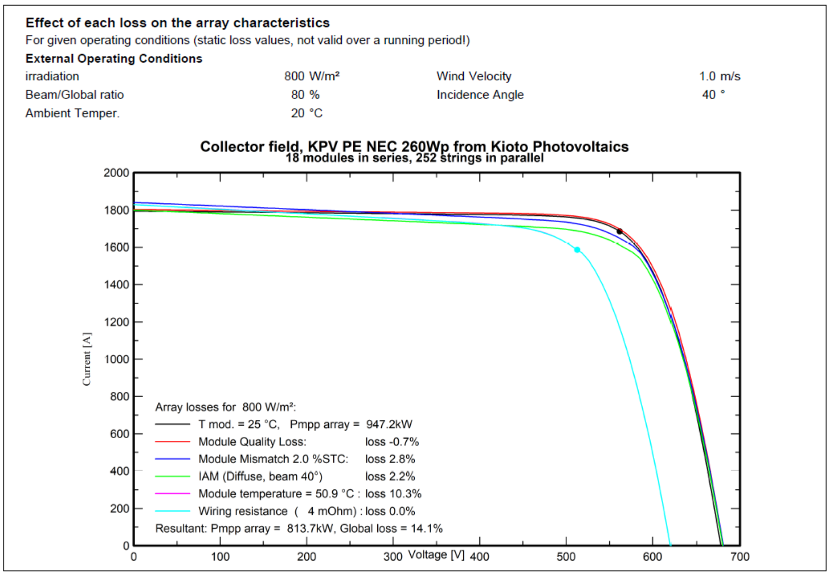


Fig. 44. illustrates the losses graph which provides the behaviour of the PV array for each loss effect. For example, the module quality loss 0.7% and the temperature losses is 10.3%. The graph is and I-V graph which also provide the MPPT of the module.

The above systems analysis i.e. the number of modules and inverters required are verified by the mathematical computations below. It is important to mention at this juncture that the estimated 6MW PV power is the expected ac voltage to be injected into the grid. Therefore, the DC power generated from PV arrays is greater than 6MW.

$$P_{dc,STC} = \frac{P_{ac}}{\text{Conversion Efficiency}} \tag{3.2}$$

$$P_{dc,STC} = \frac{6MW}{0.75} = 8MW \tag{3.3}$$

Note: $P_{dc,STC}$is dc power at standard test condition and P_{ac} is the ac power.

$$\text{Required number of modules} = \frac{\text{Estimated plant power}}{\text{Each module power}} \tag{3.4}$$

$$\text{Required number of modules} = \frac{6MW}{330W} \cong 18183 \text{ modules} \tag{3.5}$$

$$\text{Inverter Quantity} = \frac{\text{Estimated plant power}}{\text{Selected inverter power}} \tag{3.6}$$

$$\text{Inverter Quantity} = \frac{6MW}{15kW} \cong 400 \text{ inverters} \tag{3.7}$$

3.1.3 Doko PV Power Plant Simulation Results

PVsyst simulation of Doko PV power plant using real atmospheric data obtained from NASA (National Aeronautical and Space Administration,) satellite which were recorded for a period of 22years (1983 - 2005). Results of the proposed 6MW Doko PV power plants are illustrated by Fig. 45 to Fig. 49. Fig. 45 shows the monthly energy incident or sunshine on the solar panels at Doko PV power plant site. From Fig. 45, the months of January and December recorded the highest incident energy whiles June, July and August recorded the least incident energy. This is actually correct considering the weather forecast in the region. June, July and August are the raining season for the region and will therefore have the least sunshine duration and insulation. Fig. 46and Fig. 47shows the magnitude of electric power generated from the incident energy. Three distinct colours are used in indicating the amount of useful energy produced and the losses incurred by the modules and inverter. Two types of losses are made during energy conversion i.e. collection losses which is caused by the modules and system losses which is caused by inverter and other auxiliary components. Fig. 46, shows the monthly values in kWh/kWp/day whiles Fig. 47 shows these same values in percentage terms.

Some parameters used to determine the operational characteristics of PV power plants are provided below:

$$Capacity\ Factor(CF) = \frac{P_{OUT}}{P*8760} \tag{3.8}$$

$$Net\ present\ value(NPV) = \sum_{n=0}^{N} \frac{C_n}{(1+r)^n} \tag{3.9}$$

$$Levelized\ cost\ of\ energy\ (LCOE) = \frac{sum\ of\ cost\ over\ lifetime}{sum\ of\ electricity\ generated\ over\ the\ lifetime}$$

(3.10)

$$Sample\ payback\ (SP) = \frac{C-1G}{(C_{ener}+C_{capa}+C_{RE}+C_{GHG})-(C_{0\&M}+C_{fuet)}} \tag{3.11}$$

$$Equity\ payback(ED) = EP = \sum_{n=0}^{N} C_n \tag{3.12}$$

$$Annual\ life\ cycle\ savings(ALCS) = \frac{NPV}{\frac{1}{r}(1-\frac{1}{(+r)^N}} \tag{3.13}$$

$$Annual\ ghg\ emission\ reduction(A - GHG) GHG\ emission\ reduction\ cost\ (GHG - E - RC) = \frac{ALCS}{\Delta_{GHG}} \tag{3.14}$$

$$Benefit - Cost\ ratio\ (B - C) = \frac{NPV+(1-f_d)C}{(1-f_d)C} \tag{3.15}$$

P_{out}yearly generated energy, P capacity installed, N yealy project life, F_d is the debt ratio.

Figure 45

Reference Incident Energy in Collector Plane

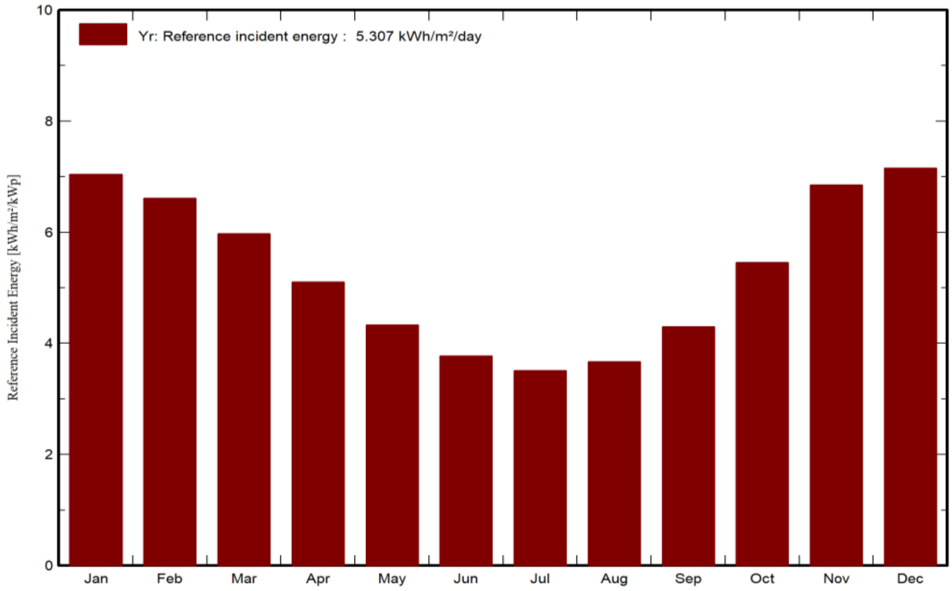


Figure 46

Monthly Useful Energy and Losses Production (kWh/kWp/day)

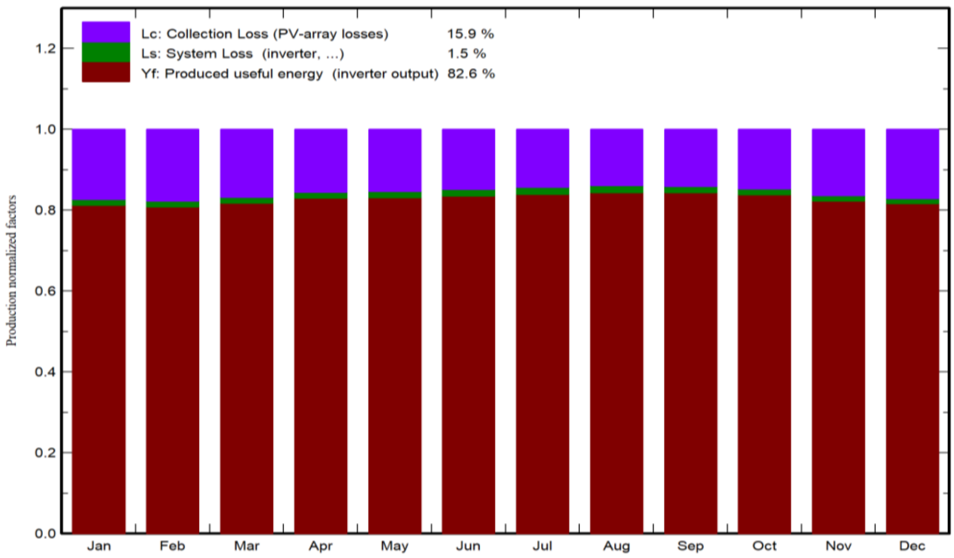


Figure 47

Monthly Useful Energy and Losses Production [percentage (%) values]

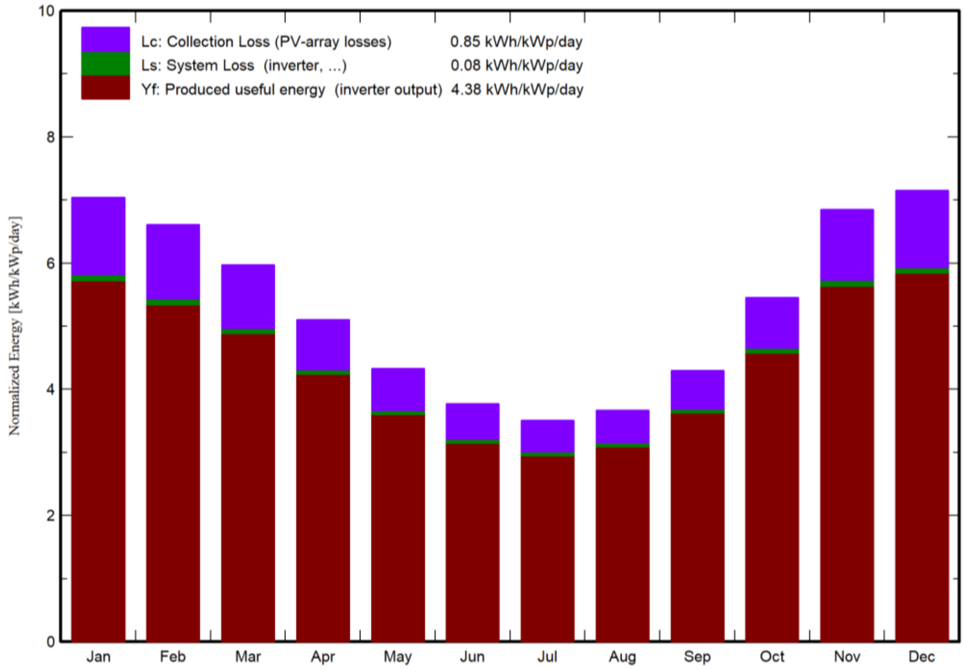


Figure 48

Monthly Performance Ratio Values

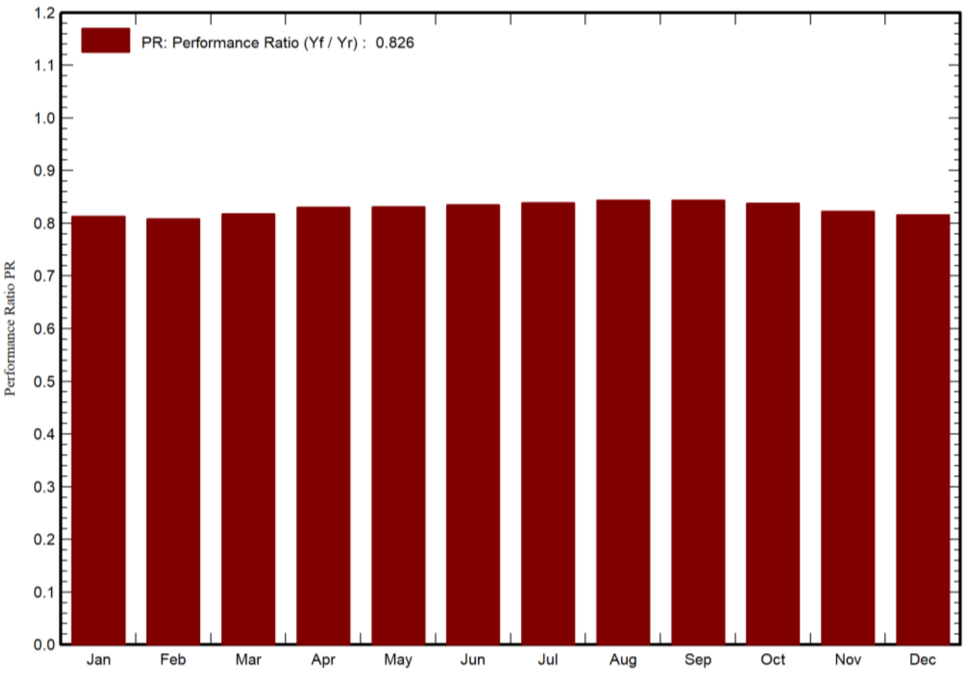


Figure 49

Loss-Line Diagram for Doko PV Plant

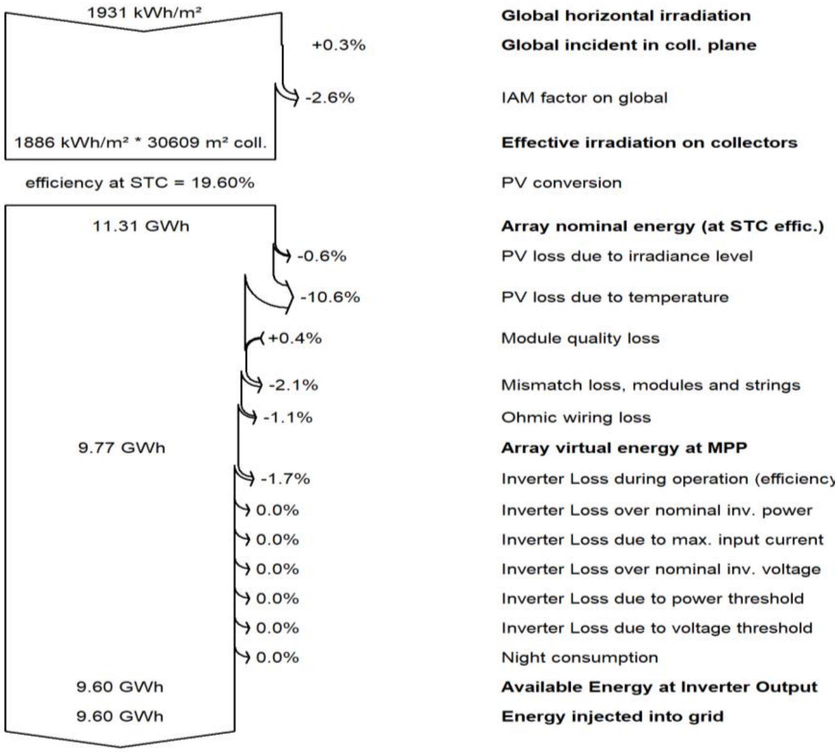


Fig. 48, shows the performance ratio of the proposed Doko power plant. Performance ratio is considered the efficiency estimator or PV systems. PR values can be expressed in unity terms or percentage terms. The closer this value is to 1 in unity terms representation, the better the PV power plant. In percentage representation, if the value is having percentage then there is possibility in successfully producing desire result.. The results indicated by Fig. 48, shows that the PR value is 82.6% which considered high and therefore proposed Doko PV power plant will have high efficiency. Fig. 49, illustrates the energy flow diagram for the proposed Doko PV power plant from incident energy to the grid injected energy. 1931kW/m^2 global horizontal irradiation is incident on the modules; the modules generate 11.31GWh of electric power from the incident energy. There are losses along the energy conversion chain, the final amount of energy produced at inverter output is 9.60GWh i.e. the grid injected voltage is 9.60GWh.

The performance ratio of an actual PV power is determined by equation below:

$$PR = \frac{\text{Real PV energy output}}{\text{Nominal plant output}} * 100 \qquad (3.16)$$

Table 2. Balance and main result

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	177.9	46.50	27.14	218.2	214.5	1082456	1064564	0.813
February	165.5	49.28	27.51	185.0	181.8	913434	897782	0.809
March	186.3	62.62	26.93	185.1	180.9	924814	909014	0.818
April	173.4	66.00	26.29	153.2	148.4	776557	763417	0.831
May	168.3	66.96	25.86	134.3	128.8	682414	670069	0.832
June	147.6	64.80	24.94	113.1	107.8	578200	566851	0.835
July	137.6	68.51	24.09	108.9	104.0	560134	548671	0.840
August	132.1	70.68	24.00	113.7	109.5	587626	575797	0.844
September	136.5	68.10	24.40	129.0	125.2	664635	652819	0.844
October	158.7	62.93	24.73	169.2	165.5	865571	851221	0.839
November	171.6	47.10	25.40	205.5	201.8	1031559	1014960	0.823
December	175.8	43.40	26.41	221.8	218.1	1103851	1086537	0.816
Year	1931.3	716.88	25.63	1937.0	1886.4	9771250	9601703	0.826

Table 3. Incident energy

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	WindVel m/s	GlobInc kWh/m²	DifSInc kWh/m²	Alb_Inc kWh/m²	DifS_GI ratio
January	177.9	46.50	27.14	0.0	218.2	23.27	2.384	0.000
February	165.5	49.28	27.51	0.0	185.0	22.02	2.217	0.000
March	186.3	62.62	26.93	0.0	185.1	27.30	2.496	0.000
April	173.4	66.00	26.29	0.0	153.2	29.84	2.320	0.000
May	168.3	66.96	25.86	0.0	134.3	32.28	2.251	0.000
June	147.6	64.80	24.94	0.0	113.1	34.02	1.975	0.000
July	137.6	68.51	24.09	0.0	108.9	39.78	1.842	0.000
August	132.1	70.68	24.00	0.0	113.7	40.47	1.768	0.000
September	136.5	68.10	24.40	0.0	129.0	37.43	1.826	0.000
October	158.7	62.93	24.73	0.0	169.2	31.76	2.125	0.000
November	171.6	47.10	25.40	0.0	205.5	22.89	2.299	0.000
December	175.8	43.40	26.41	0.0	221.8	22.32	2.354	0.000
Year	1931.3	716.88	25.63	0.0	1937.0	363.39	25.856	0.000

Table 4. Effective incident energy

	GlobHor kWh/m²	GlobInc kWh/m²	GlobIAM kWh/m²	GlobEff kWh/m²	DiffEff kWh/m²
January	177.9	218.2	214.5	214.5	22.39
February	165.5	185.0	181.8	181.8	21.19
March	186.3	185.1	180.9	180.9	26.26
April	173.4	153.2	148.4	148.4	28.71
May	168.3	134.3	128.8	128.8	31.05
June	147.6	113.1	107.8	107.8	32.72
July	137.6	108.9	104.0	104.0	38.26
August	132.1	113.7	109.5	109.5	38.93
September	136.5	129.0	125.2	125.2	36.00
October	158.7	169.2	165.5	165.5	30.56
November	171.6	205.5	201.8	201.8	22.02
December	175.8	221.8	218.1	218.1	21.48
Year	1931.3	1937.0	1886.4	1886.4	349.57

Table 5. Optical factors

	GlobHor kWh/m²	GlobInc kWh/m²	FTransp ratio	FIAMBm ratio	FIAMGl ratio	FIAMShd ratio
January	177.9	218.2	1.226	0.987	0.983	0.983
February	165.5	185.0	1.118	0.986	0.983	0.983
March	186.3	185.1	0.994	0.981	0.977	0.977
April	173.4	153.2	0.883	0.971	0.969	0.969
May	168.3	134.3	0.798	0.958	0.959	0.959
June	147.6	113.1	0.766	0.948	0.953	0.953
July	137.6	108.9	0.791	0.949	0.955	0.955
August	132.1	113.7	0.861	0.963	0.963	0.963
September	136.5	129.0	0.945	0.974	0.971	0.971
October	158.7	169.2	1.066	0.982	0.978	0.978
November	171.6	205.5	1.198	0.985	0.982	0.982
December	175.8	221.8	1.262	0.987	0.983	0.983
Year	1931.3	1937.0	1.003	0.978	0.974	0.974

Table 6. Detailed losses by inverter

	EOutInv kWh	EffInvR %	InvLoss kWh	IL_Oper kWh	IL_Pmin kWh	IL_Pmax kWh	IL_Vmin kWh	IL_Vmax kWh	IL_Imax kWh
January	1064564	98.3	18291	17645	97.5	399	0.000	0.000	0.000
February	897782	98.3	16808	15489	26.0	1157	0.000	0.000	0.000
March	909014	98.3	15979	15471	175.9	179	0.000	0.000	0.000
April	763417	98.3	13140	12778	210.2	0	0.000	0.000	0.000
May	670069	98.2	12344	12107	81.7	0	0.000	0.000	0.000
June	566851	98.0	11349	11123	78.6	0	0.000	0.000	0.000
July	548671	98.0	11464	11294	16.9	0	0.000	0.000	0.000
August	575797	98.0	11829	11624	51.8	0	0.000	0.000	0.000
September	652819	98.2	11835	11632	28.2	19	0.000	0.000	0.000
October	851221	98.3	14353	13875	314.7	4	0.000	0.000	0.000
November	1014960	98.4	16850	16253	194.8	251	0.000	0.000	0.000
December	1086537	98.4	17806	17128	26.2	491	0.000	0.000	0.000
Year	9601703	98.3	172048	166417	1302.6	2501	0.000	0.000	0.000

Table 7. Grid energy and performance ratio

	E_Grid kWh	PR ratio
January	1064564	0.813
February	897782	0.809
March	909014	0.818
April	763417	0.831
May	670069	0.832
June	566851	0.835
July	548671	0.840
August	575797	0.844
September	652819	0.844
October	851221	0.839
November	1014960	0.823
December	1086537	0.816
Year	9601703	0.826

Table 8. Hourly energy connected to the grid [MWh]

	0H	1H	2H	3H	4H	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H	20H	21H	22H	23H
January	0	0	0	0	0	0	17	55	92	122	140	147	144	130	107	73	36	1	0	0	0	0	0	0
February	0	0	0	0	0	0	9	34	68	102	126	135	133	118	91	56	24	1	0	0	0	0	0	0
March	0	0	0	0	0	0	11	41	76	108	128	137	129	114	87	55	23	1	0	0	0	0	0	0
April	0	0	0	0	0	0	13	40	70	94	108	106	103	94	74	45	17	0	0	0	0	0	0	0
May	0	0	0	0	0	0	12	38	64	82	95	97	95	79	61	36	12	0	0	0	0	0	0	0
June	0	0	0	0	0	0	8	28	50	70	79	84	78	69	54	33	12	1	0	0	0	0	0	0
July	0	0	0	0	0	0	7	27	47	62	75	77	77	70	54	37	15	1	0	0	0	0	0	0
August	0	0	0	0	0	0	9	29	50	65	77	81	78	71	59	39	17	1	0	0	0	0	0	0
September	0	0	0	0	0	0	16	42	65	81	94	87	87	73	57	37	14	0	0	0	0	0	0	0
October	0	0	0	0	0	0	24	54	81	102	115	118	113	101	78	48	18	0	0	0	0	0	0	0
November	0	0	0	0	0	0	32	67	100	122	134	137	133	119	92	58	23	0	0	0	0	0	0	0
December	0	0	0	0	0	0	30	66	102	128	144	148	143	128	102	66	31	0	0	0	0	0	0	0
Year	0	0	0	0	0	0	188	521	865	1137	1313	1354	1313	1166	915	583	243	6	0	0	0	0	0	0

Table 9. Performance coefficients

	Yr	Lc	Ya	Ls	Yf	Lcr	Lsr	PR
	kWh/m²/day	ratio	kWh/kWp/day	ratio	kWh/kWp/day	ratio	ratio	ratio
January	7.04	1.220	5.82	0.096	5.72	0.173	0.014	0.813
February	6.61	1.172	5.44	0.093	5.34	0.177	0.014	0.809
March	5.97	1.000	4.97	0.085	4.89	0.167	0.014	0.818
April	5.11	0.793	4.31	0.073	4.24	0.155	0.014	0.831
May	4.33	0.664	3.67	0.066	3.60	0.153	0.015	0.832
June	3.77	0.559	3.21	0.063	3.15	0.148	0.017	0.835
July	3.51	0.502	3.01	0.062	2.95	0.143	0.018	0.840
August	3.67	0.508	3.16	0.064	3.10	0.138	0.017	0.844
September	4.30	0.607	3.69	0.066	3.63	0.141	0.015	0.844
October	5.46	0.804	4.65	0.077	4.58	0.147	0.014	0.839
November	6.85	1.120	5.73	0.092	5.64	0.163	0.013	0.823
December	7.15	1.220	5.93	0.093	5.84	0.171	0.013	0.816
Year	5.31	0.845	4.46	0.077	4.38	0.159	0.015	0.826

The above results; figures and tables were obtained after simulation using PVsyst software. Table 2 to Table 9 were also generated by PVsyst and each one of them indicates specific system parameter. For example, Table 8 shows the hourly produced energy, it shows that from 6:00 in the morning to 16:00 in the evening, the plant is able to generate various magnitudes of power at hourly intervals. Table 7 on the other hand shows the monthly grid injected power and performance ratio of the proposed PV power plant. Analysing Table 7, I can conclude that the best PR month does not correspond to the month with highest output energy.

Table 10. Comparative analysis of tilt angles.

Tilt Angle	Yr Refrence incident energy kWh/m^2/day	Yf Produced Usedseful energy kWh/m^2/day	Perfomance Ratio	E_Array	E_Grid
20	5.42	4.50	0.829	10.018	9.846
22	5.41	4.48	0.829	9.986	9.815
24	5.39	4.46	0.828	9.944	9.773
26	5.36	4.44	0.828	9.893	9.722
28	5.33	4.41	0.828	9.832	9.662
30	5.29	4.46	0.828	9.761	9.591
32	5.25	4.34	0.828	9.682	9.514

3.1.4 Doko PV Power Plant Design Using HelioScope

In this section, the above 6MW PV power plant is designed and simulated again using HelioScope software. This will enable us to provide comparative analysis of the results generated by PVsyst and Helioscope. The same system components are utilized in both software i.e. the type of modules and inverter are the same with respect to power ratings and manufacturer. Also, the plant locations are the same. Fig. 50 shows the field arrangement of modules and inverters at the site location. A total of 18183 330Wp Kioto modules and 400 15kW Canadian solar inverters were used. The string count and module quantity technical details are illustrated by Fig. 51. The monthly and annual energy production are shown by Fig. 52, and Fig. 53. respectively. The grid recorded the highest transmission of electricity in MAY in injected 750kWh power into the grid. The annual grid injected energy is 7.244GWh. Fig. 54 shows the overall system losses. For example, the inverter losses, mismatch losses and wiring losses are 3.4%, 3.5% and 0.4% respectively.

Figure 50

Modules and Inverter Distributions

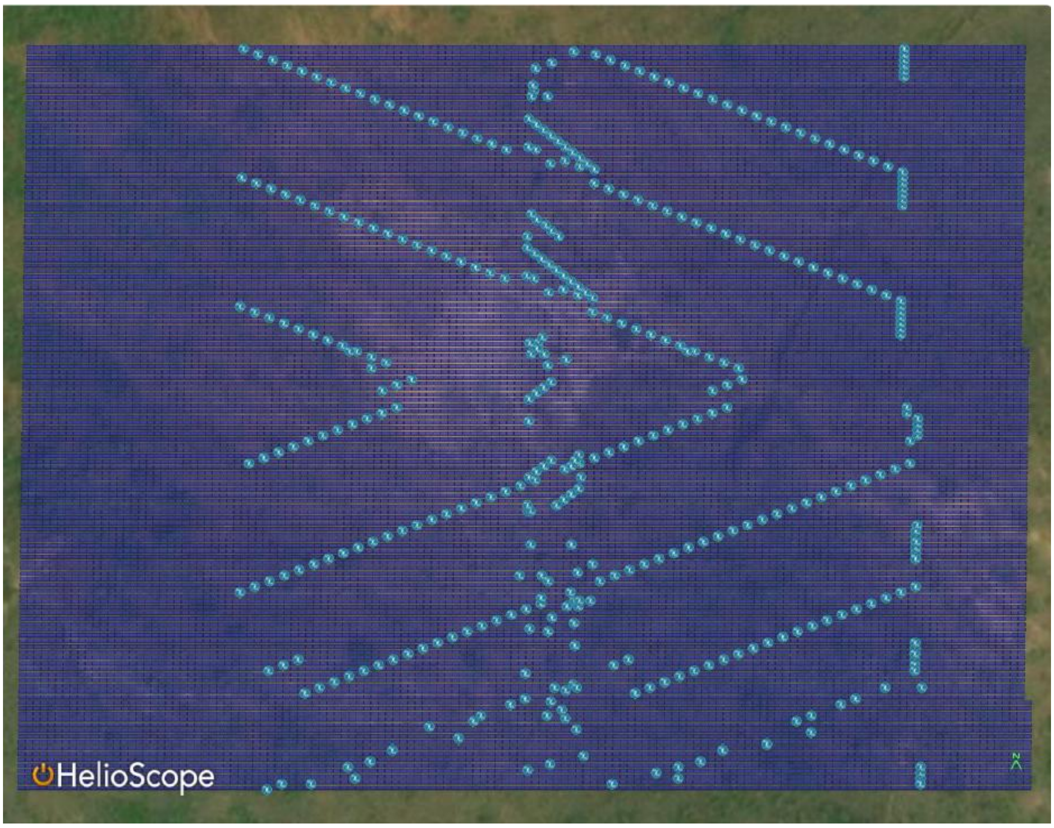


Figure 51

String and Module Quantity Details

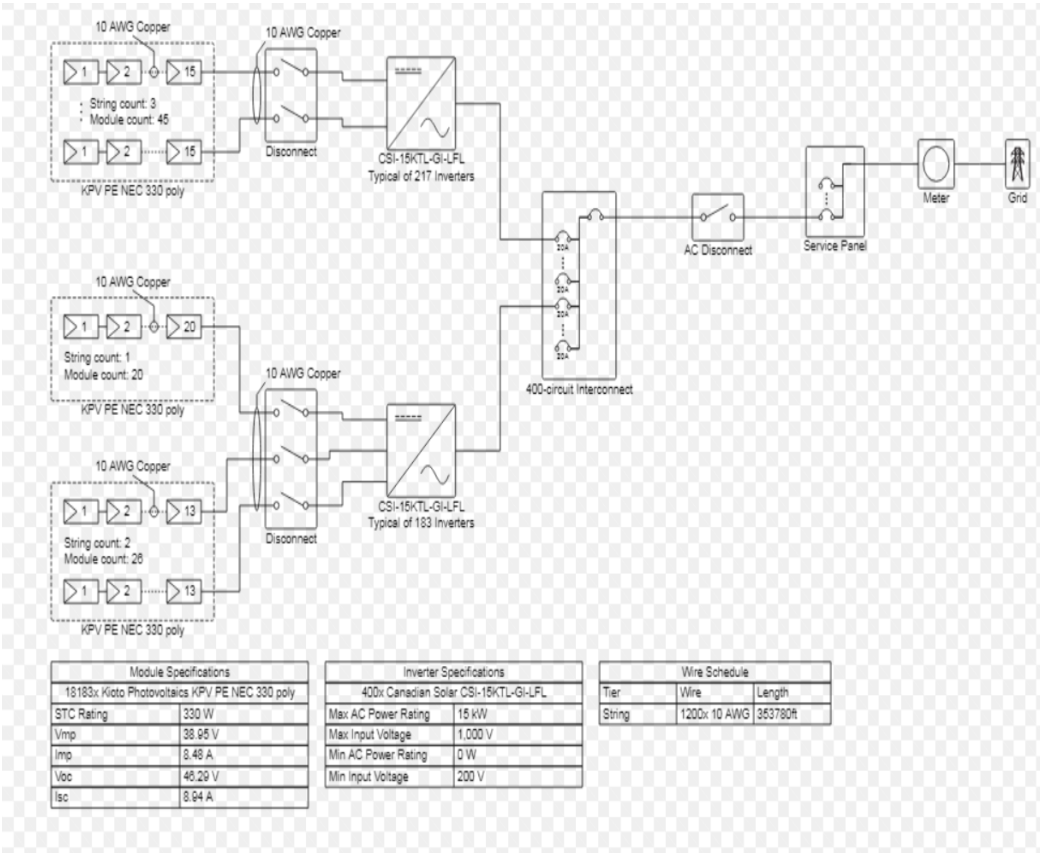


Figure 52

Monthly Energy Production

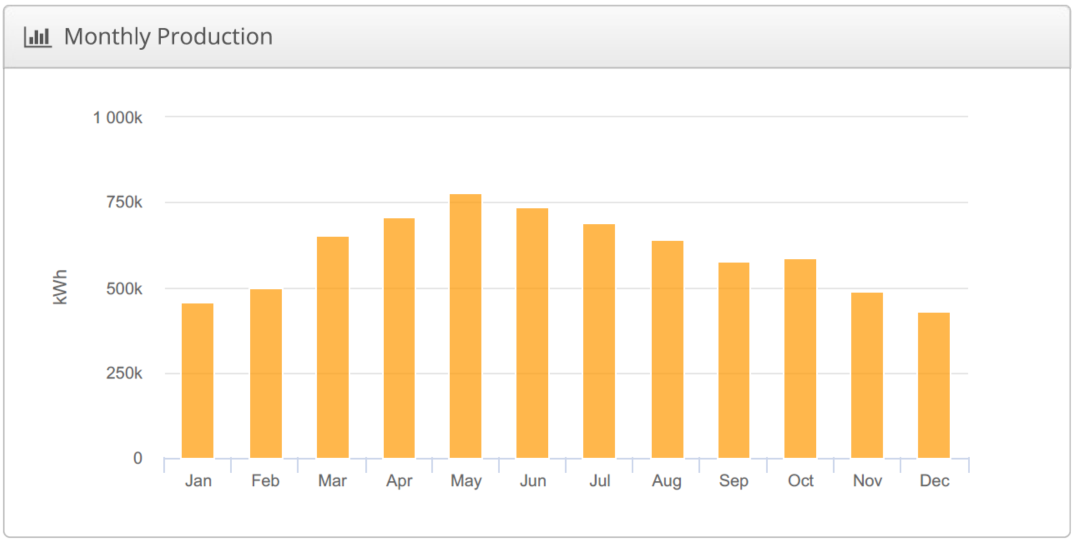


Figure 53

Detailed Annual Energy Production

Annual Production

	Description	Output	% Delta
Irradiance (kWh/m^2)	Annual Global Horizontal Irradiance	1,837.5	
	POA Irradiance	1,582.2	-13.9%
	Shaded Irradiance	1,499.4	-5.2%
	Irradiance after Reflection	1,441.3	-3.9%
	Irradiance after Soiling	1,412.5	-2.0%
	Total Collector Irradiance	**1,412.5**	**0.0%**
Energy (kWh)	Nameplate	8,483,107.3	
	Output at Irradiance Levels	8,421,817.9	-0.7%
	Output at Cell Temperature Derate	7,842,176.6	-6.9%
	Output After Mismatch	7,577,772.5	-3.4%
	Optimal DC Output	7,545,091.1	-0.4%
	Constrained DC Output	7,545,054.0	0.0%
	Inverter Output	7,280,977.0	-3.5%
	Energy to Grid	**7,244,572.0**	**-0.5%**
Temperature Metrics			
	Avg. Operating Ambient Temp		28.7 °C
	Avg. Operating Cell Temp		36.3 °C
Simulation Metrics			
		Operating Hours	4622
		Solved Hours	4622

Figure 54

Detailed Annual Energy Production

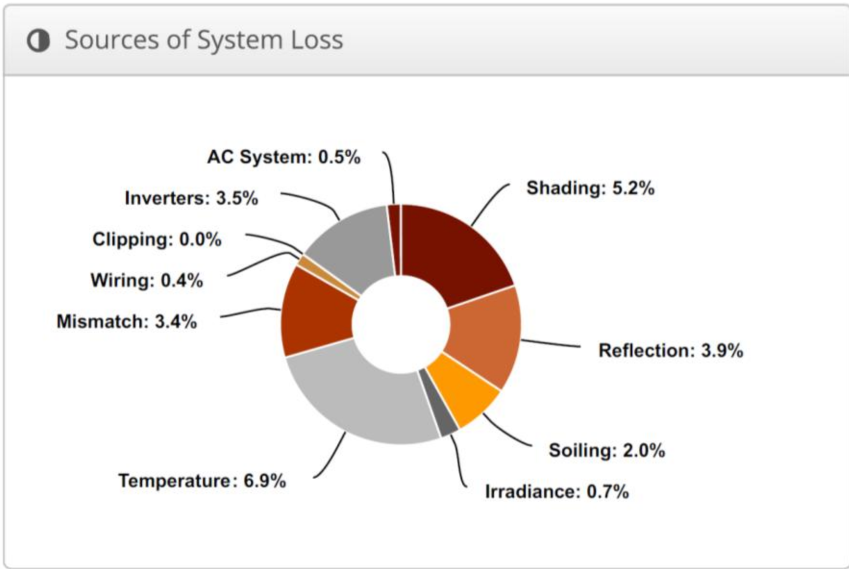


Figure 55

Comparative graph of monthly power production.

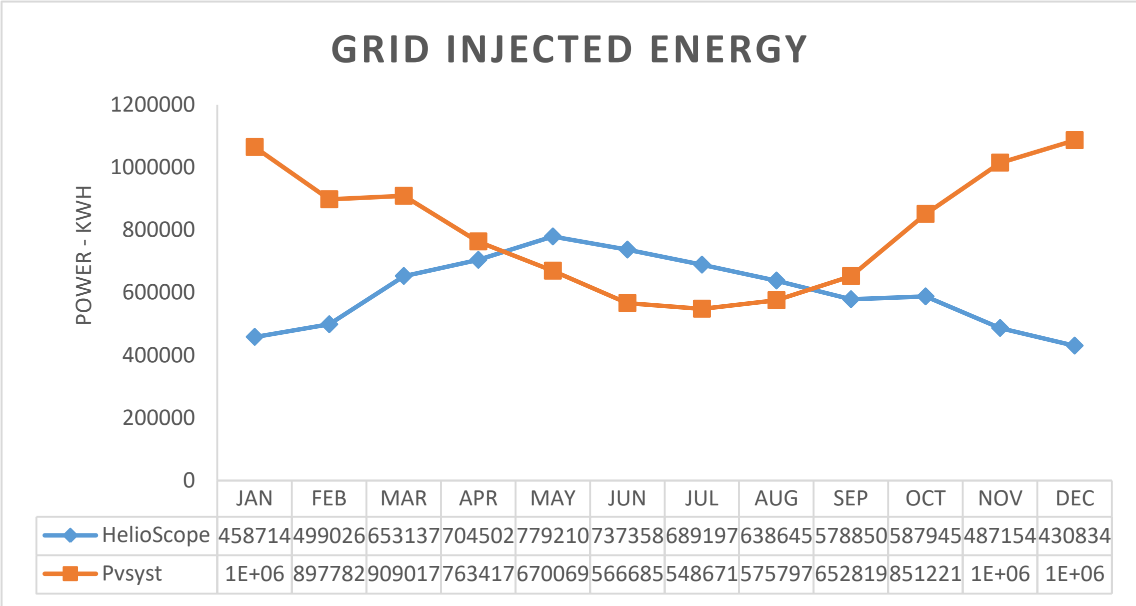


Figure 56

Comparative graph of monthly performance ratio value

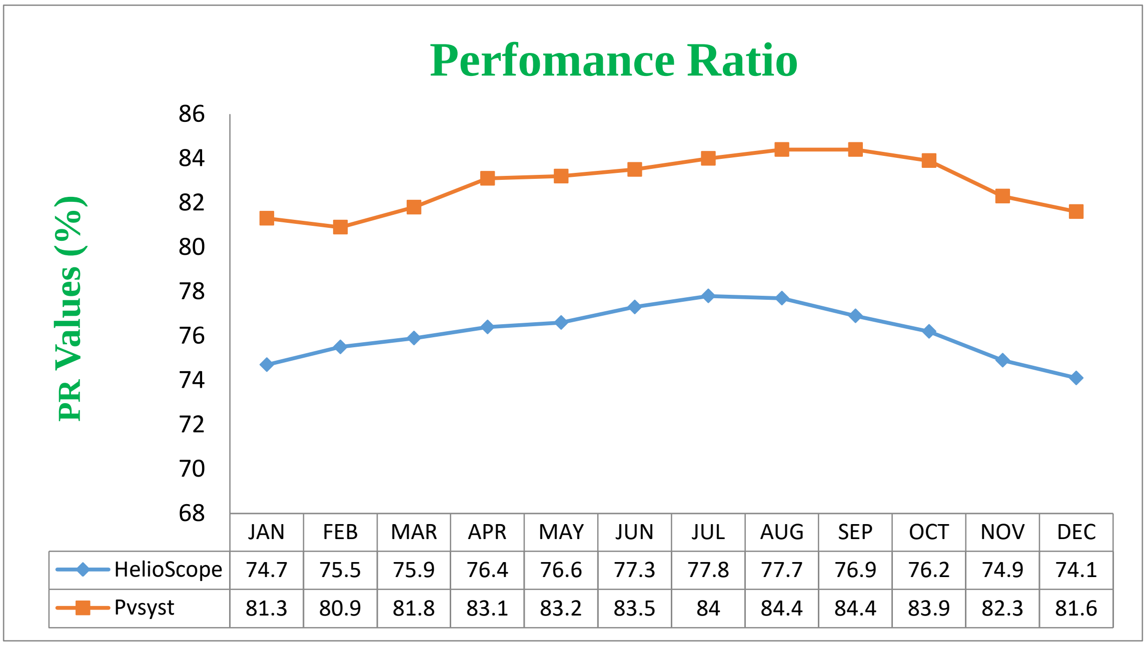


Fig. 55 and Fig. 56 shows the comparative analysis of the results obtained by PVsyst and HelioScope software. In Fig. 55, the graph of monthly grid power for PVsyst and HelioScope are compared, PVsyst generates higher grid power compared to HelioScope. Fig. 56 shows the performance ratio graph for PVsyst and HelioScope and its clear PVsyst has better performance ratio compared to HelioScope.

3.2 Doko Standalone PV System

As stated in the introduction, grid connected and standalone PV systemsare to be designed in this thesis. The above subsections were devoted to the design of the grid connected system. This section will focus on the design of standalone systems. Usually, standalone PV systems are used in residential facilities, small business or for off-grid applications such as streetlights, telecommunication installations etc. An average family of 2 to 4 people will require 1kW of electric power, however a large family of 6 people will require 2.5 to 5 kW of electric power for everyday use including cooling or heating units. Therefore, 5kW of electric power is assumed to be enough for small or large family sizes.

3.2.1 Doko Standalone System (HelioScope)

Two simulations are performed for the standalone system using HelioScope software. The two systems are chosen with respect to the biggest and smallest rooftops. The first system rated is at 75.4kW because it has the biggest rooftop area. 126 modules of 330Wp Kioto photovoltaics can occupy the available space on the rooftop. The number of inverters required for the system is 3which are rated at 15kW. Fig. 57 shows the module and inverter distribution on the rooftop.

Figure 57

75.4 kW Standalone Photovoltaic System.

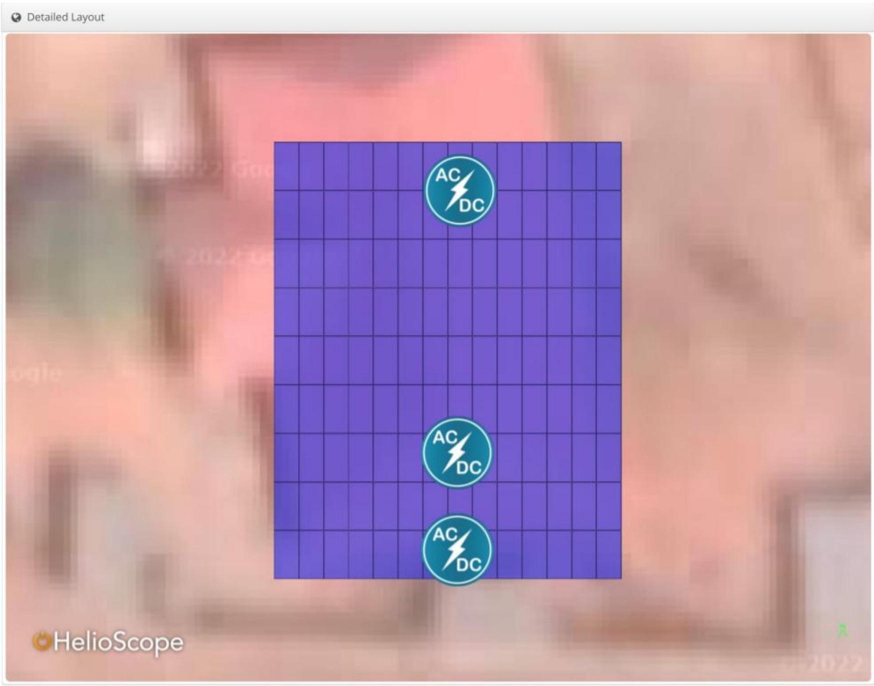
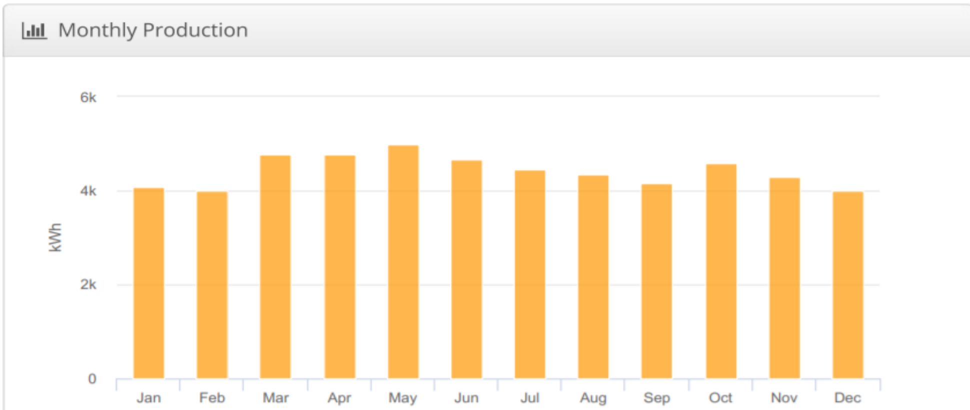


Figure 58

Monthly Energy Production for 75.4 kW



Month	GHI (kWh/m^2)	POA (kWh/m^2)	Shaded (kWh/m^2)	Nameplate (kWh)	Grid (kWh)
January	149.7	136.6	136.6	5,340.1	4,074.5
February	144.5	136.0	136.0	5,341.1	4,012.1
March	168.2	163.6	163.6	6,439.3	4,784.4
April	162.6	163.3	163.3	6,442.9	4,773.4
May	166.4	171.4	171.4	6,771.0	4,994.3
June	151.7	157.7	157.7	6,233.0	4,664.4
July	142.8	147.7	147.7	5,822.2	4,465.4
August	140.6	142.4	142.4	5,600.3	4,346.1
September	141.1	138.8	138.8	5,461.4	4,154.6
October	162.6	154.7	154.7	6,076.3	4,593.1
November	158.9	145.1	145.1	5,674.2	4,293.2
December	148.3	133.7	133.7	5,206.9	3,993.2

Figure 59

System loss graph for75.4 kW

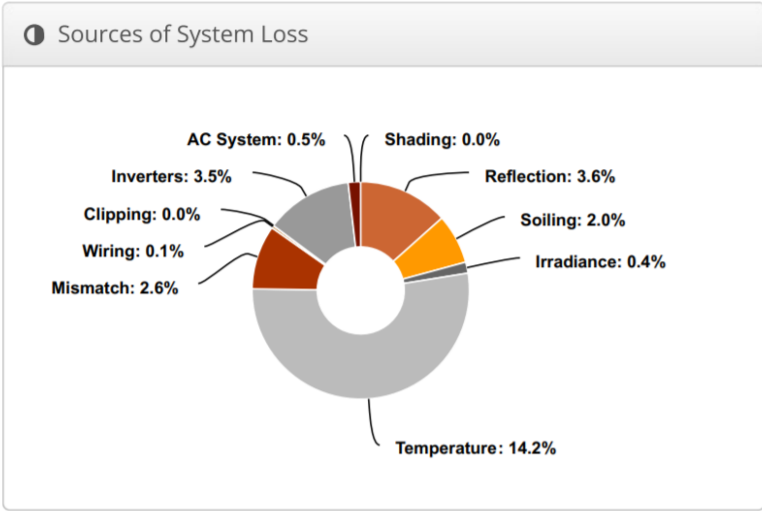


Figure 60

Annual Energy Production for75.4 kW

Annual Production

	Description	Output	% Delta
Irradiance (kWh/m^2)	Annual Global Horizontal Irradiance	1,837.5	
	POA Irradiance	1,791.0	-2.5%
	Shaded Irradiance	1,791.0	0.0%
	Irradiance after Reflection	1,726.2	-3.6%
	Irradiance after Soiling	1,691.7	-2.0%
	Total Collector Irradiance	**1,691.7**	**0.0%**
Energy (kWh)	Nameplate	70,408.6	
	Output at Irradiance Levels	70,098.8	-0.4%
	Output at Cell Temperature Derate	60,114.6	-14.2%
	Output After Mismatch	58,166.2	-3.2%
	Optimal DC Output	58,086.6	-0.1%
	Constrained DC Output	58,086.4	0.0%
	Inverter Output	56,053.4	-3.5%
	Energy to Grid	**53,148.7**	**-5.2%**
Temperature Metrics			
	Avg. Operating Ambient Temp		28.7 °C
	Avg. Operating Cell Temp		47.5 °C
Simulation Metrics			
		Operating Hours	4622
		Solved Hours	4622

The second system is also rated at 7.26kW because it has the smallest rooftop area. 22 modules of 330Wp Kioto photovoltaics can occupy the available space on the rooftop. The number of inverters required for the system is 1which are rated at 15kW. Fig. 57 shows the module and inverter distribution on the rooftop.

Figure 61

System loss graph for7.26 kW

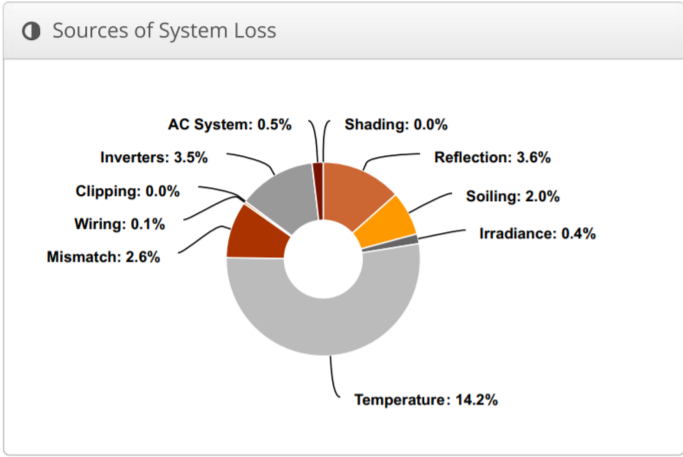


Figure 62

7.26kW Standalone Photovoltaic System.

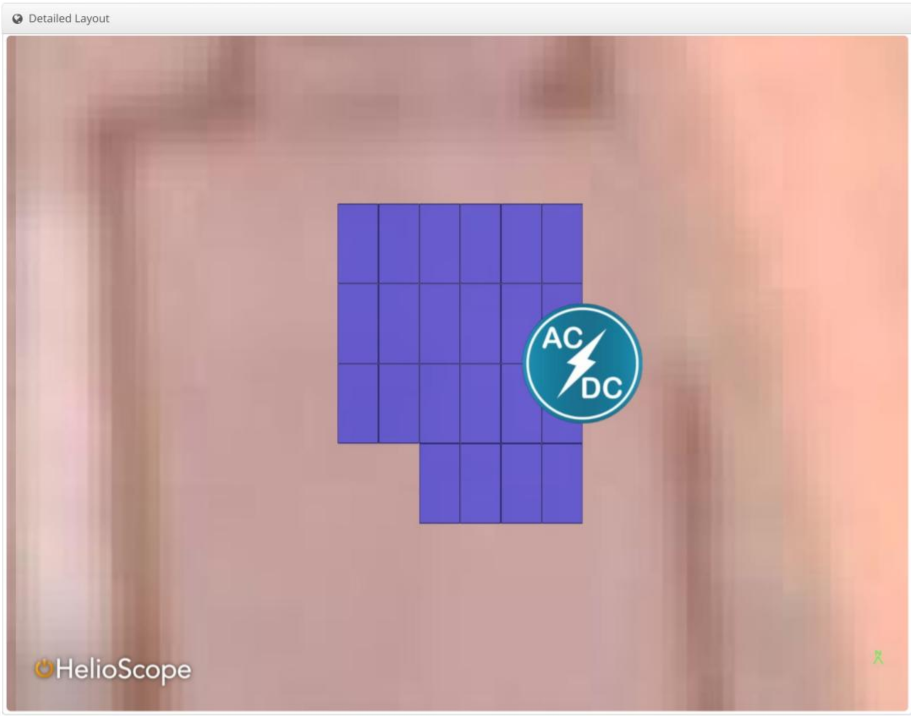
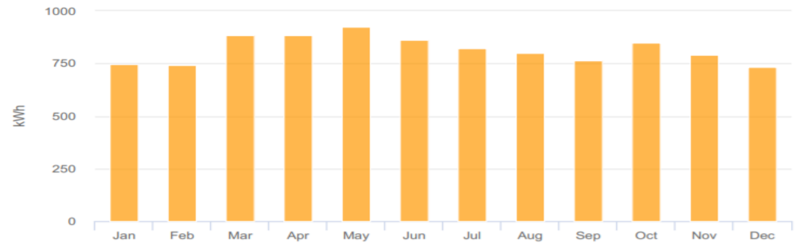


Figure 63

Monthly Energy Production for7.26kW

Monthly Production



Month	GHI (kWh/m^2)	POA (kWh/m^2)	Shaded (kWh/m^2)	Nameplate (kWh)	Grid (kWh)
January	149.7	136.6	136.6	932.4	748.8
February	144.5	136.0	136.0	932.5	740.4
March	168.2	163.6	163.6	1,124.3	884.8
April	162.6	163.3	163.3	1,124.9	884.9
May	166.4	171.4	171.4	1,182.2	925.0
June	151.7	157.7	157.7	1,088.2	862.5
July	142.8	147.7	147.7	1,016.5	823.7
August	140.6	142.4	142.4	977.8	801.2
September	141.1	138.8	138.8	953.5	766.3
October	162.6	154.7	154.7	1,060.9	847.7
November	158.9	145.1	145.1	990.7	790.4
December	148.3	133.7	133.7	909.1	732.1

Figure 64

Annual Energy Production for7.26kW

Annual Production

	Description	Output	% Delta
Irradiance (kWh/m^2)	Annual Global Horizontal Irradiance	1,837.5	
	POA Irradiance	1,791.0	-2.5%
	Shaded Irradiance	1,791.0	0.0%
	Irradiance after Reflection	1,726.2	-3.6%
	Irradiance after Soiling	1,691.7	-2.0%
	Total Collector Irradiance	**1,691.7**	**0.0%**
Energy (kWh)	Nameplate	12,292.9	
	Output at Irradiance Levels	12,238.9	-0.4%
	Output at Cell Temperature Derate	10,496.0	-14.2%
	Output After Mismatch	10,225.6	-2.6%
	Optimal DC Output	10,214.8	-0.1%
	Constrained DC Output	10,214.7	0.0%
	Inverter Output	9,857.2	-3.5%
	Energy to Grid	**9,807.9**	**-0.5%**
Temperature Metrics			
	Avg. Operating Ambient Temp		28.7 °C
	Avg. Operating Cell Temp		47.5 °C
Simulation Metrics			
		Operating Hours	4622
		Solved Hours	4622

Based on the size of rooftops available in Doko, the biggest and smallest rooftops were selected as the areas for standalone PV system implementation using HelioScope. The biggest and smallest rooftops have maximum capacity of 74.5kW and 7.26kW respectively. Fig. 57 to Fig. 64 shows the graphs of simulation for these two PV systems.

3.2.2Doko Standalone System (PVsyst)

Unlike HelioScope, PVsyst does not rely only on the space available at the rooftop of the building but takes into consideration the energy needs of the family. Therefore, the energy requirement of the family needs to be provided into the software before simulation can be made. Fig. 65. shows the home appliances with their respective rated powers and hourly based duration of usage for a day. Due to differences in pricing of electric energy during different hours of the day, the period of usage needs to provided and this is illustrated by Fig. 66.

Figure 65

Hourly Electric Power Consumption

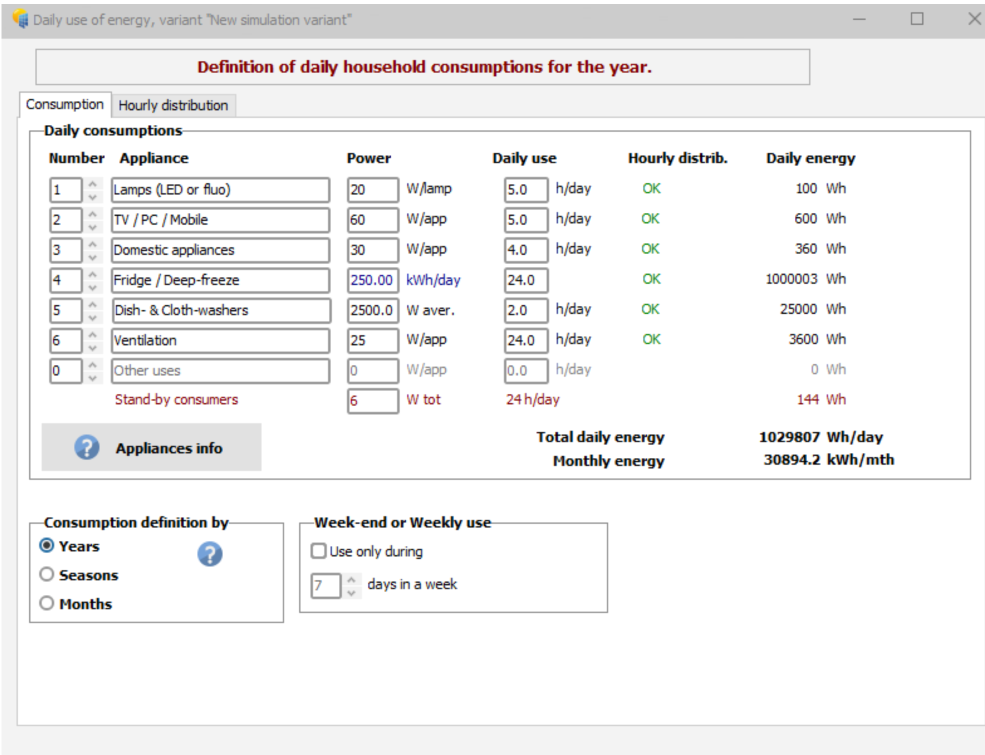
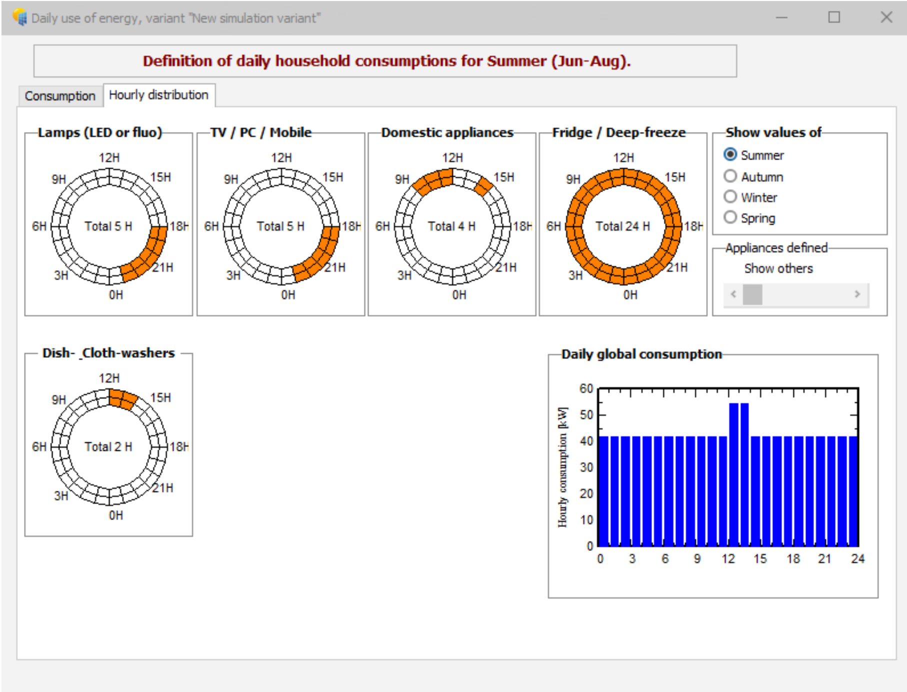


Figure 66

Hourly Electric Power Usage Distribution



Based on the hourly usage and distribution of electric power provided into PVsyst software, it was determined that an average of 10142Whof electric energy was required for a day and 30402.6kWh of electric power was required for a month. Therefore, 76.2kWp capacity of standalone PV systems was designed and simulated with PVsyst. 230 modules of Kioto photovoltaic rated 330Wp was used at an area of 431m^2. Simulation results of the 76.2kWp system with energy saving components are illustrated by Fig. 67, to Fig. 71. The energy flow diagram of the proposed standalone photovoltaic systems is shown by Fig. 67. 375.8MWh of electric power is supplied to the user from an irradiance of 1931kWh/m^2.

Figure 67

Loss-Line Diagram for Doko Standalone PV Plant

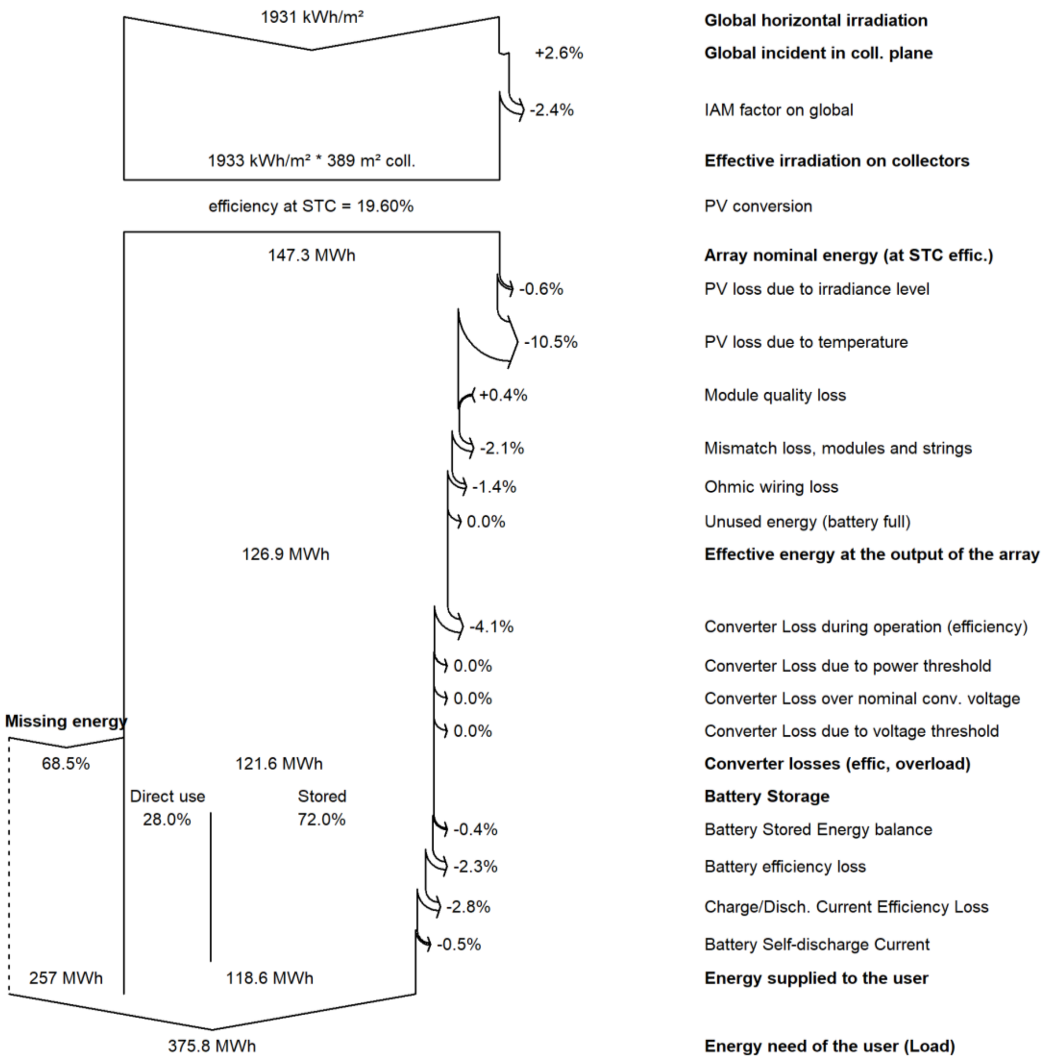


Figure 68

Reference Incident Energy in Collector Plane

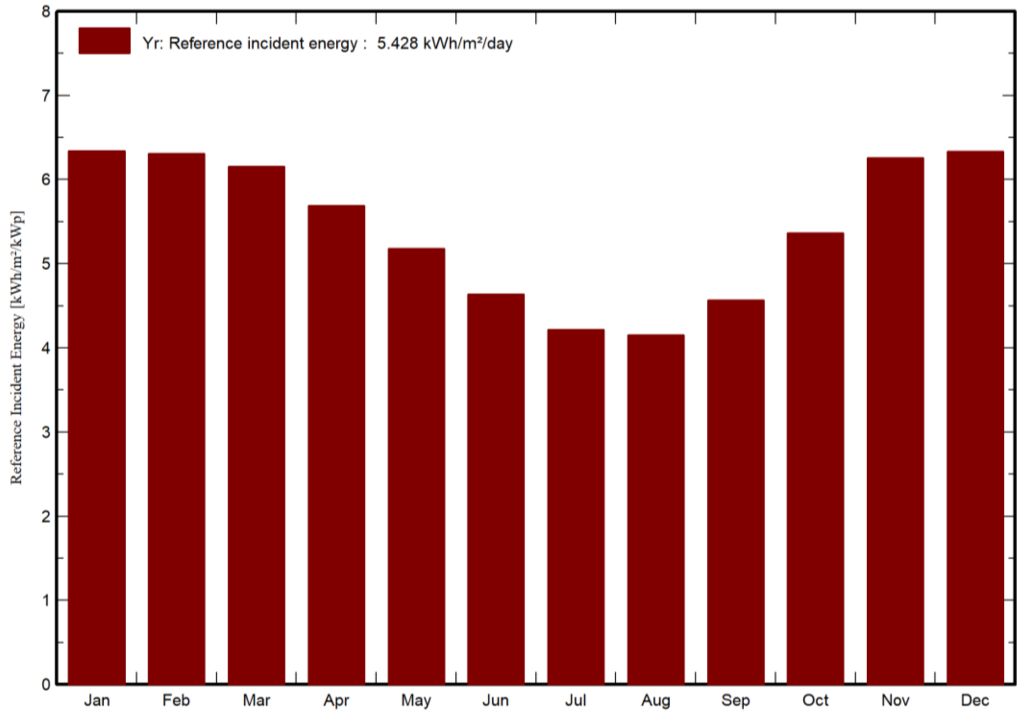


Figure 69

Monthly Useful Energy and Losses Production (kWh/kWp/day)

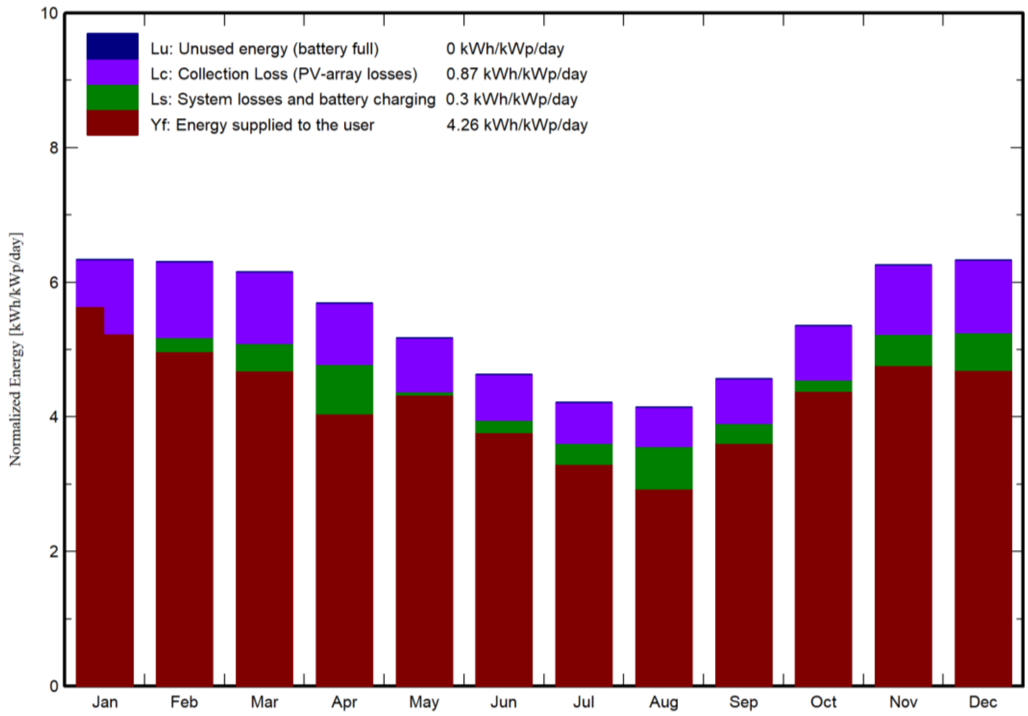


Figure 70

Monthly Useful Energy and Losses Production [percentage (%) values]

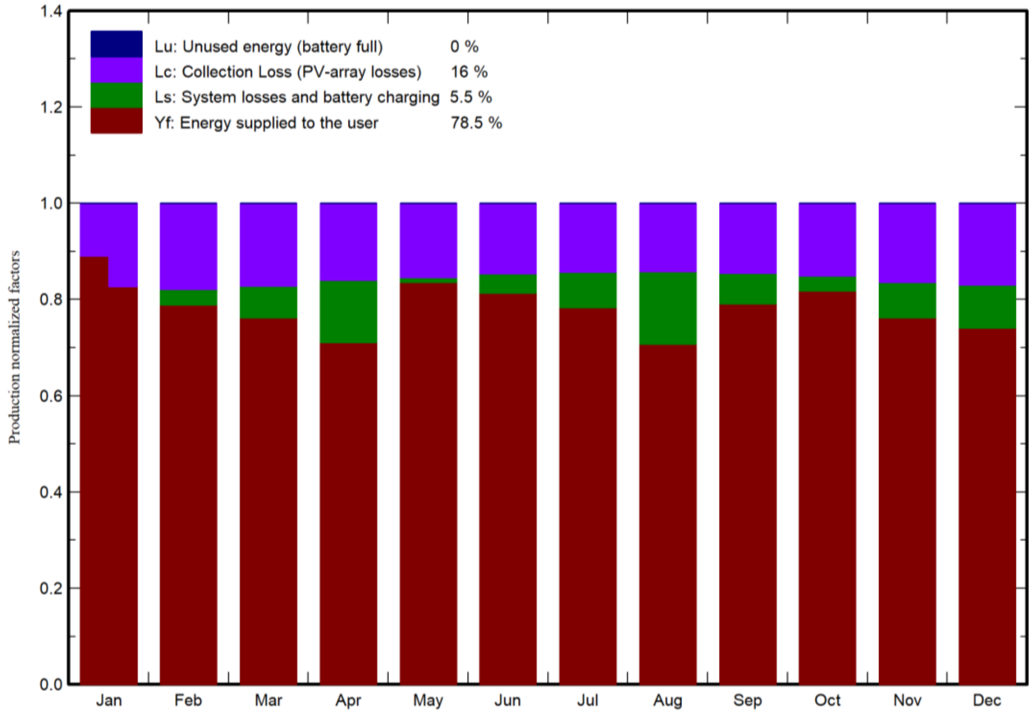
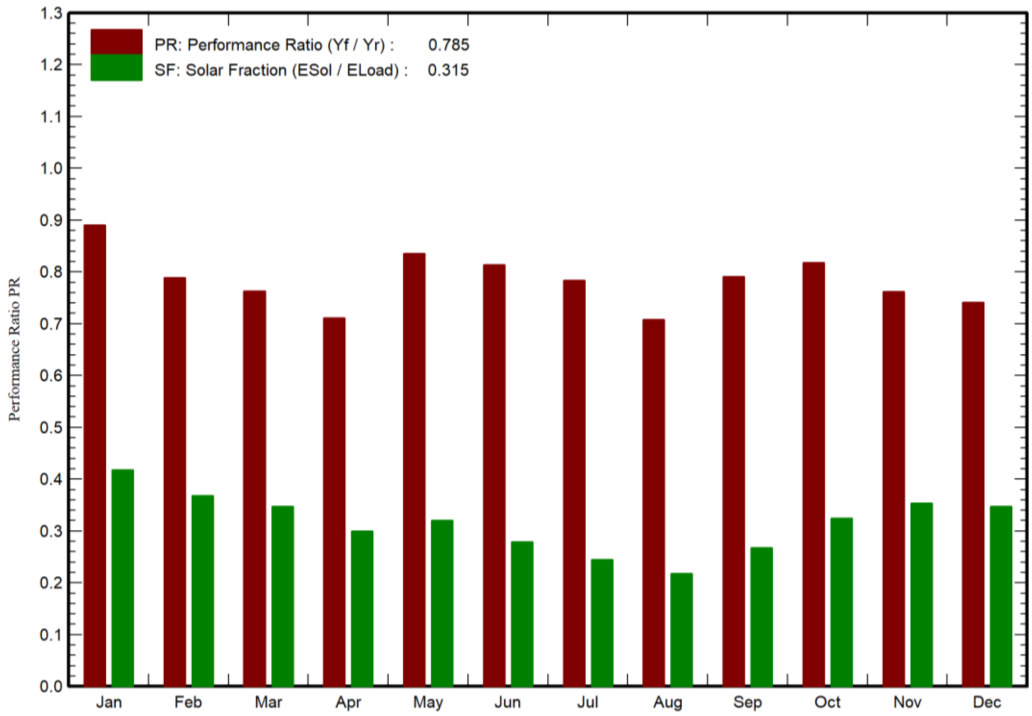


Figure 71

Performance Ratio and Solar Fraction Diagram



The cost of modules and inverters used for the grid connected and standalone systems are estimated and illustrated in Table 10.

Table 10. Module and Inverter Cost Estimations

Parameters	Type of modules	Number of Modules	Module price $133	Number of Inverters	Inverter Price$458
			Grid-connected Systems		
HelioScope	330Wp	18183	$2418339	400	$183200
PVsyst	330Wp	18183	$2418339	400	$183200
			Standalone Systems		
HelioScope 1	330Wp	126	$16,758	3	$1374
HelioScope 2	330Wp	22	$2926	1	$458
PVsyst	330Wp	231	$30723	6	$2748

3.3Power Electronic Converters

Power electronic converters are semiconductor based circuit composed of controllable or uncontrollable switches used in changing the waveform characteristics of voltages. This section presents two of such power electronic converters; the first is a DC-DC converter and the second is an inverter i.e. DC-AC converter. Power circuit of the proposed converters are analysed theoretical and simulation results are generated to support the theoretical characteristics.

3.3.1Proposed DC-DC Converter

The DC-DC converter is derived by modifying the traditional Zeta dc-dc converter. this is done by introducing a switched capacitor network with noninverting characteristics. The SC network is shown Fig. 72. It's made up of three diodes and two capacitors arranged as the Z-Source network. The improved Zeta dc-dc converter is illustrated by Fig. 73. The modified Zeta topology exhibits better performance characteristics than the conventional topology.

Figure 72

Noninverting SC Network

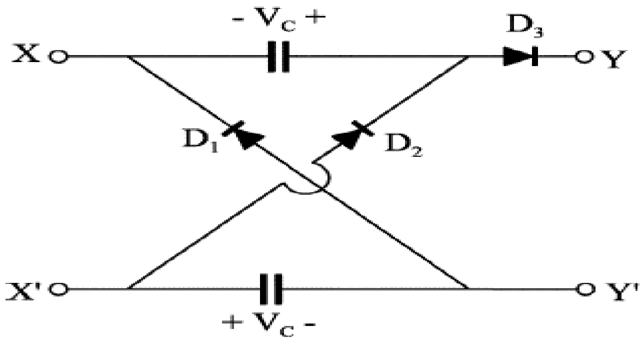
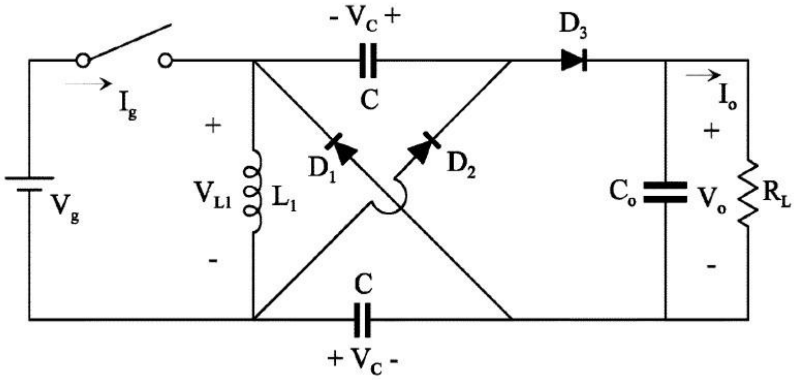


Figure 73

Improved Zeta DC-DC Converter



The operational states of the improved Zeta converter are two, this is based on the sates of the semiconductor power switch. These states are the ON state and OFF state of the switch. Fig. 74a shows the on state of the switch, in this state, all diodes are reverse biased, therefore the source voltage charges the inductor and capacitor, energy to the load is derived from the source. During the OFF state, diode D_3 is reverse biased while the others are forward biased, therefore an open circuit is created between the SC network and the load as illustrated by Fig. 74b.

The following expressions are developed during the ON and OFF states of the switch.

During ON state, the capacitor voltage V_C is expressed as:

$$V_C = \frac{1}{2}\left(V_0 - V_g\right) \quad (3.17)$$

Voltage balance analysis of will yield

$$V_C = \frac{DV}{1-D} \quad (3.18)$$

The voltage conversion ratio G is derived by substituting (3.8) in to (3.7)

$$\frac{DV_g}{1-D} = \frac{1}{2}\left(V_0 - V_g\right)$$

$$\frac{V_o}{V_g} = \frac{2D + (1-D)}{1-D}$$

$$G = \frac{V_o}{V_g} = \frac{(1+D)}{(1-D)} \quad (3.19)$$

Therefore, voltage stress of the switch G_S is expressed as

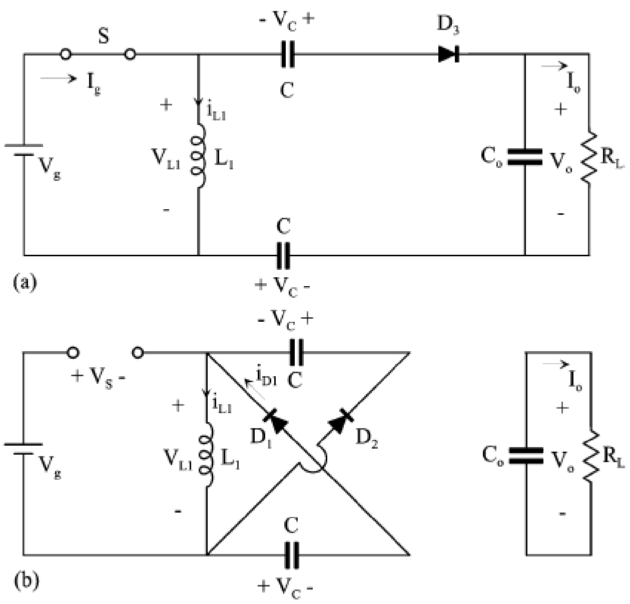
$$G_S = \frac{V_S}{V_o} = \frac{(1+G)}{2G} \quad (3.20)$$

$$G_Z = \frac{D}{-D+1} \quad (3.21)$$

Analysing equations (3.9) and (3.10), it's evident that the voltage gain of the improved Zeta DC-DC converter is higher than the voltage gain of the conventional Zeta DC-DC converter expressed by equation (3.11)

Figure 74

Operating States of Improved Zeta Converter



Simulation results of the proposed improved Zeta DC-DC converter are illustrated below. Using simulation parameters indicated in Table 11. The result of the simulation shows that the proposed Zeta converter has high voltage gain i.e. it requires less input voltage so as to generate high output voltage. Fig. 76 to Fig. 80. shows the output waveforms of the various components of the circuit. Power circuit of the proposed improved Zeta DC-DC converter is shown by Fig. 75; the circuit is made up of one inductor, three diodes, two capacitors, one filter capacitor, load resistor and an input voltage.

Table 11. Simulation Parameters

Parameter	**Value**
Input voltage	25V
Capacitance	180mf
Filter capacitance	33.33mf
Inductance	140uH
Switching frequency	20kHz

Figure 75

Circuit of Proposed Improved Zeta DC-DC Converter

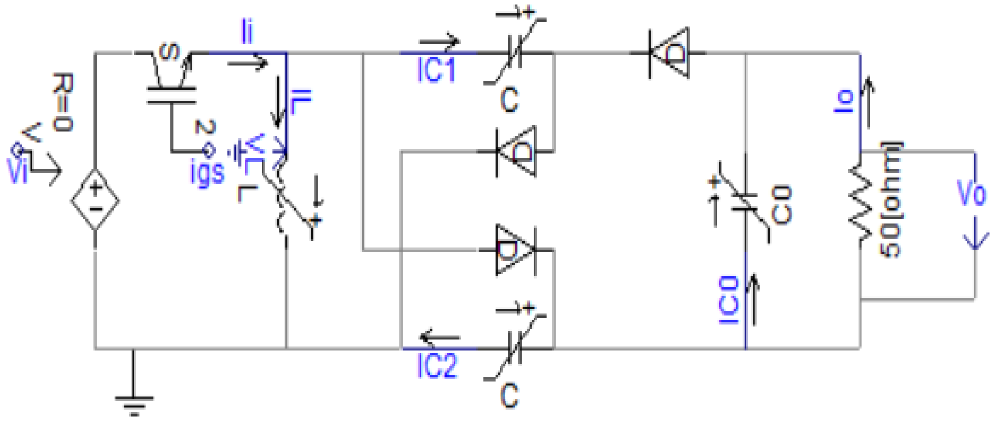


Figure 76

Inductor Current Waveform

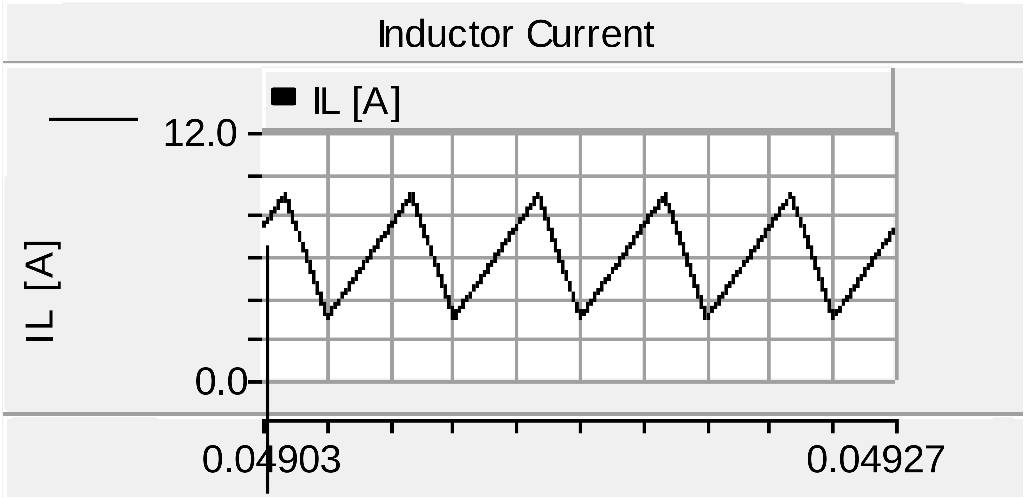
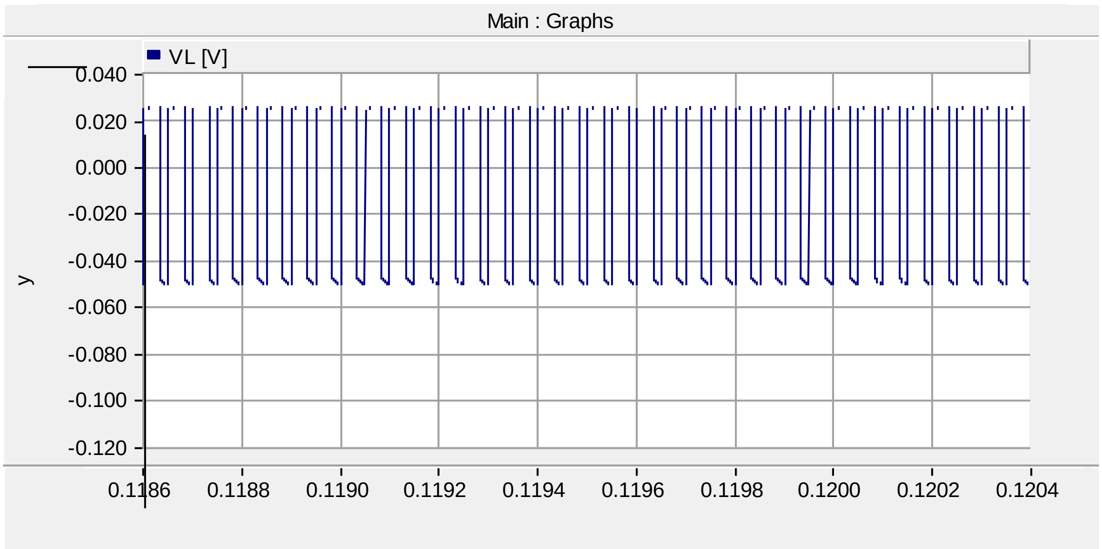


Figure 77

Inductor Voltage Waveform



The inductor current waveform is illustrated by Fig. 76. The nature of the waveform shows the proposed Zeta DC-DC converter was investigated in CCM (continuous conduction mode) mode because the lower limit of the current waveform does not fall to zero magnitude before rising again. Fig. 77 shows the inductor voltage waveform which is exactly same as the theoretical waveforms of inductors.

Figure 78

Filter Capacitor Current Waveform

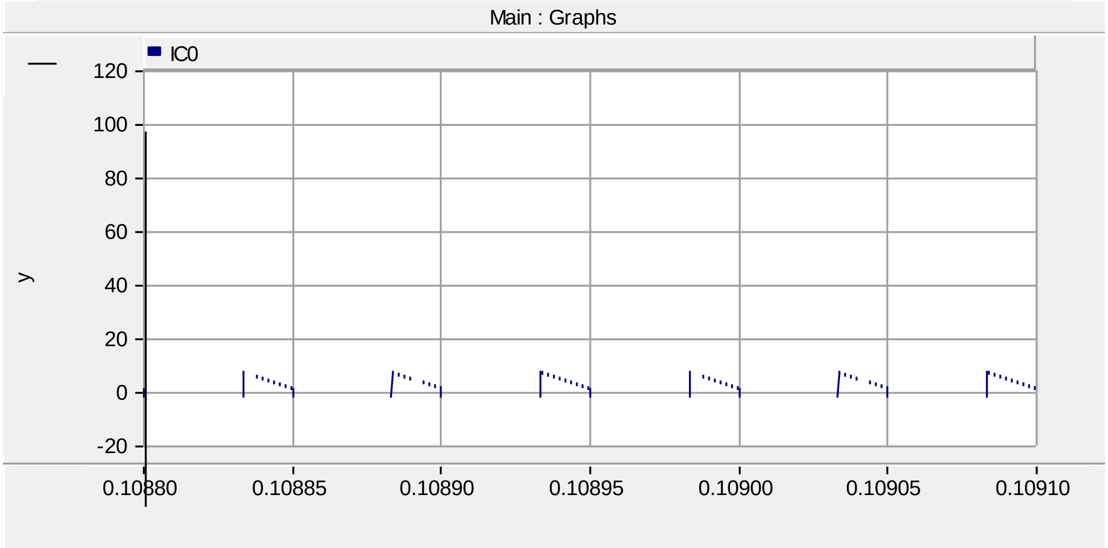


Figure 79

Load Voltage Waveform

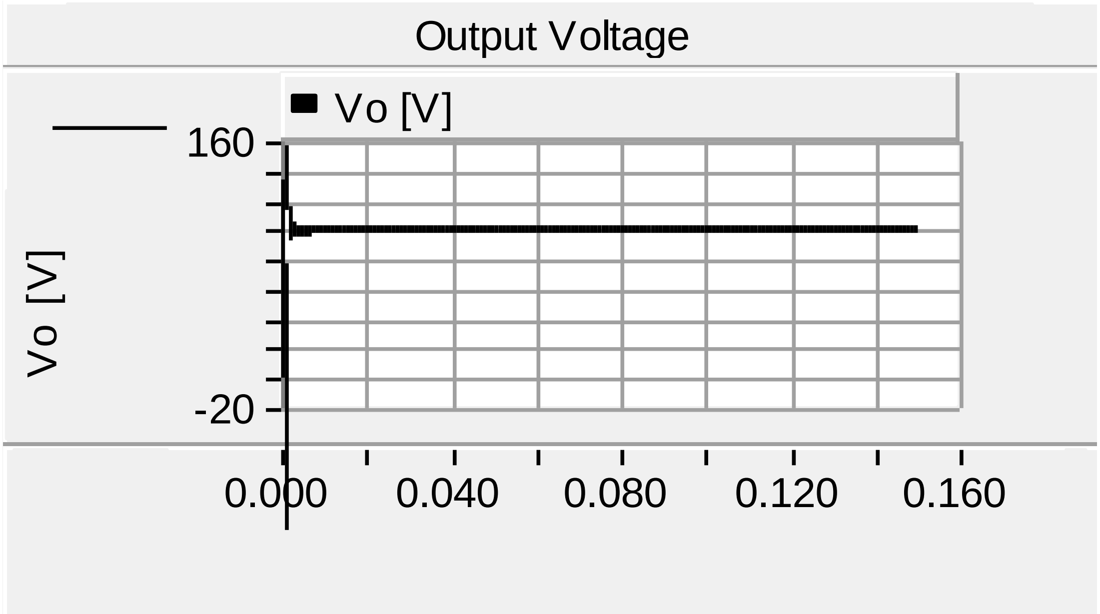
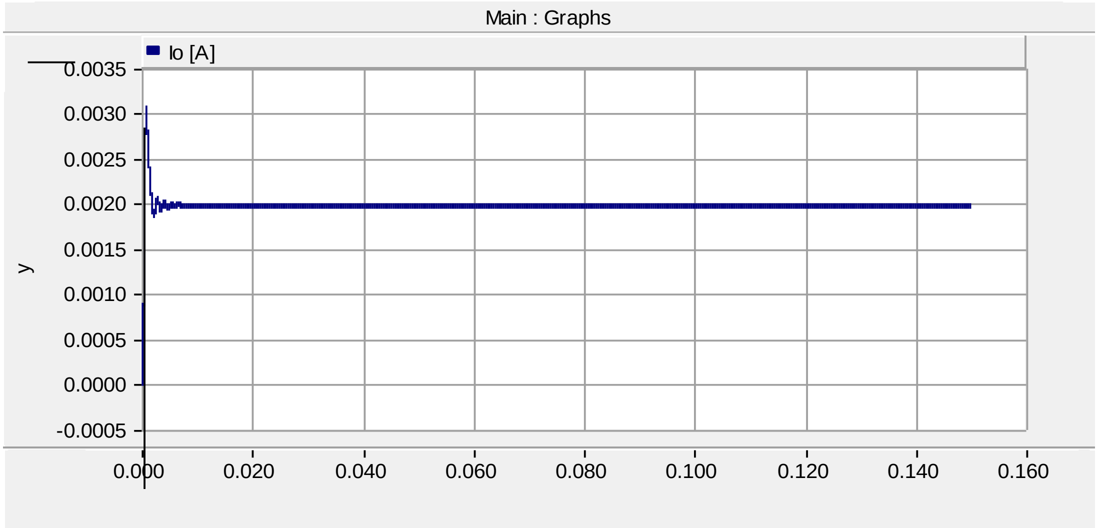


Fig. 78 shows the output current waveform of the filter capacitor. The load voltage waveform is illustrated by Fig. 79. 100V dc voltage was generated by the proposed improved Zeta DC-DC converter when an input voltage of 25V was utilized. This shows that, the proposed improved Zeta converter improves increases the source voltage by a factor of 4. Fig. 80 shows the load current waveform.

Figure 80

Load Current Waveform



3.3.2Proposed DC-AC Converter

This section proposes a high step DC-AC converter with high voltage boosting characteristics. The proposed converter is known as Tran Z-Source converter which belongs to the family of impedance based or Z-Source converters. The classical topology of this family of converters is the Z-Source which is derived by placing a Z-Source (impedance) network between the input voltage and the semiconductor power switches of the converter (IEA, 2020). Impedance based converters provide better voltage boosting capabilities and eliminates the drawbacks of the conventional voltage and current source converters. Fig. 76 shows the power circuit of the proposed Trans Z-Source converter which is voltage fed; this means that by changing the voltage source into a current source, the proposed converter can be used for applications which require current source converters.

Figure 81

Tran Z-Source Inverter

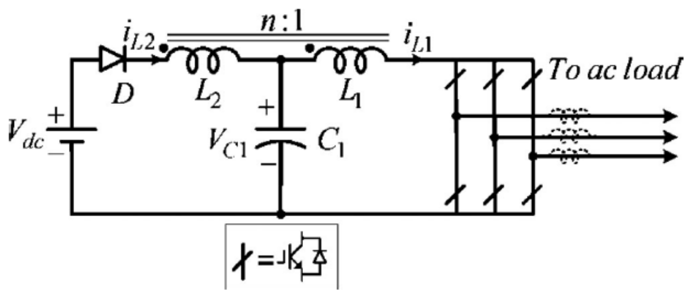


Table 13. Simulation Parameters

Parameter	Value
Input voltage	50V
Filter inductance	5mH
Filter capacitance	2200µF
Inductance	1.5mH
Resistance	46Ω
Switching frequency	8800Hz
Output frequency	50Hz

From the structure of the proposed Trans Z-Source converter, the impedance structure is composed of a diode, coupled transformer made up of two inductors and one capacitor which are located between the voltage input and three-phase inverter. The proposed converter is suitable for any number of phase application. Just like the pioneer Z-Source inverter, the proposed converter has shoot-through and non-shoot-through operations. The following expressions are developed for these states of operation.

The dc link voltage is expressed as

$$S_D\left(\frac{1}{1-(1+n)D_{ST}}\right)V_{DC} \qquad (3.22)$$

The diode voltage is expressed as

$$S_D\left(\frac{n}{1-(1+n)D_{ST}}\right)V_{DC} \qquad (3.23)$$

The capacitor voltage is expressed as

$$\left(\frac{1-D_{ST}}{1-(1+n)D_{ST}}\right)V_{DC} \qquad (3.24)$$

The inductor current i_{L1} is expressed as

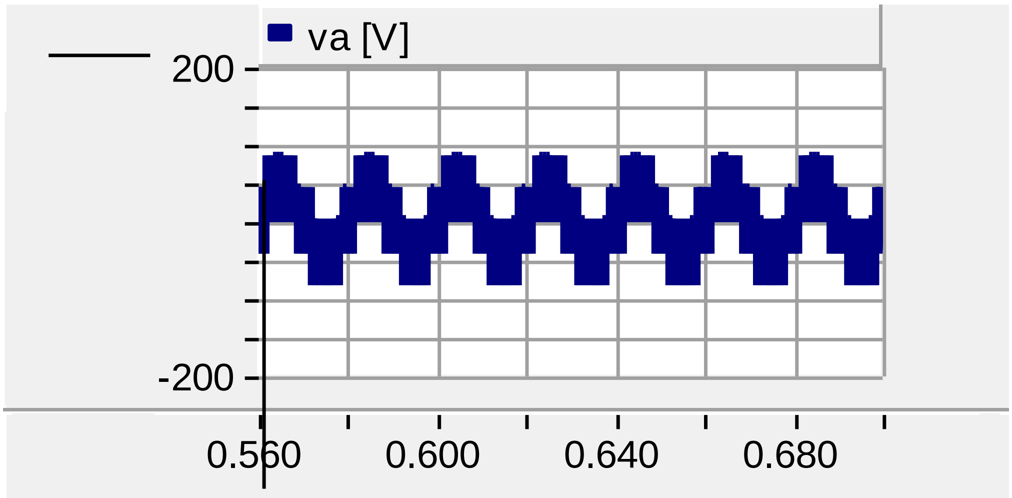
$$\overline{S_D} * i_i + S_D * i_m \qquad (3.25)$$

The inductor current i_{L1} is expressed as

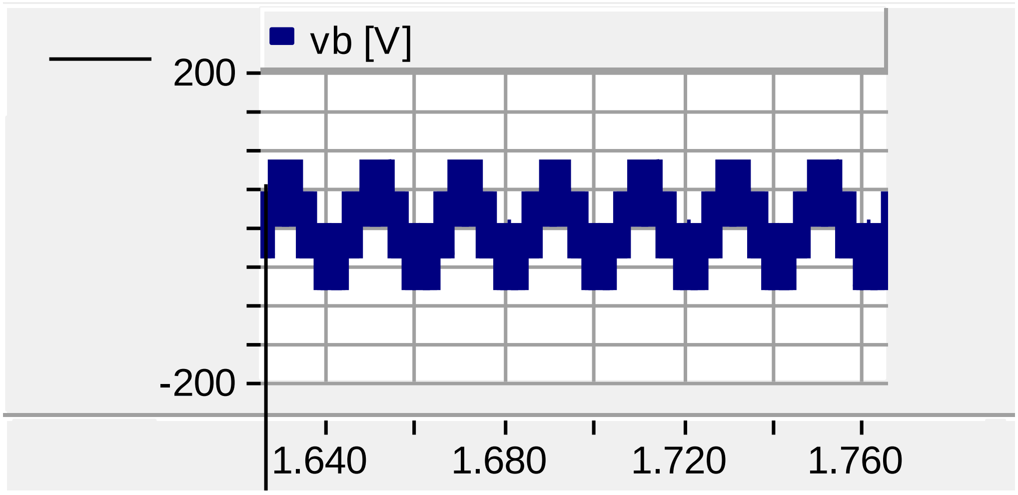
$$\overline{S_D}(i_m - i_i)/n \qquad (3.26)$$

Figure 82

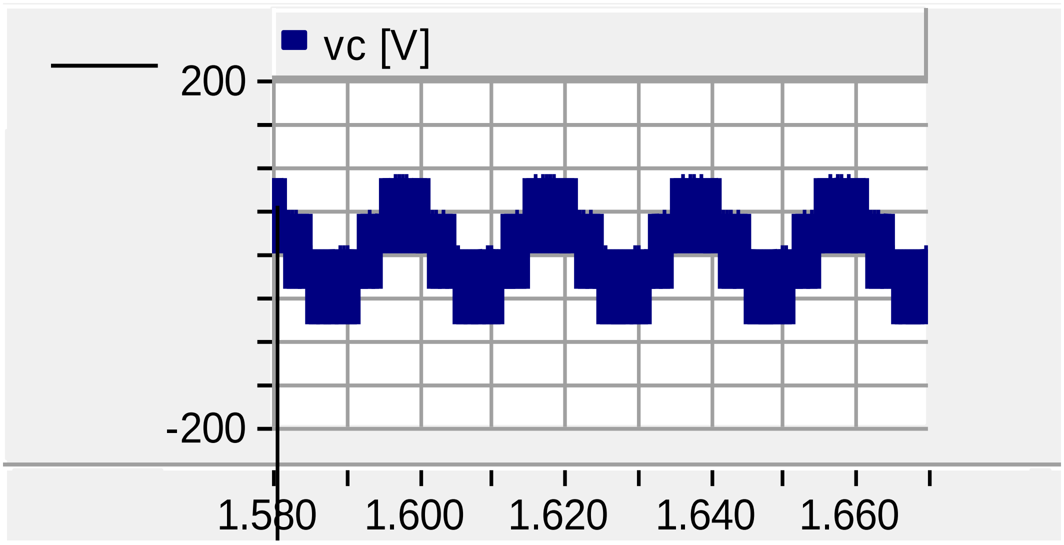
Load Voltage Waveforms



(a)



(b)



(c)

Figure 83

Input Voltage Waveform

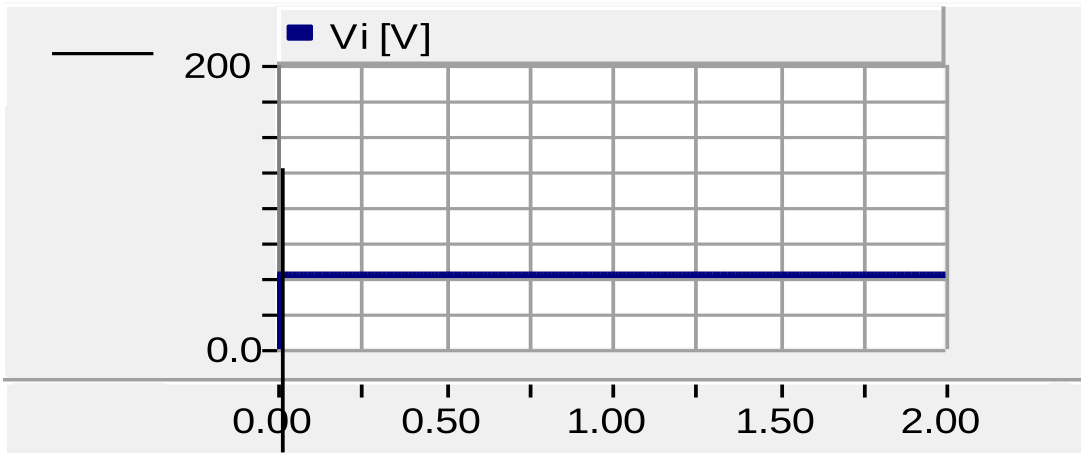


Figure 84

Phase AB Load Voltage Waveform

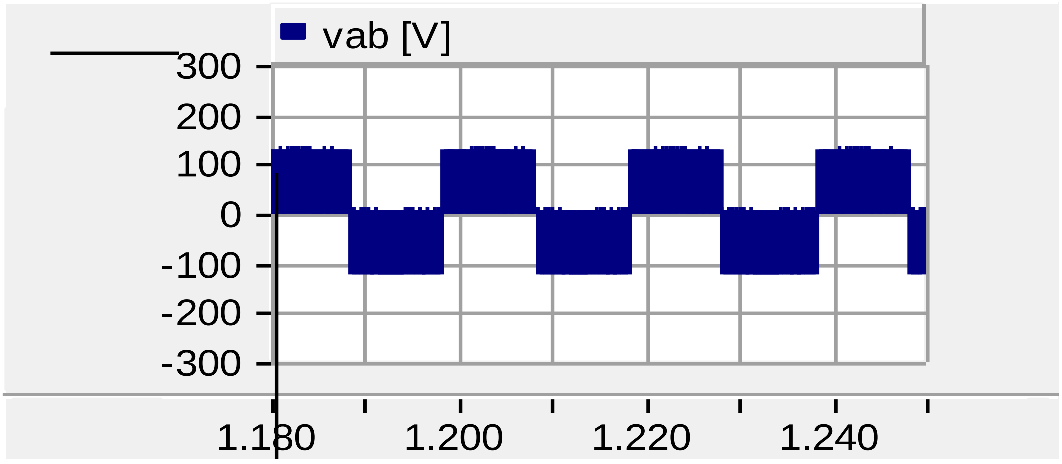


Figure 85

Load Current Waveforms

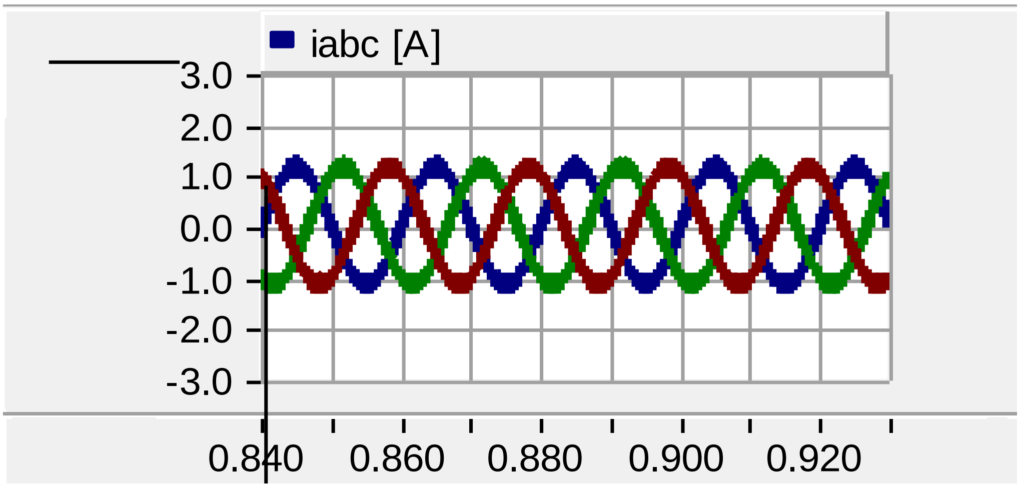
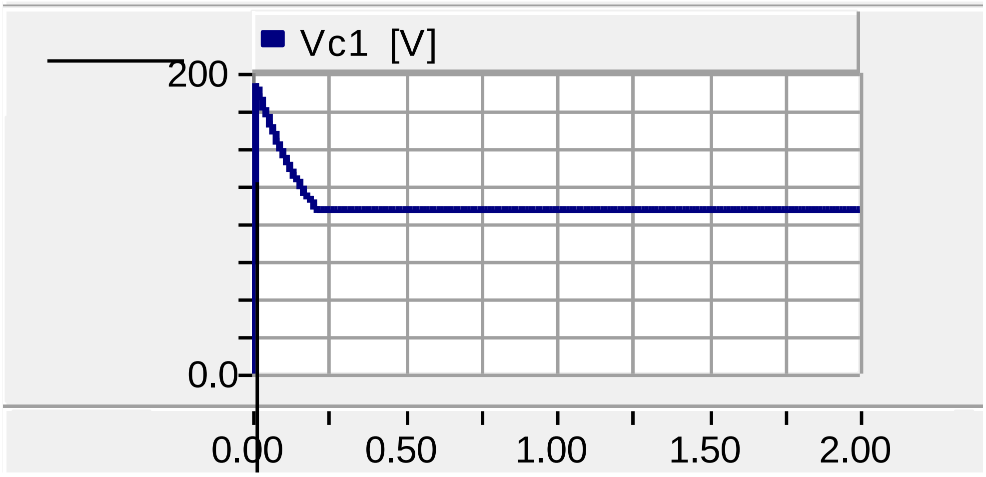


Figure 86

Capacitor Voltage Waveform



CHAPTER 4

Conclusion

4.1 Overview

This research proposed sustainable, environmentally friendly and cheap method of generating electric power for Doko Township in the Niger state of Nigeria. Photovoltaic systems have proven over the years to reliable, environmentally friendly and economical. Therefore, grid connected and standalone PV systems are proposed for electric power generation in Doko. According to the World Bank Report of 2019, grid electric power accessibility in Nigeria is currently hovering around 50% for a population of approximately 200 million. This means that, close to 100 million people in various locations of the country have to rely on other forms/sources of electric power for personal or commercial applications.

4.2 Discussion

Nigeria is located in the sub Saharan region of West Africa, along the coast of Gulf of Guinea. Unlike other African countries, Nigeria is a federal republic with 36 (thirty-six) states. Nigeria is blessed with multiple resources for electric power generation. From thermal resources such as gas and oil, and from renewable resources such as wind, hydro and solar, these combined sources can generate close to 12.522GW of electric power if properly planned. Lack of investment and poor maintenance are hugely responsible for stunted growth of the electric power sector in Nigeria. 4000MW of electric power is the highest magnitude of power Nigeria dispatches on most days.

The current state of electric power generation and distribution in Nigeria is not at an acceptable level considering the population of the country. As 2019, the world bank report puts access to electric power in Nigeria at 55.4%, which means that over 50 million Nigerians to not have access to grid connected electricity. Most of these people really on generators; these generators are noisy and costly.The challenges of electric power generation, transmission and distribution in Nigeria will continue to exist in the medium to long term unless adequate solutions are provided to resolve these challenges which are broadly categorised into sector illiquidity, inadequate transmission and distribution infrastructure and lack of gas supply. Consumers who have the resources to provide electric power mostly rely on generator sets. These generator sets as stated above are noisy hence cause noise pollution and really on fossil fuels for combustion.

As we all know, fossil fuels are being replaced by clean energy sources such as PV systems from renewable energy sources.To overcome the above challenges facing the power sector and individuals in Nigeria. This research proposed two photovoltaic systems for electric power generation for use in residential facility and for grid-connected applications. The viability of the proposed systems was determined by two highly rated, industry and academia accepted PV software known as PVsyst and HelioScope. Both software use real-time power plant location to determine the expected daily, monthly and yearly electric power output of the proposed plants. Also, one DC-DC converter and one multilevel inverter were presented to properly boost and condition the generated electric power for grid applications.

The location of the proposed PV power plant is Doko Township in Niger state of Nigeria. The grid-connected system is rate at 6MW. Using PVsyst software the following field data were utilized to generate the required energy. 18183, 330Wp Kioto modules tilted at 30^0 with 400 15kW inverters produced by Canadian Solar Inc. The energy output with the above parameters was closed to rated system output power. The power ratio is 82.6%, the reference yield energy is 1931kWh/m^2/day, From the loss-line diagram, 9.60GWh of electric power is expected to be injected into the grid. Detailed output parameters are shown in various tables in chapter 3. Using the same systems parameters used in PVsyst, HelioScope software was also used to design the same PV system and simulations carried out. This will afford us the ability to evaluate the two PV systems based on efficiency. The grid-injected energy for HelioScope software is 7.244GWh. Finally, standalone PV system for residential applications was designed using the two software. Using HelioScope software, two standalone systems were designed. This is because HelioScope only allows standalone PV system analysis when the available rooftop area is incorporated into the design. Without providing the available rooftop space, standalone systems cannot be analysed in HelioScope. Therefore, the largest and smallest rooftop areas were selected for simulation. The system with the biggest rooftop area is rated 75.4kW, 126330Wp modules, 3 15kW inverters were used. Also, the system with the smallest rooftop area is rated 7.26kW, 22 330Wp modules, 1 15kW inverters were used. The yearly output power for the 75.4kW and 7.26kW systems are53148.7kWh and 9807.9kWh respectively. The PVsyst system based on the energy assessment of the facility was rated at 76.2kW. From the loss-line diagram of the system, 9758kWh of power was provided for the end user. One DC-DC converter and one DC-AC converter were presented, theoretical and simulation results were provided. The DC-DC converter has a boost factor of 4 and DC-DC converter has boost factor of 2. Therefore, with an input voltage of 50V for both converters, the output voltages produced are 200V and 100V for the DC-DC and DC-AC converters respectively. It is evident from the generated results of this work that photovoltaic systems can play major role in improving the availability and accessibility of electric power in Nigeria. The monthly and yearly output figures from the two software illustrates that weathers conditions are at optimal conditions for solar electric power generations all year-round compared to other European countries.

4.3 Recommendations

Overcoming the drawback of lack of availability and accessibility of electricity in Nigeria requires governmental or public and private sector participations. There should be a short, medium and long term policies to guide the use of solar energy for electric power generation. The short term policy direction should focus on reducing or eliminating taxes on solar modules, inverters and other components so as to reduce cost and make them affordable for residential applications. The medium to long term should focus on building more PV power plants for grid-connected applications.

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Appendices

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Appendix A

Appendix A: 6MW PV Plant output results using PVSYST

Version 7.2.16

PVsyst - Simulation report

Grid-Connected System

Project: DOKO 6MW

Variant: New simulation variant
No 3D scene defined, no shadings
System power: 6000 kWp
DOKO 6MW - Nigeria

Author

PVsyst V7.2.16
VC0, Simulation date:
02/07/22 12:24
with v7.2.16

Project: DOKO 6MW

Variant: New simulation variant

Project summary

Geographical Site	Situation		Project settings	
DOKO 6MW	Latitude	8.95 °N	Albedo	0.20
Nigeria	Longitude	5.97 °E		
	Altitude	0 m		
	Time zone	UTC		

Meteo data
DOKO 6MW
NASA-SSE satellite data 1983-2005 - Synthetic

System summary

Grid-Connected System | **No 3D scene defined, no shadings**

PV Field Orientation
Fixed plane
Tilt/Azimuth 30 / 0 °

Near Shadings
No Shadings

User's needs
Unlimited load (grid)

System information

PV Array		Inverters	
Nb. of modules	18183 units	Nb. of units	400 units
Pnom total	6000 kWp	Pnom total	6000 kWac
		Pnom ratio	1.000

Results summary

Produced Energy	10 GWh/year	Specific production	1600 kWh/kWp/year	Perf. Ratio PR	82.61 %

Table of contents

General parameters

Grid-Connected System — **No 3D scene defined, no shadings**

PV Field Orientation

Orientation		Sheds configuration	Models used	
Fixed plane		No 3D scene defined	Transposition	Perez
Tilt/Azimuth	30 / 0 °		Diffuse	Perez, Meteonorm
			Circumsolar	separate

Horizon	Near Shadings	User's needs
Free Horizon	No Shadings	Unlimited load (grid)

PV Array Characteristics

PV module		Inverter	
Manufacturer	Generic	Manufacturer	Generic
Model	KPV ME NEC 330Wp mono silver (Power-60)	Model	CSI-15K-T400-GL01-E
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	330 Wp	Unit Nom. Power	15.0 kWac
Number of PV modules	18183 units	Number of inverters	400 units
Nominal (STC)	6000 kWp	Total power	6000 kWac
Modules	957 Strings x 19 In series	Operating voltage	160-850 V
At operating cond. (50°C)		Pnom ratio (DC:AC)	1.00
Pmpp	5442 kWp		
U mpp	586 V		
I mpp	9287 A		

Total PV power		Total inverter power	
Nominal (STC)	6000 kWp	Total power	6000 kWac
Total	18183 modules	Number of inverters	400 units
Module area	30609 m²	Pnom ratio	1.00

Array losses

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 20.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

DC wiring losses
Global array res. 1.0 mΩ
Loss Fraction 1.5 % at STC

Module Quality Loss
Loss Fraction -0.4 %

Module mismatch losses
Loss Fraction 2.0 % at MPP

Strings Mismatch loss
Loss Fraction 0.1 %

IAM loss factor
ASHRAE Param.: IAM = 1 - bo (1/cosi -1)
bo Param. 0.05

Project: DOKO 6MW

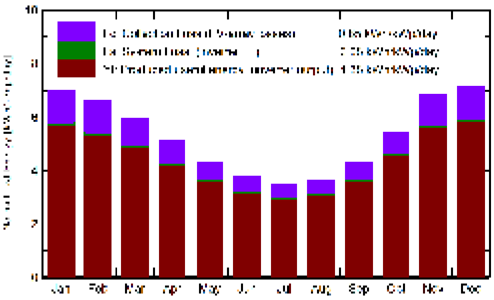
Variant: New simulation variant

Main results

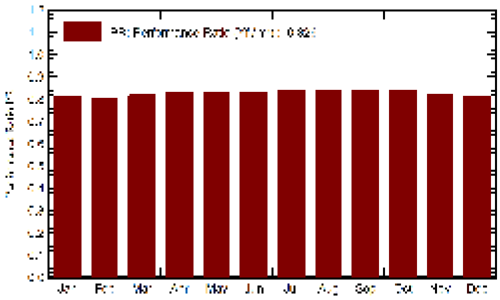
System Production

Produced Energy	10 GWh/year	Specific production	1600 kWh/kWp/year
		Performance Ratio PR	82.61 %

Normalized productions (per installed kWp)



Performance Ratio PR



Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray GWh	E_Grid GWh	PR ratio
January	177.9	46.50	27.14	218.2	214.5	1.082	1.065	0.813
February	165.5	49.28	27.51	185.0	181.8	0.913	0.898	0.809
March	186.3	62.62	26.93	185.1	180.9	0.925	0.909	0.818
April	173.4	66.00	26.29	153.2	148.4	0.777	0.763	0.831
May	168.3	66.96	25.86	134.3	128.8	0.682	0.670	0.832
June	147.6	64.80	24.94	113.1	107.8	0.578	0.567	0.835
July	137.6	68.51	24.09	108.9	104.0	0.560	0.549	0.840
August	132.1	70.68	24.00	113.7	109.5	0.588	0.576	0.844
September	136.5	68.10	24.40	129.0	125.2	0.665	0.653	0.844
October	158.7	62.93	24.73	169.2	165.5	0.866	0.851	0.839
November	171.6	47.10	25.40	205.5	201.8	1.032	1.015	0.823
December	175.8	43.40	26.41	221.8	218.1	1.104	1.087	0.816
Year	1931.3	716.88	25.63	1937.0	1886.4	9.771	9.602	0.826

Legends

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

PVsyst V7.2.16
VC0, Simulation date:
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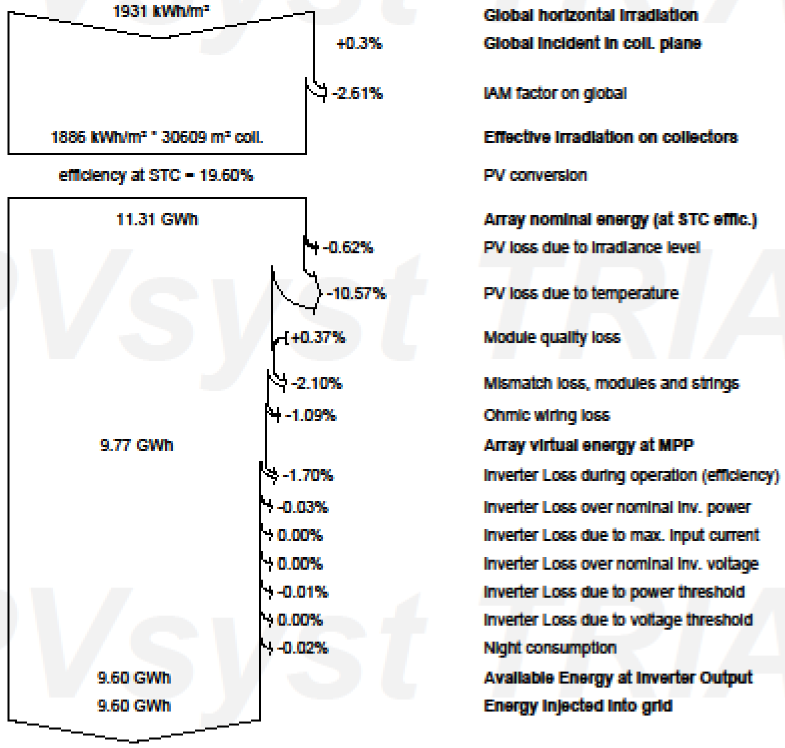
with v7.2.16

Project: DOKO 6MW

Variant: New simulation variant

Loss diagram



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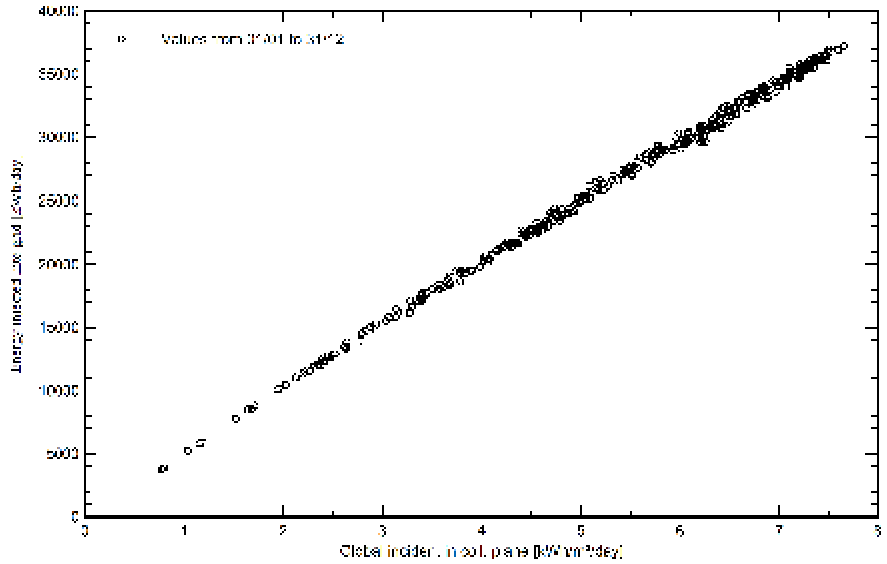
02/07/22 12:24
with v7.2.16

Project: DOKO 6MW

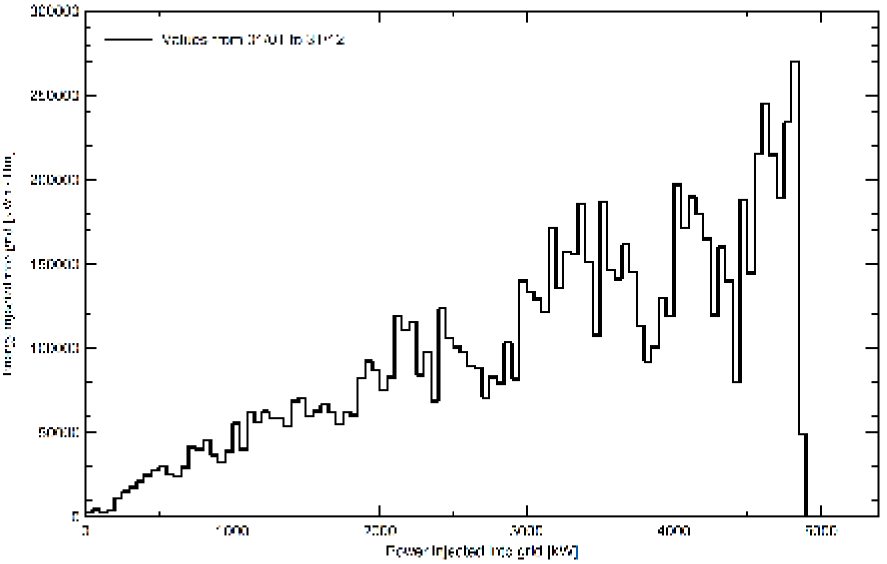
Variant: New simulation variant

Special graphs

Daily Input/Output diagram



System Output Power Distribution



Appendix B: 6MW PV Power Plant output results using Helioscope

HelioScope — Annual Production Report produced by Bashir Salihu

Design 1 DOKO PV POWER PLANT, DOKO NIGERIA

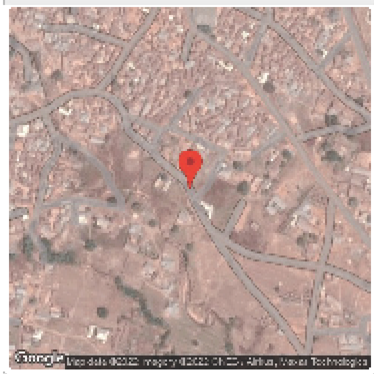
Report

Project Name	DOKO PV POWER PLANT
Project Address	DOKO NIGERIA
Prepared By	Bashir Salihu [illegible]@gmail.com

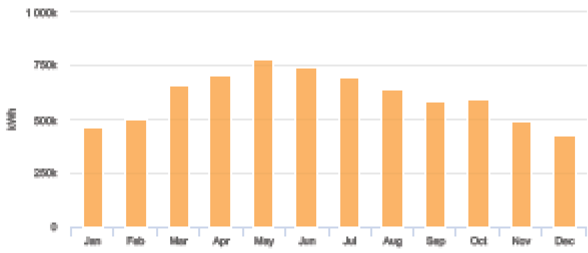
System Metrics

Design	Design 1
Module DC Nameplate	[illegible] MW
Inverter AC Nameplate	[illegible] MW Load Ratio: 1.00
Annual Production	[illegible] GWh
Performance Ratio	[illegible]
kWh/kWp	1,207.4
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)
Simulator Version	[illegible]

Project Location

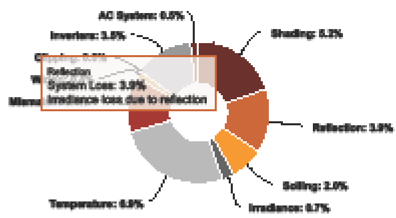


Monthly Production



Month	GHI (kWh/m²)	POA (kWh/m²)	Shaded (kWh/m²)	Nameplate (kWh)	Grid (kWh)
January	140.7	[illegible]	[illegible]	[illegible]	[illegible]
February	144.8	110.2	104.2	[illegible]	[illegible]
March	[illegible]	143.3	136.1	770,407.2	[illegible]
April	[illegible]	152.7	[illegible]	[illegible]	704,501.8
May	163.4	[illegible]	161.7	[illegible]	770,210.2
June	151.2	[illegible]	151.4	[illegible]	[illegible]
July	142.8	147.2	140.2	801,554.1	[illegible]
August	140.0	137.0	129.5	737,470.9	[illegible]
September	141.1	123.4	118.7	[illegible]	[illegible]
October	152.5	128.5	121.8	[illegible]	537,946.3
November	158.9	108.4	102.4	[illegible]	487,154.3
December	148.3	95.9	91.1	502,481.9	[illegible]

Sources of System Loss



HelioScope

Annual Production Report produced by Bashir Salihu

Annual Production

	Description	Output	% Delta
Irradiance (kWh/m²)	Annual Global Horizontal Irradiance	1,877.5	
	POA Irradiance	1,642.2	-12.5%
	Shaded Irradiance	1,459.4	-4.2%
	Irradiance after Reflection	1,441.3	-1.0%
	Irradiance after Soiling	1,412.5	-2.0%
	Total Collector Irradiance	1,412.5	0.0%
Energy (kWh)	Nameplate	8,488,107.2	
	Output at Irradiance Levels	8,431,817.0	-0.7%
	Output at Cell Temperature Derate	7,842,170.6	-6.9%
	Output After Mismatch	7,577,772.5	-3.4%
	Optimal DC Output	7,545,081.1	-0.4%
	Constrained DC Output	7,545,054.0	0.0%
	Inverter Output	7,380,877.0	-1.5%
	Energy to Grid	7,344,872.0	-0.5%
Temperature Metrics			
	Avg. Operating Ambient Temp		28.7 °C
	Avg. Operating Cell Temp		36.9 °C
Simulation Metrics			
		Operating Hours	4622
		Solved Hours	4622

Condition Set

Description	Condition Set 1											
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)											
Solar Angle Location	Meteo Lat/Lng											
Transposition Model	Perez Model											
Temperature Model	Sandia Model											
Soiling (%)	J	F	M	A	M	J	J	A	S	O	N	D
	2	2	2	2	2	1	2	2	2	2	1	2
Irradiation Variance	5%											
Cell Temperature Spread	4° C											
Module Binning Range	-2.5% to 2.5%											
AC System Derate	0.50%											

Temperature Model Parameters:

Rack Type	a	b	Temperature Delta
Fixed Tilt	-3.56	-0.075	3°C
Flush Mount	-2.81	-0.0455	0°C
East-West	-3.56	-0.075	3°C
Carport	-3.56	-0.075	3°C

Module Characterizations:

Module	Uploaded By	Characterization
KPV PE NEC 330 poly (Kioto Photovoltaics)	HelioScope	Spec Sheet Characterization, PAN

Component Characterizations:

Device	Uploaded By	Characterization
CSI-100KTL-GI-LFL (Canadian Solar)	HelioScope	Spec Sheet

Components

Component	Name	Count
Inverters	CSI-100KTL-GI-LFL (Canadian Solar)	400 (6.00 MW)
Strings	10 AWG (Copper)	1,200 (353,779.7 ft)
Module	Kioto Photovoltaics, KPV PE NEC 330 poly (330W)	18,183 (6.00 MW)

Wiring Zones

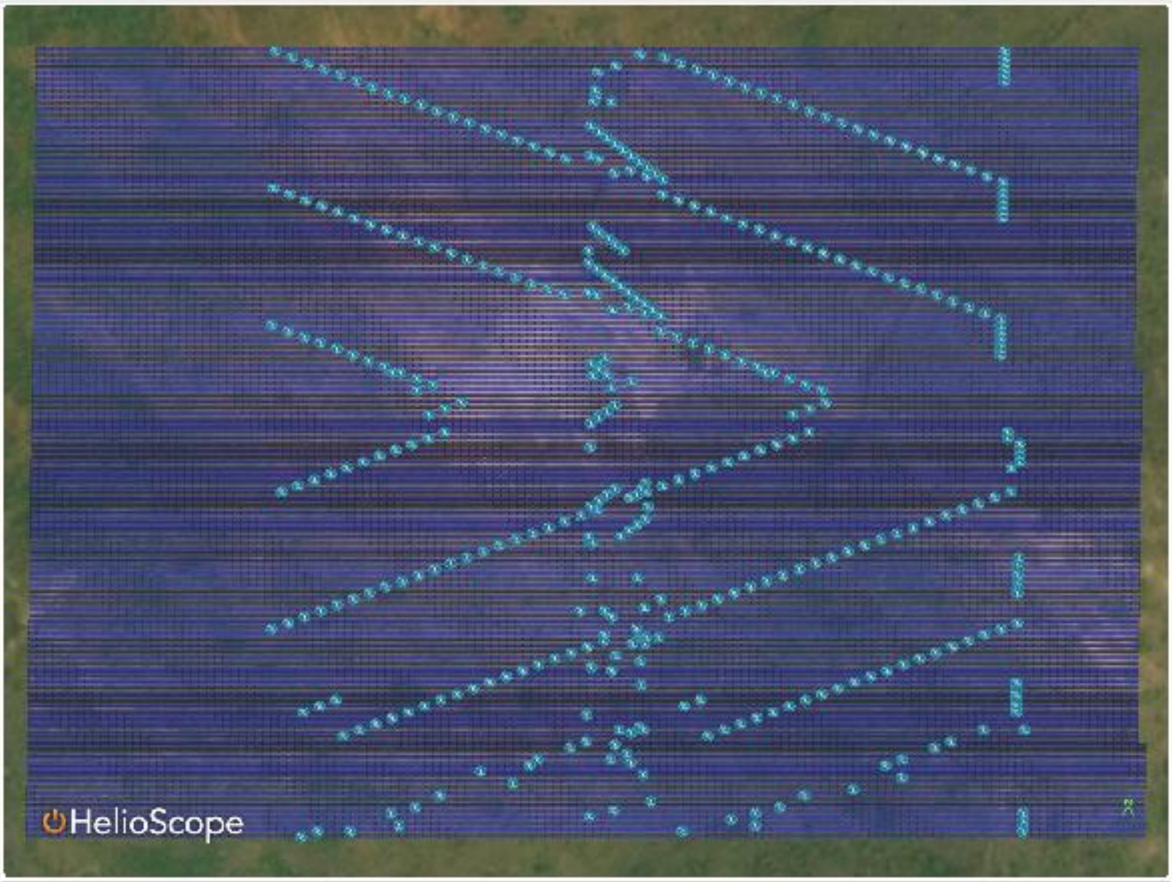
Description	Combiner Poles	String Size	Stringing Strategy
Wiring Zone	-	6-30	Along Racking

Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
[illegible]	Fixed Tilt	Landscape (Horizontal)	30°	0°	2.0 ft	1x1	18,183	18,183	6.00 MW

HelioScope Annual Production Report produced by Bashir Salihu

Detailed Layout



Appendix C: Standalone PV system using Pvsyst

Version 7.2.16

PVsyst - Simulation report

Stand alone system

Project: STANDALONE

Variant: New simulation variant

Stand alone system with batteries

System power: 76.2 kWp

DOKO STANDALONE - Nigeria

Author

Project: STANDALONE

Variant: New simulation variant

Project summary

Geographical Site
DOKO STANDALONE
Nigeria

Situation

Latitude	8.95 °N
Longitude	5.97 °E
Altitude	0 m
Time zone	UTC

Project settings

Albedo	0.20

Meteo data
DOKO STANDALONE
NASA-SSE satellite data 1983-2005 - Synthetic

System summary

Stand alone system

Stand alone system with batteries

PV Field Orientation
Fixed plane
Tilt/Azimuth 10 / 0 °

User's needs
Daily household consumers
Seasonal modulation
Average 267 kWh/Day

System information

PV Array

Nb. of modules	231 units
Pnom total	76.2 kWp

Battery pack

Technology	Lithium-ion, NMC
Nb. of units	323 units
Voltage	874 V
Capacity	5632 Ah

Results summary

Available Energy	125137 kWh/year	Specific production	1642 kWh/kWp/year	Perf. Ratio PR	20.38 %
Used Energy	30784 kWh/year			Solar Fraction SF	31.55 %

Table of contents

Project: STANDALONE

Variant: New simulation variant

PVsyst V7.2.16
VC0, Simulation date:
02/07/22 13:39
with v7.2.16

General parameters

Stand alone system — **Stand alone system with batteries**

PV Field Orientation

Orientation		Sheds configuration	Models used	
Fixed plane		No 3D scene defined	Transposition	Perez
Tilt/Azimuth	10 / 0 °		Diffuse	Perez, Meteonorm
			Circumsolar	separate

User's needs
Daily household consumers
Seasonal modulation
Average 267 kWh/Day

PV Array Characteristics

PV module

Manufacturer	Generic
Model	KPV ME NEC 330Wp mono silver (Power-60)
(Original PVsyst database)	
Unit Nom. Power	330 Wp
Number of PV modules	231 units
Nominal (STC)	76.2 kWp
Modules	33 Strings x 7 In series
At operating cond. (50°C)	
Pmpp	69.1 kWp
U mpp	216 V
I mpp	320 A

Battery

Manufacturer	Generic
Model	EM048290P5B1 290Ah
Technology	Lithium-ion, NMC
Nb. of units	19 in parallel x 17 in series
Discharging min. SOC	10.0 %
Stored energy	4461.4 kWh
Battery Pack Characteristics	
Voltage	874 V
Nominal Capacity	5632 Ah (C10)
Temperature	Fixed 20 °C

Controller

Universal controller	
Technology	MPPT converter
Temp coeff.	-5.0 mV/°C/Elem.
Converter	
Maxi and EURO efficiencies	97.0 / 95.0 %

Battery Management control

Threshold commands as	SOC calculation
Charging	SOC = 0.96 / 0.80
Discharging	SOC = 0.10 / 0.35

Total PV power

Nominal (STC)	76 kWp
Total	231 modules
Module area	389 m²

Array losses

Thermal Loss factor
Module temperature according to irradiance
Uc (const) 20.0 W/m²K
Uv (wind) 0.0 W/m²K/m/s

DC wiring losses
Global array res. 11 mΩ
Loss Fraction 1.5 % at STC

Serie Diode Loss
Voltage drop 0.7 V
Loss Fraction 0.3 % at STC

Module Quality Loss
Loss Fraction -0.4 %

Module mismatch losses
Loss Fraction 2.0 % at MPP

Strings Mismatch loss
Loss Fraction 0.1 %

IAM loss factor
ASHRAE Param.: IAM = 1 - bo (1/cosi -1)
bo Param. 0.05

Detailed User's needs

Daily household consumers, Seasonal modulation, average = 267 kWh/day

Summer (Jun-Aug)

	Number	Power	Use	Energy
		W	Hour/day	Wh/day
Lamps (LED or fluo)	1	20W/lamp	5.0	100
TV / PC / Mobile	2	60W/app	5.0	600
Domestic appliances	3	30W/app	4.0	360
Fridge / Deep-freeze	4		24	1000003
Dish- & Cloth-washers	5		2	25000
Ventilation	6	25W tot	24.0	3600
Stand-by consumers			24.0	144
Total daily energy				1029807Wh/day

Autumn (Sep-Nov)

	Number	Power	Use	Energy
		W	Hour/day	Wh/day
Lamps (LED or fluo)	10	10W/lamp	5.0	500
TV / PC / Mobile	2	100W/app	5.0	1000
Domestic appliances	1	500W/app	5.0	2500
Fridge / Deep-freeze	2		24	1598
Dish- & Cloth-washers	1		2	2000
Ventilation	1	100W tot	24.0	2400
Stand-by consumers			24.0	144
Total daily energy				10142Wh/day

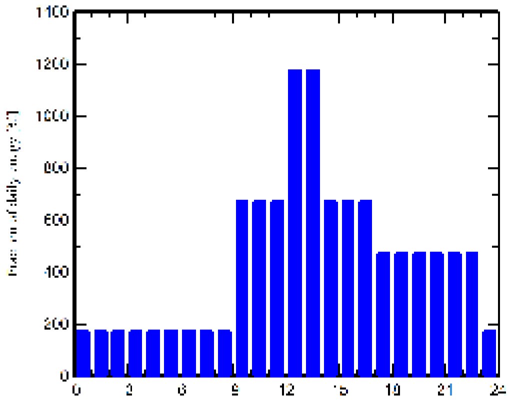
Winter (Dec-Feb)

	Number	Power	Use	Energy
		W	Hour/day	Wh/day
Lamps (LED or fluo)	10	10W/lamp	6.0	600
TV / PC / Mobile	2	100W/app	6.0	1200
Domestic appliances	1	500W/app	6.0	3000
Fridge / Deep-freeze	2		24	1598
Dish- & Cloth-washers	1		2	2000
Ventilation	1	100W tot	24.0	2400
Stand-by consumers			24.0	144
Total daily energy				10942Wh/day

Spring (Mar-May)

	Number	Power	Use	Energy
		W	Hour/day	Wh/day
Lamps (LED or fluo)	10	10W/lamp	5.0	500
TV / PC / Mobile	2	100W/app	5.0	1000
Domestic appliances	1	500W/app	5.0	2500
Fridge / Deep-freeze	2		24	1598
Dish- & Cloth-washers	1		2	2000
Ventilation	1	100W tot	24.0	2400
Stand-by consumers			24.0	144
Total daily energy				10142Wh/day

Hourly distribution



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with v7.2.16

Project: STANDALONE

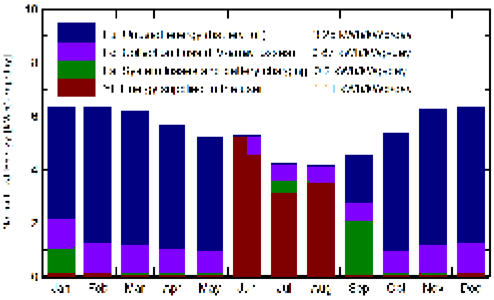
Variant: New simulation variant

Main results

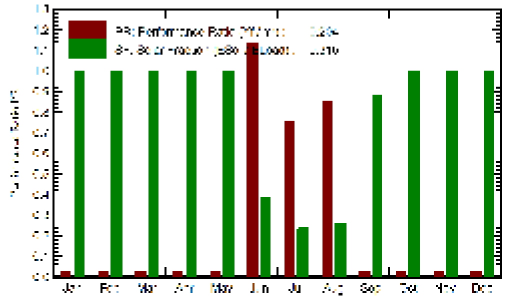
System Production

Available Energy	125137 kWh/year	Specific production	1642 kWh/kWp/year
Used Energy	30784 kWh/year	Performance Ratio PR	20.38 %
Excess (unused)	90492 kWh/year	Solar Fraction SF	31.55 %
Loss of Load		**Battery aging (State of Wear)**	
Time Fraction	18.7 %	Cycles SOW	99.9 %
Missing Energy	66799 kWh/year	Static SOW	90.0 %
		Battery lifetime	10.0 years

Normalized productions (per installed kWp)



Performance Ratio PR



Balances and main results

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_Miss kWh	E_User kWh	E_Load kWh	SolFrac ratio
January	177.9	192.0	12268	9794	0	339	339	1.000
February	165.5	173.2	11020	10653	0	306	306	1.000
March	186.3	187.0	12003	11622	0	314	314	1.000
April	173.4	166.9	10912	10544	0	304	304	1.000
May	168.3	156.4	10317	9937	0	314	314	1.000
June	147.6	135.0	8664	2	18869	12025	30894	0.389
July	137.6	126.8	8151	0	24375	7549	31924	0.236
August	132.1	125.1	8035	1	23520	8404	31924	0.263
September	136.5	133.6	8713	4037	35	269	304	0.884
October	158.7	162.4	10730	10350	0	314	314	1.000
November	171.6	183.4	11936	11568	0	304	304	1.000
December	175.8	191.6	12390	11984	0	339	339	1.000
Year	1931.3	1933.3	125137	90492	66799	30784	97583	0.315

Legends

GlobHor	Global horizontal irradiation	E_User	Energy supplied to the user
GlobEff	Effective Global, corr. for IAM and shadings	E_Load	Energy need of the user (Load)
E_Avail	Available Solar Energy	SolFrac	Solar fraction (EUsed / ELoad)
EUnused	Unused energy (battery full)		
E_Miss	Missing energy		

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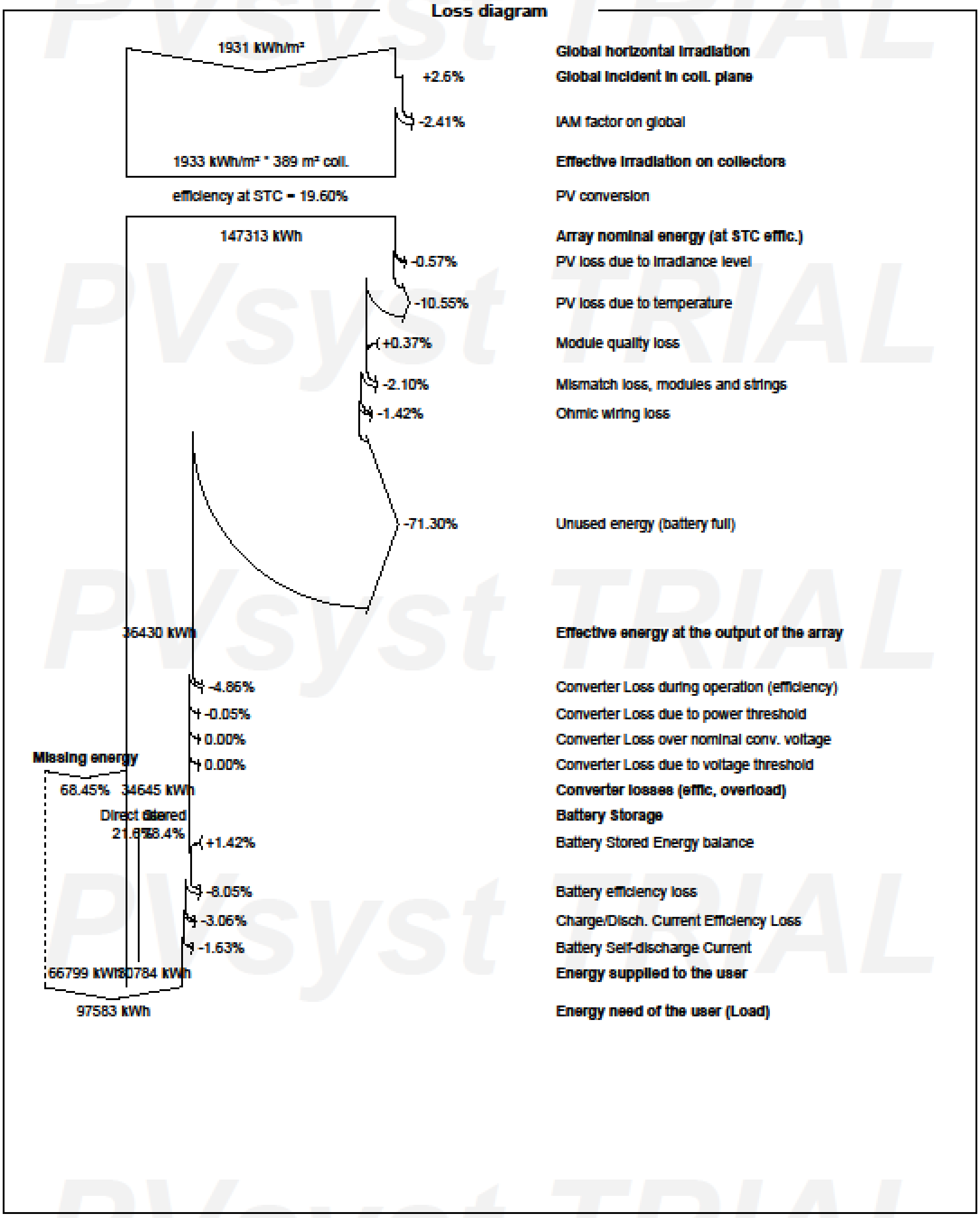
Project: STANDALONE

Variant: New simulation variant

Loss diagram



Special graphs

Daily Input/Output diagram