Stand-alone Photovoltaic scheme for Remote Rural Electrification

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Abstract- **The human activities contribute to the global warming of the planet. As a result, every country strives to reduce carbon emissions. Numbers of efforts are being undertaken by the Governments around the world to explore alternative energy sources and to achieve pollution reduction. Solar electric or photovoltaic technology is one of the biggest renewable energy resources to generate electrical power and the fastest growing power generation in the world. The main aim of this work is to analyze the interface of photovoltaic system to the load, the power electronics and the method to track the maximum power point (MPP) of the solar panel. Then main emphasis is to be placed on the photovoltaic system, the modelling and simulation photovoltaic array, and the DC/DC converter will be analyzed and evaluated. The step of modelling with MATLAB and Simulink of the photovoltaic system is shown respectively and simulation results are provided.**

***Keywords*—— PV cell, Mpp, Rural Electrification, Matlab Simulation.**

I. INTRODUCTION

Photovoltaic System (PV) is getting popular by day as the crude oil price increases and unstable in the global market [8]. Furthermore with green peace movement, and the consciousness of mankind has heightened up regarding green energy, photovoltaic may be one of the solution for better as well cleaner energy as it is naturally harness from the Sun energy. Although the technology is mainly well known in the space mission, yet it's still an alien for domestic usages. This is due to the high initial cost, generation efficiency and reliability. On the other hand, to answer the cry for alternative energy has made the PV system again popular among the researchers. Having said so, the rural areas where the grid connection is extremely expensive, PV Systems have been implied to give hope to these areas, while for the urban life, the PV Water Heater is common and can be found on the roof of the houses [4].

There are 1.6 billion people in the world today that are living without access to electricity. Many of these people live in remote rural areas in developing countries. It is well known that access to electricity and modern forms of energy are essential to all sectors of development. Bringing access to electrical services to rural people through grid-extension can be prohibitively expensive due to long distances and difficult terrain coupled with low population density and low per capita energy consumption [5].

It is often the case that this energy can be provided much more economically by producing the energy on-site using renewable energy technologies such as wind, micro-hydro and solar power. In this work Stand-alone off-grid PV-systems will be modelled that cover the electricity needs of single households, public buildings or commercial units offer a user-friendly and cost-effective electricity solution [1] [2].

Solar home systems consist of a photovoltaic (PV) array, a storage battery, a battery charge controller, an inverter and electrical loads which provide services to system users. The system operates autonomously to provide a clean, quiet and convenient source of electrical power. Solar array will be modelled and verified its characteristics [3].

It will be shown the economic way of operating solar array is to operate it on maximum power point. The performance of solar array will be compared with and without MPPT (maximum power point tracker).Algorithm will be devolved for charging control as well as supply the electricity needs of small village single households for different radiation. The all the work will be simulated in Simulink/Matlab environment**.** It will be shown that beside economic and social benefits, off grid PV systems also have positive impacts on people's health and on the environment due to the reduction of smoke and toxic waste [9].

II. PROPOSED PV SYSTEM

As for the kick start, the understanding on the operation and electrical equivalent circuit of single solar cell will be discuss without the sun light (dark), the solar cell shall function as a normal diode. If any external supply connects to it, the solar cell will function and produce the diode current (ID) [6]. In the dark, the solar cell will not produce any electric current or voltage. This solar cell model consists of a current source (Iph), series resistance (Rs) which representing the resistance inside the each cell as well in the connection between the cells, and a diode. The difference between Iph and ID will give the net current output from the solar cell [5].

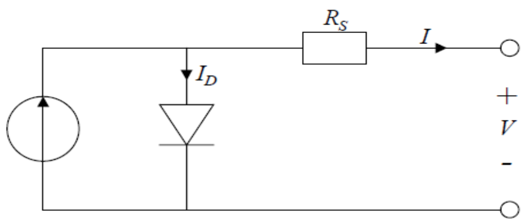


Figure 1: Model for single solar cell

The mathematical equation can be represented as in equation 1. The equation is actually using Kirchhoff Current Law (KCL) and also diode Shockley equation. The m is the representation of idealizing factor, k Boltzmann's gas constant, Tc will be absolute temperature of the cell, e will be electric charge, and V will be the voltage implied across the cell. Io is saturation current in dark surroundings and depends on the temperature.

$$I = Iph - Id = Iph - Io(exp^{\frac{e(V+IRs)}{mKTc}} - 1) \text{.........} (1)$$

The solar cell has certain parameters, such as short circuit current, open circuit voltage, maximum power point, maximum efficiency, and fill factor. Short circuit current is the best current produced when the solar cell under short circuited situation which means the voltage as zero. In other word Isc = Iph. Then another parameter of solar cell is open circuit voltage. This open circuit voltage can be obtained during night time (dark) whereby the current produced is zero and related to voltage drop across the diode [9].

It can also represented by mathematical equation such as in equation 2 whereby $\frac{mKTc}{e}$ is known as thermal voltage and Tc is the absolute cell temperature.

$$Voc = \frac{mKTc}{e} \ln\left(\frac{Iph}{Io}\right) = Vt \ \ln\left(\frac{Iph}{Io}\right) \text{--------------} (2)$$

Maximum power point is another parameter that being used in the solar cell operation whereby it states the maximum power dissipated at the load. Referring to Figure 2 courtesy from Model for Stand Alone PV system.

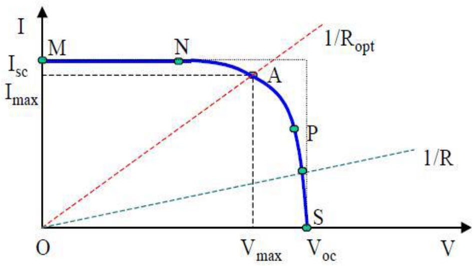


Figure 2: A typical current-voltage (I-V) curve for a solar cell.

Maximum efficiency is another parameter for solar cell need to be considered as well. Maximum efficiency in the solar cell context means the ratio between incident light power and maximum power. The equation 3 depicts clearly and as Ga is the ambient irradiation as well the A is the cell area.

$$\eta = \frac{Pmax}{Pin} = \frac{Imax\ Vmax}{A\ Ga} \text{-------} (3)$$

Fill factor (FF) is another parameter used in the solar cell analysis. Fill factor can be defined as how close the I-V curve can get close to be a square wave. Another definition of fill factor is the ratio of maximum power that can be delivered to the load compared to Isc and Voc. In equation 4, the formula is shown clearly.

$$FF = \frac{Pmax}{Voc\ Isc} = \frac{Imax\ Vmax}{Voc\ Isc} \text{-------} (4)$$

III. Cuk Converter

Introduction

The main purpose of the DC/DC is to convert the DC input from the PV into a higher DC output. The heart of MPPT hardware is a switch-mode DC-DC converter. It is widely used in DC power supplies and DC motor drives for the purpose of converting unregulated DC input into a controlled DC output at a desired voltage level. MPPT uses the same converter for a different purpose: regulating the input voltage at the PV MPP and providing load matching for the maximum power transfer [10].

Topologies

There are a number of different topologies for DC-DC converters. They are categorized into isolated or non-isolated topologies. The isolated topologies use a small-sized high-frequency electrical isolation transformer which provides the benefits of DC isolation between input and output, and step up or down of output voltage by changing the transformer turns ratio [7].

They are very often used in switch-mode DC power supplies. In PV applications, the grid-tied systems often use these types of topologies when electrical isolation is preferred for safety reasons. Non-isolated topologies do not have isolation transformers. They are almost always used in DC motor drives.

These topologies are further categorized into three types: step-down (buck), step up (boost), and step up & down (buck-boost). The buck topology is used for voltage step-down. In PV applications, the buck type converter is usually used for charging batteries and in LCB for water pumping systems. The boost topology is used for stepping up the voltage.

The grid-tied systems use a boost type converter to step up the output voltage to the utility level before the inverter stage. Then, there are topologies able to step up and down the voltage such as: buck-boost, Cuk, and SEPIC (stands for Single Ended Primary Inductor Converter). For PV system with batteries, the MPP of commercial PV module is set above the charging voltage of batteries for most combinations of irradiance and temperature.

Buck converter can operate at the MPP under most conditions, but it cannot do so when the MPP goes below the battery charging voltage under a low-irradiance and high-temperature condition. Thus, the additional boost capability can slightly increase the overall efficiency.

Cuk Converters

For water pumping systems, the output voltage needs to be stepped down to provide a higher starting current for a pump motor. The buck converter is the simplest topology and easiest to understand and design, however it exhibits the most severe destructive failure mode of all configurations [7].

Another disadvantage is that the input current is discontinuous because of the switch located at the input, thus good input filter design is essential. Other topologies capable of voltage step-down are Cuk and SEPIC. Even though their voltage step-up function is optional for LCB application, they have several advantages over the buck converter.

They provide capacitive isolation which protects against switch failure (unlike the buck topology). The input current of the Cuk and SEPIC topologies is continuous, and they can draw a ripple free current from a PV array that is important for efficient MPPT.

Figure 3 shows a circuit diagram of the basic Cuk converter. It can provide the output voltage that is higher or lower than the input voltage. Cuk converter is also able to step up and down the voltage [7]. It uses a capacitor as the main energy storage. As a result, the input current is continuous.

The circuits have low switching losses and high efficiency. The main difference is that the Cuk converter has a polarity of the output voltage reverse to the input voltage. On the other hand, the Cuk converter can provide a better output current characteristic due to the inductor on the output stage. Therefore, the thesis decides on the Cuk converter because of the good input and output current characteristics.

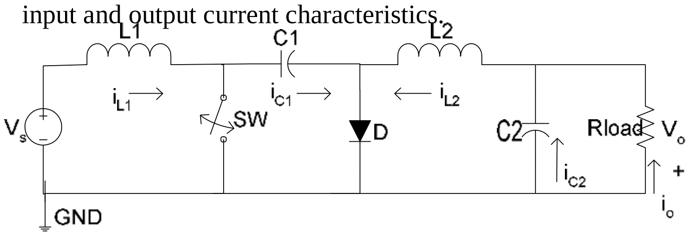


Figure 3: Circuit diagram of the basic Cuk converter

IV. MATLAB SIMULATION

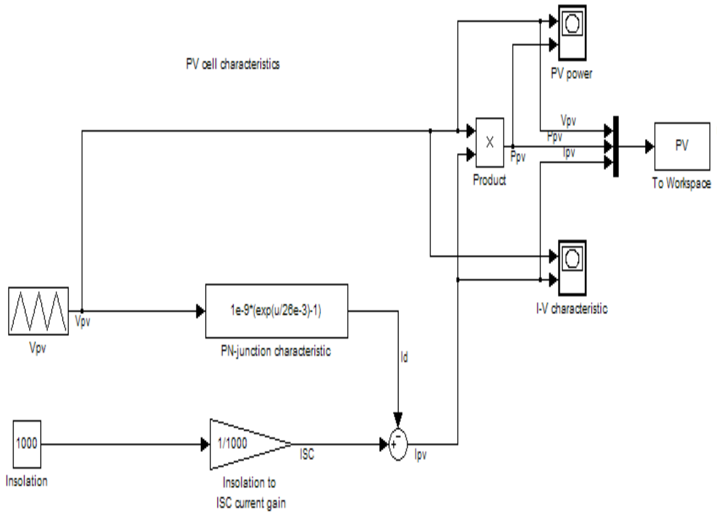
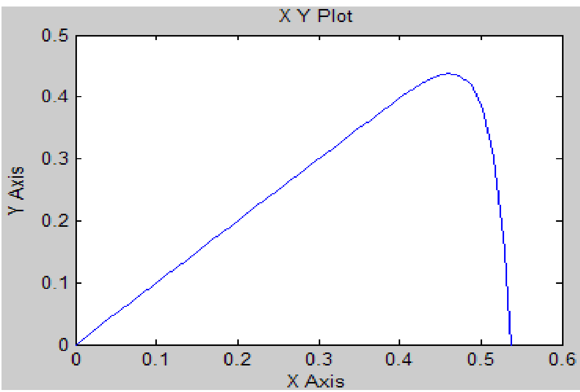


Figure 4: Matlab Simulation of PV Cell



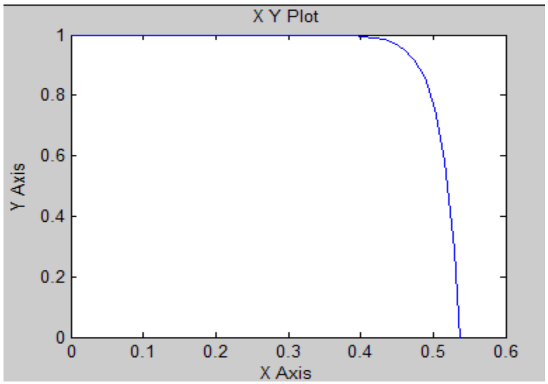


Figure 5: Waveform of PV Cell

CUK CONVERTER:-

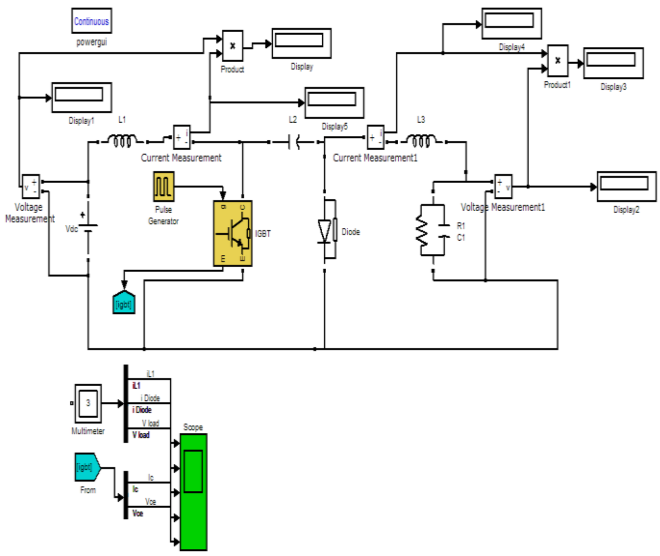


Figure 6: Matlab Simulation of CUK Converter

G(irradiation)	P(MPP power)	V(MPP voltage)	I(MPP current)
1000	0.4378	0.4600	0.9517
800	0.3458	0.4600	0.7517
600	0.2550	0.4460	0.5718
400	0.1658	0.4460	0.3718
200	0.0796	0.4180	0.1904

Table 1: Result of Different Insolation on PV Array

%D	Vin	Iin	Pin	Vout	Iout	Pout	Vout/Vin
0.2	120	0.299	35.85	-29.27	-1.102	32.26	-0.2439
0.3	120	0.8798	105.6	-50.64	-1.927	96.42	-0.422
0.35	120	1.732	207.8	-61.7	-2.178	134.4	-0.5142
0.4	120	2.089	250.7	-86.06	-3.515	320.5	-0.7172
0.42	120	3.136	376.4	-91.67	-3.146	288.3	-0.7639
0.45	120	3.351	402.1	-100.5	-4.179	420.2	-0.8375
0.48	120	4.806	576.7	-113.4	-4.223	479.1	-0.945
0.5	120	5.901	708.1	-127.4	-4.454	567.6	-1.0616
0.52	120	6.887	825.3	-139.6	-4.988	696.2	-1.1633
0.55	120	8.769	1025	-161.6	-6.023	973.2	-1.3466
0.6	120	13.49	1619	-201.7	-7.726	1558	-1.6808
0.65	120	17.33	2080	-227.1	-8.709	1978	-1.8925
0.7	120	24.36	2924	-268.7	-10.3	2768	-2.2392

0.75	120	36.62	4395	-328.3	-12.59	4131	-2.7358
0.8	120	60.79	7295	-420.2	-16.11	6769	-3.5016

Table 2: Result of Different Duty cycle

V. CONCLUSION

In this paper, from the theory of the photovoltaic, a mathematic model of the PV has been presented. Then, the photovoltaic system with DC-DC Cuk converter and resistive load has been designed.

First, the simulations of the PV panels showed that the simulated models were accurate to determine the characteristics voltage current because the current voltage characteristics are the same as the characteristics given from the data sheet. In addition, when the irradiance or temperature varies, the PV models output voltage current change.

The simulations of the PV with maximum power point, Cuk converter and resistive load were performed by varying the load, the irradiance and the temperature.

Finally, the results showed that the DC voltage generated by the PV array could produce an AC current sinusoidal at the output of the inverter. The amplitude of the current depends on the PV power.

A small villages up to 50kw load is electrified on given electric supply by this model is verified. Load voltage (AC bus voltage) is fairly constant for change in load as well as change in radiation. Voltage of dc bus is also constant for all the conditions that can be utilize for the charging of battery or dc load can directly connected.

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