Design and Simulation of Buck Boost Controller of Solar Wind Hybrid Energy System

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Abstract- Because of combustion of fossil fuels global warming caused by environmental problems, the raising prices of crude oils and natural gases. They promote continuous effort to improve energy system and its efficiency. There is a need to search for abundant and clean energy sources due to the depleted and increasing prices of oil. Solar and wind energy acts as an alternative energy source.

The objective is to design and simulate a controller for the unlimited solar power drawn from the sun and produce a higher voltage output through the dc-to-dc converters (Buck-Boost Converter). The Photovoltaic cells have a non-linear V-I characteristics and adapts the Maximum Power Point Tracker (MPPT) to achieve the maximum permissible power obtained. A controller circuit is design to track the maximum power of the photovoltaic at the peak voltage and current level. Dc-to-Dc converters (Buck-Boost Converter) are necessary to produce a higher voltage due to the low input voltage drawn from the photovoltaic cells. The voltage is maintained at a constant voltage at the output load by the switching control circuit. Wind controller circuitry comprises a non-inverting buck and boost converter circuit. The result shows that the model can simulate the photovoltaic models, wind system and track the maximum power which helps to design and improve the power of solar wind energy system.

***Keywords: Modeling, Photovoltaic System, Maximum Power Point Tracker, Buck-Boost Converter*.**

I.INTRODUCTION

With the prices of oil at its highest and the increasing demand every year, it is causing environment concerns which lead to global warming around the world. New energy sources like solar and wind power are readily available and much sought after. They produce clean energy power which does not affect the Ozone layer.

With free solar energy available, cutting down on electrical bills on industrial and home seems a possibility in the near future as the photovoltaic conversion into electrical energy. Large scale solar energy systems are being tested and might even be implemented in the coming years to cut down the emission of CO_2. Demand for photovoltaic energy will increase over the years as the breakthrough in this new technology will sustain it at a lower cost.

II. MODELING OF SOLAR PV CELL

The working condition of the solar cell depends mainly on the load and solar isolation. They operate in the open circuit mode and short circuit mode. Based these characteristics, the output voltage, current and power can be computed.[1]

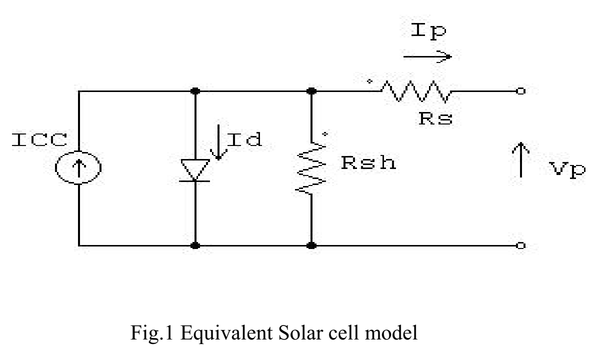

Fig.1 Equivalent Solar cell model

Iph – Photodiode current
Vd – Diode voltage
Id – Diode current
n - Diode factor (1 for ideal and >2 for real conditions)
Io - Reverse saturation current
T - Temperature for the solar arrays panel in kelvin
K – Boltzmann's constant = 1.38 x 10-23 J/K
Q – Electron charge = 1.6 x 10-19C
Rs – Intrinsic series resistance usually in milli-ohms Rsh – Shunt resistance usually in kilo-ohms
The I-V characteristics of a solar cell while neglecting the internal shunt resistance is given by

$$I_{out} = I_{ph} - I_o \left[\exp\left(\frac{q}{nKT \ln(V + IoutRs)} \right) - 1 \right] \quad (1)$$

In the event that the circuit is shorted indicating that the output voltage is =0. The current through the diode is being omitted. The short-circuit current, Isc = I can be represent by

$$I = I_{ph} - \frac{RsI}{Rsh} \quad (2)$$

Generally with the relationship that exists between Isc and Iph, the output current is given below. From the relationship, output current is approximately the almost the same as the photocurrent.

$$I = I_{sc} = \frac{I_{ph}}{\left(\frac{1 + Rs}{Rsh} \right)} \quad (3)$$

When the circuit is in open-circuit mode, the output current I is =0. At this point, the open-circuit voltage, Voc is calculated.

$$Voc = Vmax = \left(\frac{(nkT)}{q * \ln * \left(\frac{Iph}{Io} \right)} \right)$$

The output power can be expressed based on the open circuit voltage and short circuit current.

$$P = IV = \left(\frac{Iph - Id - Vd}{Rsh} \right) = V \quad (5)$$

The Pmax relationship is also represented in terms of Vmppt. The Pmax is the maximum output power and Vmppt is the optimal output voltage.

$$Pmax = I_{ph} \left\{ \begin{matrix} Voc - \left(\frac{nkT}{q} \right) \ln \left(\frac{1 + qV_{mppt}}{nkT} \right) - \frac{Voc}{\left(qV_{mppt} + nkT \right)} + \\ nkt \left(\frac{1}{V_{mppt}} \right) \ln \left(1 + \frac{qV_{mppt}}{nkt} \right) \end{matrix} \right\}$$

Iph – Photodiode current

Vd – Diode voltage

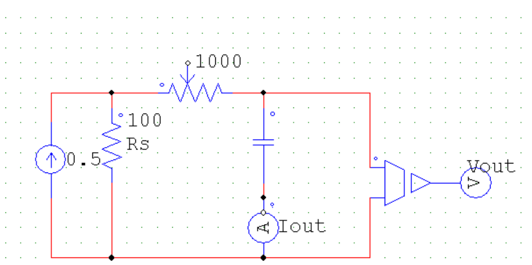

Fig.2 PV cell Simulated circuit

III. DC-DC CONVERTERS

Switch mode DC-to-DC converter are normally use to convert the unregulated Direct Current (DC) input sources into controlled DC output at certain or required voltage level.

A. Linear

The linear regulators are seen in equipment where the excess heat dissipated and low efficiency is not an issue. The integrated circuit (I.C) is use for voltage regulation. Linear regulator is known as step down regulator because it can only produce output voltage lower than the source voltage. The efficiency can range from 35% to 50%. Linear regulator is cheaper, reliable and much simpler than switching regulators but is mostly suitable for power sensitive analog circuits.

B. Switch Mode Conversion

In the Switched-mode conversion, the Dc-Dc convert one Dc voltage level by storing the incoming energy temporarily for a time period and releasing the stored energy to the output at a higher voltage. The form of storage may be in either magnetic components such as inductors or transformers and capacitors. It is an efficient method as compare to linear voltage regulators which gives unwanted voltages as heat source. This method is power efficient from 75% up to 98%.

C. Pulse Width Modulation in switching DC-DC converters

DC-DC converters can be control by the use of the Pulse Width Modulation (PWM) signal at the input gate of the switch. The switch can be of MOSFET or an IGBT type in the circuit. PWM is use in converters to control the period at the pulse to make it switch high or low, by modifying the period of the PWM signal and the time at "on" and "off" position. A continuous triangular waveform with a control signal voltage as shown in figure 2.5 is associated with the controlling of a switch. The constant peak triangular waveforms determine the switching frequency of the cycle and by amplifying the error signal of the converter output and the desired voltage, the control voltage is being output.[5]

IV. SOLAR CONTROLLER

Buck-Boost converter is combination of a buck and boost converter. It can be an non inverting topology where the output voltage is of opposite polarity as the input. It can also act as a buck converter follow by the boost converter function.

From figure 3, when the switch is in the "on state", the inductor stored the energy in the magnetic field as it is connected with the source voltage where currents will flow through. The diode is reversed biased and hence no current can flow to the load through the diode. The capacitance will provide current in this "Ton" situation. When the switch is off, inductance is disconnected from the source and there will be no current drop which the inductance will reverse it EMF. A voltage is generated as the diode at this time is forward biased; current will flow in the load and charged up the capacitance.

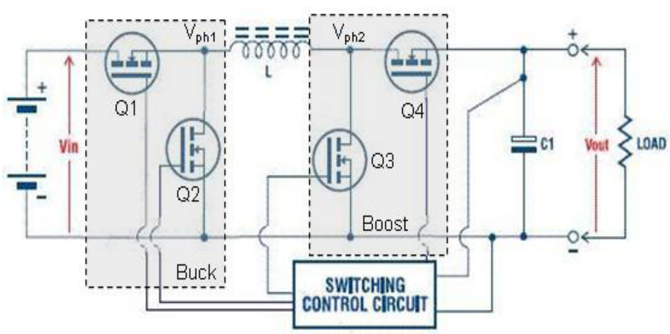

Fig.3. Buck Boost converter

A. Boost Converter

The converter is made up of an input source voltage, an inductor, a switch, capacitor and the output load. This type of configuration is use to boost up the output voltage with a lower input source. Most of the designs usually specified they require value of input voltage, output voltage and the load current whereas the inductor and ripple current are free parameters. To reduce a ripple, a larger value of inductor should be able to reduce it since it is inversely proportional to the ripple current. Likewise when choosing the inductor, it should ensure the saturation current is greater than the inductor peak current and able to cope with the rms current.

It should be noted a light load for the circuit can go in discontinuous mode. By choosing a large value inductor, the ripple current is two times larger than the minimum load current, the inductor will always operate in continuous mode. [5]
When the switch is close or on state, the voltage across the inductor is represented by equation .

$$V_L = \frac{Lid}{dt} = \frac{I_{LPK}}{t_{on}}$$

The current across the inductor is expressed by.

$$I_{Lon} = \left[\frac{V_{in} - V_{sat}}{L}\right] t_{on}$$

When the switch is open or on state, the voltage across the inductor is given by

$$V_l = \frac{Lid}{dt} = \left[\frac{I_{L\,min} - I_{LPK}}{t_{off}}\right]$$

The current across the inductor is given by

$$I_{Loff} = I_{LPK} - \left[\frac{V_{out} - V_F - V_{in}}{L}\right] t_{off}$$

The duty cycle is given as:

$$D = \frac{t_{on}}{t_{on} + t_{off}}$$

The ratio of the on-time and off-time can be represented by equation

$$\frac{t_{on}}{t_{off}} = \frac{V_{out} + V_F - V_{in}}{V_{in}\ V_{sat}}$$

The required minimum inductance value can be expressed as

$$L = \left(\frac{\{V_{out} - V_{in} + V_F\}\{1 - D\}}{min(i_{load})f}\right)$$

The capacitor value can be calculated when the ripple voltage is present at the output as follows

$$C_{out} = \left(\frac{I_{out}}{V_{ripple}}\right) t_{on}$$

$$V_{out} = \frac{V_{in}}{(1 - D)}$$

The value of D is varies in the range of 0 < D < 1. The lowest output voltage value is when D = 0, which the output voltage equals Vin and when D approaches unity, the output voltage tends to infinity.

B. Buck Converter

Buck converter components elements are the same as the Boost converter, except the arrangement of the power switch, Inductor and diode are slightly different. Again the operation consists of varying the switching duty cycle of the power switch to obtain desire output voltage. However, this time is to step down from a higher voltage to a lower voltage.

$V_{out} = V_{in} D$

It is clear that the output voltage depends directly on the duty cycle. If the duty cycle is 50%, output voltage will be one half of the input voltage.

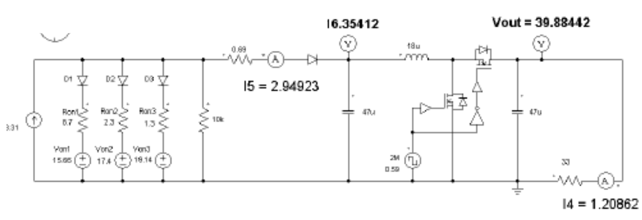

Fig.4. Solar Buck Boost Simulated Circuit for open loop Control

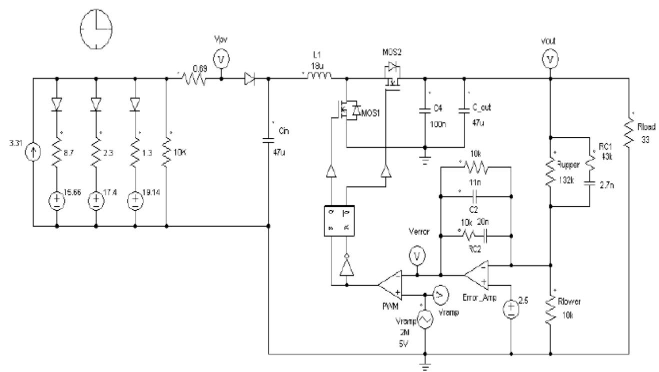

Fig.4. Solar Buck Boost Simulated Circuit for closed Control

V. WIND CONTROLLER

Most wind turbine less then 700W in the market comes in either AC or DC output option. The wind controller design here will support both option using the same hardware circuitry by changing certain components and connectors. To support AC output WTG, isolation transformer and bridge rectifier will be used, while these components will be changed in the DC output WTG version. Depending on how strong the wind blows, higher or lower input voltage can be generated from the AC type WTG. Therefore, a non-inverting buck boost topology is implemented here to regulate a constant 42V to the DC bus.[7]
The non-inverting buck-boost converter will be design to operate either in buck or boost mode alone each having their own compensation network and feedback path. Mode selection process is determined by the mode selector circuit, where the rectifier output Vrect is sense and compare with a 42V reference voltage. When Vrect is less than 42 V, circuit will acts Buck Mode. When Vrect is greater than 42 V, circuit will acts Boost Mode.[8]

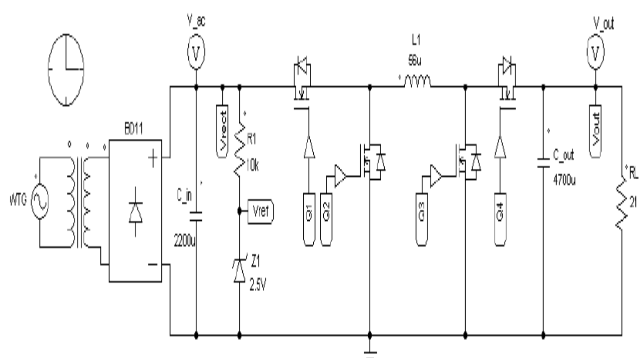

Fig.6. Wind Buck Boost Simulated Circuit for open loop Control

VI. SIMULATION RESULTS

a. PV cell simulator circuit

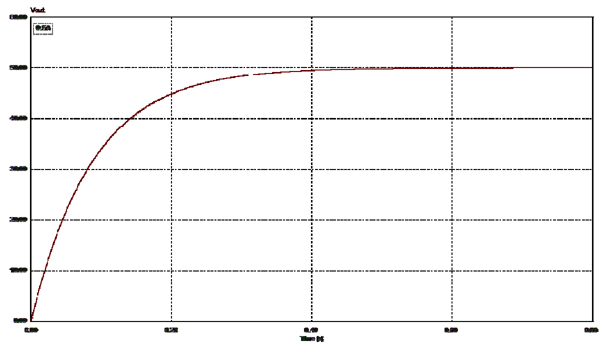

Fig.7. PV simulator voltage output

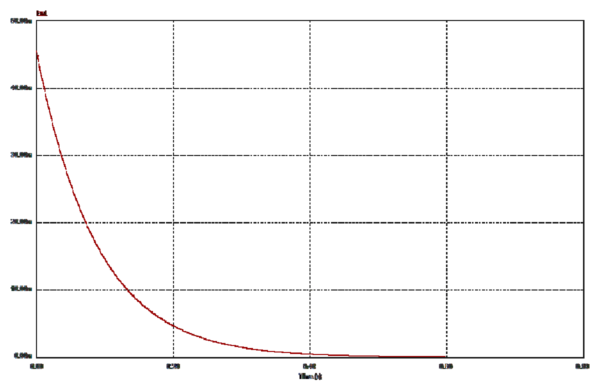

Fig.8. PV simulator current output

b. Solar Controller simulated circuit

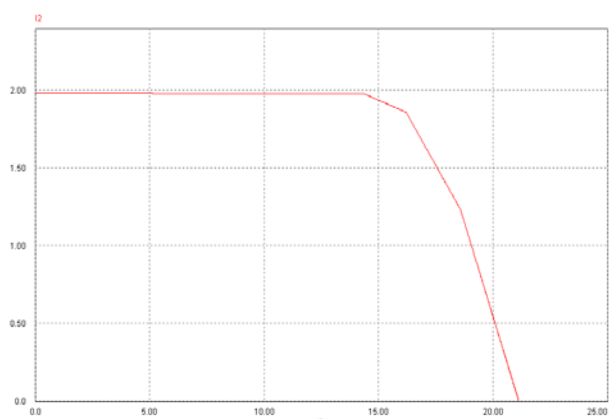

Fig.9. I-V Simulator Plot

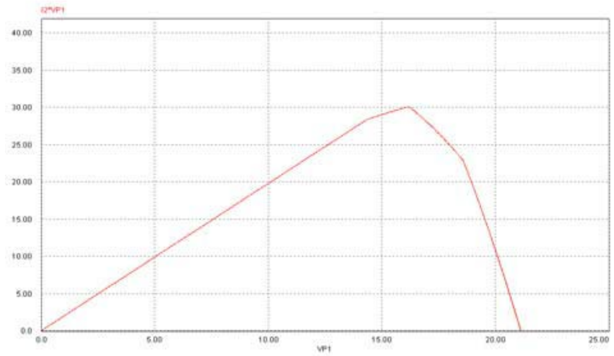

Fig.10. PV Simulator Plot

c. Wind Controller simulated Circuit.

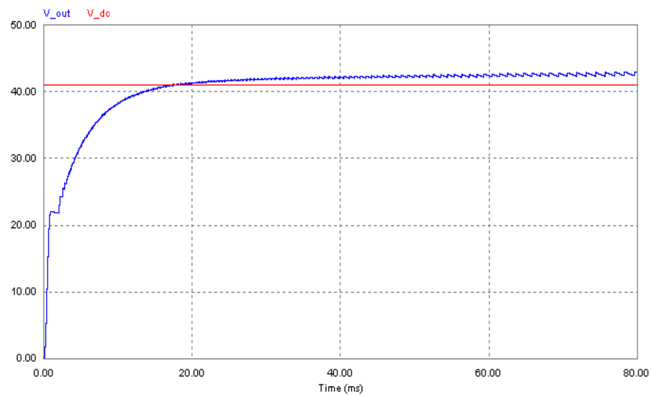

Fig.11. voltage output for load 10 ohm

VII. CONCLUSION

This paper is presenting the integrated circuit of the simulated photovoltaic cells circuit characteristics, a MPPT controller circuit. This will help us to understand the photovoltaic characteristics, dc-to-dc converters topologies, components calculation and circuit design. A power circuitry is used for DC-DC converter to get the required output. Buck boost converter must control and maintain the voltage at maximum value. And controller will track maximum power. All the hardware design required no programming as it will be done solely based on software stimulation using the PSIM program. The stimulations results reflected that the testing component is capable of producing real-life hardware performance.

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