# Modelling of Hybrid Power System and Characteristic Determination Of DC-DC Converter

G. Abhinava
School of Mechanical and Building Sciences,
VIT University Vellore, India

***Abstract* - The DC-DC converters are most widely and significantly used in the hybrid systems and is an inseparable part of the system. The converters are responsible for joining the various renewable sources of energy like wind, solar, hydro etc to the load side of the system and the error in calculating the efficiency of the converters can give rise to various problems like false estimation of load, triggering of relay circuits which adversely effects the reliability and safety of the whole system along with miscalculating the system efficiency. The converters efficiency in conventional method is calculated using a constant source of power supply which is constant and free from any disturbances and harmonics. The efficiency calculated from such sources are not applicable for the real world as the real power sources contains harmonics and distortion in its output power supply and the converters components work under higher stress condition than in first case. This reduces the converters performance and effects the efficiency also. A hybrid model comprising of the wind and solar power is simulated in the Matlabsimpower software which closely resemble the real world power source condition and the characteristic estimation of the basic type of converter is done. It is found that the efficiency obtained at rated load for a DC-DC converter is 89% where as it was found 93.8% for the constant voltage source converters.**

***Key words: Hybrid plant, DC DC converters, efficiency***

NOMENCLATURE:

$A$ :rotor swept area

$C_p$: Power coefficient

$I_0$: Cell reverse saturation current

$I_{ph}$: Light generated current

$I_{scr}$: Short circuit current at $25^0C$

$K_i$: Short circuit temp coefficient at $I_{scr}$

$V_w$: Wind speed

R : Turbine radius

$I_0$&$V_0$: Cell output current and voltage

S: Solar radiation

$\rho$: Air density

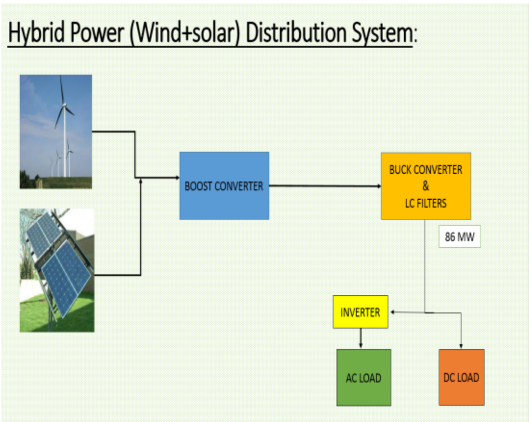
$\lambda$: Tip speed ratio

$\beta$: Pitch angle

$\Omega$ : Speed of turbine

## 1. INTRODUCTION:

The hybrid unit contains two complete generating plants, a solar plant and a wind system. The two sources are connected in parallel, and the power is connected to a DC to DC converter if load is DC or AC inverter and is then supplied from the inverters output to a single phase load. The concept of having hybrid power stations is not new, but has gained popularity in recent years [1]. Hybrid energy stations have proven to be advantageous for decreasing the depletion rate of fossil fuels, as well as supplying energy to remote rural areas [3], without harming the environment. Hybrid Electric systems combine wind and solar photovoltaic technologies offering several advantages over either single system.




The converter being the inseparable part of the hybrid system plays an important role in determining the overall efficiency of the system. The false estimation of characteristic property of the converter can lead to various complications in the system such as:

- Under/over estimation of load connected to system.
- Increasing instability of the system.
- False activation of relay circuits.
- False contingency & fault analysis.
- Implying over/under rated components in the system, further reducing system efficiency and stability.

This paper deals with the following points in determining the characteristic of the single inductor boost converter in a hybrid power plant:

- Analysing the voltage and current output response of the SIBC under different load conditions.
- Calculating the efficiency of SIBC for above load conditions.
- Analysing the SIBC voltage and current output for resistive plus inductive load.
- Estimating the efficiency curve for SIBC.

## 2. MODELLING OF HYBRID PLANT:

### *2.1. Wind power:*

Wind turbines are used to convert the wind power into electric power. Electric generator inside the turbine converts the mechanical power into the electric power. Wind turbine systems are available ranging from 50w to 2-3 MW. Mechanical output of turbine of wind generator is dependent on the speed of turbine. For small turbines, wind speed is about 3.5m/s. large wind power plants require wind speed of 6m/s. But wind speeds higher than this are available in many locations.

Wind turbine power characteristic that describes the mechanical power that is generated by the wind is given as:

$$P_m = 0.5\rho A C_p(\lambda,\beta) V_w^3 \qquad (1)$$

Performance or power coefficient Cp depends on wind speed, the speed of the turbine and the pitch of the blades. The power coefficient of the turbine is given by:

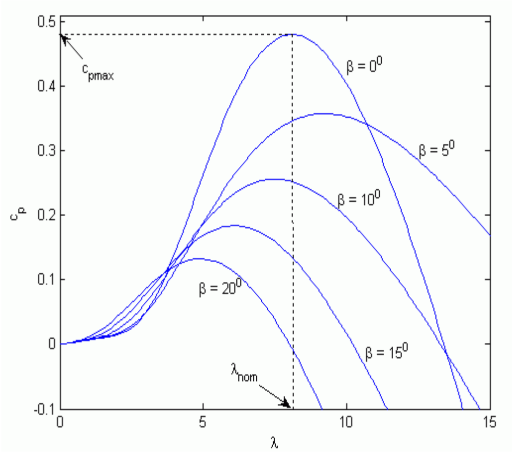
$$C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right)e^{-\frac{c5}{\lambda i}} + C_6\,\lambda \qquad (2)$$

With

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1}$$

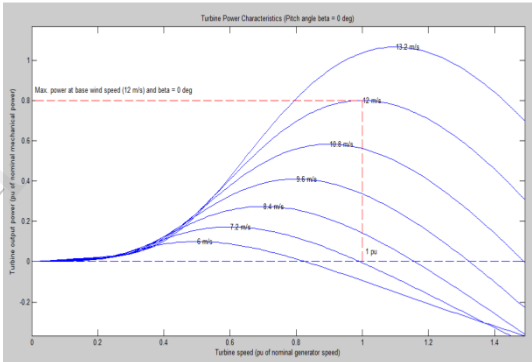
The Cp-λ characteristics, for different values of the pitch angle β, are illustrated below:






The maximum value of Cp ($Cp_{max}$ = 0.48) is achieved for β = 0 degree and for λ = 8.1. This particular value of λ is defined as the nominal value ($\lambda_{nom}$)

Plotting the Turbine Power Characteristic for the above obtained data, we get:



*Pitch controller:*

The pitch control is an essential method for controlling the rotational speed of wind turbine. It activates when the rotor speed exceeds the maximum rotor speed of turbine *Ωtn*, by giving the order to increase the pitch angle to reduce the turbine torque *Ct*. The control strategy implemented is as follows :

$$\beta_{ref} = \beta_0 = 0 \;\; for\; 0 < \Omega_t < \Omega_{tn}$$

$$\beta_{ref} = \frac{\Delta\beta}{\Delta\Omega} * (\Omega_t - \Omega_{tn}) + \beta_0 \;\; for\; \Omega_t > \Omega_{tn}$$

After, to take into account the orientation system of the blades which can be of type hydraulic or electric, we introduce a transfer function of the first order. The purpose of this system is to control the position of the blades according to a reference.

$$\beta = \frac{1}{1+\tau_b s} * \beta_{ref} \qquad (3)$$

*Drive train model:*
The drive train model is the basically the implementation of the gear assembly connecting the wind turbine shaft to the generator shaft.

The dynamic equations of the drive train on generator side is given by:

$$T'_{wtr} = \frac{J'_{wtr}\, d\Omega'_{wtr}}{dt} + D'_e(\Omega'_{wtr} - \Omega_{gen}) + K'_{se}(\theta'_{wtr} - \theta_{gen}) \quad (4)$$

$$\frac{d\theta'_{wtr}}{dt} = \Omega'_{wtr} \quad (5)$$

$$-T_{gen} = J_{gen}\frac{d\Omega_{gen}}{dt} + D'_e(\Omega_{gen} - \Omega'_{wtr}) + K'_{se}(\theta_{gen} - \theta'_{wtr}) \quad (6)$$

$$\frac{d\theta_{gen}}{dt} = \Omega_{gen}$$

The equivalent stiffness is given by:

$$\frac{1}{K'_{se}} = \left(\frac{\frac{1}{K_{wtr}}}{K^2_{gear}}\right) + \frac{1}{K_{gen}} \quad (7)$$

And the equivalent moment of inertia for the rotor is:

$$J'_{wtr} = 1/K^2_{gear} * J_{wtr} \quad (8)$$

*Permanent magnet synchronous machine:*
The load to be supplied is taken as independent source and not the grid so the power system need not supply the reactive compensation. Hence, PMSG is best suited as has the advantage of Robust design, easy control, more economic.

Thegeneral expression of the electromagnetic torque is given by:

$$T_e = \frac{3}{2}P(\overline{\psi_S} + \overline{i_S}) = (\frac{3}{2})P(\psi_{sd}\, i_{sq} - \psi_{sq}\, i_{sd})$$

*2.2. Universal bridge rectifier unit*:

When the system is discretized, the value of the snubber resistance Rs and snubber capacitance Cs can be formulated as:

$$R_s = \frac{2T_s}{C_s}$$

$$C_s < \frac{P_n}{1000 * 2\pi f * V_n^2}$$

These Rs and Cs values are derived based on two criterias as stated below:

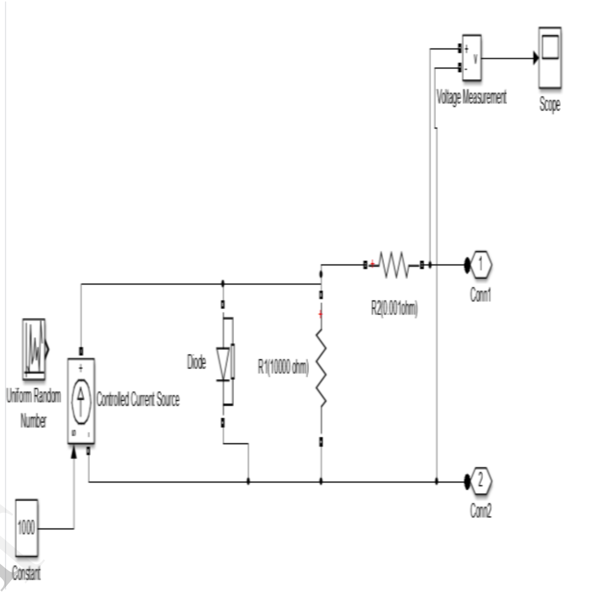
1. The snubber leakage current at the fundamental frequency is less than 0.1% of the nominal current when power electronic device are not conducting.

2. The RC time constant of snubbers is higher than two times the sample time Ts.

*2.3. Solar plant model:*

The terminal equation for the current and voltage of the array is represented as follows:

$$I = N_P I_{PH} - N_P I_S \left[\exp\left(\frac{q\left(\frac{V}{N_S} + \frac{(IR_S)}{N_P}\right)}{KT_C A}\right) - 1\right] - \left(\frac{N_P V}{N_S} + IR_S\right)/R_{SH}$$




The characteristic equation for the photovoltaic cell can be given by:

$$I_0 = (N_P * I_{ph}) - (N_P * I_{rs}) * (\exp\frac{q}{K * Tr * A} * (\frac{V_0}{N_S})) - 1$$

Where

$I_{ph} = (I_{scr} + K_i$*(T-$T_r$))*((s)/100) ;

$$I_{rs} = I_{rr} * ((\frac{T}{T_r})^3 * \exp(q * \frac{E_g}{kA} * ((\frac{1}{T_r}) - (\frac{1}{T}))$$

$$T_r = (T_{r1} - 32) + 273$$

*2.4. Boost converter:*

The efficiency of the single inductor boost converter can be given as shown below

$$\eta = P_{gen} - P_{total}/P_{gen}$$

The designing of the converter consists of the following:

1. Duty Cycle (D):

$$1 - D = \frac{V_{input}}{V_{output}} \quad (9)$$

Where 1-D is actually the proportion of the switching cycle that S is off, rather than on. So the step-up ratio is also equal to:

$$\frac{V_{output}}{V_{input}} = \frac{T_{total}}{T_{off}} \quad (10)$$

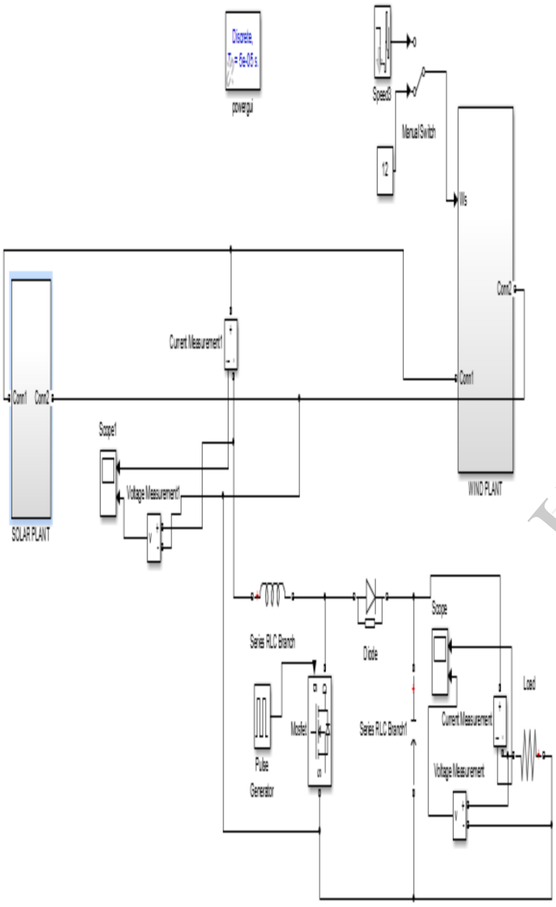
2. Capacitor (C) :

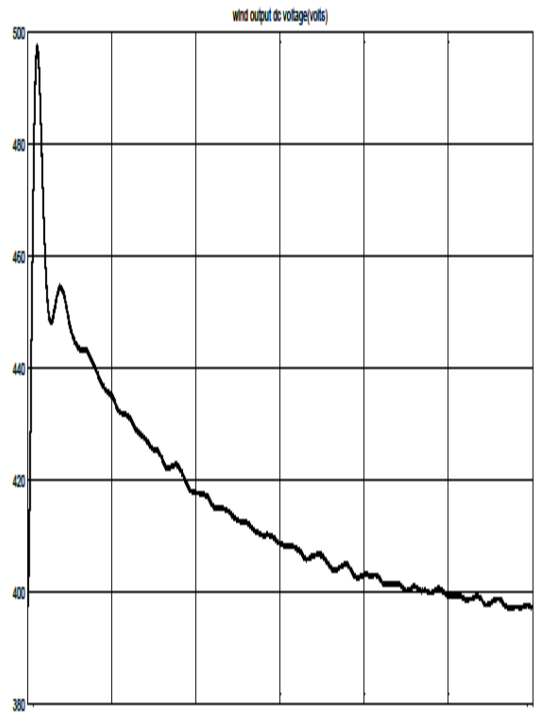
$$C = I_0 * \frac{D}{(F_s * V_d)} \quad (11)$$

3. Inductor (L):

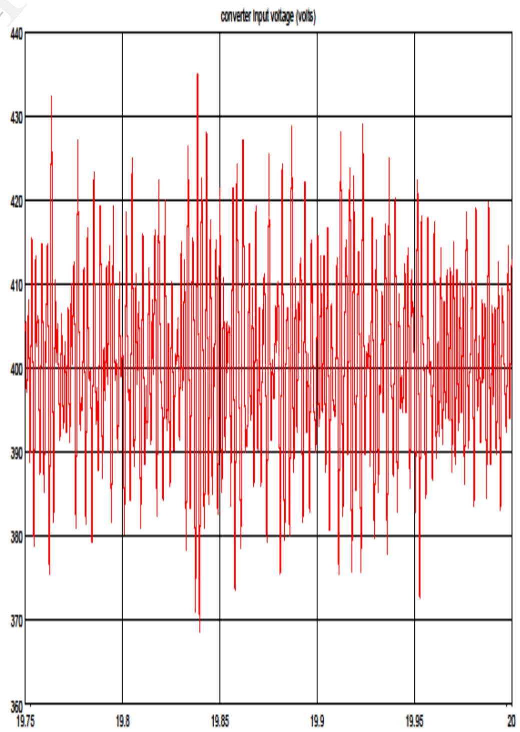
$$L = V_s * \frac{D}{F_s * R} \ , F_s = 50KHz \quad (12)$$

## 3. SIMULATION AND RESULT



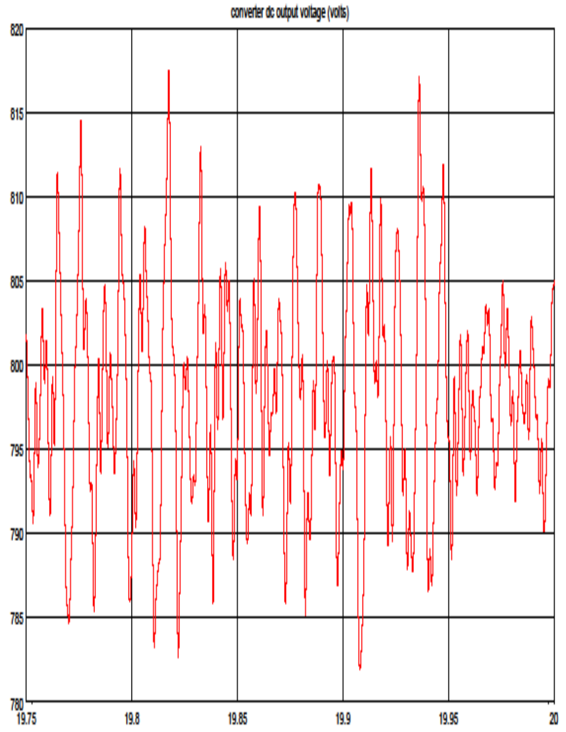




GRAPH 1: OUTPUT VOLTAGE FROM WIND PLANT

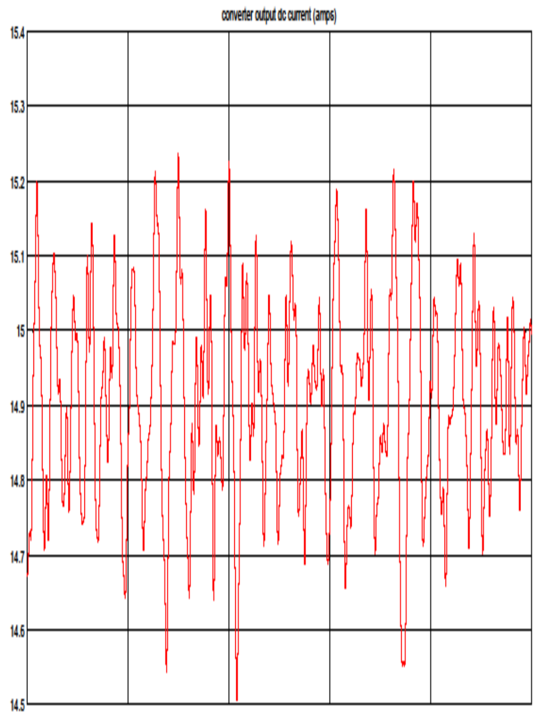



GRAPH 2: INPUT VOLTAGE TO CONVERTER AT 8KW LOAD

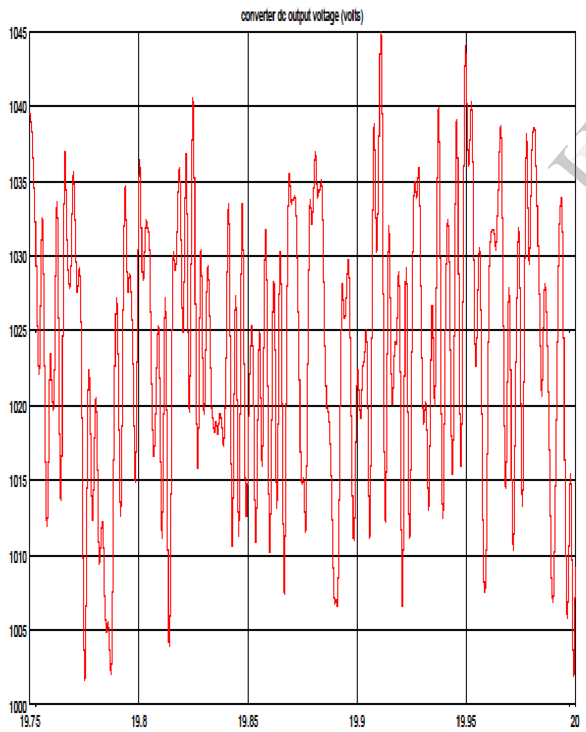
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 6, June - 2014



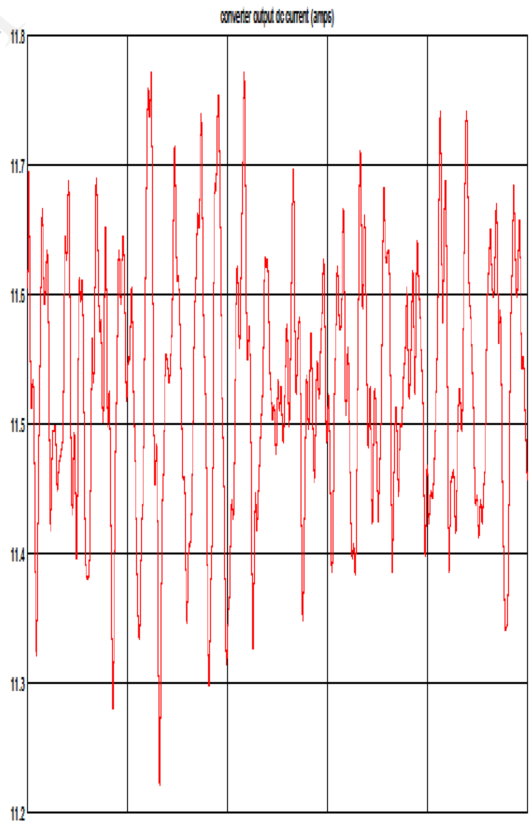

GRAPH 3:OUTPUT VOLTAGE OF CONVERTER AT 8KW LOAD




GRAPH 5: OUTPUT CURRENT OF CONVERTER AT 12KW LOAD




GRAPH 4: OUTPUT VOLTAGE OF CONVERTER AT 4KW LOAD




GRAPH 6:OUTPUT CURRENT OF CONVERTER FOR INDUCTIVE LOAD

## 4. OBSERVATION AND RESULT

It was found that the hybrid plant input to the converter contained of Harmonics [GRAPH 2] which was due to various electrical elements present in the system. The elements like inductor and the capacitors are the major source of harmonics in the hybrid power plant. They are present in the system for performing various actions like smoothing circuits and filters for smoothing the output waveforms and blocking the unwanted portion of the outputs, transformation circuits for converting AC to DC. They are also responsible for some power loss in the system and contribute towards the total losses in the system along with other elements like the diodes and the Mosfets.

It was found that the voltage of the converter output increased abnormally (to about 1125volts) [GRAPH 4] when running at half the rated load, since the inductors where not discharged completely during converter ON time and hence stored extra energy. This extra energy stored in the previous cycle gets included in the next cycle there by increasing the terminal voltage of the converter and hence we find that the terminal output voltage of the boost converter rises or peaks up during its working at less than the rated load. The rise in the terminal voltage depends inversely on the applied percentage of rated load i.e. when the load is decreased from its rated value the terminal voltage increases accordingly. This is the reason that we connect a dump load in the actual standalone hybrid systems so that the excess energy which is stored in the converters during partial load condition can be dumped off or diverted to another additional load or storage like the battery bank etc.

It was found that the current output of the converter increased considerably during overload condition [GRAPH 5] and there was a drop in output voltage. This is simply because of the fact that when the required power to meet the desired load is not available the generator shaft feels an additional negative torque which makes the terminal voltage of the generator to drop and hence the load starts to drive more current to make up for its required power requirement. To avoid such situation the hybrid systems are having under voltage relays installed which sense the decrease in terminal voltage of the generator and when the drop in voltage exceeds the permissible limit the relays activate the circuit breaker there by disconnecting the load from the system. The same technique is followed in the conventional power plants also.

While inductive load was attached the converter's output current increased by approximately 5amp [GRAPH 6] for the same kW of load.

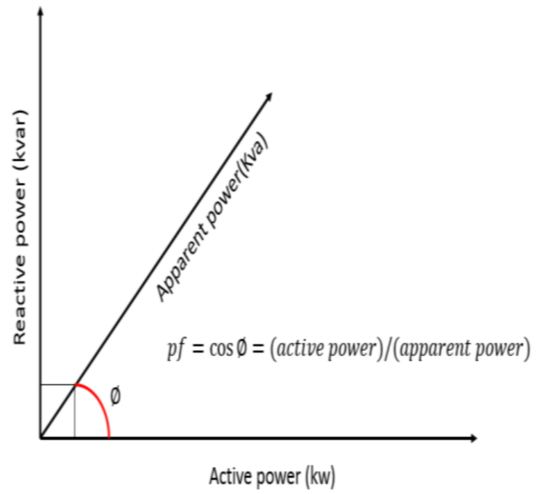



Figure: POWER TRIANGLE FOR RESISTIVE + INDUCTIVE LOAD

When the load contains inductive nature then the power drawn by the load increases as shown in the power triangle above. This is because the inductive nature of the load induces the reactive power consumption in the load and the concept of power factor is introduced in the system which increases the apparent power or the true power drawn from the source. The inductive nature of the load increases the current value drawn from the source as shown in the graph, also the loss across the load is increased due to increase in the current drawn.

EFFICIENCY OF HYBRID PLANT SIBC CONVERTER:

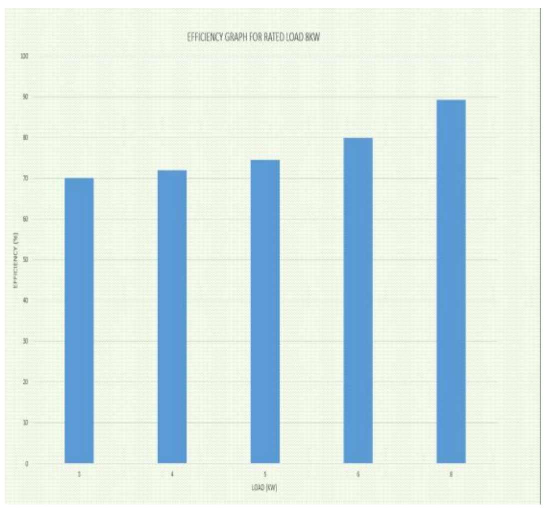
8KW LOAD – 89.28%

6KW LOAD – 79.99%

5KW LOAD – 74.50%

4KW LOAD – 72.05%

3KW LOAD – 70.07%



GRAPH 7: EFFICIENCY OF SIBC AT VARIOUS PERCENTAGE OF LOAD

Efficiency of SIBC using constant source for 8.5KW LOAD was found to be 93.86%

## 5. CONCLUSION

It is clearly seen that when the constant power source is used in the circuit for determining the efficiency of the boost converters then the effect of theharmonics present in the source supplied voltage and current is not present which falsify the output and the resultant efficiency to be used in the practical hybrid systems as they contain the harmonic in there voltage and current output. This presence of harmonics changes the nature of the applied power and apply additional stress on the components of the boost converters thereby increasing their losses and decreasing their resultant efficiency in the real world scenario.

The results when used for designing the hybrid power systems lead to false estimation of load, decrease in system overall efficiency, reduction in distribution end voltage, overloading of the transmission lines and other components. They also sometime can result in false activating of the relays which detoriates the hybrid power system performance.

## REFERENCE

[1] A. kaabeche, M. Belhamel and R. Ibtiouen; Optimal sizing method for stand-alone hybrid pv/wind power generation system; revue des energies renouvelables smee'10 bouismailtipaza (2010) 205 – 213
[2] B. Gupta "generation and economic consideration",katson publication 2nd edition, chapter1,pp1 to 10
[3] Deshmukh, M.K., Deshmukh, S.S. "Modeling Of hybrid Renewable Energy Systems", *Renewable and Sustainable Energy Reviews*, Vol. 12, No. 1, pp. 235-249, 2008
[4] I.A. adejumobi, s.g. oyagbinrin, f. G. Akinboro&m.b. olajide4 "hybrid solar and wind power: an essential for formation communication technology in frastructure and people in rural communities"inijrras 9 (1) october 2011,pp130 to 138
[5] Kanase-Patil, A.B., Saini, R.P., and Sharma, M.P. "Integrated Renewable Energy Systems For Off Grid Rural Electrification", *Renewable Energy*, Vol. 35, pp. 1342- 1349, 2010
[6] Simpowersystems; user guide version 3