PERFORMANCE PARAMETERS EVALUATION & COMPARISON OF BASIC NON-ISOLATED DC-DC CONVERTERS FOR WIND ENERGY CONVERSION SYSTEMS

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ABSTRACT: The technology involved in the generation of power from renewable sources like solar and wind in small scale and large scale is developing at a very faster rate due to increased concern over environmental pollution and energy crisis across the globe. As the generated power is highly fluctuating due to variation in wind speed and the load coming on is highly dynamic, the prime importance of power converters in wind energy conversion system is to maintain constant voltage across the DC bus irrespective of changes in either wind speed and changes in load. Also to maintain the reliability and power quality of the distributed generation system, the power converter should be operated with enhanced efficiency and less voltage ripple and current ripple. Different dc-dc converters are in use, in this paper an attempt is made to evaluate and compare the performance parameters of non- isolated DC-DC converters viz..buck, Buck Boost, Cuk Single Ended Primary Inductance Converter and Zeta converter. This paper includes dynamic modelling and simulation of wind turbine at optimum wind speed of 10m/s along with the modelling and simulation of mentioned dc-dc converters tapping unregulated voltage from wind turbine system. Their performance parameters are analysed for parameters like input ripple current, output current ripple, switch stress, switch utilization factor, efficiency at different wind speeds and compared to select a better topology. The complete system considering each converter individually is simulated in MATLAB/SIMULINK platform. The tabulated results shows that SEPIC converter has better performance parameters over other types with an highest efficiency of 92.4% and a voltage ripple of 2%.

KEYWORDS: Single Ended Primary Inductance Converter, Permanent Magnet Synchronous Generator, Maximum Power Point controller, Pulse width modulation.

INTRODUCTION

The conventional fuels used for electric power generation are depleting very fast and take millions of years to renew and their prices are also escalating. So to satisfy the required load demand the attention in power sector is been moving towards nonconventional energy sources from conventional energy sources. The popular alternate energy sources are wind, solar, fuel cell, biomass etc,, Harvesting solar and wind energy is becoming more promising as they are available everywhere irrespective of the regions and through-out the year. Among these wind energy is an attractive option whose commercial installations across world wide is increasing very rapidly about 30% over 15years. For the conversion of wind energy to electric energy it is necessary to have a wind turbine and a generator. Traditionally induction generator are used as they are robust and almost zero maintenance, but it suffers from poor power factor and require an additional excitation system. But permanent magnet machines do not require gear system for speed control and no excitation is needed.. The amount of power generated in this system depends on many parameters like speed of the turbine, turbine parameters, and the air density[1]. The turbine parameters and air density factor are taken constant. So the turbine output power is mainly dependent upon the wind speed. To maintain constant power in fixed speed turbines the yaw control or pitch control mechanisms are used which are quite complex . Variable-speed wind turbines[VSWT] are widely used as the operating efficiency is higher and cheaper than Fixed-speed wind turbines. These are more flexible in control as it uses power converters.[2]. Since the power depends on wind speed it is very much necessary to tap maximum power at any operating conditions.. To capture the maximum energy from the wind[3] VSWTs typically uses tracking method. Generally speed-control method includes a speed controller to adjust the speed of the rotor of generator, and power-control method, requires an active power controller[4]. The generated power can be fed to either for standalone loads or pumped into the power grid using power electronic interface.

A power electronic interface between the load and generator plays a significant role in the wind energy power conversion in meeting the required power demand. For grid connected or a standalone system or for battery charging purpose maintaining constant voltage at higher efficiency is the prime role of power electronic converter. So a dc-dc converter is the feasible solution. Because of many power converter stages the efficiency of power conversion falls. As per the literature the mechanical power generated is about only 50% of captured wind speed power which further reduces with many power converter stages. So it is very important to design and develop simple, cost effective highly efficient converter. A grid connected WECS is even more challenging as it is required to maintain the grid code standards with reference to grid voltage, frequency, active and reactive power management in real time with highly dynamic source.

Many dc-dc converter topologies are proposed in the literature with key requirements like good voltage regulation, less input current ripple, less output current ripple and good efficiency[5][6]. The basic converters that are proposed in literature are buck, boost, buck-boost, cuk, SEPIC, derived converters like flyback, forward, half bridge and full bridge converters and resonant converters. Each of them has its own significance and limitations like basic converters are simple to design having less number of components with simple switching strategy as there is only active device but suffer with no isolation between source and load. Derived converters are much complex in design with complicated switching control because of many active switches but gives isolation. Resonant converters are even more difficult to design with complex control but provides zero voltage or zero current switching with reduced losses.

Buck topology is most commonly used one, it gives output voltage always lesser than input voltage, supply current is continuous, less ripple applicable for lower power ratings. Boost converter provides output voltage always higher than input voltage but because the device is in series with source the supply current becomes discontinuous that leads to harmonics. Buck-Boost topology gives output voltage lesser than or more than input voltage but with negative polarity. Cuk converter an improved buck boost type that has increased number of components with good ripple factor, efficiency but output voltage polarity is negative. SEPIC goes in line with cuk but with positive polarity output[7].

In this paper, for variable wind speeds a comparative study is carried out with basic non isolated converters for a fixed load. From the results it is concluded that SEPIC converter has an average highest efficiency of 92.4% and a voltage ripple of 2%.

WIND ENERGY CONVERSION SYSTEM

Figure 1 shows the block diagram description of WECS where in the kinetic energy of wind turbine is converted to mechanical energy through wind turbine and mass drive system. The mechanical energy so obtained is further converted to AC electrical energy using Permanent Magnet Synchronous Generator (PMSG). As the availability of wind is intermittent generation of power is also highly fluctuative. The power electronic interface, the combination of 3phase diode rectifier and a DC-DC converter converts unregulated DC to constant DC voltage. The DC input is fed an inverter which converts further DC to commercial AC.

Validation of Wind turbine system

Figure 2 shows the various components required for obtaining wind turbine model which comprises of wind turbine model, mass drive train model and PMSG model.

The wind turbine converts the kinetic energy of wind to mechanical torque . The mechanical torque of the turbine is found by calculating the mechanical power captured by the turbine. The power contained in wind is given by Eqn .1

$$Pm = 0.5\rho \,\Pi\, R^2\, Cp\, V^3 \tag{1}$$

where Pm is mechanical power developed in watts

ρ is the density factor of air in Kg/m^3

R is radius of blade radius in m

Cp is power coefficient

V is the velocity of wind in m/sec

Mechanical torque Tm is given by Eqn.2.

$$Tm=Pm/Wm \tag{2}$$

where Tm is mechanical torque in Nm

Pm is mechanical power in watts

Wm is the angular speed of the blade in rad/sec

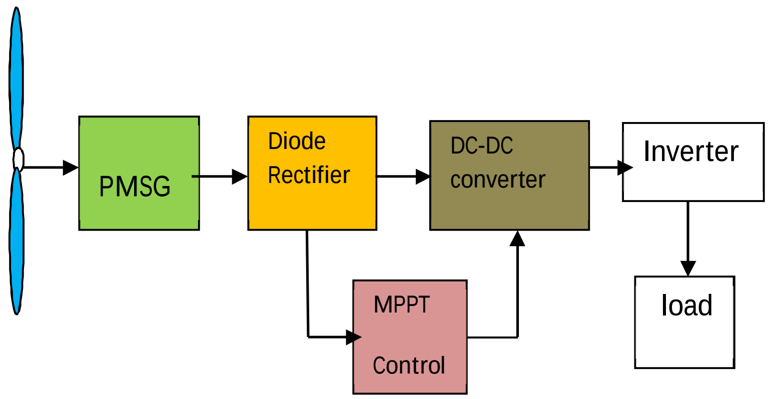


Figure1. Block diagram WECS system

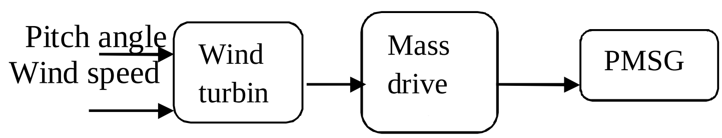


Figure 2. Block diagram of wind turbine model

The power coefficient of a wind energy converter is given by Eqn.3.

$$Cp = 0.44 - 0.0167\beta \sin \pi\, (\lambda - 2)\ 13 - 0.3\beta - 0.00184\, \lambda - 2\, \beta \qquad (3)$$

where β is the turbine blade pitch angle

λ is the tip speed ratio(TSR) given by Eqn. 4.

$$\lambda = WmR / V \qquad (4)$$

From the theoretical cp-λ characteristic it is found that, the maximum value of Cp is about 0.48 is achieved for $\beta = 0°$ and for $\lambda = 8.0$

The drive train is the next component of the wind power plant, which ensures a transmission of the mechanical torque from the turbine to the generator. The general method to model the mass drive train system is to consider the complete system as an inter connection of number of discrete masses collectively by using springs defined by their damping and stiffness. In this paper two mass drive system is considered. The fully developed PMSG model is available in Matlab/Simulink tool, which is developed based on generalized machine theory. The machine is a direct drive type with low speed and a more number of poles do not require gear box, the wind turbine and the generator are rotating at the same mechanical speed via the same shaft [5]. The PMSG is being modelled for a rating of 24V,500W, 50Hz. The generated voltage is rectified to 40V DC using a 3 phase diode bridge rectifier. Figure 3 shows the Simulink model diagram of wind turbine system.

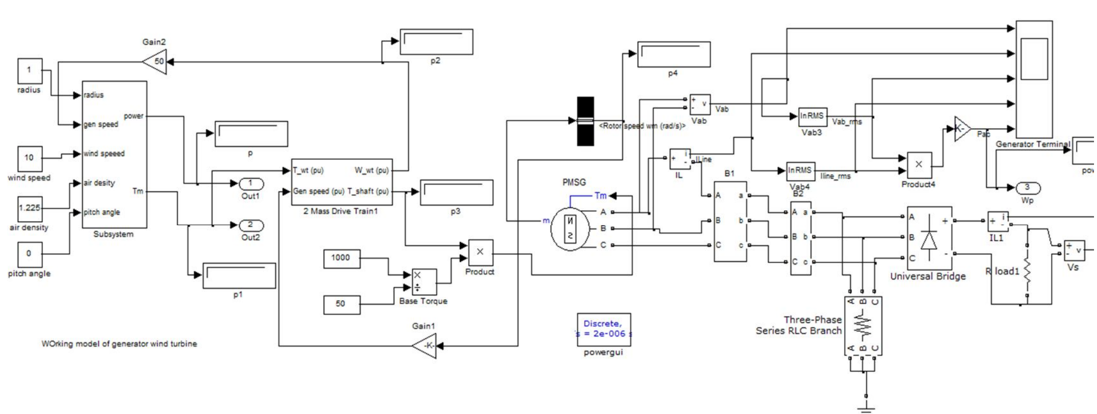


Figure 3. Wind turbine Model with PMSG

Figure 4 shows the variation of mechanical power developed and wind speed in m/s and Figure 5 depicts the changes in power coefficient Cp with λ for β = 0, from the curve it is clear that at λ= 8 the Cp value is 0.48 which is the expected standard value for the efficient operation of the wind turbine.

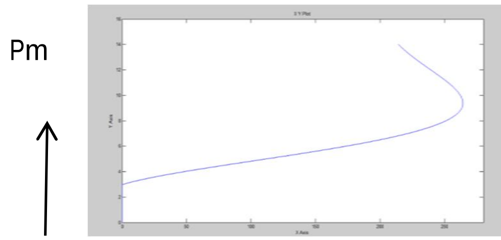


Figure 4. Variation Of Pm with windspeed

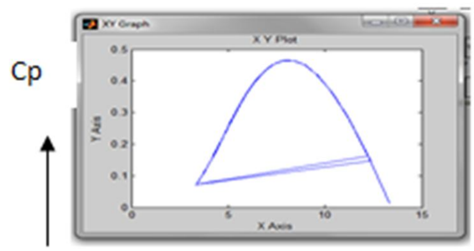


Figure 5. Cp v/s λ curve λ

The model is simulated and the waveforms of generated line voltage, line current, power and torque at wind speed of 10m/s are as shown in Figure 6. With generated peak voltage of 25Volts, generated power 315 watts, peak current of 10A.

DC-DC CONVERTERS

The role of DC-DC converter is to maintain constant output voltage irrespective in changes in wind speed. PWM technique is generally used for this purpose at constant frequency. Non isolated converters topologies like buck, boost, buck boost, cuk, SEPIC does not provide isolation between source and load but they are simple to design. The isolated types requires transformer with high-switching frequency.[7][8]In this paper a comparative study of the performances parameters of basic non-isolated converters mentioned above drawing power from wind turbine system is carried out.A Buck converter is step down type where the output voltage is always less than and with same polarity as that of input

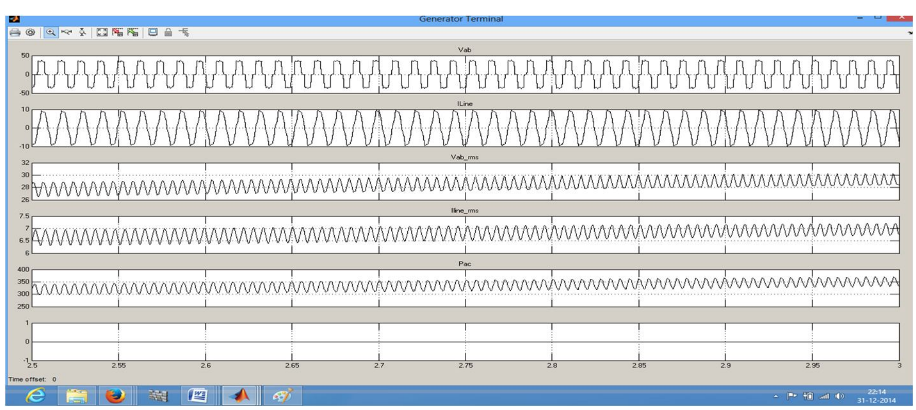


Figure 6. Waveforms of line voltage, line current, power

voltage. A Buck Boost, cuk type is both step up/ step down converter where the output voltage is lesser or more than input voltage but with opposite polarity. Similarly a SEPIC is also a buck boost type but it gives positive polarity output voltage. Each converter can be operated in continuous or discontinuous mode of operation.The circuit can be designed for continuous or discontinuous mode of operation. By varying the duty ratio the output voltage is regulated.[9][10].

Design & Modeling

To evaluate the performance parameters, the each topology is designed for the typical specifications of a standalone system drawing power from a small wind turbine are listed below
Input voltage from 3 phase rectifier Vs = 30 to 40V
Output voltage Vo = 20V,Output power Po = 300W,Inductor Ripple current L_1=10% of I_L
Capacitor Ripple voltage C_1= 5% of Vc,Switching frequency f= 100KHz

Table 4. Component List estimated

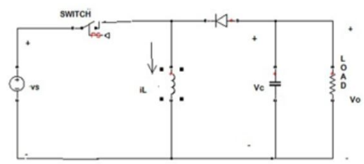
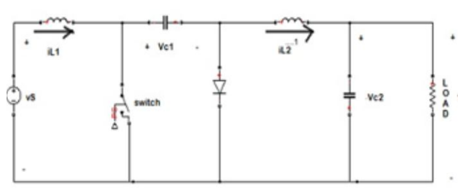
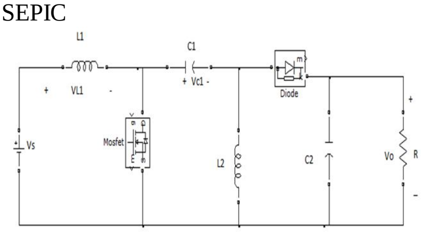
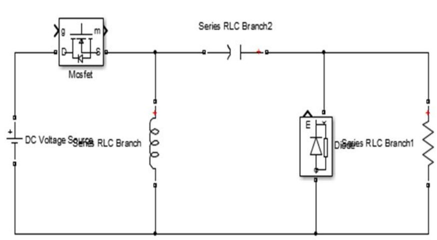
Topology	Design equations	Inductor values(H)	Capacitor values(F)
Buck-Boost 	The average output voltage $Vo = -Vs\frac{k}{1-k}$ Inductance value $L=\frac{kVs}{\Delta iL.f}$ Capacitance value $C=\frac{k}{R\left(\frac{\Delta Vo}{Vo}\right)f}$	L=83.8u	32u
Cuk 	The output voltage $Vo=-Vs/(1-k)$ The capacitance $C_1=\frac{k}{R\Delta Vc1\ /Vo\ f}$ The capacitance $C_2 =\ C_2 = \frac{(1-k)}{8(L2)\left(\frac{\Delta Vo}{Vo}\right).f2}$ The inductance $L_1 = \frac{kVs}{\Delta Il1.f}$ The inductance $L_2 = \frac{kVs}{\Delta IL2.f}$	L_1=26u L_2=16u	C1=10u C2=3u
SEPIC 	The output voltage $Vo=Vsk/(1-k)$ The capacitor $C_1= \frac{k}{R\Delta Vc1\ /Vo\ f}$ The inductance $L_1 = \frac{kVs}{\Delta Il1.f}$ The capacitance $C_2 = \frac{(1-k)}{8(L2)\left(\frac{\Delta Vo}{Vo}\right).f2}$ The inductance $L_2 = \frac{kVs}{\Delta IL2.f}$	L_1=0.25m L_2=1.2e-4	C_1=12.3u C_2=66u
ZETA 	The output voltage $Vo=Vsk/(1-k)$ The capacitor $C_1= \frac{k}{R\Delta Vc1\ /Vo\ f}$ The inductance $L_1 = \frac{kVs}{\Delta Il1.f}$ The capacitance $C_2 = \frac{(1-k)}{8(L2)\left(\frac{\Delta Vo}{Vo}\right).f2}$ The inductance $L_2 = \frac{kVs}{\Delta IL2.f}$	L_1=0.25m L_2=1.2e-4	C_1=12.3u C_2=66u

Table 4 gives circuit configuration, design equations and the estimated values of the components for the given specifications.

SIMULATION & RESULTS

The modeling and simulation of all the topologies drawing power from the wind turbine model is done in MATLAB simulink. All the topologies are simulated to study their performance at wind speed of 10m/s for the considered specifications.

Buck- Boost converter

The simulink model of Buck-Boost converter is as shown in Figure 7 the observed waveforms of the output voltage , output current and power waveforms of each topology are shown in Figure 8.

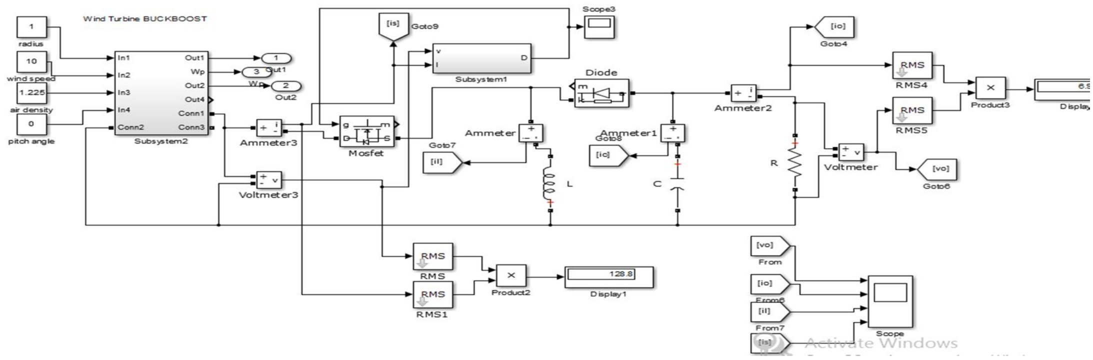


Figure 7. Buck-Boost converter

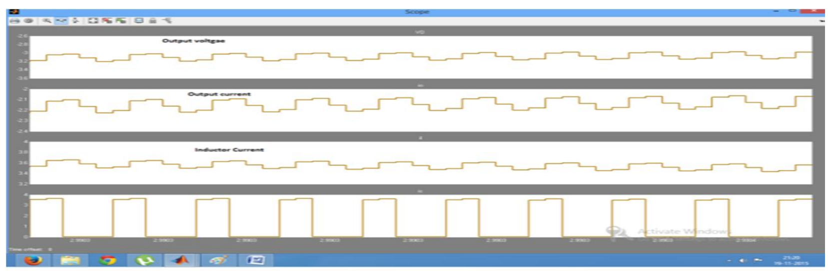


Figure 8: Output voltage, output current, output power

Cuk converter

The simulink model of Buck-Boost converter is as shown in Figure 9 and observed waveforms of the output voltage , output current and power waveforms of each topology are shown in Figure 10.

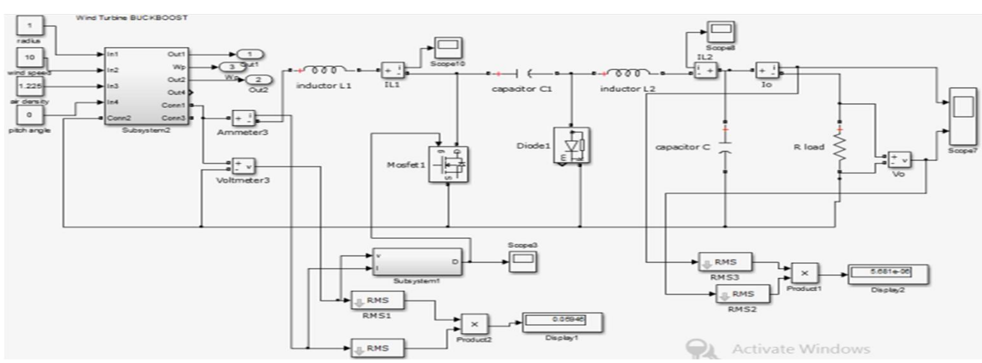


Figure 9. Simulink model of Cuk Converter

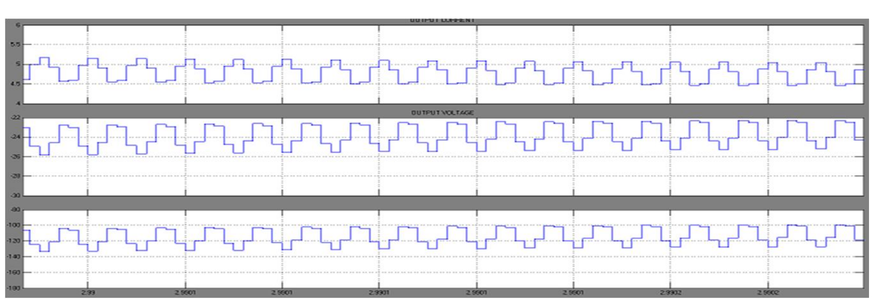


Figure 10.: Output voltage, output current, output power

SEPIC DC-DC converter

The simulink model of SEPIC converter is as shown in Figure 11 and observed waveforms of the output voltage , output current and power waveforms of each topology are shown in Figure 12.

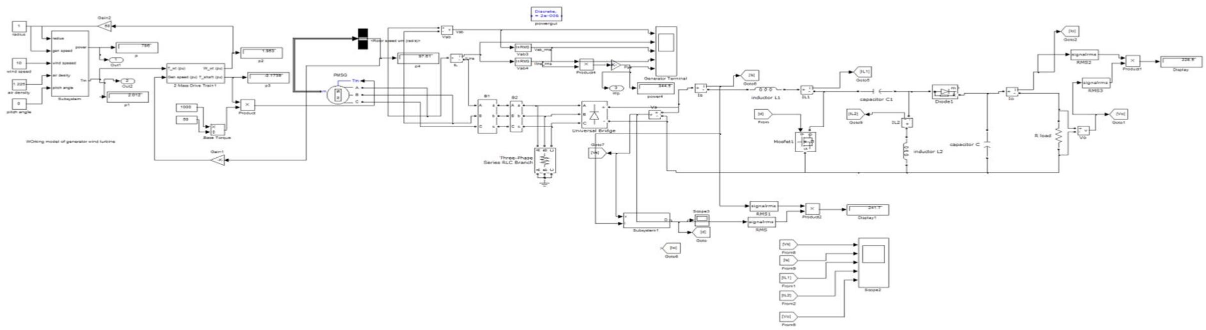


Figure 11. Simulink model of SEPIC converter

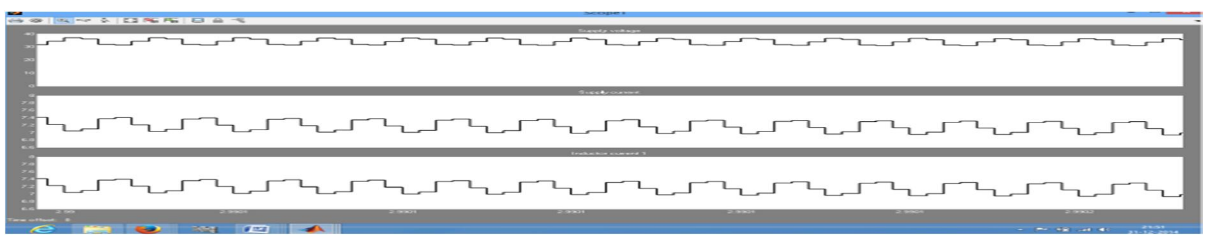


Figure12 : Output voltage, output current and power waveform

COMAPARATIVE ANALYSIS

All the topologies are simulated to study their performance at different wind speeds, the duty cycle of the converter is varied appropriately to get constant output voltage. The observed performance parameters are tabulated as shown in Table 5, Table 6, Table 7 and Table 8.

Table 5: performence parameters SEPIC Converter

Vi	D	Vo	ΔVo	Io	ΔIo	IL1	ΔIL1	IL2	ΔIL2	η	SW-str	SUF
30	0.44	23.2	1.2	4.08	0.21	3.94	0.42	-4.19	0.42	92.77	193.1	0.5179
28	0.462	23.12	1.22	4.48	0.22	3.65	0.4	-4.18	0.41	92.64	191.5	0.522
26	0.48	23.1	1.3	4.08	0.23	3.9	0.38	-4.14	0.39	92.43	190	0.5263
24	0.5	23	1.3	4.06	0.23	4.18	0.38	-4.13	0.38	92.18	188.5	0.5305
22	0.547	22.9	1.3	4.05	0.24	4.5	0.34	-4.1	0.34	91.84	187	0.5348
20	0.546	22.82	1.41	4.03	0.26	4.9	0.34	-4.07	0.31	91.38	185.7	0.5385

Table 6: performence parameters CUK converter

Vi	D	Vo	ΔVo	Io	ΔIo	IL1	ΔIL1	IL2	ΔIL2	%η	SW-str	SUF
30	0.44	-23.2	1.0	-4.1	0.26	3.35	0.33	-4.14	0.38	92.77	193.1	0.5179
28	0.445	-23.1	0.98	-4	0.17	3.56	0.32	-4.12	0.4	92.64	191.5	0.522
26	0.48	-22.9	0.94	-3.96	0.13	3.8	0.3	-4.1	0.4	92.43	190	0.5263
24	0.5	-22.8	0.9	-3.97	0.16	4.09	0.3	-4.07	0.37	92.18	188.5	0.5305
22	0.547	-22.7	0.86	-3.95	0.15	4.41	0.27	-4.05	0.35	91.84	187	0.5348
20	0.545	-22.6	1.02	-3.92	0.14	4.8	0.27	-4.2	0.53	91.38	185.7	0.5385

Table 7: performence parameters ZETA converter

Vi	D	Vo	ΔVo	Io	ΔIo	IL1	ΔIL1	IL2	ΔIL2	%η	SW-str	SUF
30	0.46	22.58	0.037	3.92	0.050	3.48	0.14	4.12	0.4	63.07	188.9	0.5293
28	0.44	22.64	0.034	3.93	0.006	3.26	0.14	4.14	0.42	61.99	190.5	0.5249
26	0.48	22.51	0.03	3.91	0.005	3.72	0.14	4.1	0.38	64.18	187.5	0.533
24	0.58	22.43	0.028	3.89	0.0047	4.0	0.129	4.07	0.37	65.27	186	0.537
22	0.547	22.32	0.025	3.87	0.0044	4.33	0.12	4.05	0.35	66.42	194.5	0.5428
20	0.545	22.19	0.025	3.85	0.0044	4.72	0.118	4.01	0.33	67.6	183.7	0.5455

Table 8: performence parameter Buck Boost converter

Vi	D	Vo	ΔVo	Io	ΔIo	IL	ΔIL	%η	SW-str	SUF
30	0.444	-23.2	1.2	3.92	0.2	7.48	0.76	61.94	190.2	0.5258
28	0.462	-23.12	1.28	3.93	0.205	7.68	0.72	63.03	188.7	0.5299
26	0.48	-23.08	1.23	3.91	0.2	7.9	0.7	64.72	187.2	0.5342
24	0.5	-22.02	1.27	3.89	0.225	8.14	0.642	65.26	185.7	0.5385
22	0.5217	-22.94	1.34	3.87	0.23	8.4	0.62	66.42	184.2	0.5429
20	0.545	-22.8	1.34	3.85	0.235	8.8	0.6	67.5	183.	0.5455

CONCLUSION

As it is the key factor to maintain the power quality in distributed generation systems power electronic converters plays a vital role. The paper presents comparative performance analysis of non isolated dc-dc converter topologies like buck boost, cuk, ZETA, SEPIC fed from a wind energy system. MATLAB/ SIMULINK platform is used to model and simulate the system. With the tabulated results the parameters comparison of SEPIC and CUK converter provides higher efficiency more than 90%, ripple current of 0.2A, ripple output voltage of 1.5V but requires additional components than buck boost converter. Zeta converter gives better performance with ripple current and voltage but the efficiency is very less of about 61%. Buck Boost converter requires less components with less ripple values but the efficiency is very less. So with a trade off between the parameters a SEPIC converter is most suitable for wind energy conversion systems.

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