ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 3, November 2017

Performance Analysis of LCL & CLL Resonant DC To DC Converters for Stand Alone Wind Energy System

S. Gobi Mohan [1], Dr. M. Annamalai[2]

Research Scholar, Department of Instrumentation and Control Engineering, NIT, Trichy, India[1].

Assistant Professor, Department Electrical & Electronics Engineering, Nizwa College of Technology, India [2].

ABSTRACT:This paper deals with performance analysis of LCL & CLL type of DC-to-DC converters for stand-alone wind energy system. The LCL & CLL resonant inverter system and DC-to-DC converter system are simulated using MATLAB Simulink power system blocks. These converters have advantages like reduced transformer size, reduced filter size and current source characteristics. The Simulink circuit models for both systems asystems are developed and they are used for simulation studies. The simulation results are compared with the analytical results.

KEYWORDS: Converter, Resonant Inverter, DC to DC Converter, MATLAB Simulink.

I.INTRODUCTION

Small – scale stand-alone wind energy is increasingly viewed as a viable and sometimes preferred source of electrical energy. Consider, for example, remote villages in developing countries or ranches located far away from main power lines. Wind energy is a quiet alternative to remote diesel generation- generation that sometimes depends on excessive transportation and fuel storage costs- and an economically justifiable alternative to a grid connection. It has been shown that a remote load has only to be a matter of a few miles away from a main power line for a stand-alone wind generator to be cost-effective [1]. Wind turbines, however, are not always very efficient in the wind speeds that are most common to a region. Typically, wind energy systems are designed to be highly efficient in high wind speed and have a cut-off wind speed- below which no energy is captured. In remote locations where wind energy is used for battery charging, the energy lost below the cut-off wind speed could be used for trickle charging or maintaining a battery's fully charged state. Wind turbines are most efficient when they are operated at one specific tip-speed to wind-speed ratio (TSR) [2]. Therefore, for the efficient capture of wind power, turbine speed should be controlled to follow the ideal TSR, with an optimal operating point, which is different for every wind speed. A typical, small-scale, stand-alone, wind electric system is composed of a wind turbine, a permanent-magnet generator, a diode bridge rectifier, and a DC power system. In many small-scale systems, the DC system is at a constant DC voltage and is usually comprised of a battery bank, allowing energy storage, a controller to keep the batteries from overcharging, and a load. The load may be DC or may include an inverter to an AC system. The load configuration is beyond the scope of this work.

Unfortunately, there can be significant problems connecting a wind generator to a constant DC voltage. At low wind speeds, the induced voltage in the generator will not be high enough to overcome the reverse bias in the diode bridge. At high wind speed, the electrical frequency increases and the reactive impedance of the generator will be high, while the impedance of the battery load will be low. In this case, the poor impedance matching will limit power transfer to the DC system [3]. In response to these problems, researchers have investigated incorporating a DC - DC converter in the DC link [4]-[7]. While allowing a constant DC voltage to the load, a DC - DC converter will allow the voltage at the output of a diode bridge rectifier to be controlled. In low wind speed conditions, the voltage may be lowered to prevent the dc link from reverse biasing the diode rectifier. Under high wind speed condition, the voltage may be increased, reducing I^2R losses. In addition, adjusting the voltage on the DC rectifier will change the generator terminal voltage and thereby provide control over the current flowing out of the generator. Since the current is proportional to torque, the DC - DC converter will provide control over the speed of the turbine.

Control of the DC-DC converter may be achieved by means of maximum power point tracking [5] or by means of a pre-determined relationship between wind speed and rectifier DC voltage [6],[7]. Maximum power point tracking

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 3, November 2017

requires continuous variation of the dc voltage to determine whether the output power may be increased. This system is relatively complex and may have limited using tracking rapid changes to the system. The relatively high turbine inertia can cause a significant time lag between the changes to the DC -link voltage and any observed change in power. Use of a predetermined relationship between wind speed and voltage may also have difficulties. Accurate wind speed measurement is difficult and requires the use of a relatively expensive anemometer if it is to be used for system control. The system proposed in this work makes use of a predetermined relationship between generator electrical frequency and DC -link voltage.

This paper deals with a buck DC - DC converter that achieves high wind turbine efficiency across a wide range of wind speeds. The system is designed for use in remote location and, therefore, includes a simple control strategy and a fault-tolerant topology. The control circuit included fault detection and has been tested with a parallel redundant DC link. Previously published works [8], [9] demonstrated the ability of the control system to detect both open- and short-circuit converter faults and switch to a parallel converter without interruption of the supply. The literature [1] to [9] does not deal with the comparison of CLL & LCL type DC-to-DC converter. This paper deals with comparison of CLL & LCL DC- to- DC converter.The system is represented in Figure.1 where V_{DC} is a variable voltage and V_{BATT} is a fixed DC voltage.

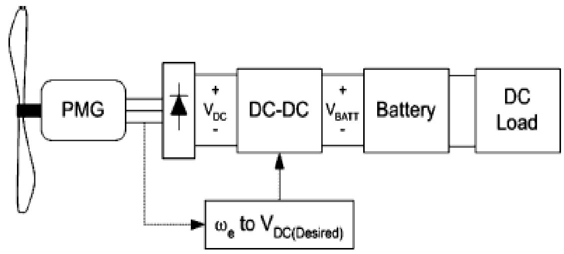

Figure.1. Schematic diagram of the stand-alone wind energy system under consideration.

II.THEORETICAL APPROACH

The fundamental equation governing the power capture of a wind turbine is turbine power, air density, the swept turbine area, the turbine coefficient of performance, and is wind speed. The coefficient of performance is a function of TSR, described by where is rotational speed, is the turbine radius, and is the wind speed. It is clear that (for this case) the maximum power captured by the wind turbine will occur when the TSR is approximately 7.5, corresponding to a 0.35. A relatively small deviation on either side of this TSR will result in a significant reduction of the power available for conversion to electrical energy. Employing control of the rotational speed of the turbine allows the TSR to be controlled and the coefficient of performance to be maximized. Thus, in turn, the generated electrical energy may be maximized.

Control over the rotational speed is achieved by varying the generator terminal voltage. A simple understanding of the ideal steady-state relationship between terminal voltage and rotational speed may be obtained by considering a generator with a fundamental current in phase with terminal voltage and neglecting harmonic currents. The generator-induced voltage and armature currents can now be obtained from the manufacturer's data by means of the governing torque and voltage equations.

Now consider the fact that the terminals of the generator are connected to a diode rectifier. Neglecting for the time-being effects of commutation overlap (which may be significant), it may be assumed that the phase voltage and fundamental component of the armature current of the generator are in phase.

An approximation of the rectified DC-link voltage may be obtained using the standard equations for a three-phase full-bridge diode rectifier with line inductance. It is possible to obtain a prediction for DC-link voltage as a function of mechanical speed (or electrical generated frequency) and TSR. In the ideal case, the generator operates at the peak of the curve.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 3, November 2017

III.DESIGN CALCULATIONS

The following assumption are made, 48V/12 transformer, f_s = 20 KHz, f_r= 56 KHz, φ = 10µwb, L_r = 9µH, R_L = 100Ω, r = $7e^{-4}$.

Using $E_1 = 4.44 \times N_1 \times \varphi \times f$

$N_1 = 54$ (1)

Using $E_2 = 4.44 \times N_2 \times \varphi \times f$

$N_2 = 13$ (2)

Using $f_r = 1/2\pi\sqrt{L_r C_r}$

$C_r = 0.75\mu F$ (3)

Using $r = 1/4\sqrt{3} \times f \times C \times R_L$

$C = 100\mu F$ (4)

IV.SIMULATION RESULTS

DC-DC converter is modified by employing half bridge inverter in the place of full bridge inverter. This modification reduces number of transistors by two. CLL DC-DC converter is shown in figure 4a. 48V DC is converted into AC using half bridge inverter. Soft switching is obtained by introducing CLL circuit. 48V AC is stepped down to 12V AC by using step down transformer. The output of transformer is rectified by using a diode rectifier and capacitor filter. Scopes are connected to display the driving pulses, inverter output and DC output. DC input voltage is shown in figure 4b. DC output voltage is shown in figure 4c. It can be seen that the DC output is free from ripple.

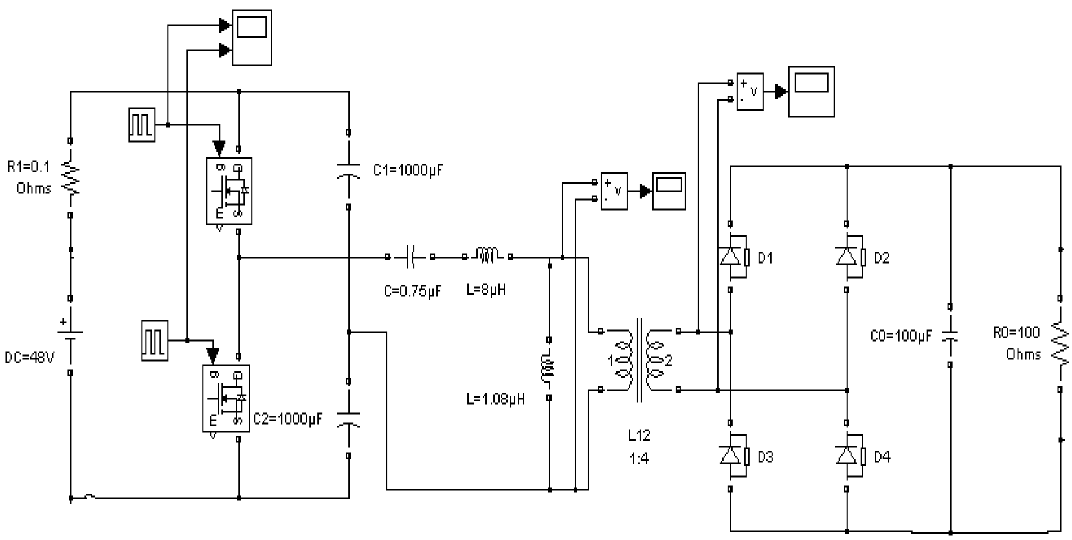

Figure. 4. a. CLL DC-DC converter circuit

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 3, November 2017

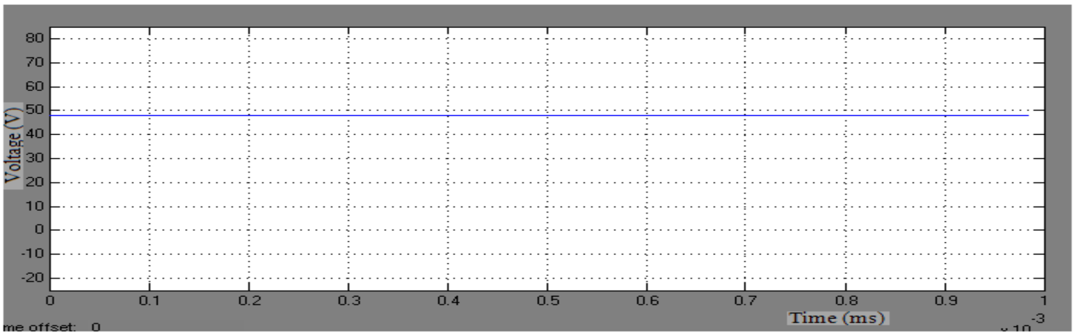

Figure. 4. b. DC Input Voltage

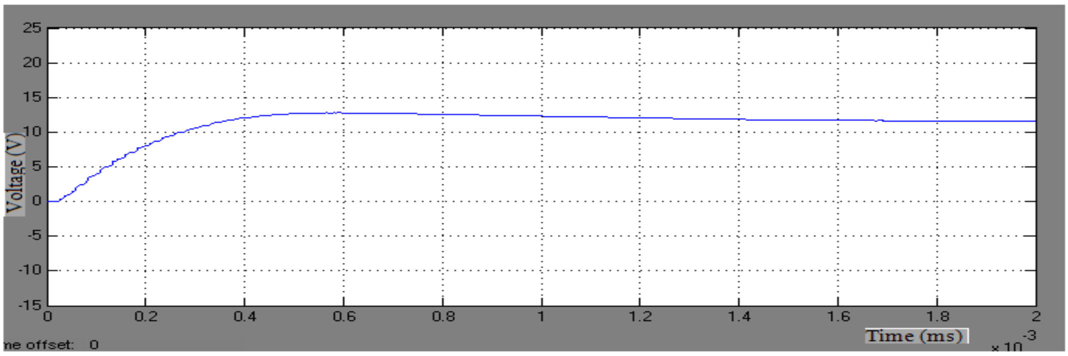

Figure.4.c. DC Output Voltage

V. COMPARISON

Simulation is done with the same input voltage and the same load resistance for CLL and LCL converters. Variation of output power with load resistance for CLL converter and LCL converter are tabulated in Table 5.1 and the graphical representation is shown in Figure 5.a. Variation of output voltage with input voltage for CLL converter and LCL resonant converter are tabulated in Table 5.2 and the graphical representation is shown in Figure 5.b. The variation of efficiency of LCL and CLL system for different values of load resistance are given in Table 5.3 and the graphical representation is shown in shown in Figure 5.c. It can be observed that LCL converter produces higher power and the efficiency is about 6% higher than that of CLL converter. The simulation results indicate that the LCL converter system produces higher power than the CLL converter system. The LCL DC-DC converter system is suitable for stand-alone wind generator since it operates at 7% higher efficiency.

Table 5.1
Variation of Output Power with Load Resistance for CLLSystem and LCL System

Load resistance (ohms)	**CLL**	**LCL**
	Output power (watts)	**Output power (watts)**
100	0.27	1.34
75	0.37	1.78
50	0.55	2.66
25	1.09	5.11

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 3, November 2017

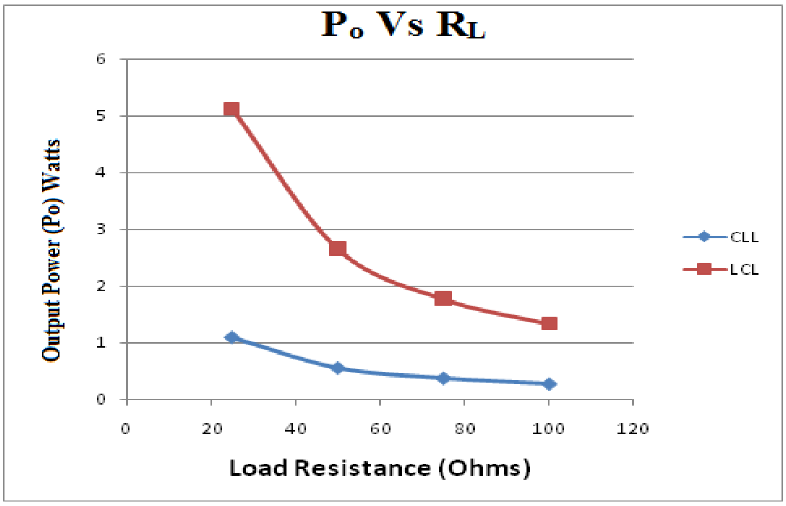

Figure.5.a Relation between Output Power and LoadResistance for CLL and LCL DC-DC Converter Systems

Table 5.2
Variation of Output Voltage with InputVoltage for CLL and LCL Systems

Input Voltage (Vin)	CLL	LCL
	Output Voltage (V_0)	Output Voltage (V_0)
48	5.27	11.59
38	3.84	8.44
28	2.41	6.09
18	1.11	3.351

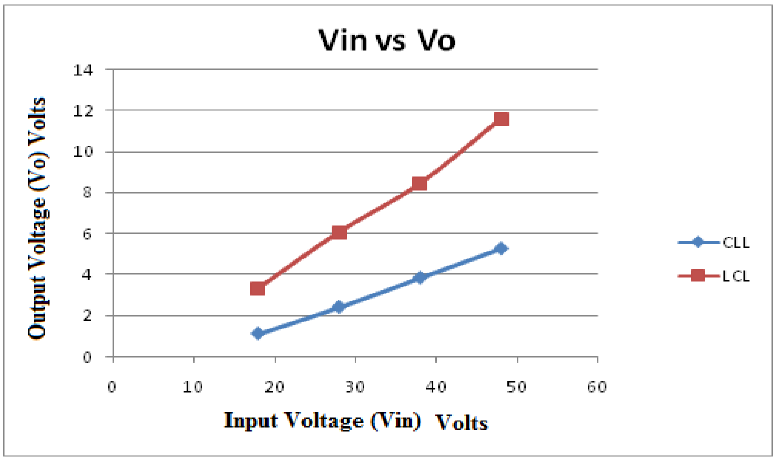

Figure 5.b Output Voltage Vs Input Voltage for CLLand LCL Converters

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 3, November 2017

Table 5.3
Variation of Efficiency with Load Resistance for CLLSystem and LCL System

R_L (Ohms)	CLL	LCL
	Efficiency %	Efficiency %
100	79.40	86.12
75	82.00	89.01
50	85.52	92.60
25	86.50	96.03

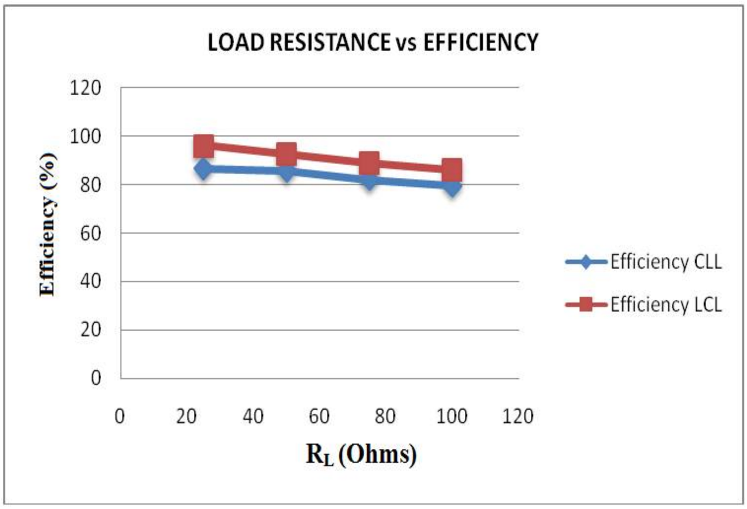

Figure 5.c. Efficiency Vs Load Resistance for CLL andLCL Converters

The comparison of closed loop response of LCL converter system with PI and PID controllers is given in Table 5.4. The settling time with PID controller is 18% less than that of PI controller system. The steady state error with PID controller is 50% less than that of PI controller system. Therefore PID controller is preferred to PI controller in the closed loop.

Table 5.4
Comparison of Closed Loop Response for LCL System

LCL Converter	Rise Time (T_r)	Settling Time (T_s)	Peak Time (T_p)	Peak Voltage (V_p)	Steady State Error (E_{ss})
PI Controller	0.015	0.61	0.44	0.22	0.016
PID Controller	0.010	0.50	0.40	0.21	0.008

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Special Issue 3, November 2017

Table 5.5
Comparison of Closed Loop Response for CLL System

CLL CONVERTER	Rise Time(T_r)	Settling Time (T_s)	Peak Time (T_p)	Peak Voltage(V_p)	Steady State Error (E_{ss})
PI Controller	0.017	0.60	0.46	0.10	0.033
PID Controller	0.013	0.51	0.42	0.05	0.009

Table 5.5 gives the comparison of response of PI and PID controlled CLL converter systems. The settling time with PI controller is 15% less than that of PID controlled system. The steady state error is 72% less than that of PI controlled system. Therefore PID controller is preferred to PI controller in the closed loop applications.

VI.CONCLUSION

The LCL & CLL type DC-DC converter systems are designed and simulated using MATLAB version 7.1 and the results are presented. These converters are popular due to reduced EMI, reduced stresses and high power density. The simulation studies indicate that LCL type DC-DC converter can be used with stand-alone wind generator. The simulation results indicate that LCL converter produces higher power than CLL type converter. The scope of this work is the comparison between CLL & LCL type converters.

REFERENCES

[1] M.Annamalai, Dr. M. Vijayakumar, "Comparison of CLL & LCL Resonant DC –DC Converter for standalone wind energy system" IEEE Conference and Proceedings, 2012.

[2] W.D.Kellogg, M. H. Nehrir, G. Venkataramanan, and V. Gerez, "Generation unit sizing and cost analysis for Stand-alone wind, photovoltaic, and hybrid wind/PV systems," *IEEE Trans. Energy Conversion.* Vol. 13, pp. 70–75, 1998.

[3] S. Drouilhet, E. Muljadi, R. Holz, and V. Gevorgian, Optimizing small wind turbine performance in battery charging applications," in *NREL/TP-441-7808*. Golden, CO: National Renewable Energy Laboratory, 1995.

[4] N. Yamamura, M. Ishida, and T. Hori, "A simple wind power generating system with permanent Magnet type Synchronous generator," in *Proc. IEEE Int. Conf. Power Electronics Drive Systems*, vol. 2, Hong Kong, Jul. 27– 29, 1999, pp. 849–854.

[5] Mangesh "Analysis and design of LCL-T resonant DC to DC converter", IEEE trans.on IE 2005.

[6] S.Arul Daniel and N.Ammasai Gounden "A novel Hybrid Isolated Generating System based on PV fed Inverter assisted Wind-driven Induction Generators". IEEE Transaction on energy conversion, pp 416- 422, Vol. 19, No.2, June 2004.

[7] M. Arutchelvi and S. Arul Daniel, "Composite controller for a hybrid power plant based on PV array fed wind-driven induction generator with battery storage", International Journal of energy Research, pp.515-524 Vol.31, April 2007

[8] Castilla M., De Vicuna L. G., Guerrero J.M., Matas J. and Miret J. (2007), "Designing VRM hysteretic controllers for optimal transient response", IEEE Transactions on Industrial Electronics, Vol. 54, No. 3, pp.1726–1738.

[9] Tan S.C., Lai Y. M. and Tee C. K. (2008), "General design issues of sliding-mode controllers in DC-DC converters," IEEE Transactions Industrial Electronics., Vol. 55, No. 3, pp. 1160-1174.