Performance Analysis of Impedance Source Inverter in Wind Energy Conversion System

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Abstract: The main thrust in Wind Energy Conversion System (WECS) is to maintain a constant voltage and frequency at the output in spite of variation in wind velocity. The impedance source inverter (ZSI) is used to feed stand alone wind energy conversion system. The Z-source inverter has been identified to exhibit in steady-state, both voltage buck-and boost-capabilities. It employs a unique impedance network included between the dc power source and converter circuit. The power conversion efficiency of Z-source inverter is appreciably improved because of the traditional three-stage conversion system, consist of rectifier, boost chopper and inverter, replaced by a two-stage conversion systems comprising of rectifier and Z-source inverter. The impedance source inverter fed wind energy system has more advantages for variable speed stand alone applications. The simulation results are intended to reach the rated voltage at the rated wind speed. The reactive power compensation gets better condition by comparing with and without impedance source inverter. As the wind speed is varying, impedance source inverter is used to be acceptable output voltage limit and frequency. The cut in and the cut out wind speed are 4 and 18 m/s and the rated wind speed is 10m/s in this research for Sittwe in Myanmar. Due to self excited induction generator (400V, 75kVA), the proper capacitor bank 4.8 kVar is chosen to satisfy the reactive power burden requirements. Thus, the inverter control is required to be stable output voltage and frequency. The performance of impedance source inverter is shown with Matlab simulation.

Key Words: Wind Energy Conversion System (WECS), Impedance Source Inverter (ZSI), Rectifier, Buck and boost.

Introduction:

Electrical energy has become more dynamic in all applications of our day-to-day life. A fundamental need in the developing countries is the electrification of rural areas and remote villages. The important feature is generating electricity by means of sources that do not involve in polluting the nature. Such non-polluting energy sources are observed in the fundamentals of science: Earth, Air, Fire and Water. They are Biomass, Wind, Solar and Hydro-power, the resources which benefit the need without polluting the nature. Among the renewable energy sources, wind energy has the largest utilization nowadays mainly because of its little effect on the environment and decreasing running cost. As the potential of wind energy is very large in hilly and costal regions in Myanmar, wind power generation is the promising way to solve the energy demand problem. According to National Aeronautics and Space Administration (NASA) data, Sittwe wind speed is one of the highest data in Myanmar. In addition to, the Stand-Alone Wind Electric Conversion System is a good solution to electrify the places where national grid line does not exist. There are three main types of wind turbines used nowadays:

(i) The fixed speed wind turbine with Squirrel Case Induction Generator
(ii) The variable speed wind turbine with Doubly Fed Induction Generator and
(iii) The variable speed wind turbine with Synchronous Generator

The fixed speed Squirrel Cage Induction Generator consumes reactive power and cannot contribute to voltage control. This can lead to voltage and rotor-speed instability. The variable speed wind turbine with Doubly Fed Induction Generator can be controlled to provide frequency and voltage control with a back-to-back converter in the rotor. In the direct-drive synchronous generator, the generator is completely decoupled from the grid by two converters, one is connected to the stator winding and another is connected to the grid. This provides maximum flexibility, enabling full real and reactive power control and fault ride-through capability during voltage dips. To facilitate variable speed operation, the Wind Energy System requires variety of power electronics converters. In this paper, impedance source inverter which has nine switching state is applied instead of traditional inverter such as voltage source inverter and current source inverter which has six switching state.

Materials: In this journal, 50 kW load is considered for the proposed system. The inductor and capacitor are required to consider in the impedance network. Figure 1 is shown the Schematic of Z-source Inverter System.

To calculate inductor and capacitor values, the total power and DC input for the system is required. Specifications for Circuit Design are DC voltage is V_{in1} (610V) at full load (50 kW) and V_{in} (648.22V) at no load. The output power is 50 kW for peak load.

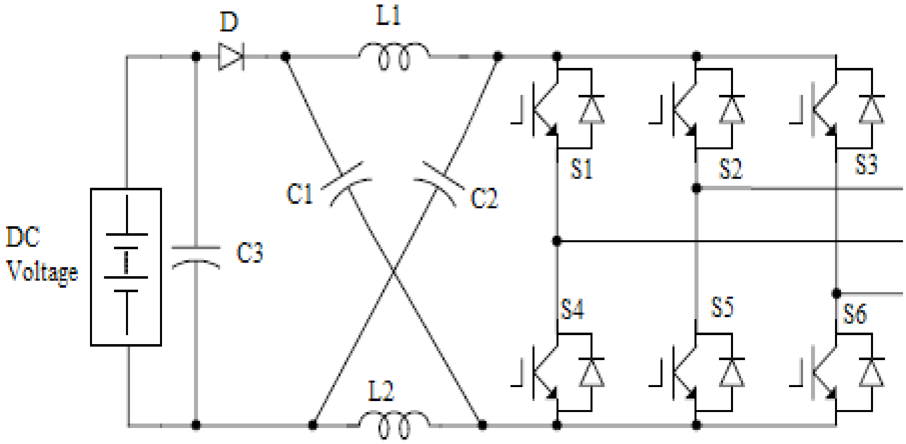


Figure 1 Schematic of Z-source Inverter System

Inductor Size in Impedance Network

Firstly, power total for the system is 50 kW and DC input voltage for full load is 610 V. Average current through inductor in impedance network is

$$I_L = \frac{P}{V_{in}}. \qquad 1$$

where

P = total power,

V_{in}= input voltage to impedance network

Therefore, the value of average current through inductor is

$$I_L = \frac{50000}{610} = 81.96A$$

In this 50 kW design, 30% (60% peak to peak) current ripple through inductors is chosen. For 100 %, average current value is 81.96 A. Hence,

I_L in 30 % = 24.588 A and

I_L in 60 % = 49.176 A

Therefore allowed ripple current = 49.176A (peak to peak)

Max current through inductor= 81.96+ 24.588= 106.55 A

Max shoot through duty cycle,

$$\frac{1}{1-2D_0} = \frac{V_{in1}}{V_{in}} \qquad 2$$

By substituting V_{in1} = 648.22V and V_{in} = 610V in Equation 2, the value of D_0 is 0.02948.

For switching frequency of 10 kHz, shoot through time per cycle = 2.95 μs

Capacitor voltage is

$$V_C = \frac{610+648.22}{2} = 629.11V$$

To keep current ripple less than 120 A, inductance must be no less than

$$\frac{2.95 \times 629.11}{49.176} = 37.74\mu H$$

For single coil on one core, flux through core

$$\varphi = PNi$$

P= constant related to core material & dimension

N= number of turns of coil

I= current through coil

Inductance of coil, $L = \frac{N\varphi}{i} = PN^2$

For 2 coil on one core , flux

$$\varphi = 2PNi$$

Resulting inductance to two coil,

$L=2PN^2$

Finally, inductor 18.87 μH is needed for the impedance network.

Capacitor Selection for Impedance Source Inverter

To calculate the capacitor value for the impedance network, voltage ripple across capacitor is $\Delta V_C = \frac{I_{av} T_o}{C}$ 3

where

I_{av}= average current through inductor

T_o = shoot through period per switching cycle

C = capacitance of capacitor in the impedance network

To limit capacitor voltage ripple to 3% at peak power, required capacitance, C

$$C = \frac{81.96 \times 2.95\mu}{629.11 \times 3\%} = 12.85\mu F$$

The capacitor (12.85 µF) is required to install for the impedance source inverter.

Method: The power conversion efficiency of ZSI is improved compared to the traditional inverters for wind electric power generation.

TABLE 1
Comparisons of ZSI with Tradition Inverters

Current Source Inverter(CSI)	Voltage Source Inverter (VSI)	Impedance Source Inverter (ZSI)
As inductor is used in the D.C link, the source Impedance is high, a constant current source is realized.	As capacitor is used in the D.C link, it acts as a low impedance voltage source.	As capacitor and inductor are used in the D.C link, it acts as a constant high impedance voltage source.
A current source inverter is capable of withstanding short circuit across any two of its output terminals hence momentary short circuit on load and misfiring of switches are acceptable.	A VSI leads to more dangerous situation as the Parallel Capacitor could feed more power in to the fault.	In ZSI, mis-firing of the switches may be acceptable.
Used in boost operation of the inverter.	Used in a buck mode of operation of the inverter.	Used in both buck and boost operating modes of the inverter.
Affected by the EMI noise.	Affected by the EMI noise.	Less affected by the EMI noise. Impedance Source acts as a filter.
Considerable amount of harmonic distortion.	Considerable Amount of Harmonic Distortion.	Harmonics distortion is low.

Discussion:

Among the renewable energy sources wind energy has the largest utilization nowadays. To facilitate variable speed operation the Wind Energy System requires variety of power electronics converters. To overcome the problems of the traditional V-source and I-source converters, this proposal presents an impedance-source power converter and its control method.

Firstly, it would like to discuss about simulation results of programmable voltage source. The voltage amplitude is changing 0.8,1 and 1.2 during 0,10 and 20 second in the programmable voltage source. The value will be 184, 230 and 276 V respectively from the source. After running simulation, the load voltage is 212 V from 0 to 10 second. During 10 second and 20 second, the load voltage reach the rated value 230 and then 232 V till 30 second. It is clearly seen that the load voltage is nearly rated voltage even though the source voltage is changing 20% of rated value. According to IEEE voltage regulation standard, voltage regulation should be 10% of rated voltage.

Next, it is connected with wind turbine instead of programmable source. It is seen that not only the wind turbine voltage but also load voltage is increasing according to the wind speed increases 4, 9 and 11m/s starting time 0 , vary another time 10 second and end 30 second. Though simulation result of wind turbine voltage and load voltage increase when it connects with impedance source inverter and without impedance source inverter, the load voltage with impedance source inverter gets the rated voltage at 9m/s. The simulation result of load voltage does not reach the rated value while it is no connection with impedance source inverter. This is one of the performances of impedance source inverter.

Another performance is that reactive power compensation in induction generator is in better condition when this inverter is connected with wind turbine. Though the difference of reactive power of wind turbine and load is 14.5kVar while it is not connected impedance source inverter, there is 8 kVar reactive power differences by connecting with impedance source inverter. There is not as much reactive power difference with impedance source inverter as without impedance source inverter.

Analysis:

In this system, stability condition is checked with root locus in Matlab program. Firstly, the system without compensation runs. After running Matlab program without compensation, it is seen in figure 2 when the transfer function G_1 is

$$G_1 = \frac{-5.88\times10^{-20}s^4+1}{5.88\times10^{-20}s^4+4.85\times10^{-10}s^2+1}.$$

From Figure 2, it is known that the system is not stable due to one zero at 6.4218×10^4 in the right hand plane. Therefore, one pole is needed to add in the right hand plane to compensate zero and to be stable.

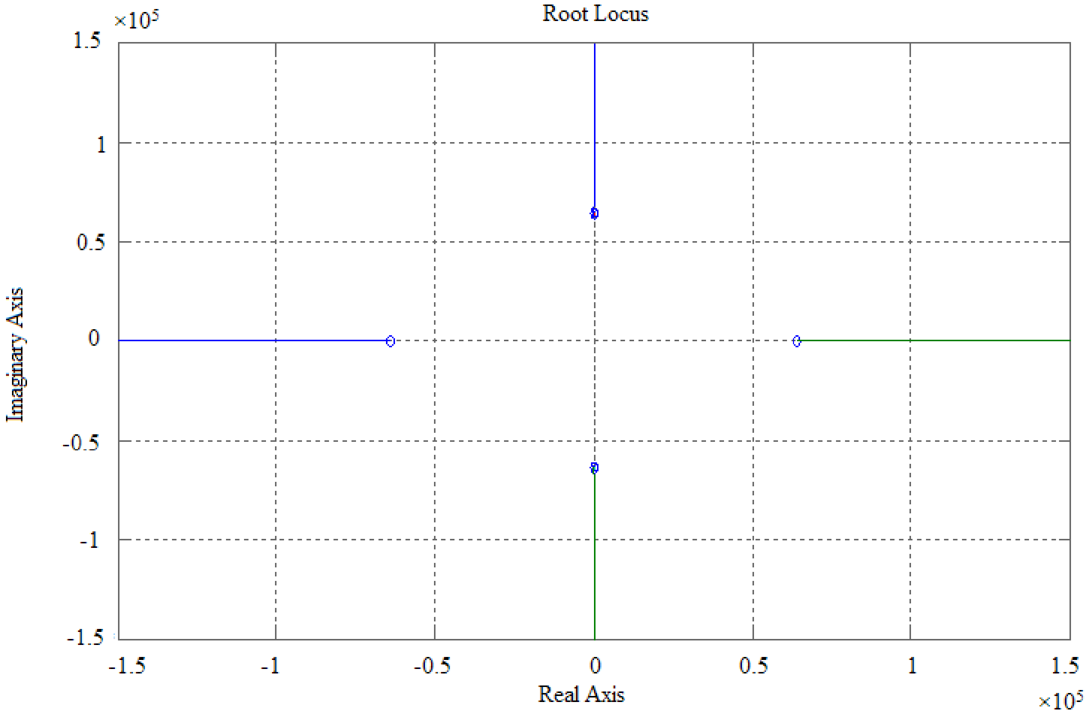


Figure 2 Root Locus Without Compensation

To remove this right hand plane zero, the same value one pole is added in the right hand plane. After adding one pole in the denominator, the transfer function becomes

$$G_1G_2 = \frac{-5.88\times10^{-20}s^5-1.33\times10^{-11}s^4+s+1.927\times10^8}{5.88\times10^{-20}s^5+3.77\times10^{-15}+4.85\times10^{-10}s^3+3.114\times10^{-5}s^2+s+64218}.$$

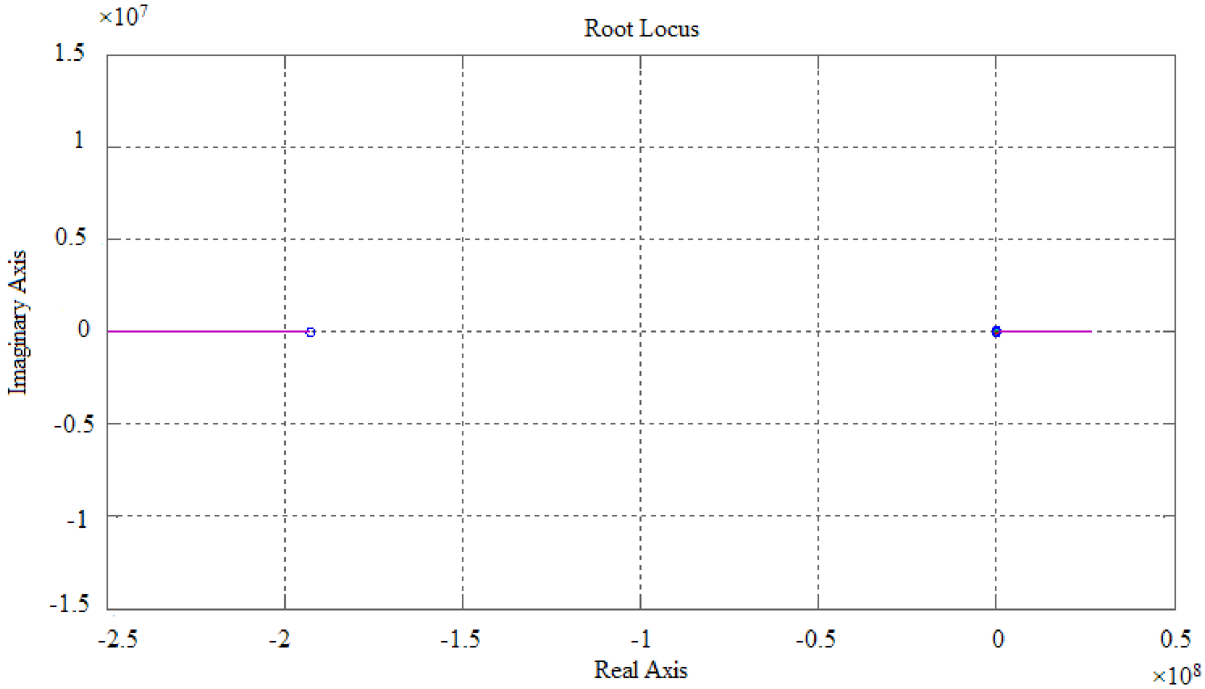


Figure 3 Root Locus after adding one pole

After running next time by adding compensation, there is no any zero and pole in the right hand plane. It can be seen that this system is marginally stable in Figure 3. In this system, lag compensation is required.

Findings: As there is one zero at 6.4218×10^4 in the right hand plane from the above root locus figure, it is needed to add one pole in the denominator. The transfer function for a lag compensator is $\frac{s+b}{s+a}$, a < b.

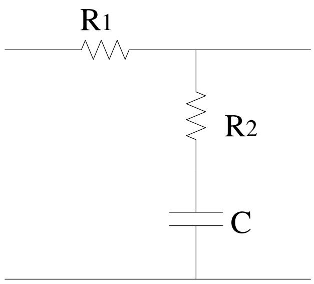


Figure.4 The Circuit of Lag Compensation

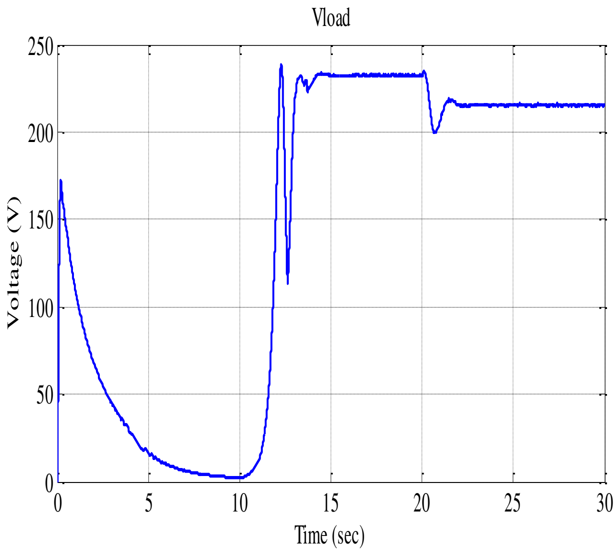
R_1 is connected in series in network and R_2 and C are connected in parallel with network. in Figure 4.

Transfer function for lag compensator G_2 $= \frac{s+1.927\times10^8}{s+6.4218\times10^4}$.

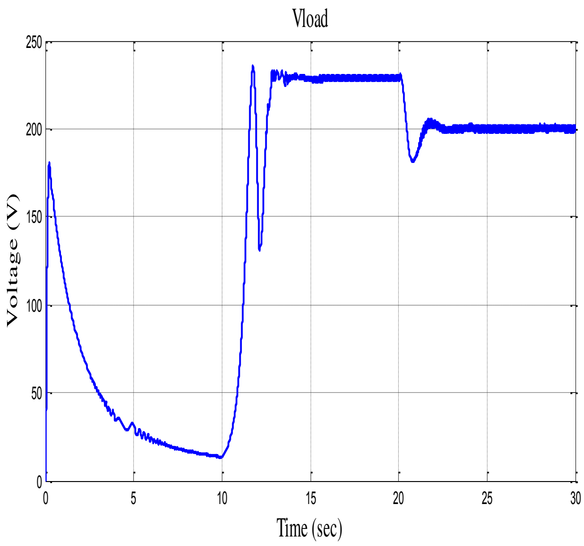
Result:

The performance of impedance source inverter is that can control load voltage within limit. This facts show in the following simulation results. Simulation result of load voltage is shown in figure 5. Firstly, cut in wind speed 4m/s produces 2V during 0 to 10, 232V at wind speed 9m/s between 10 and 20 second and 200V at wind speed 11m/s till to 30 second. The rated voltage 230V is very near to the simulation result value at the wind speed 9m/s. Though the load voltage of with impedance source inverter gets nearly rated value, which of without impedance inverter is 228V at rated wind speed during 10 to 20 second. It is clearly seen in Figure (b). When the system is not connected impedance source inverter, it does not achieve the rated voltage at rated wind speed. This is one of the performances of impedance source inverter by comparing with and without impedance source inverter.

Simulation result of reactive power which can produce from wind turbine is shown in figure 6. In figure (a), the wind turbine reactive power is zero at 4m/s during 0 to 10 second, the system absorbs 39 kVar at 9m/s between 10 and 20 second and 66kVar at 11m/s till to 30 second. This means that the system needs reactive power 39 kVar because of the inductive load. The simulation result of wind turbine reactive power during without impedance source inverter is shown in figure (b). The wind turbine reactive power is 44.5 kVar at 9m/s between 10 and 20 second. The wind turbine reactive power of without impedance source inverter is more than that of with impedance source inverter. The system required more reactive power than with impedance source inverter. If the system is not connected with impedance source inverter, the system faces with this disadvantage. The reactive power is not good for the system.

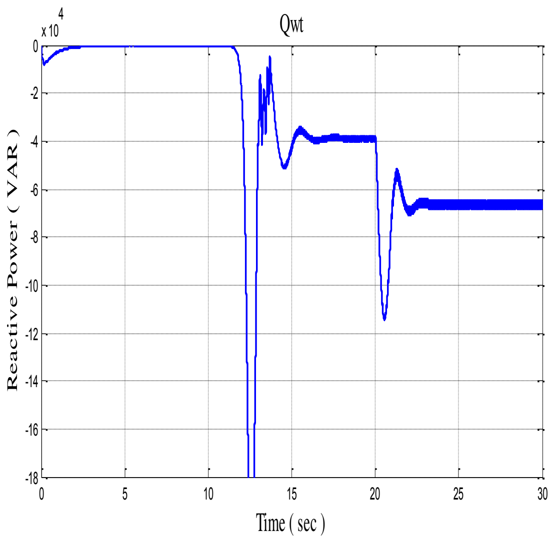


(a) With impedance source inverter

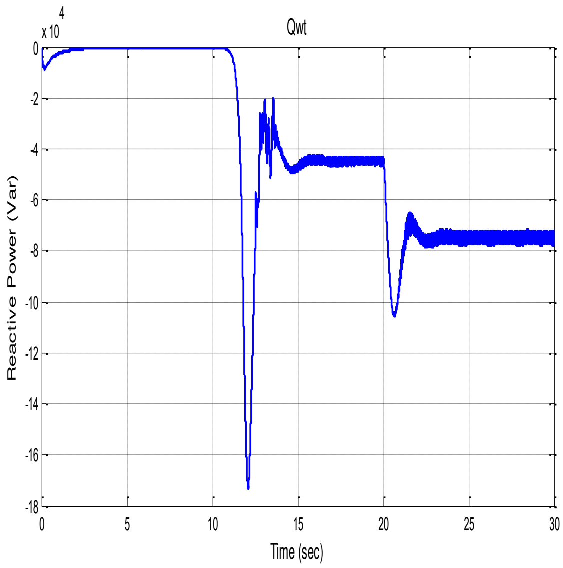


(b) Without impedance source inverter

Figure 5 Simulation Result of Load Voltage



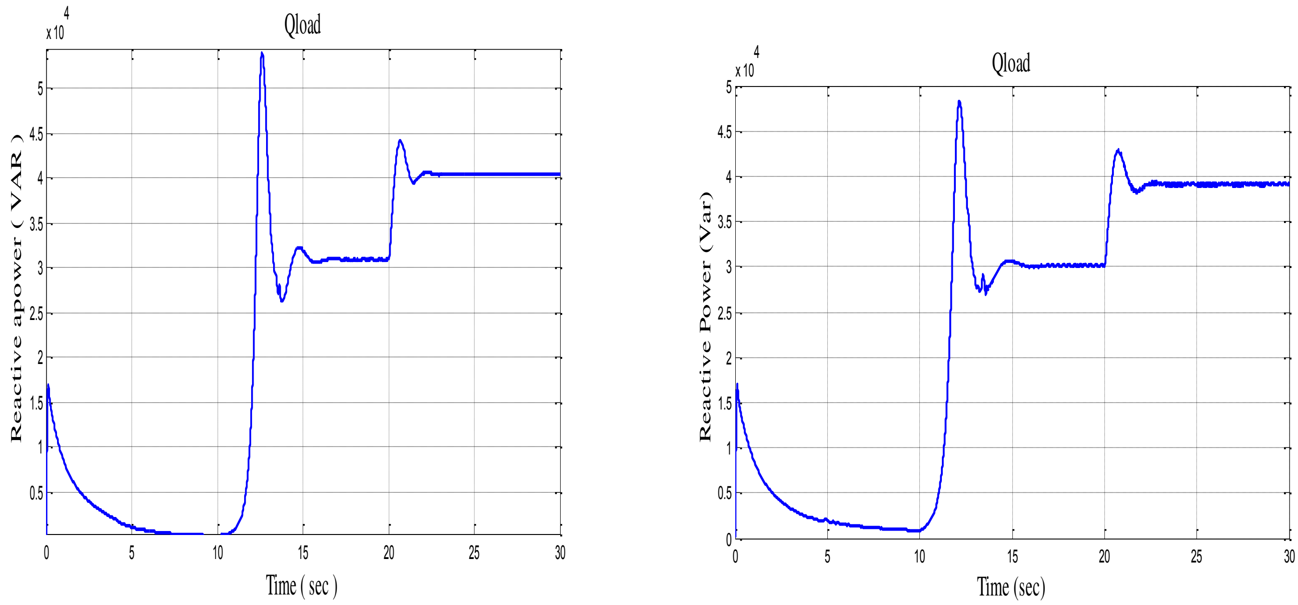
(a) With impedance source inverter



(b) Without impedance source inverter

Figure 6 Simulation Result of Wind Turbine Reactive Power

Figure 7 shows simulation result of load reactive power. When the system is joined with impedance source inverter, the simulation result is shown in figure (a). The load reactive power is 140Var at 4m/s from 0 to 10 second, 31kVar at 9m/s during 10 to 20 second and 40.5kVar at 11m/s till to 30 second. This mean that the load absorb reactive power. The simulation result of load reactive power is shown in figure (b). During 10 to 20 second, the load reactive power is 30kVar at rated wind speed. The system gives only 30 kVar reactive power though the system requires 44.5kVar. But, it is seen another performance of impedance source inverter. If the system is with impedance source inverter, the system gives reactive power 31kVar when the system needs 39kVar.



(a) With impedance source inverter (b) Without impedance source inverter

Figure 7 Simulation Result of Load Reactive Power

Another performance is reactive power consumption difference between with impedance source inverter and without impedance source inverter. Though the difference of reactive power of wind turbine and load is 14.5kVar while it is not connected impedance source inverter, there is not as much reactive power difference with impedance source inverter as without impedance source inverter. There will be 8kVar reactive power difference by connecting with impedance source inverter. This performance is very clearly by comparing in figure 8(i) without impedance source inverter and (ii) with impedance source inverter.

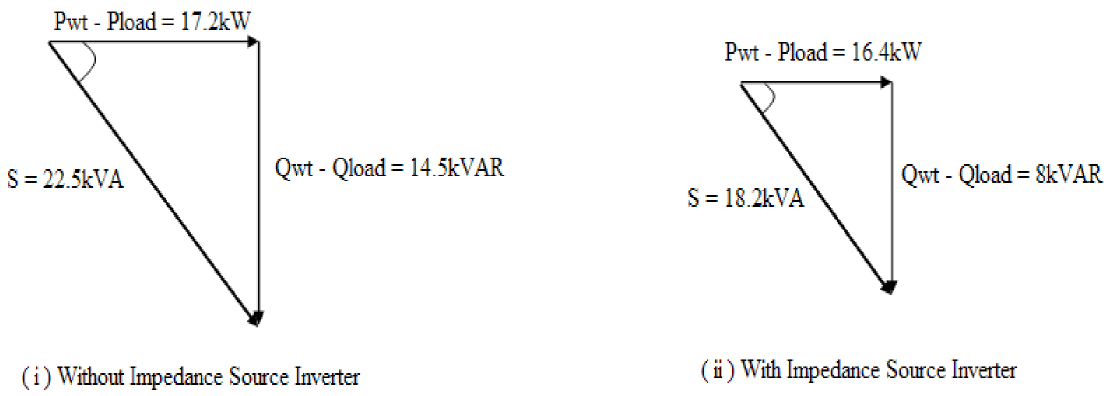


Figure 8 Comparison of Reactive Power Consumption

Table 2 Comparison Simulation Result of With Impedance Source Inverter and Without Impedance Source Inverter

Time (sec)	Wind speed (m/s)	ZSI	Vwt (V)	Pwt (W)	Qwt (Var)	Vdc (V)	Vload (V)	Pload (W)	Qload (Var)
0 ~ 10	4	WO	7	60	-30	16	13	3200	860
		With	1.2	1.5	0	2.7	2	500	140
10 ~ 20	9	WO	244	71×10^3	-44.5×10^3	568	228	53.8×10^3	30×10^3
		With	257	71×10^3	-39×10^3	583	232	54.6×10^3	31×10^3
20 ~ 30	11	WO	316	120×10^3	-75×10^3	735	228	47×10^3	39×10^3
		With	336	121.5×10^3	-66×10^3	762	200	50.7×10^3	40.5×10^3

Recommendations:

There are many places to get wind energy in Myanmar. According to NASA data, Sittwe wind speed data is one of the highest places in Myanmar. For this model, Sittwe Town is chosen. Wind power very often is a source of voltage fluctuations and flicker. Voltage control problems caused by deficit of reactive power in the grid can be remedied by installation of fixed or mechanically switched shunt capacitors. The wind speed are 4, 5, 6, 7, 8, 9, 10 and 11 m/s and induction generator (400V, 75kVA) is applied. The rated wind speed is 10 m/s. The cut in and cut out wind speed are 4 and 25 m/s. Due to self excited induction generator, the proper capacitor bank 4.8 kVar is chosen to satisfy the reactive power burden requirements. The universal bridge is used to convert ac to dc. And then, that dc voltage is converted to ac by using inverter. The wind power generation system is connected to load through an impedance source inverter which has the designed inductors (3.03 mH) and capacitors (14.45 μF). The full load power is 50 kW.

When the wind speed is less than cut in speed and more than cut out speed, the wind turbine does not operate and hence no energy is supplied to the load. If this proposed system connects with the grid, it is assumed that the impedance source inverter can get more performance due to both power from source and grid. Installing induction generators with grid is increasing more than that of stand alone system. Doubly fed induction generator is mostly connected to the grid and can achieve for the large scale ratings.

Conclusion: With unique features like single stage power conversion and improved reliability, the Z-source technology can be applied to the entire spectrum of power conversion. The output voltage of the ZSI entirely depends on the shoot through states. If we increase the shoot through time period we can get any desired voltage. The shoot through time is varied according to wind velocity. Traditional VSI and CSI have various limitations like obtainable output voltage were very low, they can served as either buck converter or boost converter but not as both. ZSI has removed all the limitations and effectively replaced the traditional inverter system. It is found to be an effective solution for voltage dip and surge condition. Keeping the input voltage, output voltage and modulation index constant, the performance of ZSI is compared for all switching techniques.

In this paper, Matlab model is running and check stability. From root locus, it can be seen to continue to be stable. When compensator is added, this model may be stable. After simulation with the programmable voltage source, the load voltage changing is within 10% limit according to IEEE standard though the source voltage is 20 % varying. The simulation result of load voltage does not reach the rated value while it is no connection with impedance source inverter. The load voltage with impedance source inverter gets the rated voltage at 9m/s. Another performance is that reactive power compensation in induction generator is in better condition when this inverter is connected with wind turbine. There is not as much reactive power difference with impedance source inverter as without impedance source inverter.

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