

# Using Y-source network as a connector between turbine and network in the structure of variable speed wind turbine

*By Mahmoud Zadehbagheri*

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## ABSTRACT

Environmental factors such as air pollution and increase in global warming by using polluting fuels are the most important reasons of using renewable and clean energy that runs in global community. Wind energy is one of the most suitable and widely used kind of renewable energy which had been in consideration so well. This article also introduces an electric power generation system of wind based on Y-source and improved Y-source inverters to deliver optimal electrical power to the network. This new converter is from impedance source converters family. This presented converter has more degrees of freedom to adjust voltage gain and modulation. Also, by limiting the range of simultaneous control (shooting through) while it maintains the highest power of maximizer, it can operate in higher modulation range. This causes the reduce of stress in switching and thus it will improve the quality of output. Recommended system had been simulated in MATLAB/SIMULINK and shown results indicate accurate functionality.

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## 1. INTRODUCTION

Using clean and renewable energy had been major concern for global communities and been introduced as an important and vital matter. Environmental factors such as air pollution and increase in global warming by using polluting fuels are the most important reasons of using renewable and clean energy. Another advantage of using renewable energy sources is minimizing the size of power production units and increasing the distributed generation units, the proximity of the units of production and consumption of electric power and thus reduce losses, and increase efficiency [1]. One of the highly used renewable energy that had been in consideration is wind energy. Using wind energy specially in windy areas in addition to the economic saving, increased quality will also be delivered. Electric power generation system from wind energy has been divided into 4 sections: 1) wind turbine; 2) electric generators; 3) power electric devices and; 4) controlling systems. Which by increase in this industry and technology there has been much progress in these sections and power electric devices, different generators, and control systems had been presented [2]. For example, with progress in materials science and further showing off the permanent magnet machines, using wind energy in different speed without gearbox is highly regarded. Thus, study of the electrical power generator systems from wind energy based on stimulating converters with permanent magnet is essential from different points of view. In the field of power electronic devices, there had been more different suggestions with unique features presented which the most important one is using one boost converter and source voltage inverter. Electric power generation systems from wind energy with different speed has many positive features such as; small size, high efficiency, lower installation cost, and lower maintenance cost compare to systems with fixed speed. Considering permanent magnet generators that can connect to the network directly and without using gearbox, has attracted more attention. Hence, the purpose of this article considering the importance of the power electric devices in delivering electric power to the network (connector between wind turbine and the network), is to suggest using Y-source network in variable speed wind turbine systems based on permanent magnet machines as electronic converter. Mainly voltage source inverters only can show buck performance (reducing) as a result, the alternating current (AC) output voltage will be limited by direct current (DC) voltage source. Also, in renewable energy applications input DC voltage fluctuates in a wide range and so there is need for buck-boost function. To overcome this problem, firstly we use DC/DC converters which it is placed between the source

and inverter. By adding a DC/DC converter the structure will have two stages. In two stages structure due to the lack of optimum combination, efficiency of the system and its performance will extremely reduce. To fix these problems, impedance source inverters had been introduced, while they are single-stage due to the removal dead time solving the DC bus short connection problem, they have high reliability. By introducing these converters study field of many such as modulation, modeling, control, etc [4] is provided for the converters [3]. Although buck-boost topology which is used to convert DC/AC as theory can boost the voltage to any desired value, but the ability of these converters boosting will be limited by passive elements and all the factors. Specially in high duties of self-charging convert cause massive losses in passive elements and this cause instability and limiting the boost of voltage. Impedance networks cover the entire range of power electronics, converting completely from inverter and rectifier to converting phase and frequency. There have been many different structures to solve limitations and problems of traditional structures of voltage source current and traditional current source for impedance network converters in the articles [4]. Placement and proper implementation of the impedance supply network with switching and the appropriate setting, reduce the power converting levels in power system chains. This improves reliability, stability and improvement and also efficiency. The general scheme of impedance source converters structure with different switch for different applications is shown in Figure 1 [3], [4].

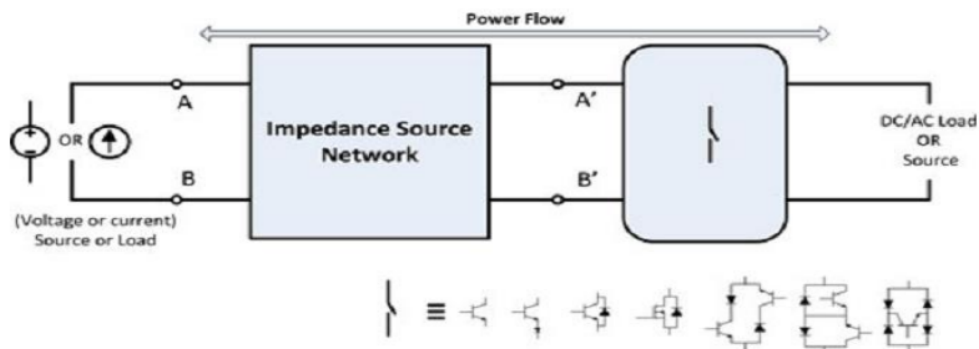


Figure 1. General scheme of impedance source converters structure with different switch for different applications [3]

So far, there has been many impedance source networks with the ability of maximizing which the most important one is Z-source. Features of this converter let researchers to think about solving the problems of this structures and present structures like (Quasi-Z), (Embedded-z), (*Tapped – Inductor*), (T-source), (*I – Source*) impedance source. Y-source converter has been introduced recently and is used as DC/DC and AC/DC with three coils which had been coupled. This converter has many different features. The interest of this converter in equal duties is different to other converters and has more freedom to (the number of turns of coils and switch timing ( $d_{st}$ )) adjust the interest of voltage compare to classic impedance source converters. Theoretical point of view, by adjusting the number of turns in coils  $d_{st}$  to any value, we can see the increase in voltage [5]. In the following proposed system, variable speed wind turbine based on Y-source inverter has been investigated and the results have been provided.

## 2. THE PROPOSED WIND TURBINE SYSTEM

Proposed system based on Y-source inverter and PMSG generator shown in Figure 2. In the following we will discuss different parts of the proposed system.

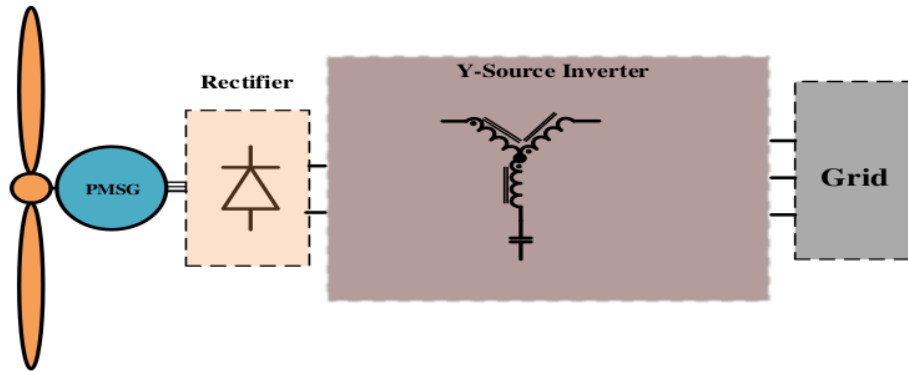


Figure 2. Proposed system scheme

### 2.1. Modeling of wind turbine

To obtain a proper expression of wind energy, this energy must be measured in some way. Calculating this energy with simple rules of classical physics, the kinetic energy of wind will be calculated.

$$E_{wind} = \frac{1}{2} m V_w^2 \quad (1)$$

In this equation  $m$  is equivalent to mass of a volume of air passing through the turbine. It is assumed that the total volume of wind moving at the same speed of  $V_w$ . Wind speed unit is meter per second m/s. assuming constant speed of volume of wind hitting turbine blades, a period of time  $t$ , we can define the mass as below:

$$m = \rho A V_w t = \rho \pi R^2 V_w t \quad (2)$$

Which  $\rho$  is air density,  $A$  the area swept by the turbine blades and  $R$  is the radius of the turbine blade. Substituting (2) in relation (1) to the kinetic energy of the wind will be expressed is being as:

$$E_{wind} = \frac{1}{2} \rho \pi R^2 V_w^3 t \quad (3)$$

Using the above equation, the real power in wind power, in every moment of time will be calculated is being as:

$$P_{wind} = \frac{E_{wind}}{t} = \frac{1}{2} \rho \pi R^2 V_w^3 \quad (4)$$

This equation shows that wind energy is heavily dependent on the wind speed. The affiliation with the cube of wind speed is specified So a slight change in wind speed, will create significant change in wind energy. Also, it is possible to get more energy from the wind by increasing the radius of the turbine blades. However, calculated power in (4) is the potential of wind power which is been calculated in wind speed  $V_w$  and  $R$  radius of turbine blade. From this amount, only a portion of that is converted into mechanical energy. This percentage will be calculated as Albert Betz determined in 1919 by presenting this method [6]. Based on this method, when the turbine blades are in wind direction, the wind speed reduce, as a result received energy by turbine will be less than maximum energy in the wind speed. The relationship between received energy by turbine,  $P_{turbine}$ , and maximum energy of wind,  $P_{wind}$ , and power factor of wind turbine,  $C_p$ , is being as:

$$C_p = \frac{P_{turbine}}{P_{wind}} \quad (5)$$

This ratio is calculated is being as: [7]:

$$C_p = c_1(c_2 \frac{1}{\alpha} - c_3\beta - c_4\beta^x - c_5)e^{-c_6 \frac{1}{\alpha}} \quad (6)$$

$$\frac{1}{\alpha} = \frac{1}{\lambda + 0.08\beta} \frac{0.035}{1 + \beta^3} \quad (7)$$

$$\lambda = \frac{\omega_m R}{V_W} \quad (8)$$

In above,  $\beta$ , is the angle of rotor blade which is shown in the Figure 3.  $\lambda$  is the severity rate of speed of wind turbine and  $\omega_m$  is angular velocity of the generator and wind turbine. Constant values ( $c_1$  and  $c_6$ ) are depends on type of turbine [7]. In the angle  $\beta = 0$  maximum power is available.

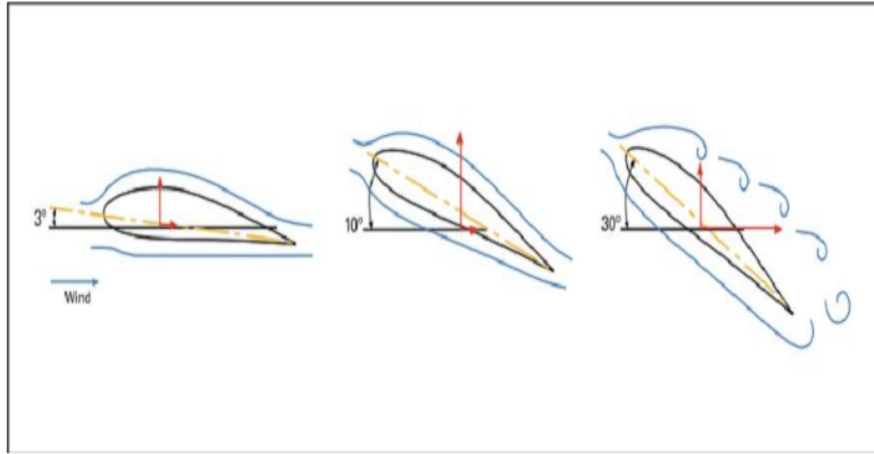


Figure 3. Turbine blade's angle diagram

At the end the equation of turbine blade is as below:

$$P_{turbine} = \frac{1}{2} \rho \pi R^2 C_p(\lambda, \beta) V_W^3 \quad (9)$$

Turbine mechanical torque,  $T_m$ , is obtained from below equation:

$$T_m = \frac{\frac{1}{2} \rho \pi R^2 C_p(\lambda, \beta) V_w^3}{\omega_m} \quad (10)$$

The following will be the simulation of wind, the effect of  $\beta$  on  $C_p$  has been investigated and ratio of highly optimized speed  $\lambda_{opt}$ , which  $C_{p, opt}$  is produced because of that, had been calculated. To gain this goal  $C_1$  to  $C_6$  parameters is being as:

17 e 1. C1 to C6 constants

$C_1$	$C_2$	$C_3$	$C_4$	$C_5$	$C_6$
0/5	116	0/5	0	5	21

To simulate the wind in here we have used linear form which is like increasing and decreasing of gradient.

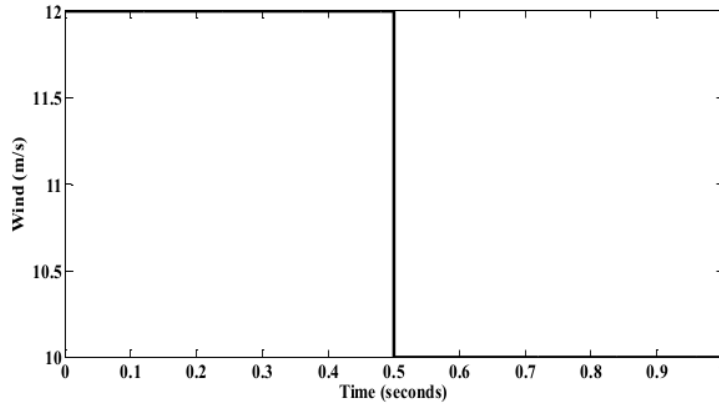


Figure 4. Entrance wind model

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## 2.2. Modeling of permanent magnet synchronous generator (PMSG)

The dynamic model of electric machines is necessary for investigating the dynamic conditions and potential errors. Dynamic modelling based is on voltage equations, flow, flux-flow, and park conversion. In electric machines depends on input and output variables, different models can be simulated. In here based on the functionality of this generator in combination with wind turbine and selected control system, the speed of machine as entering, and three-phase current of machines as output is considered for turbine-generator. Thus, the equations will change is being as [8], [24]:

$$i_{ds} = \frac{\frac{1}{s}(-v_{ds} - R_s i_{ds} + \omega_e L_q i_{qs})}{L_d} \quad (11)$$

$$i_{qs} = \frac{\frac{1}{s}(-v_{qs} - R_s i_{qs} - \omega_e L_d i_{ds} + \omega_e \lambda_M)}{L_q} \quad (12)$$

4

The power delivered to the load can be calculated by the following equation:

$$P_S = P_m - P_{cus} = T_e \frac{\omega_e}{p} - 3R_s I_S^2 \quad (13)$$

$$P_S = P_m - P_{cus} = T_e \frac{\omega_e}{p} - 3R_s I_S^2 \quad (14)$$

$$I_S = \sqrt{i_{ds}^2 + i_{qs}^2} \quad (15)$$

## 3.2. Control system

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The inverter control system is used to control active power and reactive power injection to the network and maximum control is shown in Figure 5. The control system has two parts: 1) MPPT 2) active and reactive power control of the exchange with the network.

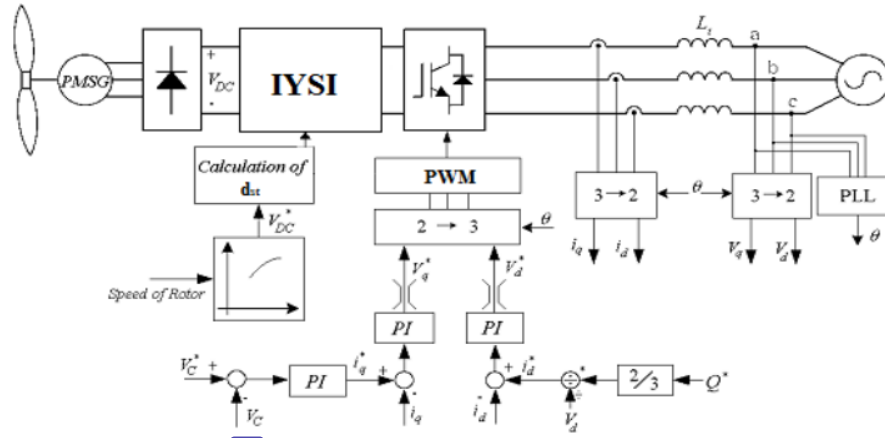


Figure 5. The control system considered for the proposed wind turbine system

### 3.2.1. MPPT control system

There is need for MPPT control for adjusting the speed of rotor to get the highest power from wind turbine. Because the output voltage is not constant and it become short-circuit because of the switches sometimes, for controlling signal we use capacitor voltage which is constant. The below equation shows the relationship between capacitor (C2) and output voltage [9], [10], [23].

$$V_{C_2} = (1 - D) V_o \quad (16)$$

And according to the equation  $V_o = \frac{1}{1 - D(1 + 1 + n_{21}/1 - n_{32})} V_{in} = B V_{in}$  and placement in the above equation, the relation between the capacitor voltage C2 and the input voltage is being as:

$$V_{C_2} = (1 - D) \frac{1}{1 - D(1 + 1 + n_{21}/1 - n_{32})} V_{in}$$

$$V_{C_2} = (1 - D) \frac{1}{1 - ED} V_{in} \quad (17)$$

Thus, the signal controller according to the number of courses intended for the windings is calculated as following:

$$D_{sc} = \frac{V_{in} - V_{C_2}}{V_{in} - EV_{C_2}} \quad (18)$$

### 3.2.2. Control of active and reactive power delivered to the network

Active power, P, and reactive power, Q, obtained from (19), (20):

$$P = \frac{3}{2} (v_d i_d + v_q i_q) \quad (19)$$

$$Q = \frac{3}{2} (v_q i_d - v_d i_q) \quad (20)$$

$v_d, v_q$  is network voltage,  $i_d, i_q$  injected current to the network in the frame of reference  $d-q$ . If the reference voltage become as network voltage then  $v_q = 0$ . Thus above equations will change to followings [11], [12], [21]:

$$P = \frac{3}{2} v_d i_d \quad (21)$$



$$Q = -\frac{3}{2} v_d i_q \quad (22)$$

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From the (21) and (22) we realize that we can control active and reactive injected powers to the network by controlling  $i_d$  and  $i_q$ . To do that there are two direction of control will be considered. In the first direction by adding the amount of reference for reactive power,  $i_d$  will be adjusted and the amount of reference of  $i_d$  to reach power factor the unit will be considered as zero. In the next direction by capacitor voltage in inverter mode or output voltage in converter mode for controlling the output active power,  $i_q$  will be adjusted [13]-[15], [22].

### 3. SIMULATION AND RESULTS

In this section, to investigate wind turbine systems there is an opinion based on Y-source inverter, the em simulated and result is shown. We used MATLAB/SIMULINK for simulation Figure 6. Simulation parameters are shown in Table 2 and Table 3. Voltage curve DC based on rotor speed is shown in Figure 7. We use this curve to find highest point of power and control inverter. To find this curve firstly in a few different speed (0.6-1.26 p.u) rotor and in highest power delivered to the network, the speed of rotor and DC link voltage has been measured which is shown in red in the figure. Then a polynomial function is guessed based on that which shows DC link voltage behavior change with respect to rotor speed changes in all the speeds with a very good approximation and low error. See Figure 7. Wind model applied to the system based on figure 5 which the speed reduces from 12 meter per second to 10 meter per second.

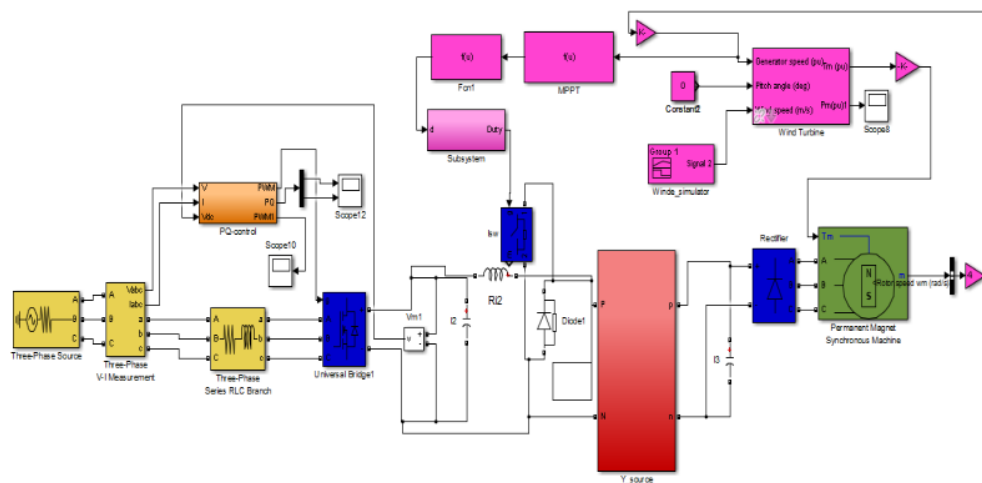


Figure 6. Simulated model in MATLAB/SIMULINK

Table 2. PM generator parameters	
AMOUNTS	PARAMETERS
0.9585(Ω)	$R_s$
5.25(mH)	$L_d, L_q$
4	P
6.329(kg.cm <sup>2</sup> )	J

Table 3. Simulation parameters	
AMOUNTS	PARAMETERS
10(kHZ)	Switching Frequency ( $F_s$ )
76(V)	Network Effective Voltage
500(μF)	Filter Capacitor (C)
0.5(mH)	Inductance (L)
20: 40: 20	Conversion Ratio ( $N_1 : N_2 : N_3$ )



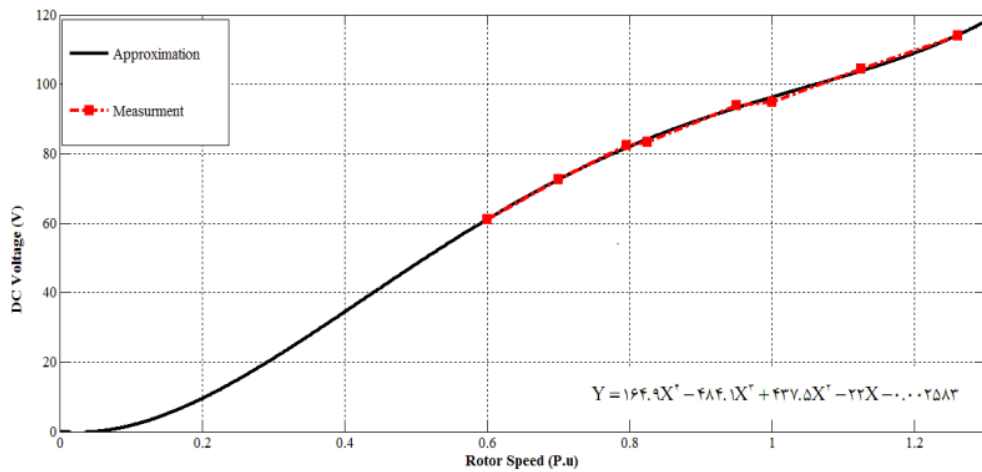


Figure 7. DC link voltage changes curve based on changes in rotor speed

In Figure 8, changes in the speed of rotor by changing wind speed is shown in different time. Considering the curve of the changes in rotor speed and changes in wind speed curve, it is obvious that the speed of rotor has changed for delivering the highest power from turbine with the change of the speed of wind. To know these changes, we need to look at Figure 9 and Figure 10, which in order they show mechanical and electrical curve. It is shown that after a short period of time the mechanical power curve of turbine production has reached the highest power and followed it (based on wind speed). DC link voltage inverter and its big scheme is in Figure 11. As it can be understood from the figure, voltage level changes from maximum to zero and vice versa, the reason of these changes are short circuits in the inverter bases in transition at the 0.2 time. Thus, in this situation, we use Y-source converter capacitor voltage to control MPPT and control active and reactive power which injected to the network. Inverter capacitor voltage is shown in Figure 12. Figure 12 and Figure 13 shows that the system met the requirements for connecting to the network because the level of capacitor voltage is kept in a constant level and reactive power exchange to the network is almost zero (unity power factor). The power delivered to the network at wind different speeds and the efficiency of the proposed system are shown in Figure 15, and Figure 16, respectively.

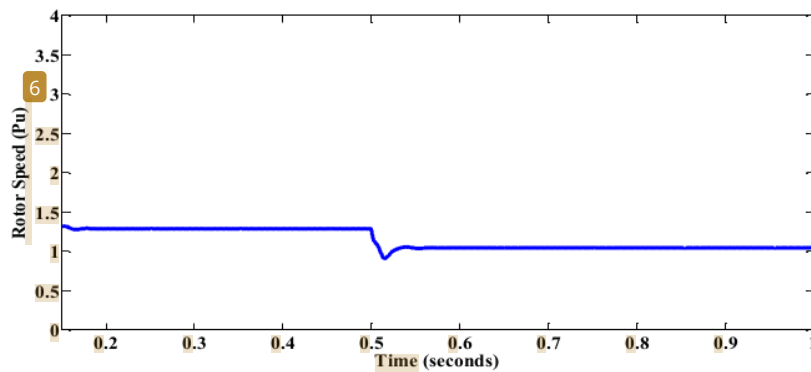


Figure 8. Rotor speed (p.u) according to variations in wind speed

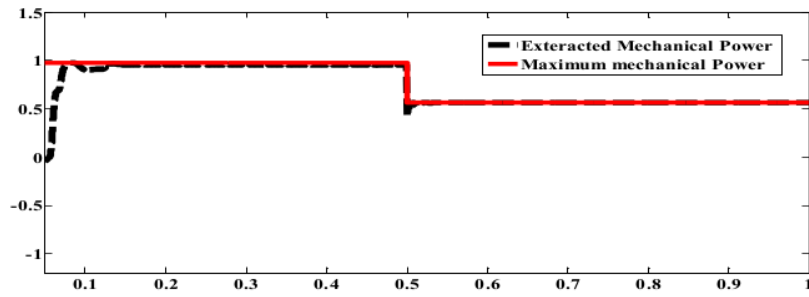
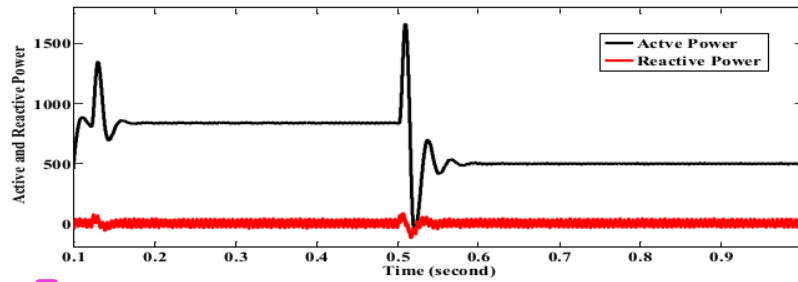
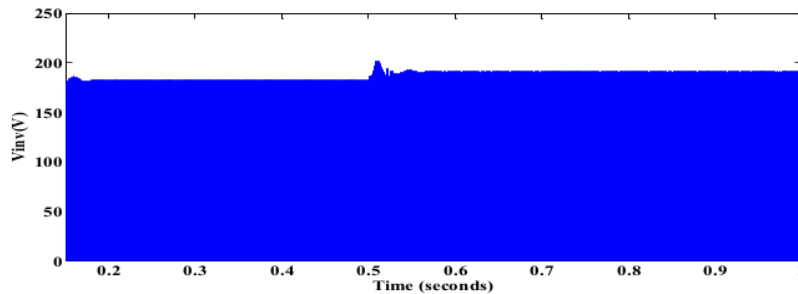


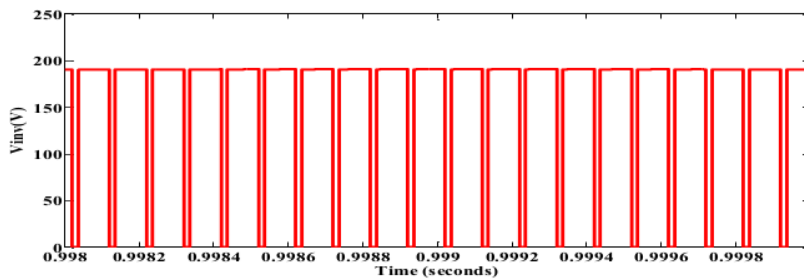
Figure 9. Curve of turbine mechanical power



2 Figure 10. Active and reactive power which is delivered to the network under changes of wind speed



(a)



(b)

28 Figure 11. (a) inverter DC link voltage and (b) inverter DC link voltage in magnified mode under changes of wind speed

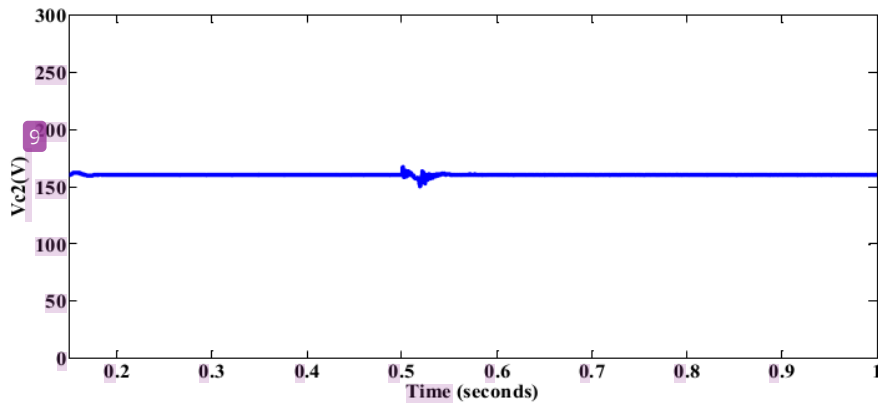


Figure 12. Capacitor voltage (C2) under changes of wind speed

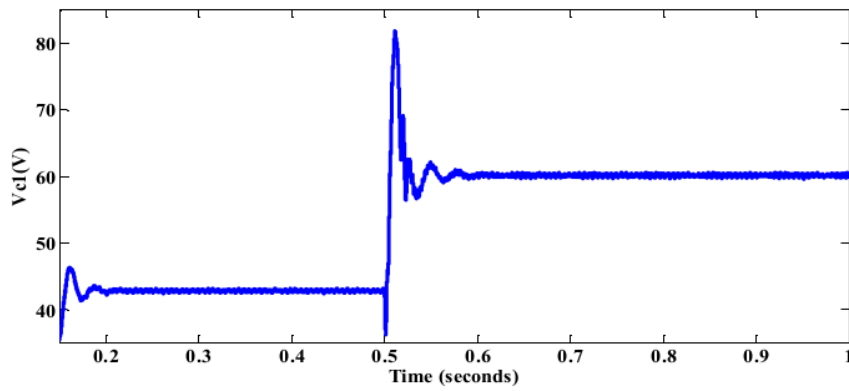


Figure 13. Capacitor voltage curve (C1) under changes of wind speed

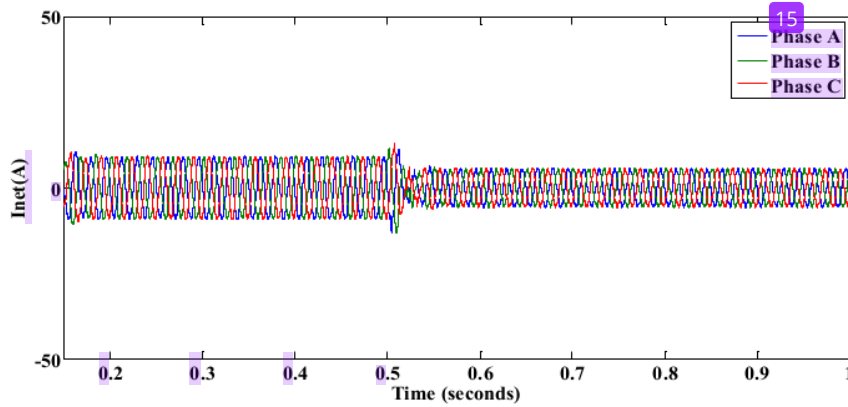


Figure 14. Injection current to the network by the proposed system

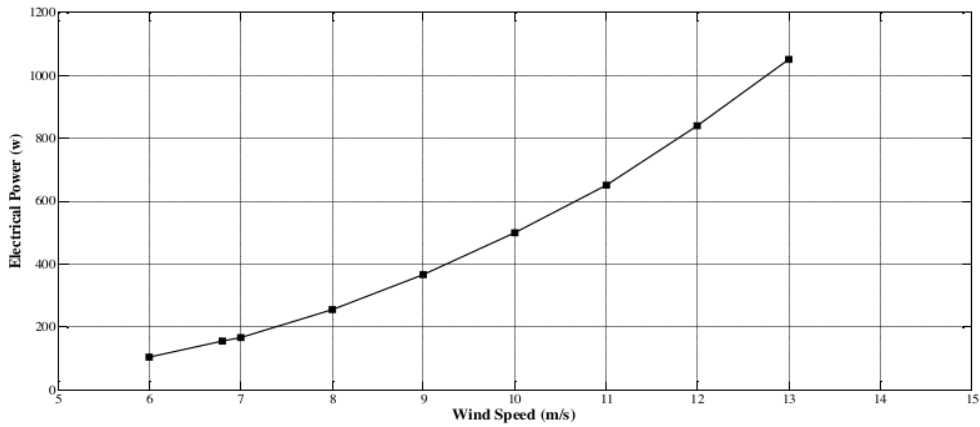


Figure 15. Power delivered to the network by the proposed system

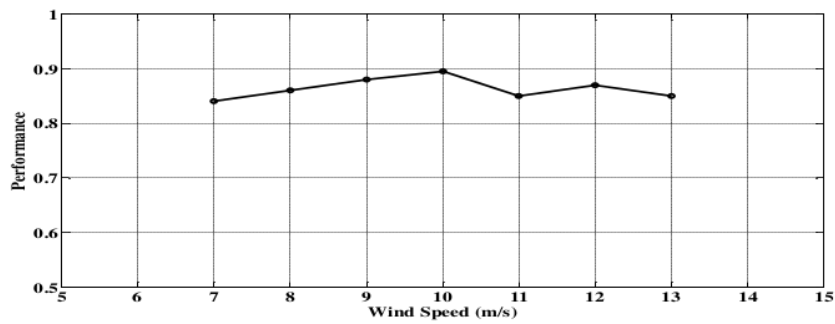


Figure 16. Performance of proposed system

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### 3.1. Simulation of improved Y-source

Here, for comparison the improved Y-source converter has been simulated and the results are presented. The simulated circuit is shown in Figure 17.

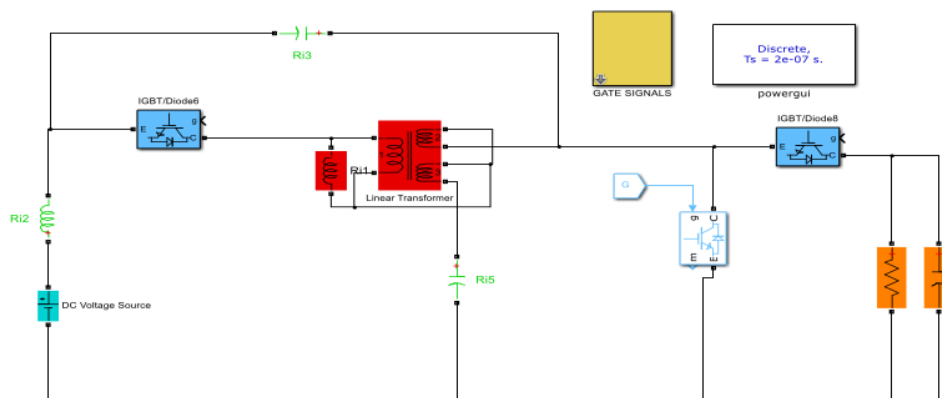


Figure 17. Simulated converter in MATLAB/SIMULINK software

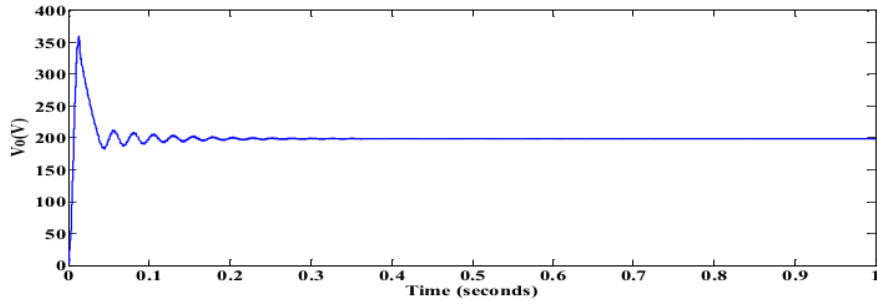


Figure 18. Output voltage of IYSI

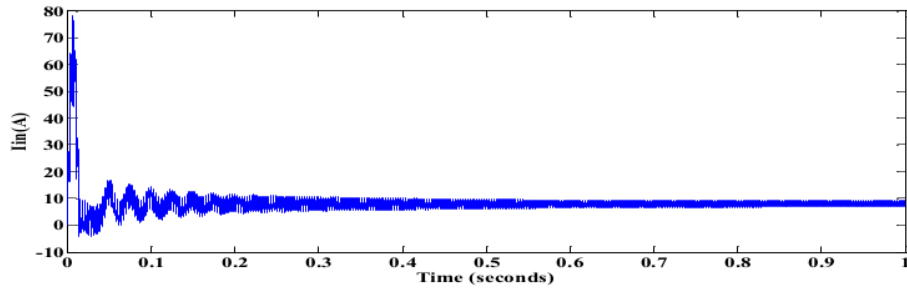


Figure 19. Input current of IYSI

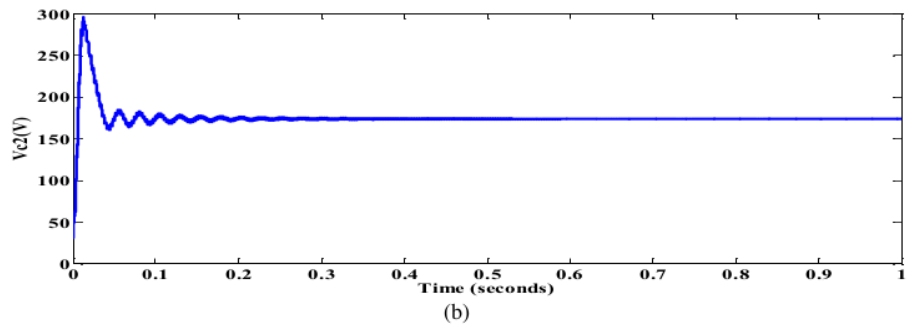
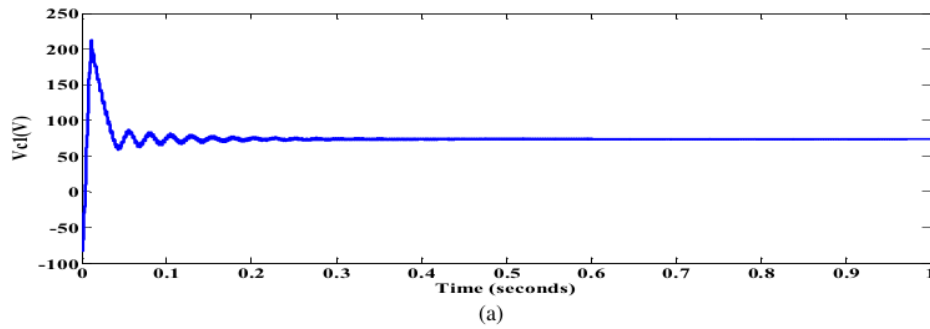


Figure 20. Capacitors voltage of IYSI, (a) c1, (b) c2

### 3.2. Comparison results of the proposed system with other systems

Table 4. Structures compare of IYSI, YSI, ZSI

Converter	Semiconductor Number	Number of Capacitors	Number of Inductances	Transformer
Improved Y-Source inverter	1	2	1	1
Y-Source inverter	1	1	0	1
Z-Source inverter	1	2	2	0

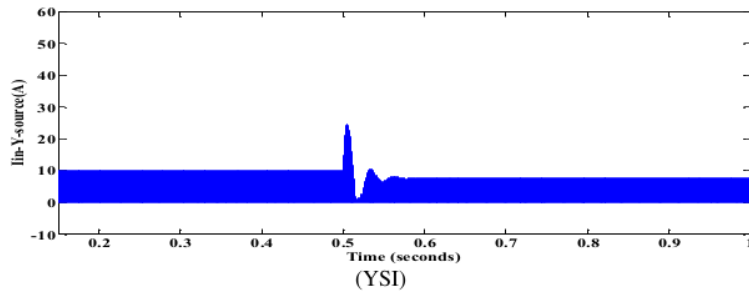
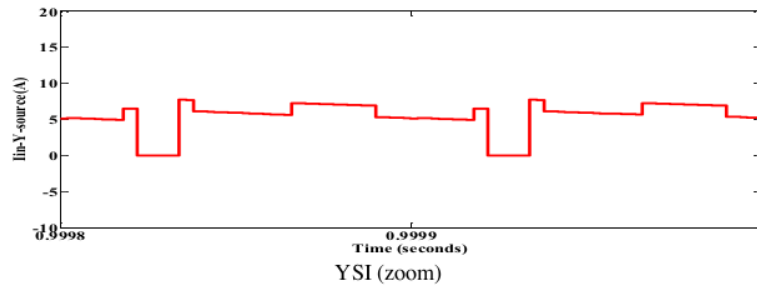
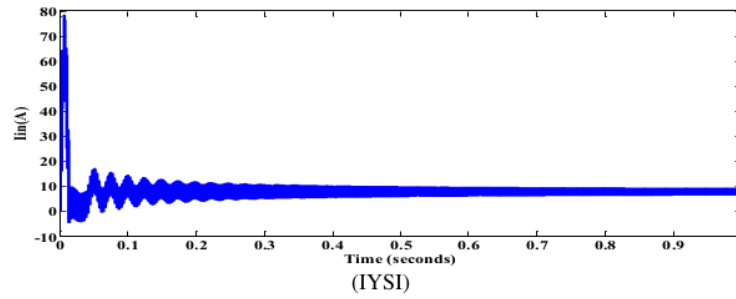
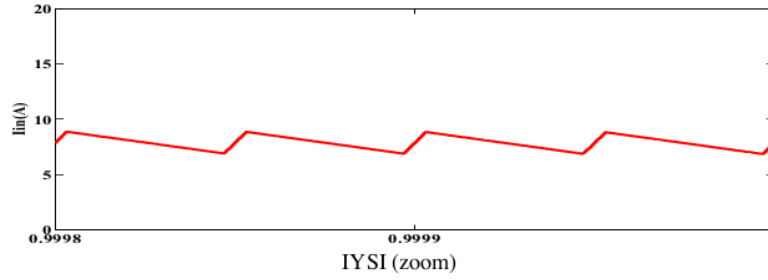


Figure 21. Comparison of the input current of IYSI and wind turbine system including YSI

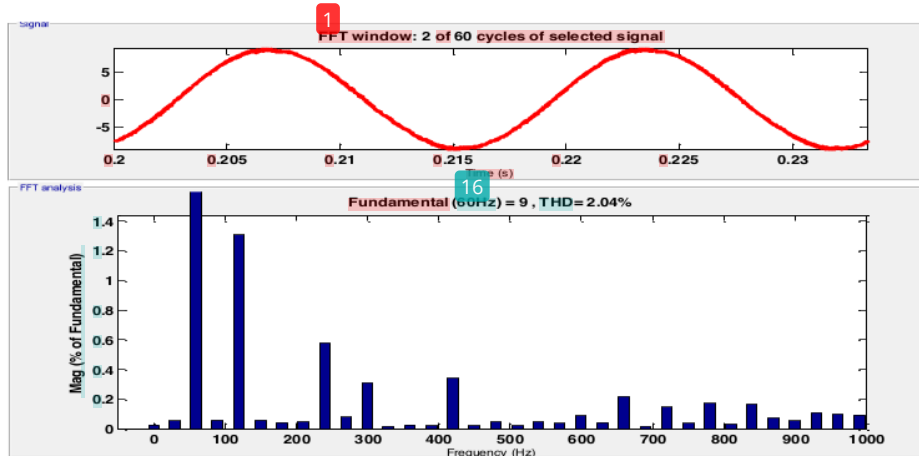


Figure 22. Injection current harmonics to the network and THD (IYSI)

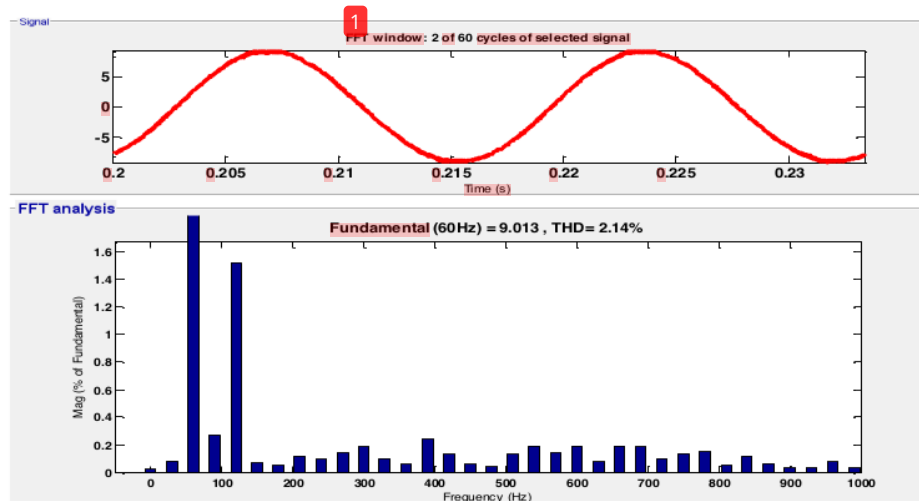


Figure 23. Injection current harmonics to the network and THD (YSI)

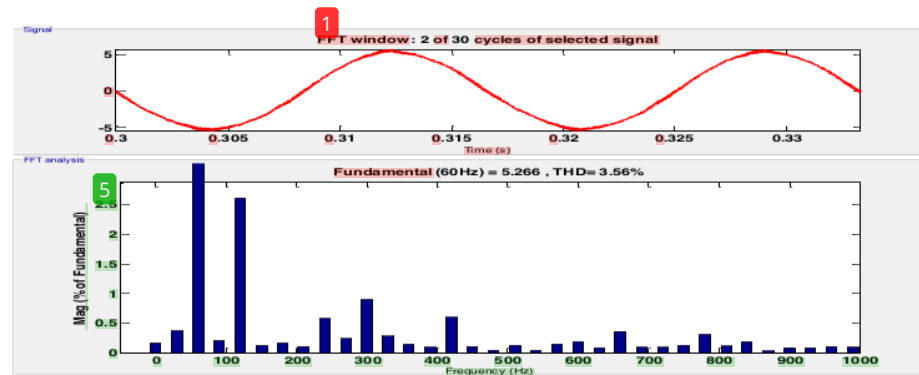


Figure 24. Injection current harmonics to the network and THD (Z-Source)



Table 5. Numerical comparison of THD (YYSI, YSI, ZSI)

19	CONVERTER	THD
	Improved Y-Source inverter	2.04%
	Y-Source inverter	2.14%
	Z-Source inverter	3.56%

#### 4. CONCLUSION

As mentioned before, environmental factors such as air pollution and the increase in global warming by using polluting fuels are the most important reasons of using renewable and clean energy that runs in global community. Wind energy is one of the most suitable and widely used kind of renewable energy which had been in consideration so well. In this article we discussed a new structure of wind turbine based on Y-source inverter as connector between the network and generator. All parts of the suggested system were discussed and at the end the result of simulation which it was done by MATLAB/SIMULINK software were shown. The result shows the correct functionality of the system and controlling system under changes of the wind speed.

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