International Journal of Multidisciplinary and Current Research

Research Article

ISSN: 2321-3124
Available at: http://ijmcr.com

Separate control of active and reactive power of Doubly-Fed Induction Generators (DFIG) Based on Wind Turbines at Unbalanced network Voltage Conditions

Shahram Ahmadi, Amir Abdollahi and Masoud Rashidinejad

Department of Power Engineering, Sirjan Science and Research branch, Islamic Azad University, Sirjan, Iran

Accepted 02 May 2014, Available online 20 May 2014, **Vol.2** (**May/June 2014 issue)**

Abstract

In order to convert wind energy into electric one, several generators are being used in connection with multiple structures of power electronic tools. Today, Doubly-Fed Induction Generators are used as the most common energy converter system. Depending on DFIG field of use, electric system is analyzed separately from or in connection with mechanical system. In the present paper, electrical system has been analyzed and investigated separately from mechanical system, considering changes in speed. From another point of view, wind turbine systems are investigated in two forms; in connection with multi-bus network or infinite bass. At the first state, the connection between DFIG system and network as well as its effect on several modes such as stability in multi-bus system is analyzed. But in order to investigate the DIFG system individually and apply modern control methods on it, the system is considered to be in connection with infinite bus. So in this study, we have applied this mode, considering the topic in question. According to the procedure used in this study, the coiled rotor will be fed using infinite bus of inductive machine stator. Rotor of the machine is fed using Back-to-Back configuration, and maximum external power will be received from the stator for applying several torques. For this purpose, active and reactive powers have been controlled separately by introducing a new control method. Imbalance in network voltage will result in fluctuation in electromagnetic torque and non-sinuous changes in the current injected to the system. In the present paper, we have investigated the system when being faced to normal network voltage conditions as well as to imbalance in voltage, indicating preservation of stability of the system as well as its acceptable output when being under modern control.

Keywords: *active, reactive, Wind Turbines*

1. Introduction

Dispersed generation is a new tendency in production of electrical power. The idea allows electricity consumers who, themselves, produce their required electricity, to dispatch the extra electrical power to the power network. So many of factories, offices, and hospitals are in need of sources with high degree of reliability for electricity generation, air conditioning, and water heating. To raise the reliability of feeding sources and decrease the costs, some offices and factories use combined production or generic energy factories. This type of factories often uses additional and useless materials such as wood wastes or additional heat due to an industrial process to generate electricity. In some cases, electricity is produced from a locally fed fuel such as natural gas or gasoil, and then the extra amount of heat produced by thermal energy source of the generator is used to provide hot water as well as industrial heating. In the case an industrial process needs a large amount of heat to be provided through a non-electrical source such as fossil or biomass fuel, use of a combinatorial-production factory would be economical.

To date, supervision- and technologic- related issues have meant that the electricity generated by household consumers cannot be easily and safely accompanied by input power feeding. Electric companies should be able to separate various parts of power network. When a power line fails, workers must make sure about the power outage before working on it. They also spend a lot of time to maintain the electricity quality in their network. Distributed installations of electricity may worsen control of such problems.

Appearance of power electronic equipments with high degree of reliability has made installation of combinatory-production equipments even those at household scale economical and safe. These installations can produce household hot water, electricity, and heat, and sell the extra energy to Electricity Corporation. Progresses in field of Electronics have made it easy to access security and quality issues of electric companies. In order to obviate obstacles in the way of reaching raise in distributed generation level, regulators may work on a background with variable level, through ensuring performance of concentrated and distributed generations.

Distributed generation is not restricted to fossil fuels. At this time, some countries and regions have a remarkable amount of renewable energy sources in wind turbines and biomass combustions. It is necessary to make change in the technology required for transport management and electricity distribution in order to increase the distributed generation.

Regardless of the type of distributed generation systems, these systems are investigated in terms of several factors such as design of power converters structure, improvement of generator performance, getting island-like, performance type in multi-bus networks, improvement of stability, power quality problems, provision of reactive power, etc. Considering the extensive range of the subject aforementioned, in some cases, DG1 system is to be considered as connected to infinite bus to analyze the system performance, and changes in parameters imposed on the system are investigated.

Studies indicate that effect of change in rotor speed and switching lead to appearance of some harmonics in stator current, and consequently, in rotor current. If these harmonics enter the control loop, there will be some fluctuations happened in controller output and thus in the system output. Here a method is introduced to extract harmonic components of electromagnetic torque as well as active and reactive powers. Switching process is carried out by omitting the components remarked above and creating suitable reference for the controller system.
Finally, some recommendations have been made in order to go on with study on DFIG system, considering the modern control method. Furthermore, a new method for obtaining machine parameters has been developed, considering the modern method for extracting rotor current from voltage and current of stator.

Innovations

According to the performed studies, changes in speed of inductive machine lead to creation of some negative-order uncalled-for components and harmful harmonics in stator current, and consequently, in rotor current. There are similar conditions in double-fed generators used significantly in wind turbines. Apart from any type of control system carried out on DFIG system, entrance of these uncalled-for components into the control system causes fluctuated performance in system output in forms of torque, active and reactive powers. In order to prevent such fluctuations, several bottom-passing filters are considered to be used. In addition to have some problems in design, these filters have some faults such as creating delay in response. In this part, a method will be presented to remove these components.

The usual method for converting power in DFIG structure is to use Back-to-Back converters to do AC-DC-AC convert. These converters are switched to remove harmonics of the current injected into the network of at least 2 kilo hertz. In the method remarked, it is necessary to have a DC link with completely smooth voltage so that the minimum ripple on DC voltage will directly affect the injected active power. In addition, due to the low-degree reliability of DC link in the above structure, there will be several problems with the system.

Considering the points noted above, it would be really useful to introduce a method which removes the direct connection between active power and DC link through using soft switching process and has rapid and suitable responses at various speeds. In this article, a modern control method has been analyzed, and analytic curves have been presented in simulation environment in order to prove the separation of fluctuating models of active and reactive powers and torque caused by changes in speed and switching.

In this paper, we have also presented a modern method in order to estimate rotor current and decompose it into symmetric components. Using this method, the controller loop newly designed acts in the way that creates the rotor current and use it as a reference to compare it with triangular carrier.

Using Back-to-Back converter to inject DFIG power into the network

Considering the power converter structures presented to inject DFIG power into the network, the two-step converter AC-DC-AC seems to have a wide use in DFIG structure. Nevertheless, hard switching, low-degree reliability of DC link capacitor, weak power coefficient of line, and harmonic distortion in line current and machine are among disadvantages of this type of converters.

Figure. 1 shows the usual converter for injecting power from DFIG into the network, as well as structure of the machine. Directions of power and current shown in the figure have been utilized to draw simulated curves. In the above structure, the converter located on the network side has the task of injecting power from network side into the rotor or vice versa to control injecting maximum power from machine stator into infinite bus. Furthermore, the converter is able to inject reactive power into the network and receive it from the network. It also controls DC link voltage and its constancy. Inductors connecting this converter with infinite bus have been also used as a bottom-passing filter in order to remove high harmonics of current caused by switching. Injection of power can be done by optimize use of inductors of bottom-passing filter. This converter and the converter located on the rotor side are of VSC type. For suitable performance of the system at several speeds of rotor, values of inductors and capacitors should be chosen in the optimized manner. Therefore, in order to obtain a suitable performance for the system presented, it is necessary to make DC link voltage constant and

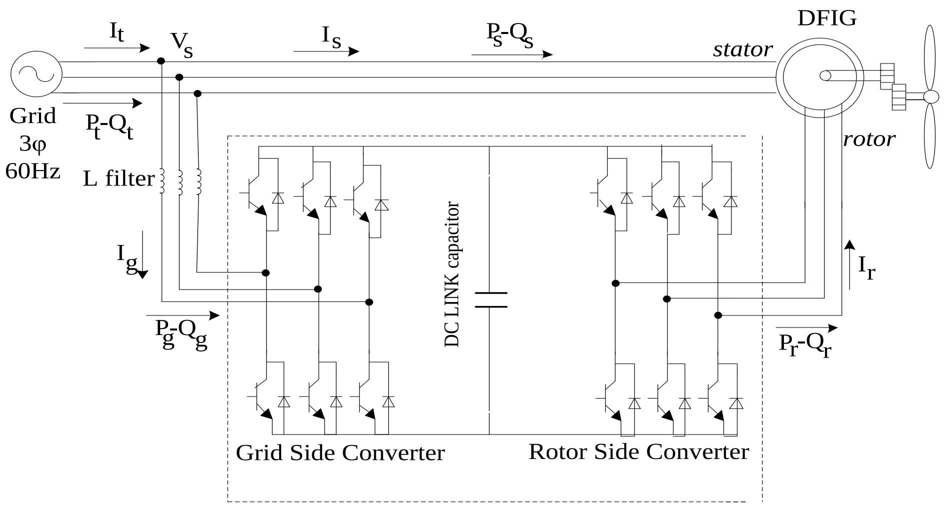

Figure 1: use of converter for injecting power from DFIG into the network schematic design of controller of the converter located on the network side

without any ripple. In spite of existence of this constant voltage, switching controllers should act in the way that active and reactive powers of stator can be controlled in an optimized and most efficient manner through suitably injecting current into the rotor. In order to attract the maximum active power from the stator at the speeds below synchronous, the power should be multiplied by slippage value. The result value should be injected into the rotor. For speeds above synchronous, power will be in the opposite direction from the rotor and have the value aforementioned.

In the following, principles governing the above structure and the modern control method presented in this paper will be described. Controllers designed have been considered for the network and rotor sides both, and the results of using this method will be presented in the next chapter.

RSC controller structure

The converter located on the rotor side is of VSC type, and through a switching method namely PWM, controls rotor current, and thus, DFIG system. Introducing a modern method used to control switching in the system, inductive machine will be controlled by changing domain and phase of rotor current, active and reactive powers on stator side, and also electromagnetic torque of inductive machine.

Input mechanical power of the system should be equal to summation of output power of the system, rotor, and losses. Overlooking system losses, the relationship between electric and mechanical powers is as follows:

$$T_{\mathrm{e}}\omega_r = P_r + P_s \tag{1}$$

Where

P_s, P_r, ω_r, and T_e are active power of stator, active power of rotor, rotor speed, and electromagnetic torque of synchronous machine, respectively. In order to control the converter located on rotor side, active power will be considered by extracting from the relationship (1). It is worth noting that fluctuating modes due to changes in speed and switching are omitted from torque and active power of stator relationships in the relationship (72-3), and the constant mode of stable state of the relationship has been considered only.

$$P_{\mathrm{r}} = T_e\omega_r - P_s \tag{2}$$

As a result, active power reference for the convereter located on the rotor side will be as the relationship (3):

$$P_{r-ref} = \frac{p\omega_r}{\omega_s}\left(\frac{3}{2}\left(v_{ds}^{+}i_{ds}^{+} + v_{qs}^{+}i_{qs}^{+}\right) - R_s\left(|\vec{\iota}_s^{+}|^2 - |\vec{\iota}_s^{-}|^2\right)\right) + \frac{3}{2}\left(v_{ds}^{+}i_{ds}^{+} + v_{qs}^{+}i_{qs}^{+}\right) \tag{3}$$

In order to create suitable references for reactive power for switching the converter located on the rotor side, it is possible to use a constant number for various speeds. Totally, the relationship between active and reactive powers in terms of voltage, and the current of d-q axis are defined, according to the matrix existing in the relationship (4):

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \frac{3}{2}\begin{bmatrix} v_d & v_q \\ v_q & -v_d \end{bmatrix}\begin{bmatrix} I_d \\ I_q \end{bmatrix} \tag{4}$$

From the relationship (5), positive-order current of dq axis of stator is calculated as follows:

$$\begin{bmatrix} \mathrm{i}_{\mathrm{ds}}^{+} \\ \mathrm{i}_{\mathrm{qs}}^{+} \end{bmatrix} = \frac{2}{3\left({\mathrm{v}_{\mathrm{qs}}^{+}}^{2} + {\mathrm{v}_{\mathrm{ds}}^{+}}^{2}\right)}\begin{bmatrix} \mathrm{v}_{\mathrm{ds}}^{+} & \mathrm{v}_{\mathrm{qs}}^{+} \\ \mathrm{v}_{\mathrm{qs}}^{+} & -\mathrm{v}_{\mathrm{ds}}^{+} \end{bmatrix}\begin{bmatrix} \mathrm{P}_{\mathrm{r,ref}} \\ \mathrm{Q}_{\mathrm{r,ref}} \end{bmatrix} \tag{5}$$

Now, stator current can be obtained using the noted method. Schematic design of control system of the converter located on the rotor side is shown in figure. (2).

Figure. 2: schematic design of control system of the converter located on the rotor side

For changes in rotor speed, control system of the converter should work in the way that maximum active power from the suction stator side and reactive power from the stator side are equal to 0. Accordingly, output pulses of the PWM generator will be controlled, using three gain variables. The gains K_{P} and K_2 have been specified to control the active power and domain of the current injected into the rotor, respectively. K_{Te} has been also determined to control the torque.

The inductor machine needs a limited amount of reactive power so as to act in a correct way. So, the reactive power required by the machine is provided by stator or rotor. In a DFIG system connected to network, reactive power will be supplied by network, and in the isolate mode of a network, an external source such as capacitor bank should be used to supply reactive power.

Exploiting progresses carried out in field of electronics, it is possible to supply reactive power through rotor or stator. In the case purpose is to attract maximum active power from stator, reactive power should be supplied by the converter locate on rotor side and its injecting current, otherwise, constraint of nominal current of machine will be violated. Since reactive power is in direct relationship to response of infinite network, injecting or attracting it from the network should be carried out exactly according to the principles related to network calculations.

For the converter locate on network side, in the ideal condition, it should be tried to control active and reactive powers separately. Apart from calculations related to network, sometimes, some compromises are reached between supplying reactive power and constancy of voltage of DC link. In this case, sometimes, reactive power is attracted from or injected into the network.

In the optimum condition, reactive power of the converter located on network side should follow the determined reference, without needing other parameters to undertake unjustified changes.

Capability to supply reactive power has some limitations such as voltage, speed, and nominal current. This limitation changes with change in work point. In the present paper, limitation of nominal current of converter has been compensated to supply reactive power.

Control structure of the converter located on network side

In the system under study, the converter located on the network side is controlled using phase shift and change in domain of the signal compared to triangular carrier. In Back-to-Back structure, relationships between time changes of DC link voltage, input power $\mathrm{P_g}$, and rotor power $\mathrm{P_r}$ are stated by ignoring losses of converters as follows:

$$\mathrm{CV_{dc}}\frac{\mathrm{dv}}{\mathrm{dt}} = \mathrm{P_g} - \mathrm{P_r} \tag{6}$$

In order to create a suitable reference to control the converter located on the network side, the relationship (6) has been used. In this condition, value of $\frac{\mathrm{dv}}{\mathrm{dt}}$ will be equal to zero because there is no voltage ripple for the DC link capacitor, based on the explanations remarked above. Setting the left side of the relationship on zero value will create suitable reference for active power. Purpose of this method is to directly transfer the power of two converters. It should be noted that it would be possible if the DC link voltage does not have any ripple. In fact, the DC link is created with the minimum ripple, and input power will be equal to output one. According to the points remarked above and using the relationship (6), reference for active power of the converter will be as follows:

$$\mathrm{P_{g-ref}} = \mathrm{P_g} - \mathrm{P_r} = \mathrm{P_g} - (\mathrm{T_e}\omega_\mathrm{r} - \mathrm{P_s}) \tag{6}$$

In order to control reactive power of the converter using the suitable reference $(\mathrm{Q_{g-ref}})$ for several speeds and subtracting the sensed reactive power $(\mathrm{Q_g})$, desirable relationship will be created. Considering reference of active and reactive powers using the relationship (5), reference current comparable to triangular carrier will be generated. So as to control the converter at various speeds, reference current at desired frame will be create with respect to phase of $\mathrm{I_g}$ current. In general, the converter located on the network side is undergone switching using changes in domain and phase of the reference current at several speeds and frequency of 5000 Hz. It should be noted that DC link voltage depends directly on input and output powers of the capacitor. Suitably choosing the reference of active power for the tow converters located on the network side and rotor, value of this voltage will remain constant, and there will be no need to sense the DC link voltage. This is an advantage of the presented control method.

Considering the points noted aforementioned, DFIG system is able to inject nominal power at various speeds. Accordingly, considering wind speed to be as the determinant and unpredictable factor, the system will need to be controlled exactly. In the studies carried out on wind turbines, the noted converter has been finally recognized as the prevalent factor responsible for injecting power. For this purpose, a plan should be made so as to switching power electronic tools which have been put in the structure.

It is necessary to consider important factors in using wind turbines and exactly identify the prevalent structure when doing study and research in this regard. In this paper, a modern control method has been introduced. Among the advantages of this method are elimination of fluctuating factors and simple control structure together with high degree of accuracy. So as to investigate response of these controllers and the general structure, typical model has been simulated and investigated in the

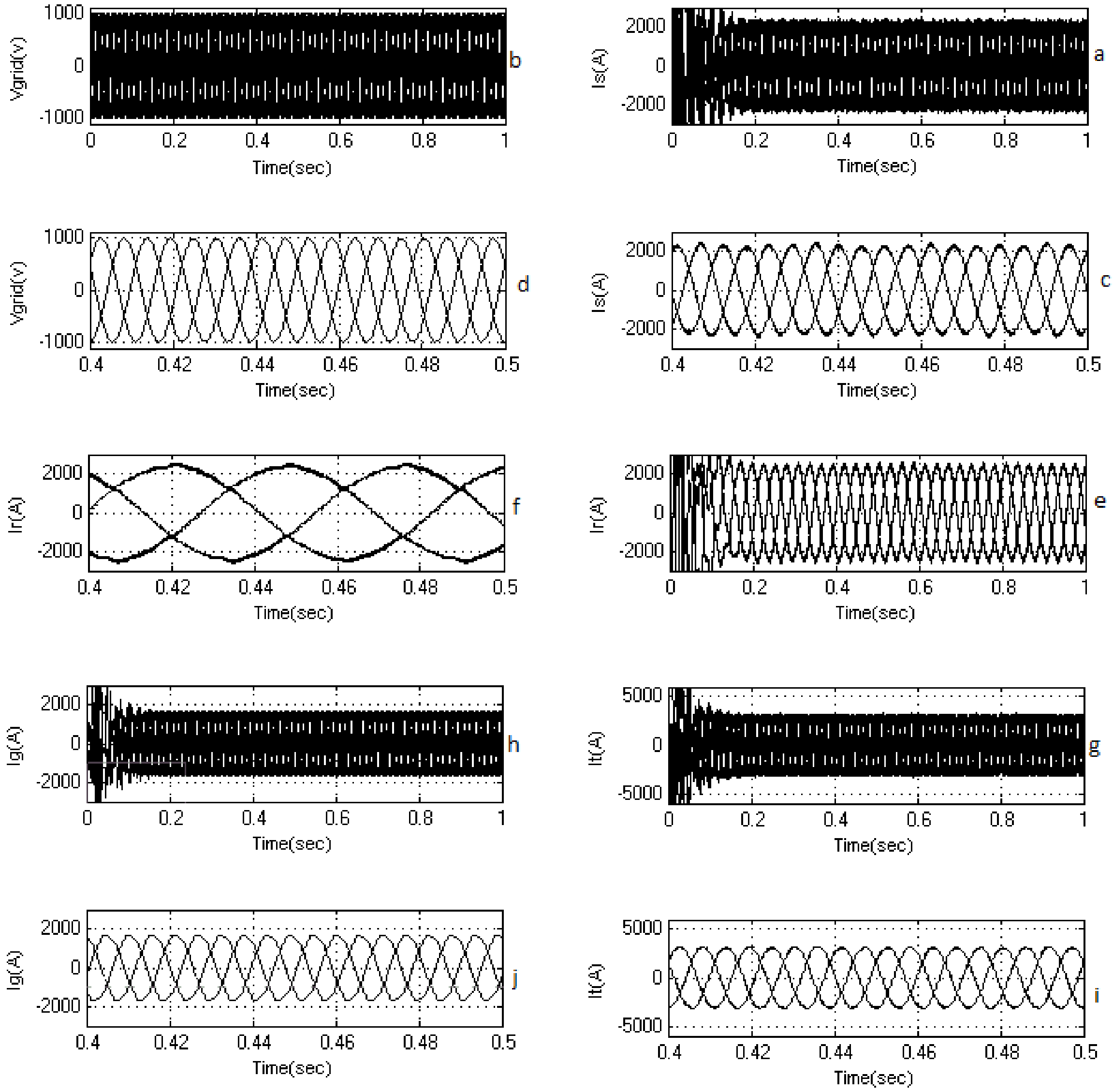

Figure (2): output of the simulated system for machine speed of 2160 RPM at voltage balance condition; a) stator current, b) network voltage, c) Upscaling stator current at permanent mode, d) Upscaling network voltage , e) Rotor current f) Upscaling rotor current , g) infinite bus current , h) current of the converter located on network side , i) Upscaling infinite bus current , j) Upscaling current of the converter located on network side

following chapter.

Simulation Results

In this part, DFIG model has been simulated in SIMULINK/MATLAB environment, choosing high-power typical machine and using Back-to-Back converter and controllers designed. Results of the simulation have also been investigated. In this section, machine parameters are extracted from credible articles, and software analysis has been conducted by connecting the stator to infinite bus and considering changes in rotor speed. Taking DC link capacitor of prevalent converters into consideration, the noted converter has been used as controller of rotor current by creating voltage with suitable frequency on the rotor side. In order to control rotor current and thus active and reactive powers as well as electromagnetic torque, a DC-AC converter with prevalent configuration has been used on the rotor side. Switching frequency for the converter located on network side and that located on the rotor side are both equal to 5 KHz.

Purpose of this part is to prove efficiency of the control method used in this research. Investigations have been carried out in two sections including balanced and unbalanced voltage. First, the suggested method has been simulated for balance mode of network voltage. Then, curves of power, current and quality analysis have been presented by creating imbalance in voltage.

Accordingly, the designed control method controls output of DFIG system within an acceptable range during changes in speed, through changing portions existing in the control loop, so that stator current, rotor current, and rotor voltage do not exceed the nominal bound. Through studying researches carried out on DFIG, the final purpose

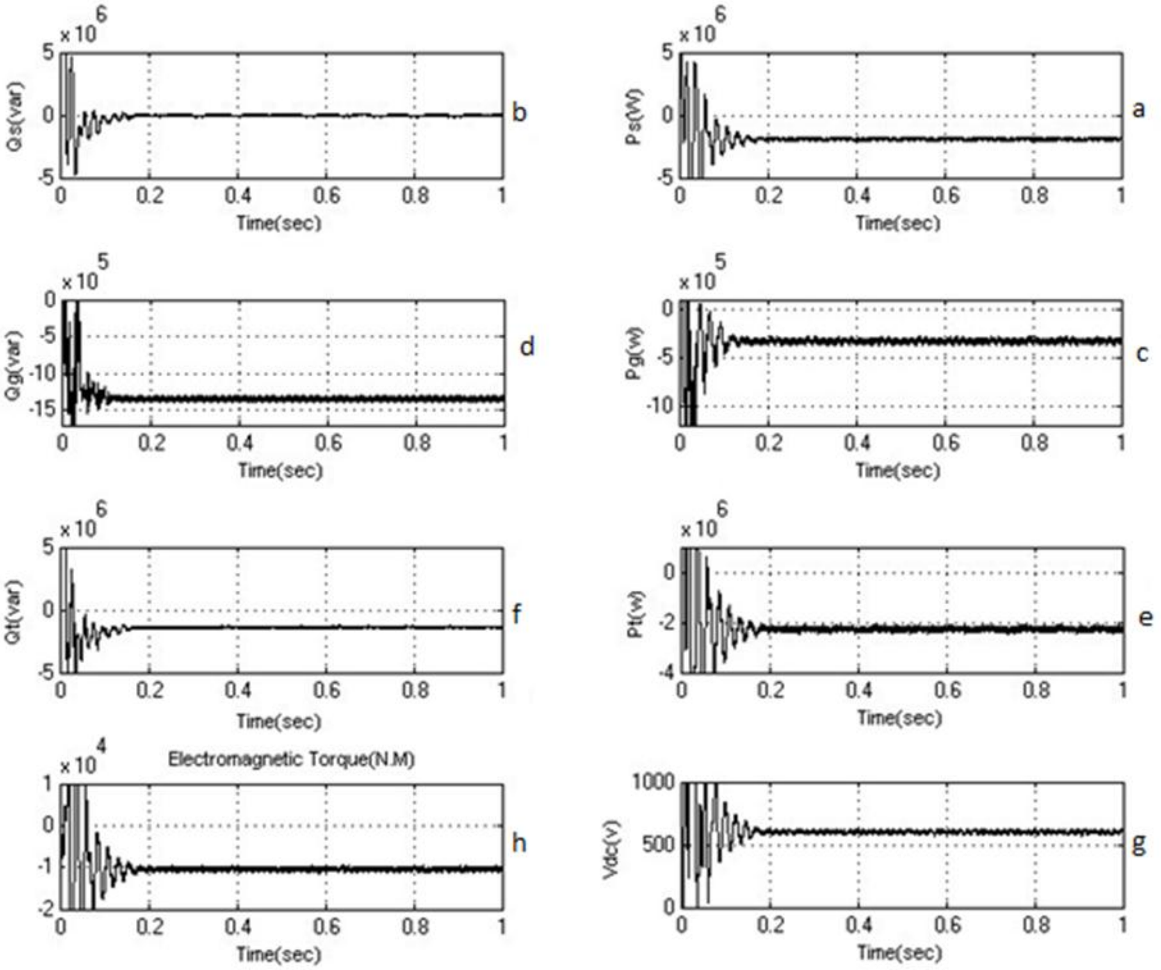

Figure (3): output power of the simulated system for machine speed of 2160 RPM at voltage balance mode a) active power of the stator , b) reactive power of the stator , c) active power of the converter located on network side , d) reactive power of the converter located on network side , e) active power of infinite bus , f) reactive power of infinite bus , g) DC link voltage , h) Electromagnetic Torque

is to inject maximum of active power from the system into the network. In this way, we have tried to convert maximum of energy from mechanical type into electrical one for several input mechanical power and changes in rotor speed. The important point is that active and reactive powers of stator are controllable so that the remarked powers are separately controlled at several speeds and in a specific range without making system to undergo unacceptable changes.

Output of simulated system at speed of 20% higher than synchronous

Figure (3) shows output current of the simulated system for nominal voltage of inductor machine and at the speed of 20% higher than synchronous.

Considering the obtained curves, current of stator and rotor is around the nominal value. Frequency of stator current and injecting current from the converter located on network side are equal to 60 Hz, and frequency of rotor current is equal to 12 Hz. The important point in the controller structure is to control rotor current, and thus, current, active and reactive power of the stator. For this purpose, desirable output will be obtained by controlling phase shift and value of rotor current and creating active power balance between the two converters.

At speeds higher than synchronous, active power will also be attracted from the rotor side. Furthermore, nominal power of the machine can be attracted from the stator side. Figure (3) shows active and reactive powers of several parts of the simulated system. In order to meet the nominal current limitation of the machine, reactive power of the stator has been fixed on zero. Negative sign indicates injection of active or reactive power from the system into the network. DC link voltage created by the converter located on the network side has been shown in the figure (3). So as to investigate quality of injecting power, THD current of stator as well as output current of the converter, along with network current have been shown in figure (4).

In order to investigate output current harmonic of the system, its THD with the frequency value of up to 5 KHz

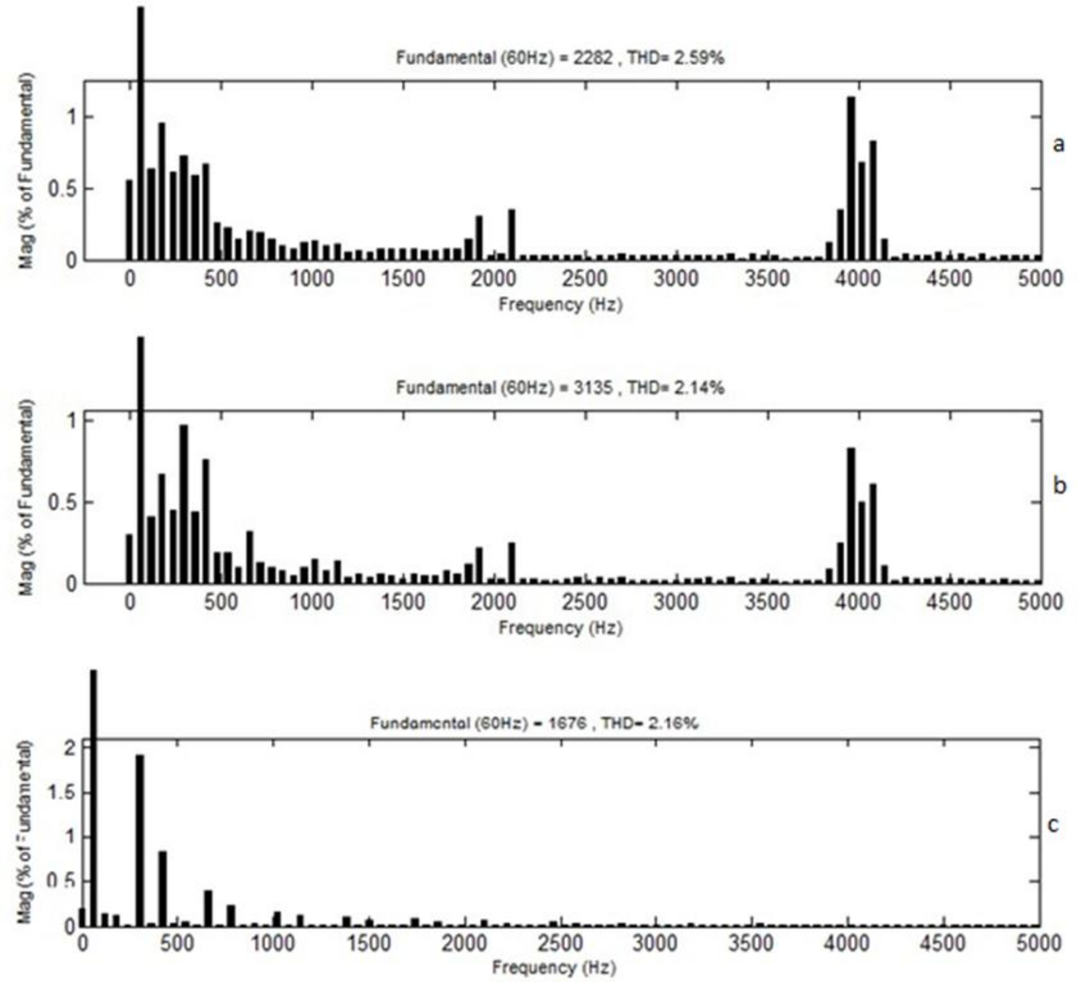

Figure (4): Output current of the simulated system for machine speed of 2160 RPM at voltage balance mode : a) THD of stator current, b) THD of infinite bus current , c)THD of injecting current from the converter located on network side

has been shown in figure (4). Considering the information obtained, harmonic domain of stator current, network, and output value of the converter located on the network side is small and acceptable. This has proved to be true by considering the power curves.

Controllability of output power of the simulated system at speed of 20% higher than synchronous at network voltage balance condition

One of the important advantages of the methods in question is controllability of output power for various slippages. Changes in reference of active and reactive powers, and consequently, changes in domain and phase of rotor current result in desirably control of output power of the system. In this part, changing reference of active power at t=0.3 s, the power attracted from the rotor is decreased while reactive power remains in the previous value. By maintaining the previous mode, reference of reactive power changes at t=0.5 s, and the stator has attracted the reactive power. In such circumstances, active power will not also undergo any remarkable changes. At t=0.7 s, maintaining the previous mode, reference of reactive power changes and stator of the machine will inject reactive power. At t=1 s, the primitive mode has been applied to the system, and maximum active power has been attracted from the stator while its reactive power has been fixed on zero. Apart from primitive changes in output during the change in reference, active and reactive powers will be controllable separately. Change in reference of power created is in a stair-like form. Curves of output power of the system versus noted changes have been shown in figure (5).

Following the above changes, current of rotor and stator will be also changed. While applying stair-like changes to in reference of active and reactive powers, the important point is preservation of nominal value of current of rotor and stator. In the next step, system stability will be reached. After applying the changes,

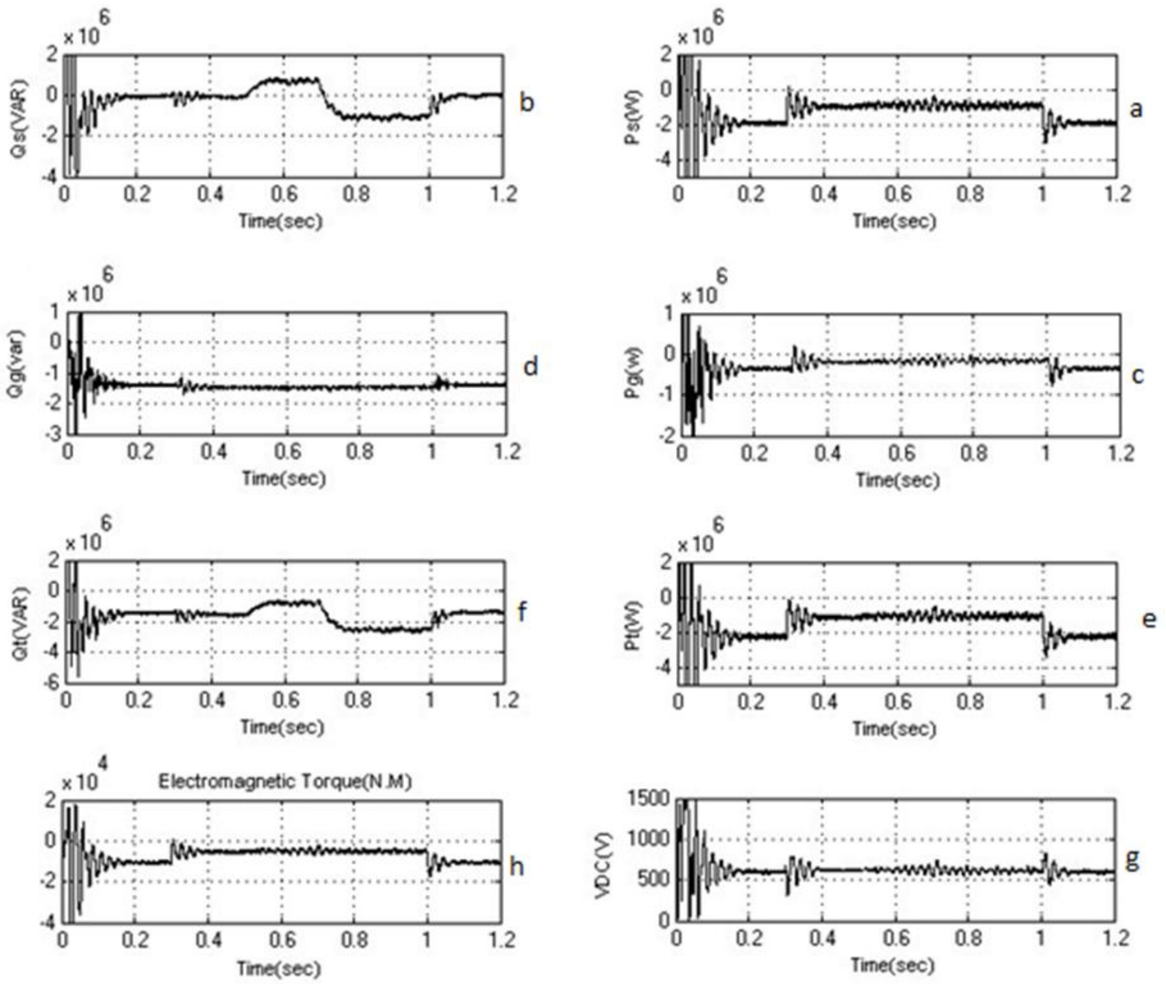

Figure (5): Controllability of output power of the simulated system for machine speed of 2160 RPM at voltage balance mode: a) active power of the stator , b) reactive power of the stator , c) active power of the converter located on network side , d) reactive power of the converter located on network side , e) active power of infinite bus , f) reactive power of infinite bus , g) DC link voltage , h) Electromagnetic Torque (t= 0.3 sec. change in reference of active power, t=0.5 sec. change in reference of active power in positive direction, t=0.7 sec. change in reference of active power in negative direction, t= 1 sec. change in reference of active and reactive power into the primitive mode).

stable mode should be of an acceptable power quality. In addition, active power of DC link voltage will be at stable mode while applying the changes to the reference. Considering the control of rotor current, output of the system will be controllable while applying the changes aforementioned. Current of stator and rotor have ben shown in figure (5).

Following the above changes, current of rotor and stator will be also changed. While applying stair-like changes to in reference of active and reactive powers, the important point is preservation of nominal value of current of rotor and stator. In the next step, system stability will be reached. After applying the changes, stable mode should be of an acceptable power quality. In addition, active power of DC link voltage will be at stable mode while applying the changes to the reference. Considering the control of rotor current, output of the system will be controllable while applying the changes aforementioned. Current of stator and rotor have ben shown in figure (6).

As shown in the figure (7), the power injected from the converter located on the network side did not have much change. Change in active power of stator has only caused active power of the converter located on the network side to be balanced, with a small change, against attracted power of the rotor. A series of changes in current of the converter located on the network side is an indication of this point.

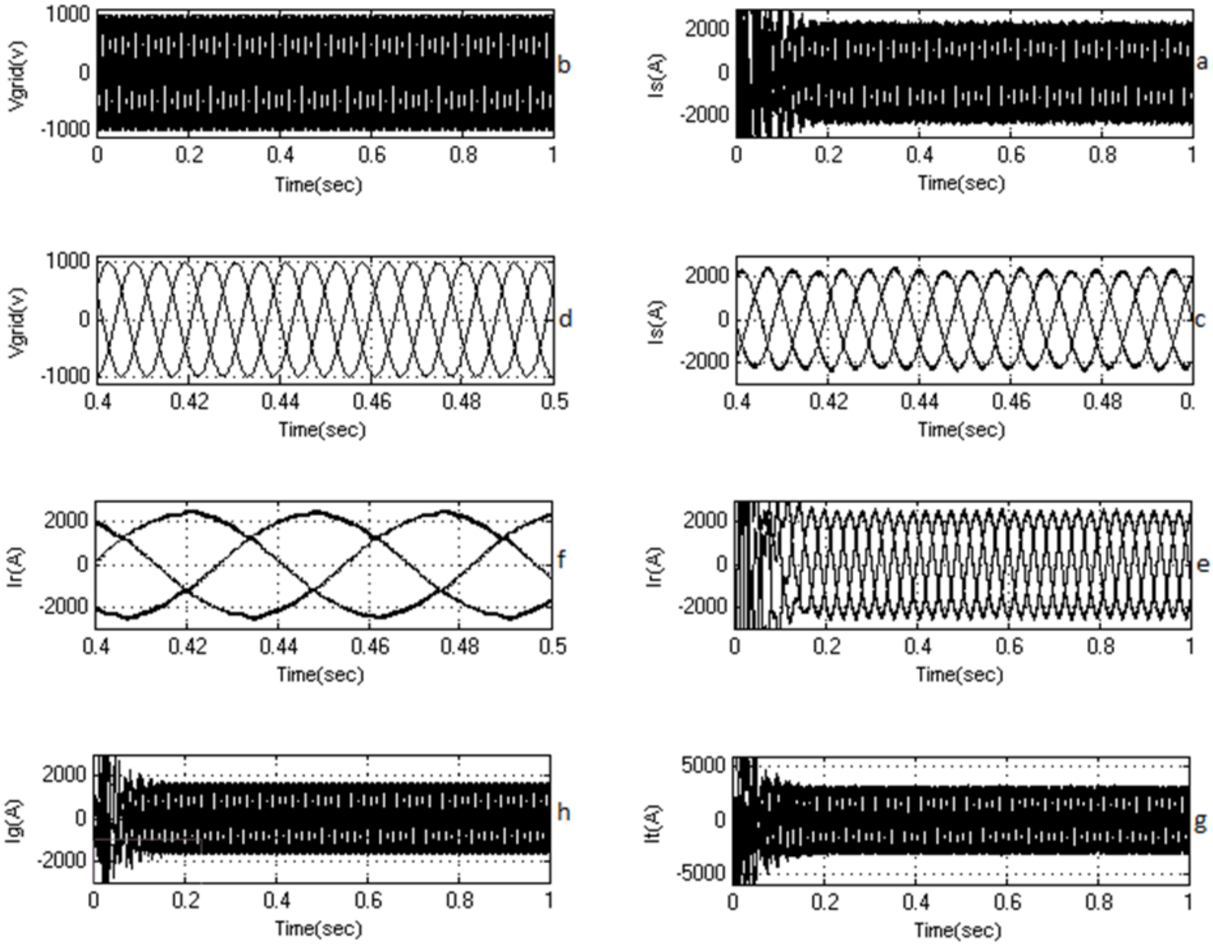

Figure (6): Current of stator and rotor during changes in refrence of active and reactive powers for machine speed of 2160 RPM at voltage balance mode a) stator current b) Upscaling stator current during change in reference of active power c) Upscaling stator current during change in reference of active and reactive powers into the primitive mode d) Upscaling stator current during change in reference of active power e) rotor current f) Upscaling rotor current during change in reference of active power g) Upscaling rotor current during change in reference of active and reactive powers into the primitive mode h) Upscaling rotor current during change in reference of reactive power (t= 0.3 sec. change in reference of active power, t=0.5 sec. change in reference of active power in positive direction, t=0.7 sec. change in reference of active power in negative direction, t= 1 sec. change in reference of active and reactive power into the primitive mode).

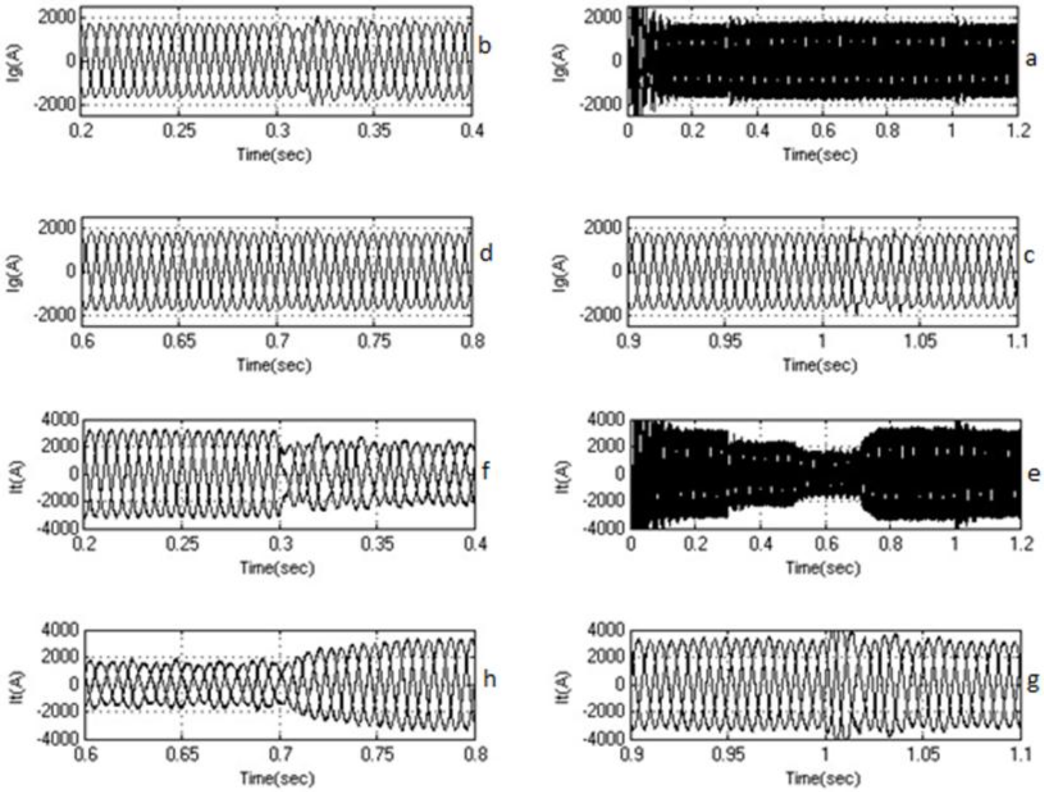

Figure (7): Current of the converter located on the network side during changes in reference of active and reactive powers for machine speed of 2160 RPM at voltage balance mode a) Current of the converter located on the network side b) Upscaling current of the converter located on the network side during change in reference of active power c) Upscaling current of the converter located on the network side during change in reference of active and reactive powers into the primitive mode d) Upscaling current of the converter located on the network side during change in reference of reactive power e) network current f) Upscaling current of the converter located on the network side during change in reference of active power g) Upscaling current of the network during change in reference of active and reactive powers into the primitive mode h) Upscaling current of the network during change in reference of reactive power (t= 0.3 sec. change in reference of active power, t=0.5 sec. change in reference of active power in positive direction, t=0.7 sec. change in reference of active power in negative direction, t= 1 sec. change in reference of active and reactive power into the primitive mode).

Controllability of output power of the simulated system at speed of 20% higher than synchronous at network voltage imbalance condition

In this section, controllability of the system has been at network voltage imbalance condition. Conditions all are similar to those of the previous state, and the only different is voltage imbalance condition. It is expected that suitable and non-fluctuating response confirms suitability of control method used in this research. Figures (7-4) b and (7-4) d clearly show output current of the system and imbalance in network voltage, respectively. Taking a careful look at this figure, it is possible to see balance in current of several parts and their sinusoidal changes, indicating the efficiency of the method used. Like previous modes, rotor current has sinusoidal changes, leading sinusoidal current to get out stator resulting in lack of fluctuation of electromagnetic torque.

Figure (8) shows output power and DC link voltage, along with electromagnetic torque. Paying attention to these curves, it is indicated a little fluctuation in output power for imbalance in voltage compared to the previous mode. Ripples generated on the output power of the converter located on the network side are larger than those on the other powers since this converter has the task of creating DC link voltage without ripple. So, considering this main purpose, its output current has more ripple than other currents, due to imbalance in voltage. But with respect to the constancy of DC link voltage and lack of fluctuation in it, rotor current has no ripple, and consequently, output current of stator will have no fluctuating harmonics.

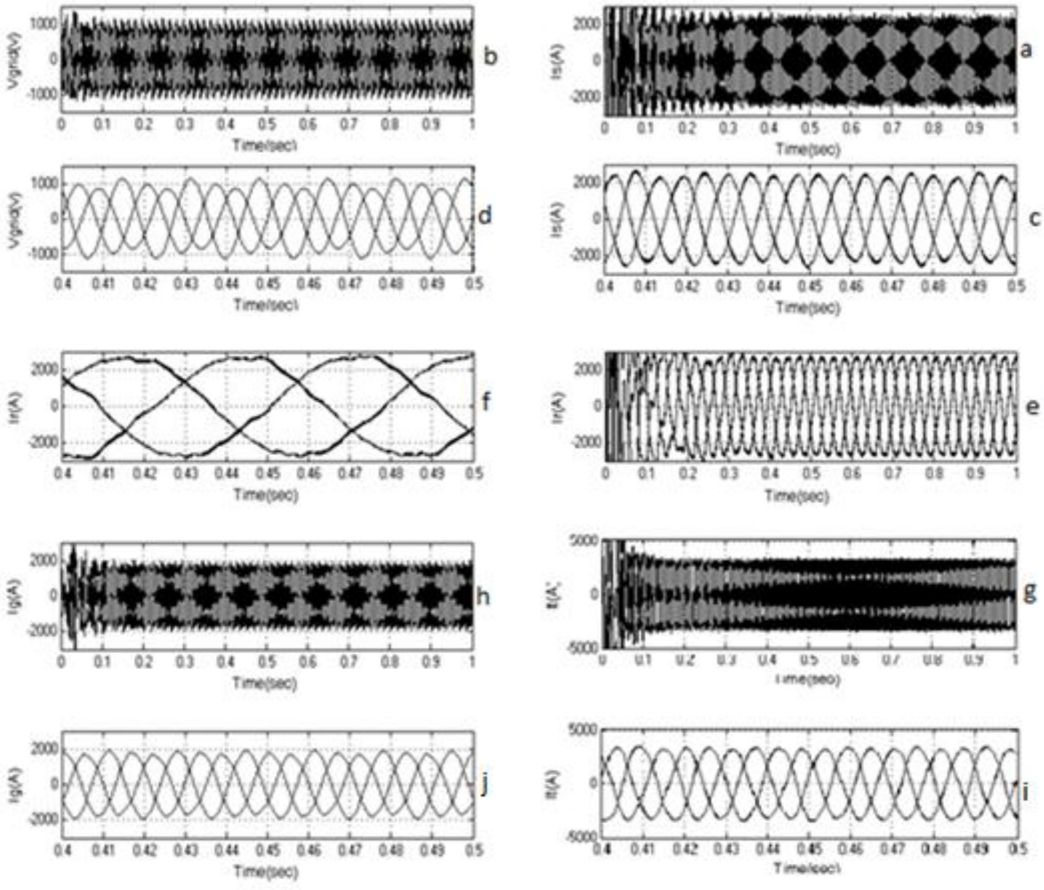

Figure (8): output of the simulated system for machine speed of 2160 RPM at voltage imbalance mode: a) stator current , b) network voltage , c) Upscaling of stator current at permanent mode d) Upscaling of network voltage e) rotor current f) Upscaling of rotor current g) infinite bus current h) current of the converter located on the network side i) Upscaling of infinite bus current j) Upscaling of current of the converter located on the network side

Figure (9) shows harmonic spectrum and THD of stator currents, infinite bus, and the converter located on the network side. Considering the data extracted from MATLAB environment, it is shown that the currents are completely sinusoidal. Harmonic spectrum of these currents is also an indication of lack of harmonic components as well as high degree of its power quality. THD values are in IEEE standard range. As stated before, value of current harmonics of the converter located on the network side is more than that of the others. In the credible articles presented in field of investigation of DFIG at voltage imbalance conditions, these harmonics are omitted by bottom-passing filters. But the point is that output of the system is acceptable when there is no bottom-passing filter.

Conclusion

Several methods have been designed and investigated so as to electrically control and convert power of wind turbines. AC-DC-AC two-step converter is a famous and prevalent structure in power conversion. For the above conversion, several configurations of electronic pieces have been determined, each has some advantages and disadvantages. Principles of converting control power of stability of DFYIG system and injection is the maximum of power of the network. In structure of Back-to-Back converter, it is possible through switching converter at high frequencies. Another point in the prevalent structure is constancy of DC link voltage, which requires creation of extra signal in control loop.

In order to inject electrical power into the network, it is necessary to use converter. Accordingly for several types of generators used, various converters have been designed. When designing several converters, the important point is their suitable response for several working modes. For instance, for inductor generator, control of rotor current is counted as one of the main control-based purposes. Now, changes in wind speed and for several types of control loop, switching direction of designed converter should have a suitable response. Furthermore, reduction in switching losses and losses during the ON mode of keys is also one of the main

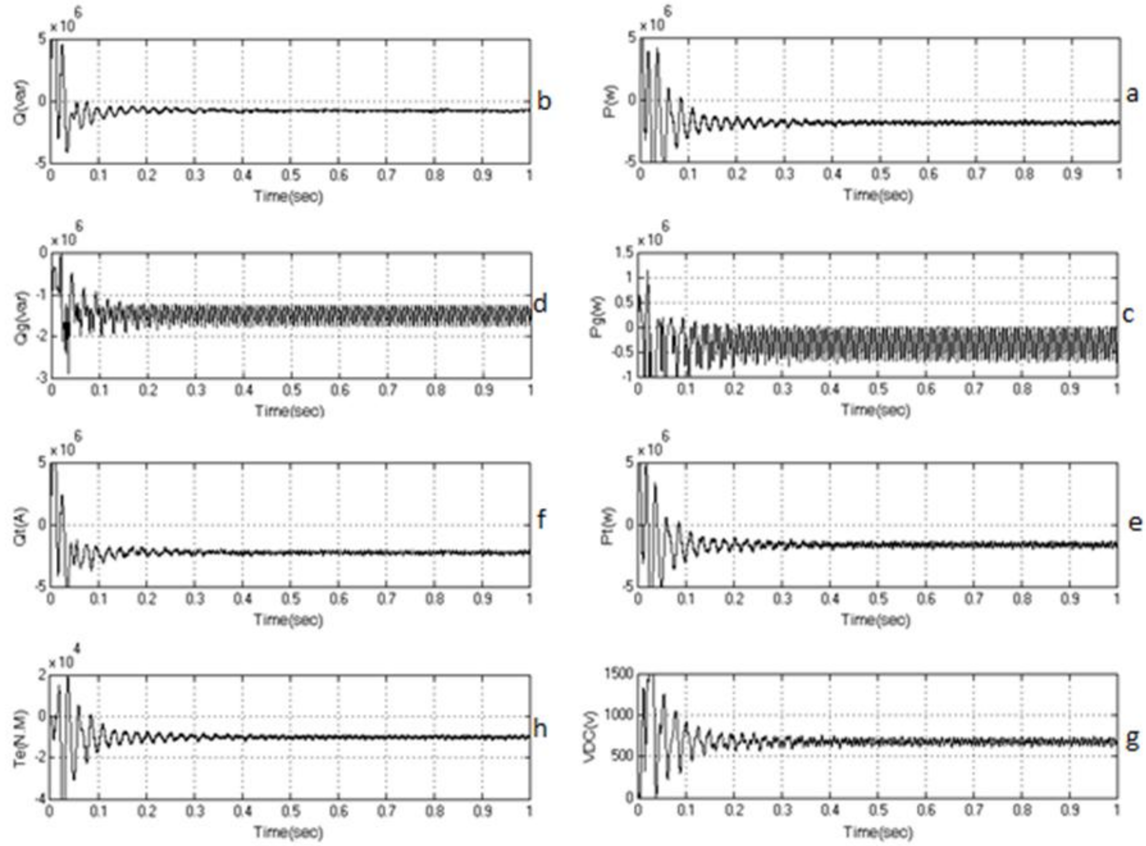

Figure (9): output power of the simulated system for machine speed of 2160 RPM at voltage imbalance mode: a) active power of stator , b) reactive power of stator , c) active power of the converter located on network side , d) reactive power of the converter located on network side , e) active power of infinite bus , f) reactive power of the converter located on network side , g) DC link voltage , h) Electromagnetic Torque

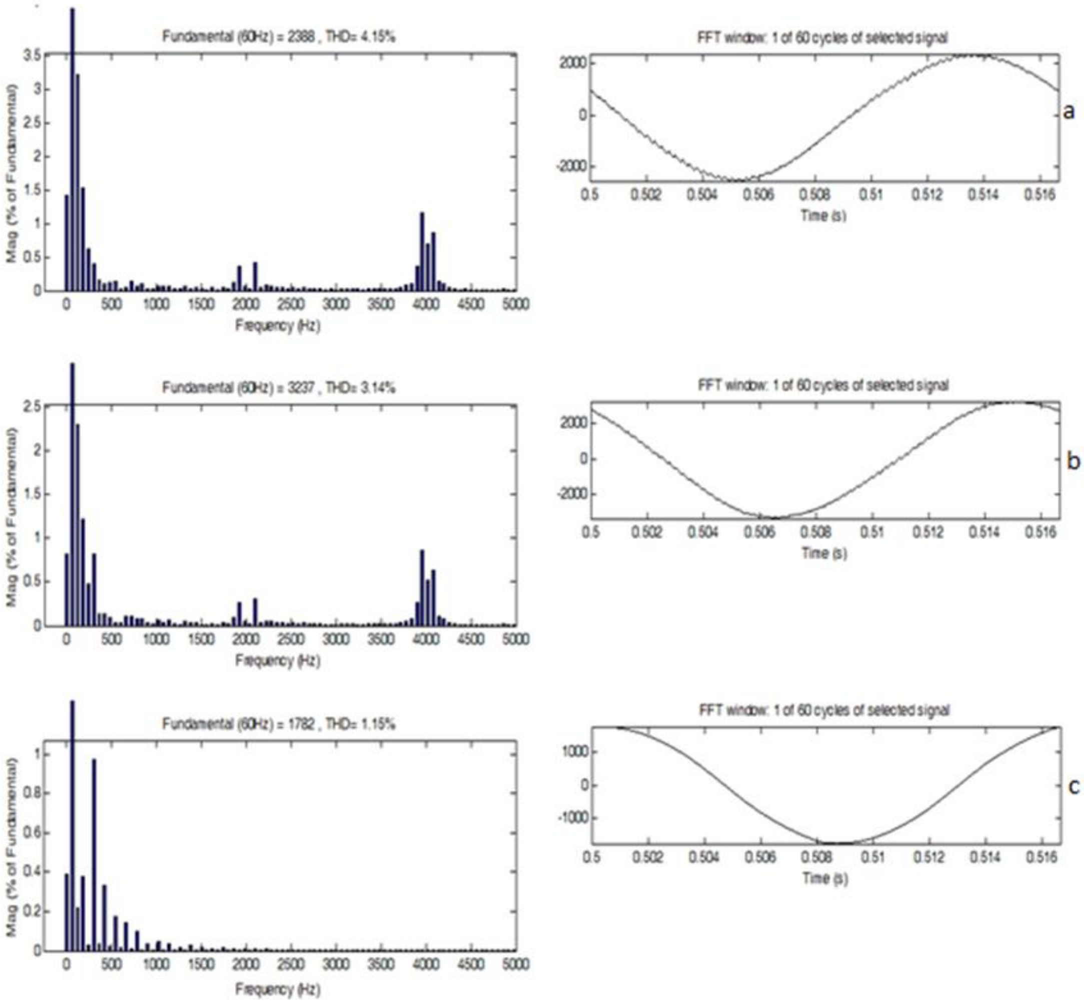

Figure (10): output current of the simulated system for machine speed of 2160 RPM at voltage imbalance condition; a) THD of infinite bus current b) THD of the current injected from the converter located on network side c) THD of the stator current

factors making a converter more preferable than another one. In this way, several control methods have been considered for switching converters. Purposes such as rapid and suitable response, control of torque, control of active and reactive powers, system stability, and control of voltage or rotor current by using several switching methods has led to design of different control approaches.

References

[1] Puttgen H. B., MacGregor P. R., Lambert F.C., Distributed Generation: Semantic Hype or The Dawn of a New Era, IEEE Trans. On Power and Energy,1(1): 2003. 22 – 29.

[2] Distributed generation: the power paradigm for the new millennium by Anne-Marie Borbely and Jan F. Krieder, 2001 by CRC Press LLC.

[3] Three-phase doubly fed induction generators: an overview M. Tazil V. Kumar R.C. Bansal3 S. ong Z.Y. Dong W. Freitas H.D. Mathur, IET Electr. Power Appl., 2010, Vol. 4, Iss. 2, pp. 75–89.

[4] POWER ELECTRONICS HANDBOOK by MUHAMMAD H. RASHID, 2001 by ACADEMIC RESS.

[5] P.M. Espelage and B.K. Bose, "High-Frequency Link power conversion" IEEE Trans. on Industry Applications. Vol.13, No.5, pp.387-394, 1988.

[6] F. Schwartz, "A Doublesided cycloconverter" IEEE Trans. on Industrial Electronics and Control Instrumentation. Vol. IECI-28, No.4, pp.282-291, 1981.

[7]Analysis of electric machinery and drive systems, by Paul C.krause, Oleg Wasynczuk, Scott D.Sudoff, second Edition, 2002.

[8] Gonzalo Abad, Member, IEEE, Miguel A´ ngel Rodr´ıguez, Member, IEEE, Grzegorz Iwanski, and Javier Poza, Member, IEEE, “Direct Power Control of Doubly-Fed-Induction-Generator-Based Wind Turbines Under Unbalanced Grid Voltage,” IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 25, NO. 2, FEBRUARY 2010.

[9] Stephan Engelhardt, Istvan Erlich, Christian Feltes, Jörg Kretschmann, and Fekadu Shewarega, Klaassens, “Reactive Power Capability of Wind Turbines Based on Doubly Fed Induction Generators,” IEEE Trans. on Energy Conversion, Vol. 26, No. 1, pp. 364-372, March. 2011.

[10] Lie Xu, Senior Member, IEEE, "Coordinated Control of DFIG's Rotor and Grid Side Converters During Network Unbalance," IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 23, NO. 3, MAY 2008

[11] L. Helle and S. Munk-Nielsen, "Comparison of converter efficiency in large variable speed wind turbines," . Applied Power Electronics Conference and Exposition, Sixteenth Annual IEEE APEC 2001, vol.1, pp.628 – 634, March 2001.

[12] H.L. Hess and E. Muljadi, "Power converter for wind turbine application," . IEEE Power Engineering Society Summer Meeting. Vol. 2, pp.1275-1276, 2000.

[13] M.N. Eskander and M.T. El Hagry, "Optimal performance of double output induction generator used in WECS," Fifth European Conference on Power Electronics and Applications. Vol.8, pp.276-281, 1993.

[14] H.Akagi andH. Sato, "Control and performance of a doubly-fed inductionmachine intended for a flywheel energy storage system," IEEE rans.Power Electron., vol. 17, no. 1, pp. 109–116, Jan. 2002.

[15] R. Pena, J. C. Clare, and G. M. Asher, "Double fed induction generator using back-to-back PWM converter and its application to variable-speed wind-energy generation," Proc. IEE B Electr. Power Appl., vol. 143, no. 3, pp. 231–241, May 1996.

[16] I. Takahashi and T. Noguchi, "A new quick-response and high-efficiency control strategy of an induction motor," IEEE Trans. Ind. Appl., vol. IA-22, no. 5, pp. 820–827, Sep.–Oct. 1986.

[17] M. Depenbrock, "Direct self control of inverter-fed induction machines,"IEEE Trans. Power Electron., vol. 3, no. 5, pp. 420–429, Oct. 1989.

[18] G. S. Buja and M. P. Kazmierkowski, "Direct torque control of PWM inverter-fed AC motors—A survey," IEEE Trans. Ind. Electron., vol. 51, no. 4, pp. 744–757, Aug. 2004.

[19] M. P. Kazmierkowski and A. Kasprowicz, "Improved direct torque and flux vector control of PWM inverter-fed induction motor drives," IEEE Trans. Ind. Electron., vol. 42, no. 4, pp. 344–350, Aug. 1995.

[20] P. Vas, Sensorles Vector and Direct Torque Control. Oxford, U.K.: Clarendon, 1998.

[21] U. Baader, M. Depenbrock, and G. Gierse, "Direct self control (DSC) of inverter-fed induction machine—A basis for speed control without speedmeasurement," IEEE Trans. Ind. Appl., vol. 28, no. 3, pp. 581–588, May–Jun. 1992.

[22] L. Zhong, M. F. Rahman, W. Y. Hu, and K. W. Lim, "Analysis of direct torque control in permanent magnet synchronous motor drives," IEEE Trans. Power Electron., vol. 12, no. 3, pp. 528–536, May 1998.

[23] A. D. Cheok and Y. Fukuda, "A new torque and flux control method for switched reluctance motor drives," IEEE Trans. Power Electron., vol. 17,no. 4, pp. 543–557, Jul. 2002.

[24] T. Noguchi, H. Tomiki, S. Kondo, and I. Takahashi, "Direct power control of PWM converter without power-source voltage sensors," IEEE Trans.Ind. Appl., vol. 34, no. 3, pp. 473–479, May–Jun. 1998.

[25] M. Malinowski, M. P. Kazmierkowski, S. Hansen, F. Blaabjerg, and G. D. Marques, "Virtual-flux-based direct power control of three-phase PWM rectifiers," IEEE Trans. Ind. Appl., vol. 37, no. 4, pp. 1019–1027, Jul.–Aug. 2001.

[26] G. Escobar, A. M. Stankovic, J. M. Carrasco, E. Galvan, and R. Ortega, "Analysis and design of direct power control (DPC) for a three phase synchronous rectifier via output regulation subspaces," IEEE Trans. Power Electron., vol. 18, no. 3, pp. 823–830, May 2003.

[27] W. El-Khattam , M. M. A. Salama , " Distributed generation technologies , definitions and enefits " , Electric PowerSyst. Res. , pp. 119-128 , 2004.

[28] G. Pepermans , J. Driesen , D. Haeseldonckx , R. Belmans ,W. D'haeseleer, "Distributed generation : definitions benefits and issues " , Energy Policy, pp. 1-12 , 2003.

[29] A. Thomas, A. Goran, S. Lennart, " Distributed generation: A definition ", Electric Power Syst. Res. 57 (3) ,pp. 195-204, 2001.