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Mitigation of Voltage Sag And Swell In DFIG Interconnected With Grid

K.Susmitha[1], Geethanchali[2], Bhuneshwari.R[3], Vardhini.N[4]
[1,2,3,4]*(UG Scholar, Department of EEE, K.Ramakrishnan College of Technology, Tamilnadu, India)*

Abstract : *This paper proposes improved ride through of Doubly Fed Induction Generator integrated to a grid under voltage sag and swells. Voltage sag and swell are the most important power quality problems that influences the performance of the DFIG interconnected to the grid. The behavior of DFIG interconnected with grid is investigated for voltage sag and swell. A converter is proposed which improves the ride-through of DFIG interconnected with grid. Simulation is carried out using MATLAB SIMULINK to emphasize the use of proposed converter in enhancing the overall system performance and maintaining the system stability.*
Keywords – *Power Quality, Voltage Sag, Swell, Grid, DFIG*

I. INTRODUCTION

It is an acknowledged truth that wind, solar and biomass are emerging sources that has immense potential compared to conventional energy sources. Furthermore renewable energy is sustainable, reusable, clean and eco-friendly. With rampant shortage of fossil fuels and increasing carbon emissions renewable energy is witnessing a rapid revolution. Among the available renewable energy sources Wind energy is witnessing rapid growth and is one of the most promising due to economical viability.In India, the total installed capacity of wind power generation is 25,188 MW as on January 2016 mainly spread across South, West and North regions. According to Ministry of New and Renewable Energy the potential of wind resource in india is around 300,000 MW assessed at 100m Hub height. The Ministry of New and Renewable Energy has set the target for Wind Power generation capacity at 60,000 MW within 2022. The revolution in wind energy harnessing lead to the development of a highly efficient variable speed wind turbines with voltage source converter which is more advantageous than the fixed speed wind turbines.

Doubly Fed Induction Generator is one such based on variable speed wind turbine with back to back converter. The stator of the generator is directly connected to the grid while the rotor is connected through a back-to-back converter.[1][2].The rotor side converter uses a high frequency switching pulse width-modulated (PWM) converter to achieve high control performance, such as fast dynamic response with low harmonic distortion. Furthermore, with this control strategy, the induction generator can operate over wide slip range which allows making better use of the available wind energy, [3]. Back to back converter only needs to handle a fraction (25–30%) of the total power to achieve full control of the generator. Therefore, the amount of losses in the power electronic converter is reduced, compared to a system where the converter has to handle the entire power. The system cost is lower due to the partially-rated power electronics switches.

The main drawback of DFIG wind turbine is its vulnerability to grid side voltage sags and short circuits. Whenever a fault occurs on the grid side, the current through the rotor rise and if proper protection is not given to back to back against these high currents, it will be damaged.

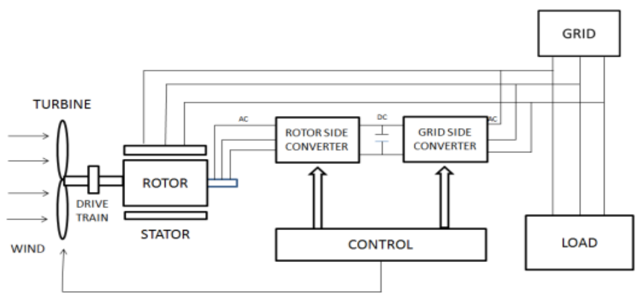


Fig 1: Detailed configuration of DFIG interconnected with grid.

II. WIND TURBINE MODELING

The Wind turbines are used to transform the kinetic energy present in the wind into mechanical energy by producing rotational torque on the turbine. The energy present in the wind is in the form of kinetic energy and its magnitude depends upon the air density and the velocity of the wind. The power developed in the turbine due to wind is given by the following equations:

$$P_m = \frac{1}{2} c_p (\lambda,\beta)\rho A v^3 \quad (1)$$

Where c_p is the Power Co-efficient, ρ is the air density in kg/m^3, *A* is the area of the turbine blades in m^2 and *V* is the wind velocity in m/sec. Cp is the ratio of actual electric **power** produced by a wind turbine divided by the total wind **power** flowing into the turbine blades at specific wind speed. This coefficient decides the "maximum power devloped" by the wind turbine at a given wind speed. Power co-efficient is a function of the tip-speed ratio (λ) and the blade pitch angle (β).

Where the rotational speed of the generator and R is the radius of the rotor blades. Hence, the TSR ultimately depends upon the rotational speed of the generator. For a given wind speed, there exists only one rotational speed of the generator which gives the maximum value of c_p, at a given β.

III. DOUBLY FED INDUCTION GENERATOR

The detailed layout of a DFIG along with wind turbine and converter system is shown in Fig. 1. The wound rotor induction generator is fed from both stator and rotor side. Stator windings are directly connected to grid whereas rotor winding is fed power through AC/DC/AC converter from the grid.Converter needs to control the power flow both in magnitude and direction in order to feed electrical power to grid at constant voltage and constant frequency over wide range of wind speed. Hence PWM converters is developed based on two four quadrant IGBT. Rotor side converter(RSC) and Grid side converter (GSC) are the two converters connected in back to back configuration with a dc link capacitor between them.

The mechanical power and the stator electric power output are computed asfollows:

$$P_m = T_m\omega_r \quad (2)$$

$$P_s = T_m\omega_s \quad (3)$$

For a loss less generator the mechanical equation is:

$$J\frac{d\omega r}{dt} = T_m - T_{em} \quad (4)$$

In steady state at fixed speed for a loss less generator

$$T_m = T_{em} \text{ and } P_m = P_s + P_r \quad (5)$$

It follows that

$$P_r = P_m - P_s = T_m\omega_r - T_s$$

$$= \frac{\omega s-\omega r}{\omega s})\omega_s$$

$$= -sT_m\omega_s = -sPs \quad (6)$$

Where *s* is defined as the slip of the generator

$$S = \frac{\omega s-\omega r}{\omega s} \quad (7)$$

The above equation shows that the only when the slip of the machine is negative the electrical output power from the rotor is a fraction of stator power.. The Pr depends upon the slip sign. The value of Pr is positive for negative slip (speed above synchronous speed) and it is negative for positive slip (speed lower than synchronous speed). Significantly Pr is transmitted to DC link capacitor [17] during super synchronous speed operation which tends to raise the DC voltage with negative phase sequence whereas Pr is taken out from the DC link capacitor during sub synchronous speed operation which tends to decrease the DC bus voltage with positive phase sequence.

Hence the grid side converter generates or absorbs the Pgc and thereby maintains the DC link at a constant level. For a steady state lossless back to back converter Pr is equal to Pgc and the speed of the wind turbine is determined by the power Pr absorbed or generated by the rotor side converter.

The rotor side converter controls the wind turbine output power as well as the voltage across grid terminals. The grid side converter regulates the voltage of the DC bus capacitor. The figure 2 and 3 shows GSC and RSC control system.

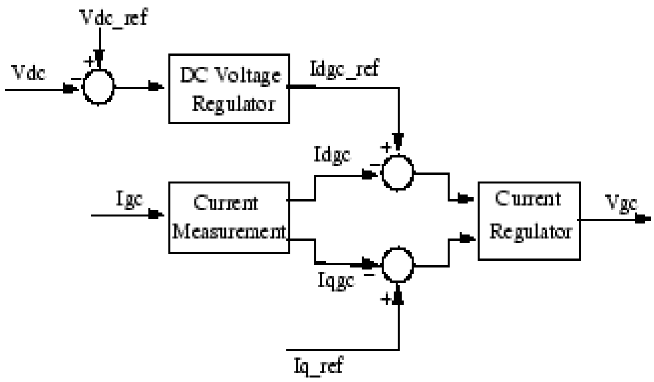


Fig 2: Grid side converter control system.

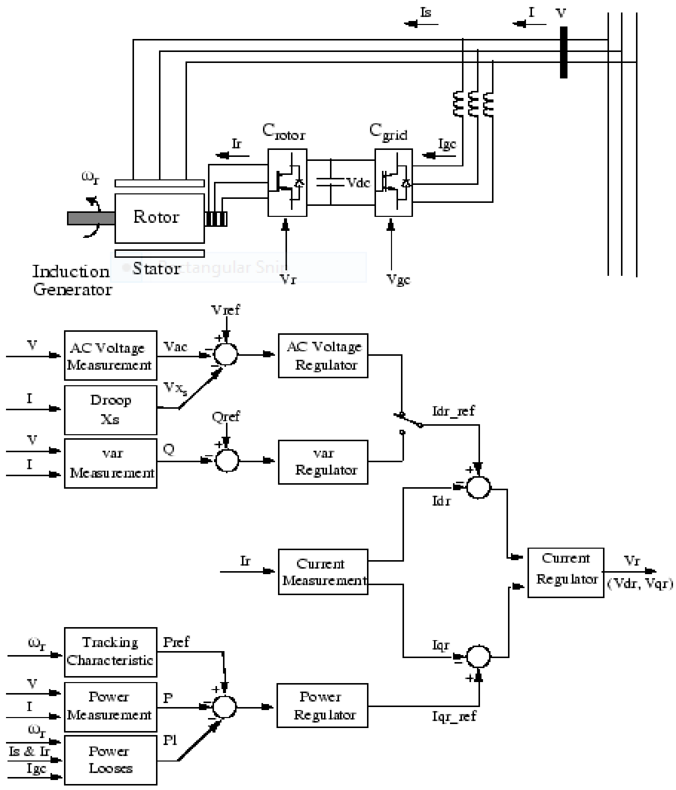


FIG 3: ROTOR SIDE CONVERTER CONTROL SYSTEM

IV. VOLTAGE SAG

Voltage sag is one of the most detrimental power quality disturbance as they adversely affect the satisfactory operation of several types of equipments.

Voltage sag is a phenomenon of sort duration reduction in rms value of voltage and it is caused by events such as power system faults, load variations, transformer energization and the starting of large induction motors at the same time. The flow of fault current through the system due to various fault is the main reason of voltage sag. This fault current is capable of affecting the end user equipments.

A fault in a transmission line is capable of affecting an equipment located hundreds of kilometers away from the fault. Voltage sags can be either symmetrical or unsymmetrical, depending on the causes. If the individual phase voltages are equal and the phase relationship is 120º, the sag is symmetrical. Otherwise, the sag is unsymmetrical.

A three-phase short circuit or a large motor starting can produce symmetrical sags. Single line-to-ground, phase-to-phase, or two phase-to-ground faults due to lightning, animals, accidents, and other causes, as well as energizing of large transformers can cause unsymmetrical sags.

V. VOLTAGE SWELL

A voltage swell is a phenomenon of short duration increase in voltage values. When the Voltage swells lasts longer than two minutes then they are classified as over voltages. Large load changes and power line switching are the main reason behind this phenomenon. If the voltage swells increases beyond the safety limit they can damage electrical equipment.

The voltage regulating equipment of the power system or utility may or may not react quickly enough to prevent all swells or sags. Hence there is a need to eliminate the voltage swell in order to improve the stability of the system eventually protecting the system from overall damage.

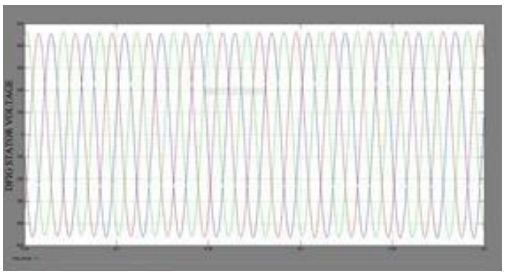
VI. CUK CONVERTER

Cuk converter is essentially a boost converter followed by a buck converter with a capacitor to couple the energy. It is an inverting converter, so the output voltage is negative with respect to the input voltage. The Cuk converter has an output voltage magnitude that is either greater than or less than the input voltage magnitude.It uses a capacitor as its main energy-storage component, unlike most other types of converters which use an inductor. The Cuk converter can either operate in continuous or discontinuous current mode.

VII. SIMULATION AND RESULTS

Figure 4 shows a 1.5 MW, 575V, 50 Hz DFIG is connected to a 1.75 MVA Transformer. The 575 V is stepped up to 25 KV and connected to a 25 KV grid via 30km transmission line and resistive load.

A. Normal operating condition



The fig 4.1 shows the three phase sinusoidal output waveform of DFIG stator voltage.

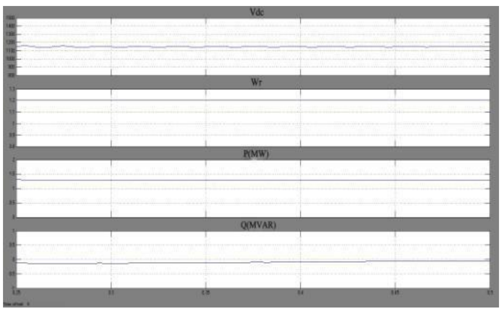
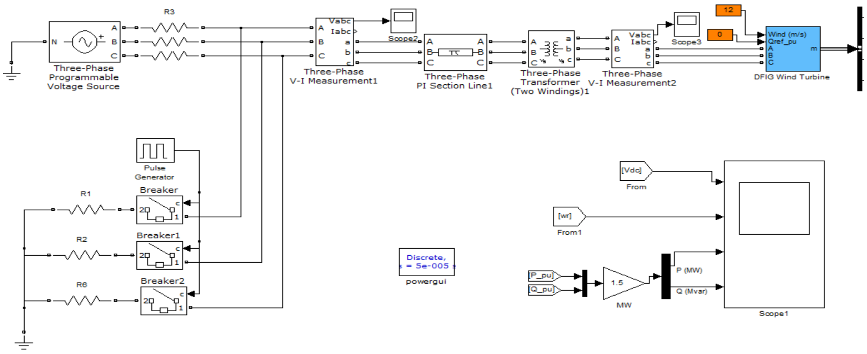


Fig4.2: DFIG output waveform.

The fig 4.2 shows that the real power, reactive power, rotor speed, Vdc is maintained constant at normal operating condition.

B. DFIG WITH FAULT A



The fig 5 shows DFIG interconnected to grid with type A voltage sag.

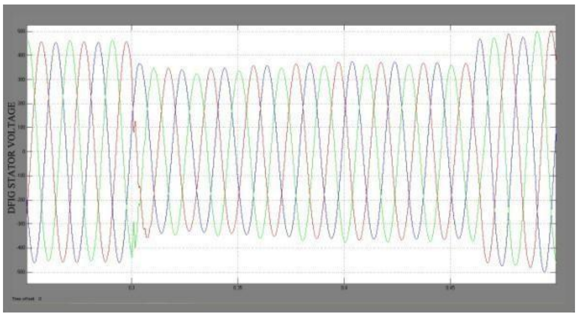


Fig 5.1: DFIG stator voltage waveform during TYPE A voltage sag.

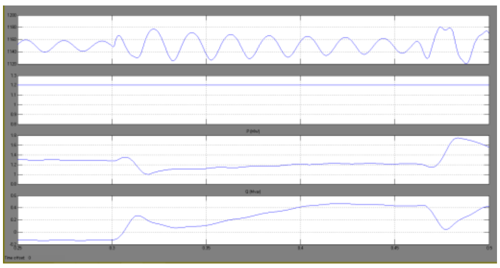
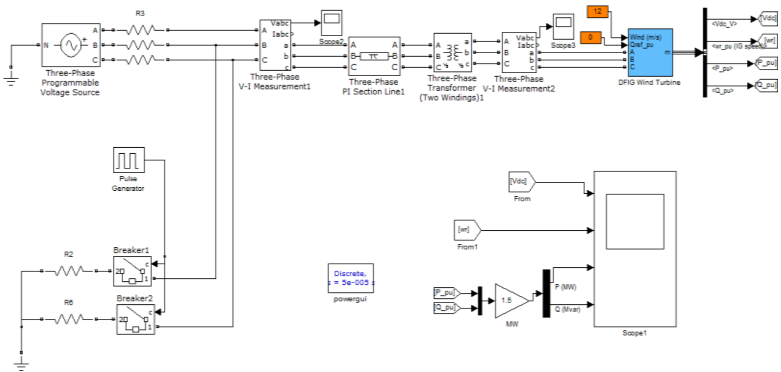


Fig 5.2:Variation of real power, reactive power, rotor speed, Vdc during type A voltage sag.

C. DFIG with TYPE C Fault.



The fig 6 shows DFIG interconnected to grid with type C voltage sag.

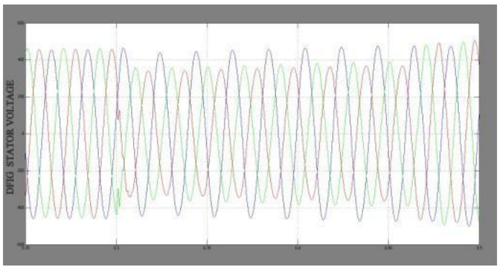


Fig 6.1: DFIG stator voltage waveform during TYPE C voltage sag.

The fig 6.1 shows that two phases of DFIG stator voltage has same lower magnitude than the third phase.

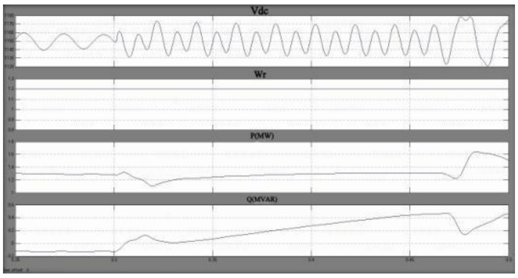


Fig 6.2: DFIG output waveform.

The fig 6.2 shows the variation of real power, reactive power, rotor speed, Vdc during type C voltage sag.

D. DFIG with TYPE D Fault

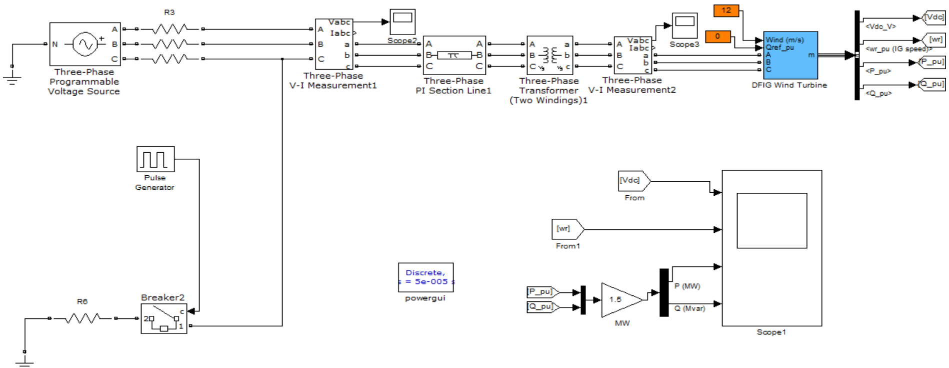


Fig 7: TYPE C VOLTAGE SAG across resistive load.

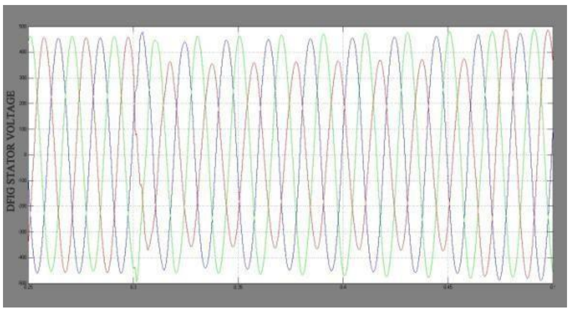


Fig 7.1: DFIG stator voltage waveform during TYPE D voltage sag

The fig 7.1 shows that two phases of DFIG stator voltage has same higher amplitude than third phase.

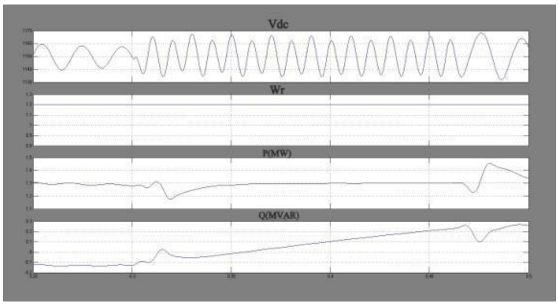


Fig 7.2: Real and reactive power variation during TYPE C voltage sag.

The fig 7.2 shows the variation of real power, reactive power, rotor speed, V_{dc} during type D voltage sag.

VIII. CONCLUSION

Thus the proposed system results in improved ride through of Doubly Fed Induction Generator integrated to a grid under voltage sag and swells. Also the influence of the Voltage sag and swell on the performance of the DFIG interconnected to the grid has also studied. The behavior of DFIG interconnected with grid is investigated for voltage sag and swell are analysed using MATLAB SIMULINK.

The result has also been compared and the proposed inverter confirms the adoptability and suitability for the existing grid connected DFIG System.

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