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Converter Protection Scheme for Doubly-Fed Induction Generators during Disturbances

[1]Kadam D.P. , [2]Dr. Kushare B.E.

[1]Assistant Professor, K. K. Wagh Institute of Engineering Education and Research
Nashik (MS), India.

[2]Professor & H.O.D., K. K. Wagh Institute of Engineering Education and Research
Nashik (MS), India.

Abstract:

With the increasing share of wind in power generation, the dynamic behavior of the power system will change considerably due to different technologies used for wind and conventional generators. This paper will describe the sustainability of Doubly-Fed Induction Generator during the abnormal condition on grid also during the fault condition. For the selection of the suitable ratings of crowbar (chopper resistors) approximations are to be carried out. For simulation studies taking wind speed variations into account, or when the rotor shaft speed deviation becomes significant, the turbine's speed and its pitch control systems have to be considered. The short-circuit current contribution of DFIG has received much attention. Wind turbines with a doubly fed induction generator have a crowbar to protect the power electronic converter that is connected to the rotor windings of the induction generator. A Grid fault ride through capability of Doubly Fed Induction Generator in Wind Energy Transfer System is determined using PSCAD / EMTDC Software Simulation. DFIG Rotor side converter is very much sensitive to Grid Fault. A single line to ground fault at grid is taken for study. Voltage dip occur on stator voltage and current rises instantaneously, with this rotor side current increased which will result in damage of rotor side converter.

Keyword: Wind Farm, PSCAD, Doubly-fed induction generator (DFIG), flux linkage, grid fault, wind power generation

I. Introduction

The past decade has seen the emergence of wind as the world's most dynamically growing energy source. With the increasing share of wind in power generation, the dynamic behaviour of the power system will change considerably due to different technologies used for wind and conventional generators. Therefore, WTs and wind parks have to be considered in power system dynamic stability studies for which, however, suitable WT models are needed. These models have to compromise between accuracy, for considering relevant dynamic interactions between grid and WT, and simplicity required for the simulation of large systems. WT modelling is a topical research currently conducted by many academic institutions and developers. Different publications came out in the recent past from which, taking into account the aspect of large-scale stability studies, [1]–[7] should be mentioned. Despite the effort made, the WT model still needs some refinements, extensions, and adaptations. In case of severe grid faults, the DFIG and its associated converter system have to be protected against damage, for which the crowbar (CB) is a widely used approach. The CB is a resistance connected to the rotor circuit for a short period for de-energizing the machine while the converter is disconnected. CB switching is triggered on the basis of rotor current and/or converter dc-link voltage values. In normal operating mode, the rotor side converter controls active and reactive currents and thus P and Q of the DFIG independently. The corresponding controller will be derived based on the DFIG equations. Simplified models are presented also for the converter dc-link and line side converter. For simulation studies taking wind speed variations into account, or when the rotor shaft speed deviation becomes significant, the turbine's speed and its pitch control systems have to be considered. For this purpose, a generic model is proposed.

There is need to study effect of these factors to identify the main issues which are responsible for detoriation of power quality, reliability, security and stability of large wind farm grid. Hence, it is necessary to address these issues including stability and reliability of grid as well as satisfactory operation of generator including ride through capability during normal as well as fault conditions.

II. INDUCTION GENERATOR

The IG consists of a three-phase wound rotor induction machine, mechanically coupled to either a wind or hydro turbine, whose stator terminals are connected to a constant voltage and constant frequency utility grid. The variable frequency output is fed into the ac supply by an ac–dc–ac link converter consisting of either a full-wave diode bridge rectifier and thyristor inverter combination or current source inverter (CSI)-thyristor converter link. One of the outstanding advantages of DFIG in wind energy conversion systems is that it is the only scheme in which the generated power is more than the rating of the machine. However, due to operational disadvantages, the DFIG scheme could not be used extensively. The high maintenance requirements, low power factor, and poor reliability are the few disadvantages due to the sliding mechanical contacts in the rotor. This scheme is not suitable for isolated power generations because it needs grid supply to maintain excitation. This generator has the advantage of being relatively cheap and robust. On the other hand, its speed cannot be continuously controlled, and it is a large and rather uncontrollable consumer of reactive power: this is a major disadvantage with respect to the grid voltage stability.

The doubly fed induction generator is a more suitable generator for wind turbines. It is constructed as an induction generator with wound rotor. The stator windings are directly connected to the grid. The rotor windings are connected to the grid through a Thyristor frequency converter. The frequency converter only has to process the generator's slip power fraction, which is generally no more than 30% of the generator rated power. This reduced rating for the frequency converter implies an important cost saving, compared to a fully rated converter. To start up a machine from zero speed, an additional soft-starter connected to the stator windings may be needed. Doubly fed induction generator by means of controlling the rotor currents through the frequency converter, the speed and stator reactive power of the generator can be controlled in a small range around the generator's rated values. The extent of this range depends on the rating of the frequency converter.

III. DFIG PROTECTION

This section describes the short-circuit behavior of doubly fed induction generators and the crowbar protection that is applied to protect the generators.

In normal operation, the space vectors rotate at a synchronous speed with respect to the reference frame. Ignoring the stator resistance, the derivative of the stator flux is directly proportional to the grid voltage. When the voltage drops to zero (in case of a fault at the generator terminals), the stator flux space vector stops rotating. This produces a dc component in the stator flux. The dc component in the rotor flux of the machine is fixed to the rotor and will continue rotating. This will thus add an alternating component to the dc component of the stator flux. The maximum value that the currents reach depends mainly on the stator and rotor leakage inductance. The speed at which the dc component will decay is mainly determined by the transient time constants of the stator and rotor. The voltage dip will cause large (oscillating) currents in the rotor circuit of the DFIG to which the power electronic converter is connected. A high rotor voltage will be needed to control the rotor current. When this required voltage exceeds the maximum voltage of the converter, it is not possible any longer to control the current as desired. This implies that large currents can flow, which can destroy the converter. In order to avoid breakdown of the converter switches, a crowbar is connected to the rotor circuit. This can, for example, be done by connecting a set of resistors to the rotor winding via bi-directional thyristors. When the rotor currents become too high, the thyristors are fired and the high currents do not flow through the converter but rather into the crowbar resistors. The enabling of the crowbar can be followed by different actions. The whole wind turbine can be disconnected from the grid, but it is also possible to disconnect the converter from the rotor without disconnecting the wind turbine from the grid. The generator then operates as an induction machine with a high rotor resistance. The third possibility is to keep the turbine connected to the grid and the converter connected to the rotor. With this type of control, it is possible to resume normal operation immediately after clearance of the fault. When the dip lasts longer than a few hundred milliseconds, the wind turbine can even support the grid during the dip

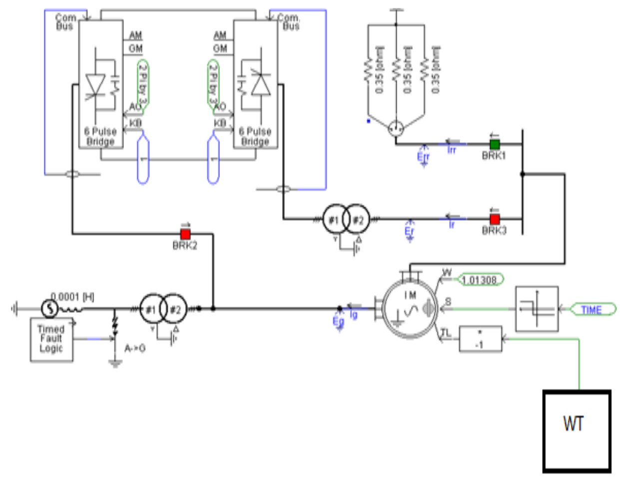


Fig. 1.Crowbar resistors in the rotor circuit

The value of crowbar (chopper) resistance can be calculated from maximum current through rotor winding, which is mainly depends on maximum value of stator current that can be flow at the time of fault or abnormal condition. The maximum value of stator current is given in equation (1), this is found through approximations.

$$i_{s,\max} \approx \frac{1.8V_s}{\sqrt{X_s'^2 + R_{cb}^2}} \qquad (1)$$

From (1), it can be observed that the maximum short-circuit current of the DFIG strongly depends on the value of the crowbar resistance. This section will investigate how a good value for the bypass resistance can be determined. There are two main requirements that give an upper and a lower limit to the resistance.

- The resistance should be high to limit the short-circuit current.
- It should be low to avoid a too high voltage in the rotor circuit.

A too high voltage can result in breakdown of the isolation material of the rotor and the converter. It is further possible that when the voltage becomes higher than the dc link voltage, large currents will flow through the ant parallel diodes of the converter, charging the dc link to an unacceptable high voltage. A lower value will result in higher currents in the rotor of the machine. The thermal time constant of the rotor will however be generally high enough to handle the short-circuit currents for a short period. Therefore, the maximum value is more important than the minimum value. An approximation of the maximum stator current is given by (17). As all parameters are transferred to the stator side, the maximum rotor current (reduced on the stator side) will have approximately the same value. The voltage across the bypass resistors, and thus across the rotor and converter is

$$\sqrt{2}V_r \approx R_{cb}\, i_{r,\max} \qquad (2)$$

Combining this equation with (1), the maximum value of the bypass resistors can be determined as

$$R_{cb} < \frac{\sqrt{2}V_{r,\max} X_s'}{\sqrt{3.2V_s^2 - 2V_{r,\max}^2}} \qquad (3)$$

Where $V_{r,\max}$ is the maximum allowable rotor voltage. It is only an approximation, as it is based on a number of assumptions and approximations.

IV.RESULTS

Simulation is done with PSCAD / EMTDC Software. Single Line to Ground Fault on grid is taken for study. Doubly Fed Induction Generator with Fault at 10 sec duration 0.3 sec without bypass resistor

Following Results are obtained without bypass resistors (crowbar)

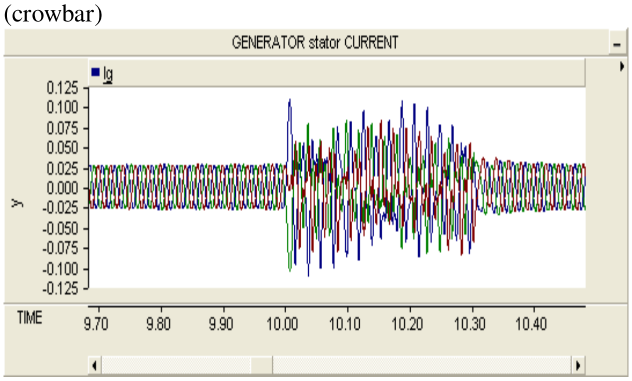


Fig. 2 Generator Stator Current

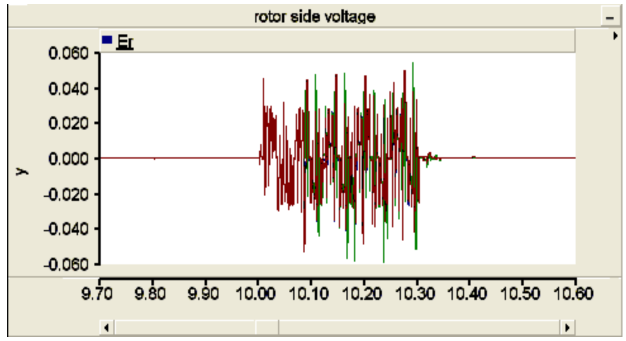


Fig. 3 Rotor Side Voltage

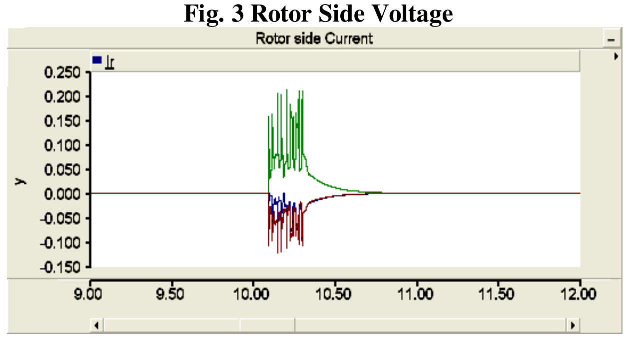
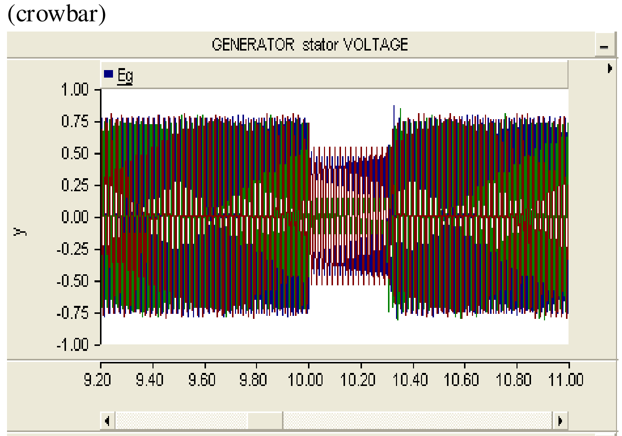


Fig. 4 Rotor Side Current

Following Results are obtained with bypass resistors (crowbar)



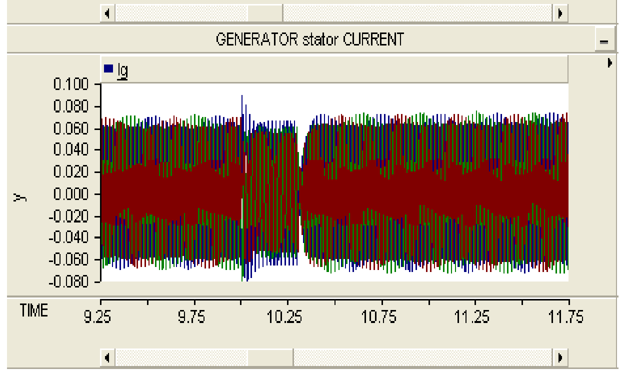


Fig. 5 Generator Stator Voltage & Generator Stator Current

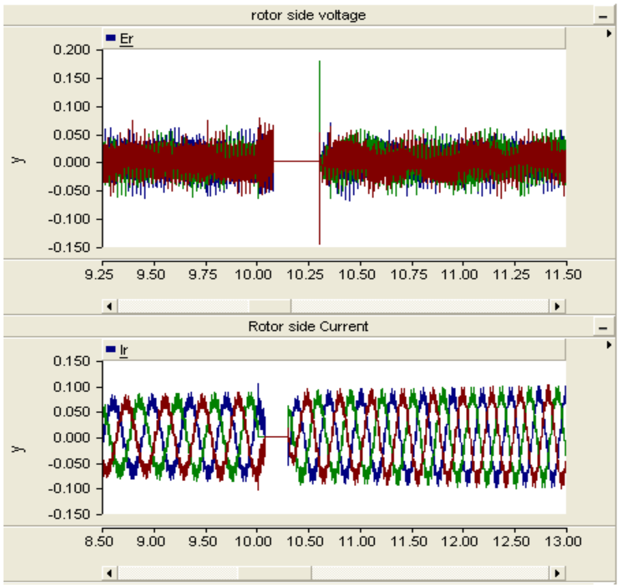


Fig. 6 Rotor Side Voltage & Rotor Side Current

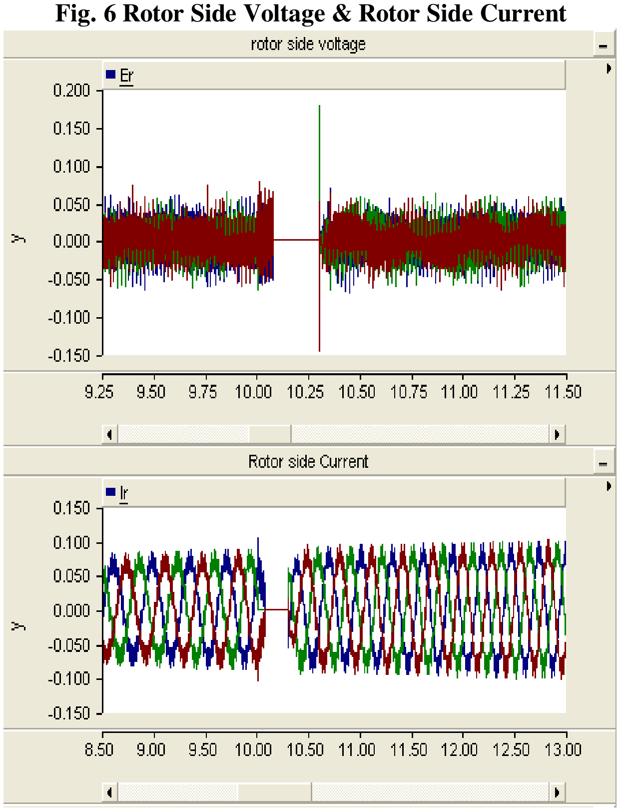


Fig. 7 Rotor Side Voltage & Rotor Side Current

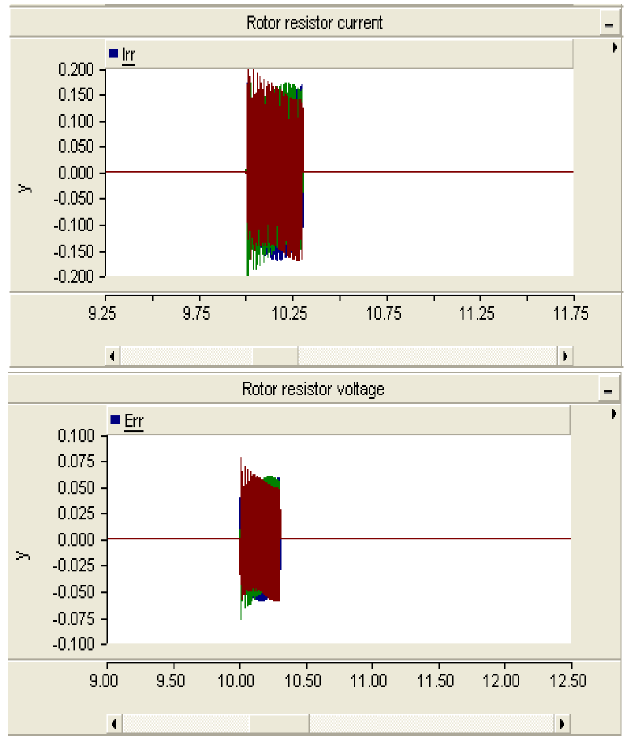


Fig. 8 Rotor Resistor Current & Rotor Resistor Voltage

V. CONCLUSION

The necessary conditions for deciding the upper and lower limit of resistance are as following

- ➢ The resistance should be high to limit the short-circuit current.
- ➢ It should be low to avoid a too high voltage in the rotor circuit.

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Prof. Kadam D.P graduated in Electrical Engineering from Govt. College of Engineering, Amaravati in 1997 & his Master's Degree in Electrical Engineering from Walchand college of Engg., Sangli, Shivaji University, Kolhapur with Power System as a specialization. He is working as an Assistant Professor at K.K.W.I.E.E. & R, Nashik, Maharashtra, India.He is pursuing Ph.D from Pune University. His research area includes Optimization of Reactive Power, Power Quality & FACTS. His total experience spans over 11 years.

Prof. Dr. B. E. Kushare graduated in Electrical Engineering from Govt. College of Engineering, Aurangabad and obtained Gold Medal for University Topper in 1989. He completed his ME Electrical Control System from Pune University in 1992 and obtained Ph.D. in Power Quality from Pune University in 2006. He is also a Certified Energy auditor. He Published around 100 International and National Papers. He is also a consultant to various industries in India and abroad. He is working as Professor & Head of Electrical Engg. Dept. at K.K.W.I.E.E. & R , Nashik, Maharashtra, India.