A Novel Topology for Enhancing the Low Voltage Ride through Capability for Grid Connected Wind Turbine Generators

R. A. Ibrahim*, M.S. Hamad*, Y.G. Dessouky*, B.W. Williams†

* Arab Academy for Science and Technology & Maritime Transport, Alexandria, (*Egypt*)
† Strathclyde University Glasgow, Scotland, (*United Kingdom*)

I. *Abstract*

Energy shortage and environmental pollution have led to the increasing demand of using renewable sources for electricity production. Currently, power generation from wind energy systems (WES) is of global significance and will continue to grow during the coming years leading to concerns about power system stability where wind farms replace conventional generating technologies that use fossil fuels as the primary energy source. One of these concerns is Low-Voltage Ride-Through (LVRT). In this paper, a novel topology based on the use of magnetic amplifier for enhancing the low voltage ride through capability for grid connected permanent magnet synchronous generators (PMSG).

Keywords-component; permanent magnet synchronous generator, low voltage ride through, wind energy grid connection, magnetic amplifier, renewable energy

II. *Introduction*

With the increasing penetration of wind energy and the improvement of its technology make it important to carefully reconsider the operating characteristics of wind farms, especially during grid fault conditions. Previously, disconnection of distributed generators (DGs) if one of the parameters (e.g. voltage, frequency, etc.) was beyond or below the permissible band was not a problem as the installed DG capacity was low. However, with installed mega watt (MW) of wind power, disconnection of the DG is no longer valid. Disconnection of many wind turbines (WT) during fault and evoked loss of a large share of generation can be dangerous for the stability of the power system operation. For these reasons, wind turbines are expected to behave like conventional synchronous generators during voltage dips, remaining connected and supplying reactive power during and after the voltage dip. During normal operation of WT and with the absence of grid voltage dips, the wind energy conversion system (WECS) extracts maximum power from the wind regardless of wind speed. This function of the turbine controller is known as maximum power point tracking (MPPT). The maximum extracted power passes through many stages of power electronic conversions till finally being exported to the grid. When a fully rated converter WT is connected to an AC network and a network fault occurs, the wind turbines DC link voltages will rise rapidly as the WT grid side converters are prevented from transmitting all the maximum active power coming from the generators. Therefore, to maintain the wind turbines' DC link voltages below their upper limit, the excess power has to be dissipated or the generator power has to be reduced.

III. *Objective*

Methods for LVRT capability enhancement and overcoming the rise in DC link voltage vary according to the turbine variables and utility grid variables. To enhance the LVRT capability for WT, blade pitch angle control can be used through shifting the WT blades from an angle where it extracts maximum power to another angle of attack, thus reducing the amount of power being extracted from the wind and compensating the rise in the DC link voltage. Another suggested solution is to oversize the DC link capacitor to compensate for the DC link voltage rise during grid dips. Active crow bar technique is considered one of the mostly used solutions for LVRT. By the insertion of a resistor in the dc link controlled by a power electronic switch, excess energy is dissipated and a balanced power flow is restored. Other methods for LVRT improvement can be through de-loading of the wind turbine by the proper control of generator side converter, grid side converter control. The former controls the generator electromagnetic torque by controlling the generator armature current while the latter maintains the DC link voltage constant by controlling the grid side converter. VAR and voltage compensation (shunt/series, shunt & series) has been one of the effective techniques in enhancing the LVRT capability on a larger scale such as wind farm level at the point of common coupling. VAR compensators employ the use of Static VAR Compensators (SVC), STATCOM, Magnetic Energy Recovery Switch (MERS), Dynamic Voltage Restorer (DVR) and Thyristor Controlled Series Capacitor (TCSC).

This paper proposes a novel topology that can be used to enhance the LVRT capability for PMSG grid connected wind turbines. The topology is based on series voltage compensation using magnetic amplifiers. Magntic amplifier has been known for years and is used in varaiety of applications such as position control. It is a device which acts as a variable inductance if inserted between a source of e.m.f and a load. Through proper control of its control winding current, magnetic amplifier will eventually act as a current limiter and a series voltage compensator at the event of transient voltage dip to enhance LVRT capability.

IV. *Approach:*

The WECS employed for grid connection of PMSG wind turbine is found in figure (1) which consists of the drive train, PMSG, diode bridge rectifier, boost converter circuit and a voltage source inverter (VSI). 1.5MW, 690 V, 11.5Hz PMSG grid connected system modeliing have been carried out which covers the following:

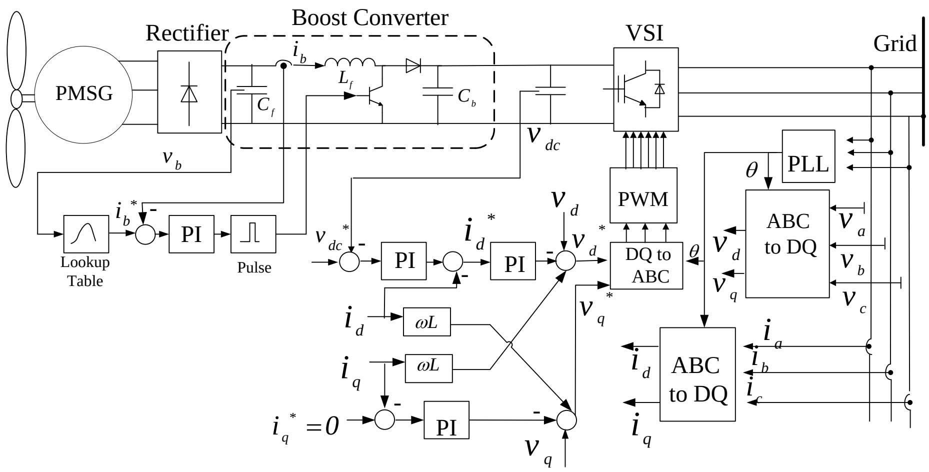
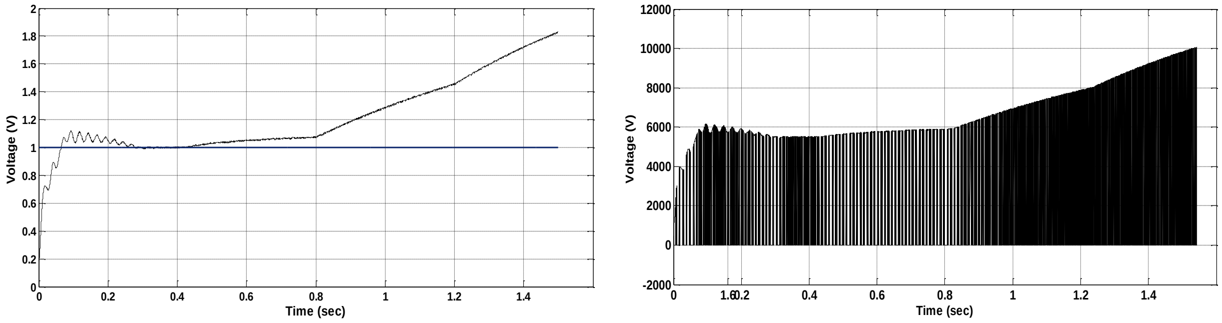


Figure 1: Block diagram for system under investigation

1- Aerodynamic wind turbine model
2- Permanent magnet synchronous generator model in *dq* frame
3- Boost converter control for maximum power point extraction of wind
4- Voltage source inverter control for maintaining the DC link voltage and export power extracted from wind to the electrical grid

The system in figure (1) has been studied for several grid voltage dips of 30%, 60% and 90% at 0.4, 0.8 and 1.2 sec to demonstrate the impact on the system element s and some of the simulation results are shown in figure (2). During the voltage dip incidance, the grid power will fall in response to the voltage dip while the PMSG will continue to extract maximum power from the wind turbine through the boost converter.Since the grid power has fallen to very low value, the power extracted from the wind will be transformed into stored energy in the DC link capacitor. As for figure (2), grid voltage dips cause a rapid rise in the DC link voltage, reaching almost to double the normal voltage which the capacitor can tolerate when a 90% dip occurs. The rise level depends on the capacitor size , dip voltage duration and network effective impedance, which can be more than just double the normal capacitor operating voltage. The DC link voltage rise accompanies more voltage stresses on the PWM VSI.



(a) **(b)**

Figure 2: Effect of 30%, 60% and 90% grid voltage dips on PMSG grid connected system (a) DC link voltage (p.u) (b) Inverter IGBT switch voltage (V)

As previously demonstrated, grid voltage dips can cause severe damages to the power converters due to the energy unbalance between the PMSG output power and grid electrical power which must be dissipated in the DC link capacitor accompanied by a rapid rise in the capacitor's voltage. The new topology suggested in the paper is based on using magnetic amplifier as series voltage compensators to compensate the DC link voltage rise during voltage dips.

Magnetic amplifiers, also known as transductors, have been used in applications such as instrumentation, relays, position servo mechanism, and automatic battery chargers since 1916. Magnetic Amplifiers are known for their high efficiency (up to 90 percent), reliability (long life, freedom from maintenance, reduction of spare parts inventory), ruggedness (shock and vibration resistance, high overload capability, freedom from effects of moisture); and needs no warm-up time. They have been used in vast applications, both in low and high power, one of which is voltage and frequency control

Figure 3 : PMSG wind energy converter system with magnetic amplifier

Fundamentally, the magnetic amplifier is a device whose input (control) signal is a voltage applied to a coil linking an iron cored system. Other coil linking the system (main coil) carry the load current which is supplied from a low impedance source of alternating e.m.f. Variation of the control current signal changes the flux level in the core and modifies the operating conditions in the load circuit so that the load current is modulated according to the variations of the control signal. Changing the control current I_c demagnetizes the core and changes the effective impedance seen by the main coil. This is done by forcing the operating point away on the B-H curve from the saturation region (effective impedance seen by the main coil is low) to the linear region (effective impedance seen by the main coil is high).

V. Results

The magnetic amplifier have been used and tested for LVRT enhancement as seen in figure (4). During normal operation with the absence of any grid faults, the magnetic amplifier is driven into saturation by the control winding current (controlled current source in figure (3)) with minimum voltage drop exerted on its main winding terminal. To generate the control winding current I_c, current controlled class 'A' chopper is used which activates as soon as the DC link voltage hits a predetermines threshold. Some simulation results can be found in figure (4) for a 20kw, 24 poles PMSG grid connected system which validates the idea of using the magnetic amplifier in the enhancement of the LVRT capability for PMSG WT. When 90% voltage dip occurs at 0.5sec, the control winding current controller senses the DC link voltage rise and activates the control current action. As seen in figure (4), the DC link voltage is prevented from rising but with a system overshoot of 0.06%. Overshoot problem can be avoided if magnetic amplifier is optimally designed. It is shown that the voltage stresses on the PWM VSI are minimum and that the magnetic amplifier was able to compensate for the power unbalance during the voltage dip. In the event of grid voltage restoration, magnetic amplifier control winding action is reversed to restore the system to its original state just as before the voltage dip.

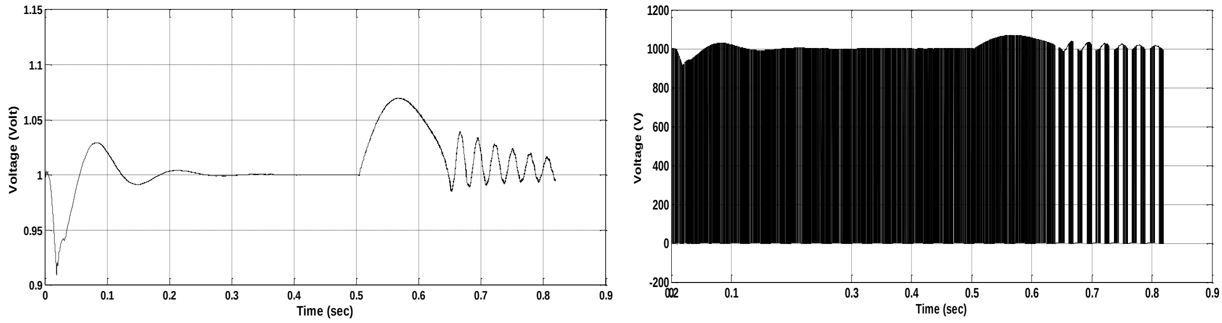


Figure 4: System response for 90% grid voltage dip with magnetic amplifier added (a) DC link voltage (p.u) (b) Inverter IGBT switch voltage (V)

VI. Conclusion:

Enhancement of low voltage ride through capability for wind turbines is becoming one of the most important issues related to the utilization and connection of wind turbines to the electrical grid. Several techniques have been adopted in literatures that ensure that grid codes are being complied in the event of grid voltage dips which, not only ensure the stability of the electrical grid post the voltage dip, but also ensure the safety of wind farm during the dip event. A novel topology based on using magnetic amplifiers in the event of grid voltage dips is demonstrated. Simulation results show that magnetic amplifier can be used to enhance the LVRT capability for direct driven PMSG WES. The application extends for the use with DFIG wind energy systems as well.

Publication issued

1- R.A. Ibrahim, M.S. Hamad, Y.G. Dessouky and B.W. Williams, "*A review on recent low voltage ride-through solutions of wind farm for permanent magnet synchronous generator*", SPEEDAM 2012, International Symposium on Power Electronics, Electrical Drives, Automation and Motion, June 20-22, 2012, Sorrento, Italy.

2- R.A. Ibrahim, M.S. Hamad, Y.G. Dessouky and B.W. Williams, "*A Novel Topology for Enhancing the Low Voltage Ride through Capability for Grid Connected Wind Turbine Generators*", ECCE 2012, IEEE Energy Conversion Congress and Exposition, September 15- 20, 2012, Raleigh, North Carolina.