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A Low Voltage Ride Through Capability Of DFIG Using FACTS Devices

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Abstract— *The number of wind installations has grown worldwide at unprecedented rates in new scenario. Widespread tripping of wind generators following disturbances could lead to propagation of transient instabilities and could potentially cause local or system wide blackouts. This has provoked many utilities to adopt low voltage ride-through (LVRT) for wind turbines. This paper presents the LVRT characteristic, reviews the effect that voltage dips have on the operation of doubly fed Induction generator. This paper provides a comparative study on the low voltage ride-through (LVRT) capacity of wind energy conversion systems (WECSs) under variable Speed Induction Generator (DFIG), with FACTS (Flexible AC Transmission) devices like STATCOM (Static Synchronous Compensator).*

Keywords— *Wind Farm, DFIG, STATCOM, Low Voltage Ride Through (LVRT).*

I. INTRODUCTION

Wind power as a renewable source is currently preferred due to its abundant and clean nature. In the past several years, wind energy has been one of the fastest growing energy sources in the world. Wind turbine is a rotating machine which converts the kinetic energy of wind into mechanical energy. If the wind turbine is connected to a generator, which converts the mechanical power into electric power, the machine is then called a wind turbine generator. A group of wind turbines in the same location is called wind farm. With the development of wind power technology, the energy gain is not the only criteria to be considered when installing wind turbines; the impact on the environment, the power quality, and the maintaining of power grid stability are some of the important issues. More and more complicated control strategies have been implemented in wind system.

The kinetic energy of moving air molecules are converted into rotational energy by the rotor of wind turbine. This rotational energy in turn is converted into electrical energy by wind electric generator. The amount of power, which the wind transfers to the rotor, depends on the density of air, the rotor area, and the wind speed.[1]

II. DOUBLY FED INDUCTION GENERATOR

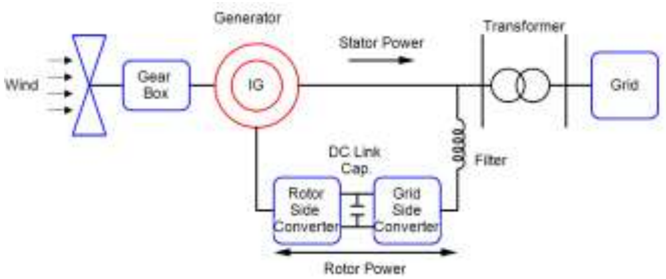


Figure 1 Doubly fed Induction Generator

Conventional wound-rotor induction machine in which the stator is directly connected to the grid through a transformer and the connection of the rotor to the stator (and grid) is via a back-to-back voltage source convertor.[2] The rotor converter system consists of a grid side converter (GSC)and rotor side converter (RSC) connected via a DC link. A simplified schematic diagram of a DFIG based wind energy generation system is shown in Fig1.The generator is called DFIG because the power is fed from both stator and the rotor circuits to the grid. The rotor circuit handles typically about 25-30% of the generator rated power, this percentage allows the DFIG to have about 30 ± % operational speed range around the synchronous speed and reduces the rating and the cost of the rotor converter [3, 4].

The size of the converter is not related to the total generator power but to the selected speed range and, hence, to the "slip" power, thus the cost of the converter increases when the speed range becomes wider. The selection of the speed range, therefore, is based on the economic optimization of investment costs and on increased efficiency. Since the DFIG is connected to the grid, the high transient currents due to the grid disturbances may destroy the power electronic devices of the rotor converter. A protection system called "crowbars" are being used in which the rotor winding can be short circuited during the fault period via a small resistance and released when the fault is cleared.

A. Design of GSC Controller of DFIG

The rotor-side converter is used to control the machine speed and the reactive power supplied through the machine stator, while the grid-side converter is used to maintain the dc bus voltage constant. The reactive power of this converter can be controlled, and one strategy is to maintain the power factor of this converter at unity. This minimizes the current flowing in the grid side converter. [5]

B. Design of RSC Controller of DFIG

The purpose of the rotor inverter is to control the generator speed to achieve maximum power from the wind over a range of wind velocities. The rotor side inverter control scheme is based on a multitier structure that comprises a speed, active power, reactive power and current control loop. It should be noted that omission of the power control loop is possible by implementing decoupled current control. [5]

III. Low Voltage Ride Through (LVRT)

When a fault occurs on the network, the drop in voltage it causes can have undesirable effects on wind turbines delivering power to the grid. But in general, protection devices in the machines and/or plant act to disconnect the plant from the network. The resulting loss in active power generation makes it more difficult for the system to recover from the low voltage event. This problem led network administrators and regulating agencies to impose Low Voltage Ride-Through (LVRT) capability requirements on wind farms connected to the system [6]. While specifics vary from network to network, LVRT requirements generally specify a worst-case fault scenario (including % drop in voltage, duration, and recovery time) during which the wind plant must remain connected to the grid.

The wind farm performance for the three LVRT solutions is simulated for different types of short circuit, namely three phase short circuit at the point of common connection (PCC) of the wind farm to the grid (the worst case in terms of power flow interruption), as well as other types of faults (double line, single phase to ground), and with faults occurring at different distances from the farm, resulting in various low voltage levels at the PCC.

The code is described by a LVRT curve. A typical LVRT code is shown in Fig. 2 [7]. It requires that wind turbine should keep connecting with grid if the after fault voltage is always above the LVRT curve, and it would be permitted to disconnect from grid only when the voltage drops below the curve. A network fault occurs at t_i= t , it subsequently causes a voltage dip from v_i to v_r, and the fault is cleared at t_r= t . This process corresponds to the fault period. The voltage will start to recovery after the fault cleared. At the instant t_f= t, the voltage reaches v_f which is ordinarily larger than 0.8pu. Then, the power system gradually turns back to the normal operation. This process is called dynamic voltage recovery time. Accordingly the whole LVRT course is composed of two important periods: fault period and dynamic voltage recovery period. Utilities and system operators have defined different spans of these two periods to satisfy their own power grid requirements.

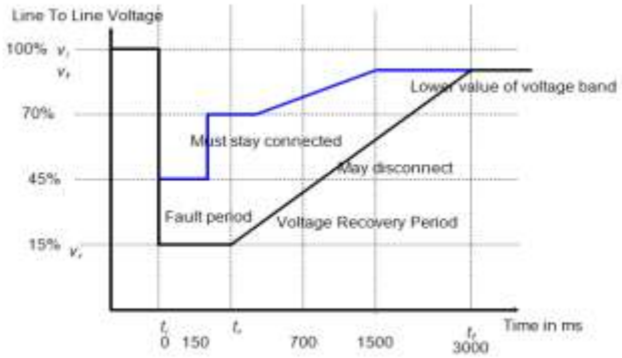


Figure 2 Typical limit curve for LVRT requirements

1. Fault period

As the fault is not cleared during the fault period, the terminal voltage of wind farm will undergo an incessant drop. The mutation of voltage produces an overcurrent and overvoltage in both of rotor winding and stator winding. For doubly-Fed induction generators, the capacity of back-to-back converter is only a fraction of rated power. When the voltage drop-value is too large and beyond the tolerance of the converter, wind turbines must disconnect from the network to protect themselves from being destroyed. Thus, wind farm cannot get through the low voltage successfully. To deal with this problem, protection measures must be taken to deter the overcurrent and overvoltage.

a. Measures to Enhance the Ride-through Capability during Fault Period

Large numbers of researches have been undertaken in this direction, and many achievements have come forth. The measures that can enhance the ride through capability during the fault period are summarized as follows. In-depth analysis is beyond the scope of this paper. Details introduction may be found in [8-9].

- Improving the control strategy of converter.
- Using a Crowbar circuit or a DC dumping circuit.
- Using energy storage equipment.
- Using a dynamic voltage restorer.

2. Fault Clearing Time

Deterring the over current and overvoltage during the fault period certainly can help Profited wind turbines get through this period. However, if the fault is unable to be cleared in a long time, it still can lead to wind turbines disconnection. Fault clearing time is decided by relay protection operating time and circuit breaker operating time. In Germany and England, the permitted fault period durations are 0.15s which is just enough to clear fault by main protection, that is to say, in order to keep wind turbines connecting with network, the fault must be reliably cleared by main protection. Therefore under a serious voltage dip, Germany and England have more rigid requirements to the reliability and speed of relay protection than to the ability of enduring low voltage of wind turbines.[7] By contrast, in USA, China and Canada, the permitted fault period durations are 6.25s which allows backup protection to clear fault, but still must be operated by zone 2 protection. Besides, the long-time existed fault demands a higher competence of wind turbines to endure low voltage. From the preceding analysis, we can learn that more rigid demands of reliability and speed of relay protection are needed while higher requirements of LVRT capability are constructed. Moreover, it also can be seen in following studies that a swift removal of fault is beneficial for dynamic voltage recovery.

IV. FACTS Devices Overview

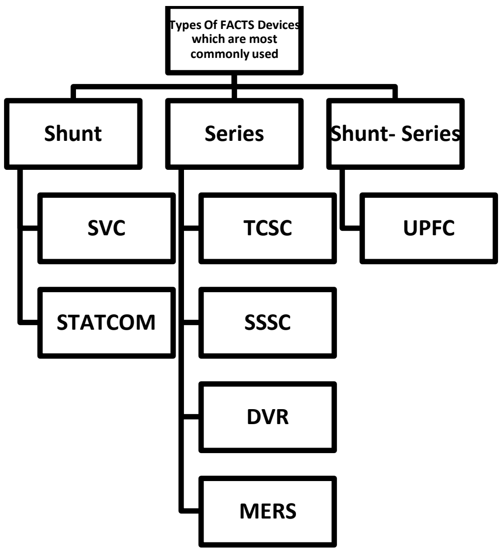


Figure 3 LVRT Improvement using facts devices

FACTS are defined as "Alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability" [10]. One of the major causes of voltage instability is the reactive power limit of the system. The voltage fluctuation limit of a bus in the power system depends on the reactive power support (and control) that the bus can receive from the system. When the system approaches the Maximum Loading Point (MLP) or voltage collapse point, both real and reactive power losses increase rapidly. Therefore, the reactive power supports have to be local and adequate. In terms of wind energy applications, there are times when wind farms are subjected to short duration disturbances due to short circuits. During these disturbances the system voltage rapidly collapses. Smaller scale wind turbines are normally disconnected from the system until healthy conditions have been restored. For larger wind farms, it is often a requirement that they remain connected to the system during such disturbances and also provide support to the system to aid recovery to a pre-disturbance state.

A. Static Synchronous Compensator (STATCOM)

STATCOM is another very popularly used Flexible AC Transmission System (FACTS)device that is capable of generating and/or absorbing reactive power and is applied to voltage support at a given bus [13]. It consists of a Voltage Source converter (VSC) and a DC energy storage device connected in shunt to the distribution network through a coupling transformer [12]. The VSC converts the DC voltage across the storage device into a set of three-phase AC output voltages. It can continuously generate or absorb reactive power by varying the amplitude of the converter voltage with respect to the line bus voltage so that a When system voltage is v high, it absorbs reactive power. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize its terminal voltage from a DC voltage source. . The major features of STATCOM are quick response time, less space requirement, optimum voltage platform, higher operational flexibility and excellent dynamic characteristics under various operating conditions [14].

The real and reactive power injected by the STATCOM is given by equations

$$P = \frac{V_1 V_2 \sin\delta}{X} \quad \text{..................................... (1)}$$

$$Q = \frac{V_1(V_1 - V_2\cos\delta)}{X} \quad \text{............................. (2)}$$

Where, δ is the angle difference between V_1 and V_2. In steady state operation, P and Q is active and reactive power.

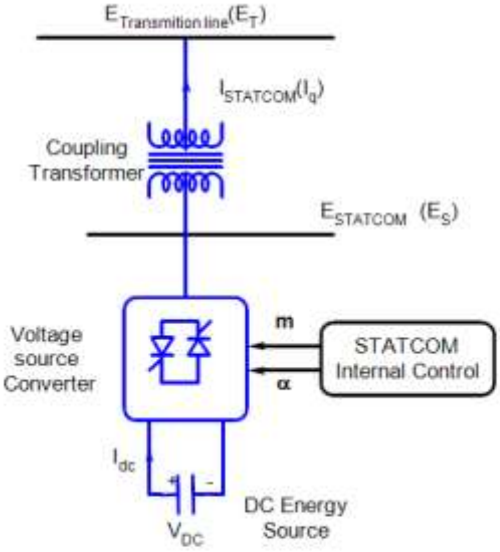


Figure 4 Shunt Compensation using STATCOM

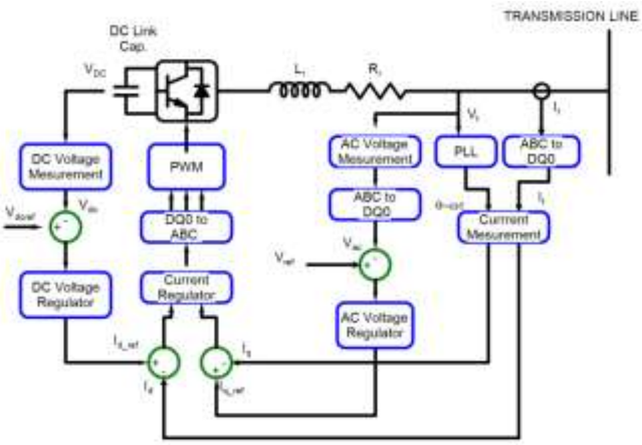


Figure 5control strategy of STATCOM

Controlled current flows through the tie reactance between the STATCOM and the distribution network. When system voltage is low, the STATCOM generates reactive power.

B. Design of the STATCOM

The VAR rating of the STATCOM

$$kVAR = 2 \times \pi \times f \times V_{L-L}^2 \times C_{dc} \quad \text{.............. (3)}$$

Where, V_{DC}= DC Link capacitor,

V_{L-L}= Line to Line Voltage

DC Capacitor Voltage

$$V_{dc} = \frac{2\times\sqrt{2}\times V_{L-L}}{\sqrt{3}\times m} \quad \text{................................. (4)}$$

Where, m= Modulation index

V_{DC} = DC Link Voltage

Ripple Filter

$$L_f = \frac{\sqrt{3}\times m\times V_{dc}}{12\times\alpha\times f_s\times I_{cp\%}} \quad \text{.............................. (5)}$$

Where, L_f= Ripple filter inductor

$I_{CP\%}$=current ripple in %

Frequency of 5 kHz or less than that, the ripple filter capacitor is designed as *Cf*= 5 µF. A series resistance (*Rf*) of 5 ohm is included in series with the capacitor (*Cf*). [11]

V. SIMULATION & RESULT

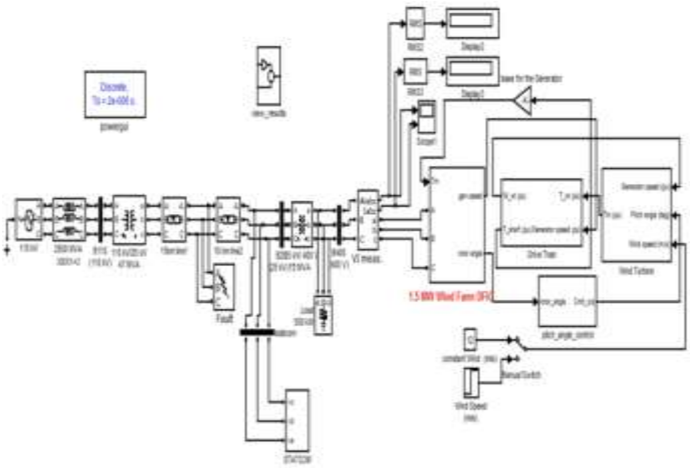
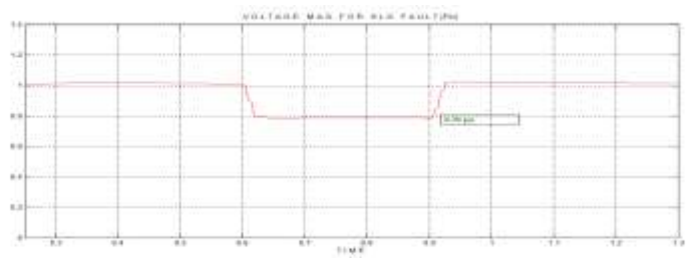
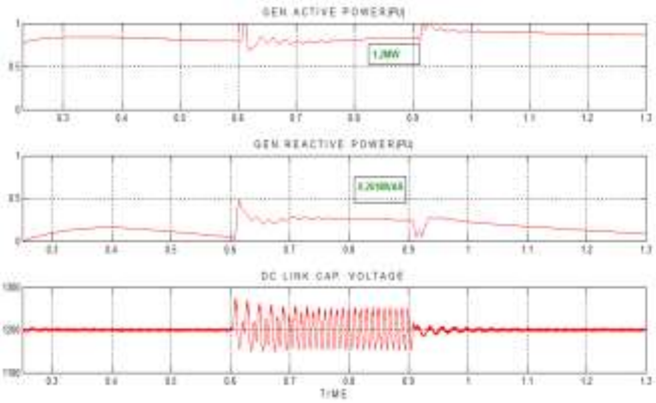


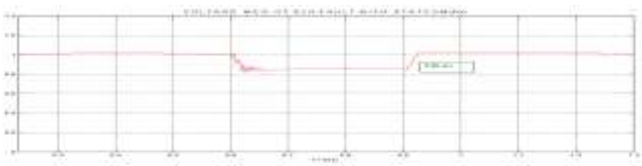
Figure 6 MATLAB SIMULATION of STATCOM with DFIG.



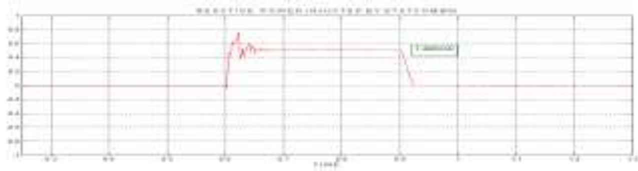
(a)



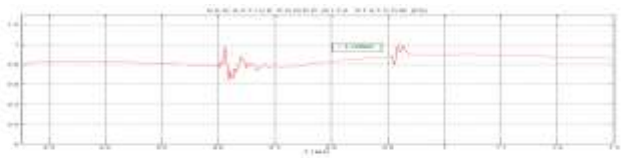
(b)



(c)



(d)



(e)

Figure 7 (a).voltage dip during SLG fault(b) gen. active ,reactive power, and dc link voltage(c)LVRT improvement using STATCOM (d) STATCOM reactive power during fault(e) generator active power with STATCOM

As shown in figure 6 1.5 MW DFIG connected with grid . SLG fault occurs at distribution side during 0.6 to 0.9s .Due to SLG fault voltage dip up to 0.79 pu ,and generator active power decrease to 1.2MW.This disturbance also effect DC link capacitor voltage . Using STATCOM voltage level increases from 0.79 pu to 0.86 pu and generator active power also increase from 1.2 MW to 1.32MW. From this MATLAB simulation we can see that STATCOM try to connect DFIG to grid so continue power generation and improve power quality.

VI. CONCLUSIONS

With the large installed capacity of 1.5MW wind turbines, LVRT capability enhancement is becoming one of the most important grid connection issues. This paper demonstrates how network voltage dips affect the LVRT capability of DFIG wind turbines by having destructive effects on the power electronic converters and the electrical generator.

The application of STATCOM connected to a wind-turbine-driven DFIG to allow uninterruptible Low Voltage ride-through of grid voltage faults is investigated. The STATCOM can compensate the faulty line voltage, while the DFIG wind turbine can continue its nominal operation and fulfil any grid code requirement without the need for additional protection methods.

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TABLE 1 Parameters of DFIG for WEGS

Parameter	**Value**
Normal wind speed	12 m/s
Nominal Apparent Power	1.5/0.9 MVA
Nominal Active Power	1.5 MW
Grid Voltage	110kV
Grid Frequency	50 Hz
Distribution Line voltage	25KV
Wind Turbine Bus Voltage	400V
Nominal DC Link Voltage Vdc	1.2 kV
DC Link Capacitance C	10 mF
Generator Pairs of Poles p	3
Transmission Distance	30km

TABLE 2 parameters of STATCOM

Parameter	**Value**
STATCOM Ratting	3MVAR
DC Link Nominal Voltage	2300V
DC Link Total Capacitance	5mF
Switching frequency	5000Hz
Filter Inductor value	0.016H
Filter capacitor value	100 µF
Filter Resistance value	78.54 mΩ
Load Transformer rating:	3 MVA25 KV /1.2k V