ISSN: 0976-3104
SUPPLEMENT ISSUE

IMPROVEMENT OF LVRT CAPABILITY BY COMBINING -SWITCH TYPE FAULT CURRENT LIMITER AND SUPER CAPACITOR FOR DFIG BASED WIND TURBINES

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ABSTRACT

Background: *An improved Low Voltage Ride Through (LVRT) control approach for a Doubly Fed Induction Generator (DFIG) based Wind Energy Conversion System (WECS) is offered in this paper. DFIG is sensitive to grid voltage variation; hence it requires reactive power support to overcome this drawback for safe and stable operation of power grid. The DFIG is interfaced to the AC network through a Grid Side Converter (GSC) and a Rotor Side Converter (RSC) to facilitate the variable speed operation of the wind turbine. When compared with pitch angle control, rotor side converter and grid side converter is simple and permits rotor speed to increase further than the prescribed value. Grid side converter (GSC) control diminishes the DC link instability and Rotor Side Converter (RSC) control reduces the transient current during the period of fault. The benefit of energy storage, which helps to improve the LVRT, is also applied.* ***Methods:*** *The Switch Type Fault Current Limiter (STFCL) and Super Capacitor (SC) are the two essential proposed methods used in this system. The STFCL excellently decreases the over current in the rotor side throughout the fault. Since the Fault Current Limiting Inductors are located in series with the stator to limit the rotor over current throughout the fault. On the other hand SC improves the system stability. It has huge power concentration to balance the system power.* ***Results:*** *The viability of the proposed method is established by the experimental results on a 1.5 MW DFIG system using MATLAB/SIMULINK software. From the above methods, the design of energy storage and STFCL with control on RSC and GSC the rotor voltage, current, real and reactive power remains within the safe working limit throughout the period of fault. This control works for both symmetrical and asymmetrical fault.* ***Conclusions:*** *The proposed control technique enables DFIG to carry on the power production during fault and offer the reactive power support to the grid. With this scheme, rotor current and voltage waveforms are enhanced. The torque oscillation is reduced and successfully suppressed the transient rotor current.*

THE IIOAB JOURNAL

KEY WORDS
Doubly fed induction generator (DFIG), Low Voltage Ride Through (LVRT), Super capacitor (SC), Switch type fault current limiter (STFCL)

Received: 10 January 2017
Accepted: 20 March 2017
Published: 2 April 2017

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INTRODUCTION

Demand of energy is increasing now a days and found difficult to balance the supply of power and demand with the conventional fossil fuel power plants. Due to the rising concern of green environmental protection and reduction of conventional sources, renewable energy is becoming an interesting subject. Among all existing non conventional energy source, wind electrical power significantly produces bulk value of electrical power. Wind power is fresh and renewable. Exponential raise of the wind electrical power generation has prepared the power system network more susceptible to the grid disturbances. Many countries revised their grid code to make sure the steady operation of the power system. LVRT is one of the most essential grid code requirements, which requires that wind turbine should stay connected to the grid and supply the stability throughout the fault. The wind system should stay connected to grid during fault and supply reactive power support to the wind system. DFIG is accepted in wind power market. Even though DFIG can generate more power, it has less mechanical stress and has independent control of active and reactive power, but less stable and consistent system. The typical DFIG wind turbine is shown in Fig.1[1].

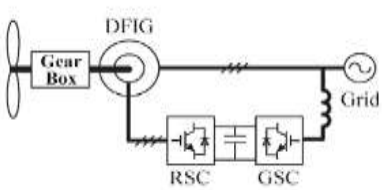

Fig. 1: Configuration of DFIG based WECS

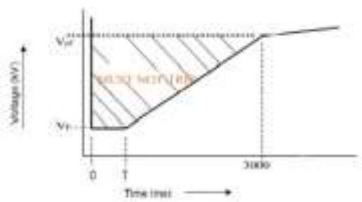

Fig. 2: A Typical LVRT Curve

In this system, the stator is connected to the grid and rotor is connected through a back to back converter fed to the grid. LVRT is the ability of the wind system to stay connected to the grid even with a serious voltage issue. When system becomes abnormal like voltage sag, it may cause certain undesired characteristics on equipment like uncontrolled active and reactive power and diminishing grid code requirements. When a grid fault occurs, the voltage across the rotor circuit becomes high which results in demagnetizing effect. Hence large inrush current flows in rotor and Stator circuit [1]. This paper proposes a combined protection and control strategy including the Super Capacitor (SC) and Switch Type Fault Current Limiter (STFCL). On selection of a suitable value for DC side super capacitor (SC), in such a way that it could facilitate wind turbine for LVRT without any need to crowbar protection. In [2] the integration of a short-term energy storage device in a DFIG design was considered in order to smoothen the fast wind-induced power variations thereby enhancing its low-voltage ride through (LVRT) capability. A decoupled P–Q control scheme of a super capacitor energy storage system was proposed in [3], this energy storage interfaced through a STATCOM, for Low Voltage Ride Through as well as damping enhancement of the DFIG system. Two-layer constant power control scheme has been proposed[4]. In this scheme, each DFIG wind turbine in the wind farm is equipped with a super capacitor energy storage system. On the other hand STFCL inserts fault-current-limiting inductors into the stator branches upon event of a grid fault, which helps weaken the rotor back-EMF voltage and diminish the rotor over current. The LVRT capability of RSC is therefore successfully strengthened. The existing crowbar circuit provides a bypass for the fault current, whereas the STFCL limits the fault current and rotor back-EMF voltage and strengthens the controllability of RSC. The crowbar circuit can only protect the DFIG from overcurrent, whereas the STFCL can protect the DFIG from overvoltage, overcurrent, and overtorque simultaneously. The STFCL can also offer better reactive power support for the grid with the improved controllability of RSC. With the help of STFCL, the DFIG is able to ride through the most serious grid faults [5].

GRID CODE REQUIREMENT

Due to the considerable raise of wind power penetration in the electrical power system, several countries have revised their grid code by essential detailed technical requirements for the wind farms. Grid code typically refers to huge wind farms, which is linked to the transmission system. Grid codes state that wind farms must contribute to power system control as much as conventional power generation stations and withstanding of wind system during unusual condition. The Grid Codes address fault acceptance, reactive power/voltage control requirements, ramp rate control and frequency response ability. The typical LVRT curve as per Indian Wind Grid Code(IWGC) is shown in [Fig.2].

EXISTING CONTROL METHODS

LVRT capability enhancement techniques use existing methods such as crowbar circuit, DC chopper, series dynamic braking resistor, reverse current tracking method , stator current feed back technique, flux linkage tracking, rotor side converter control, grid side converter control, turbine drive train model and pitch angle control are discussed below

Crowbar method

Crowbar method is the conventional method to enhance the LVRT capability of the wind turbines. Fig.3[6] shows the crowbar circuit. During voltage dip, the rotor circuit is disconnected and the DFIG run as squirrel cage induction motor. The operator can organize the switching by adjusting the triggering. By adjusting the value of crowbar resistance, operation of crowbar may vary. This is the simplest method and has the advantage of low cost. The foremost difficulty is its high short circuit current at the time of voltage sag, thereby drawing more reactive power from the network[6].There are different methods to improve the stability namely passive crowbar, active crowbar and stator crowbar.

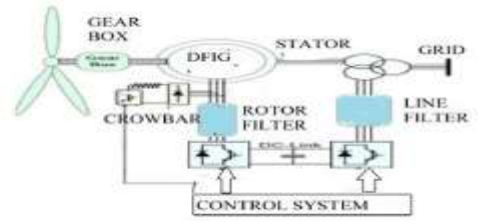

Fig. 3: A Typical Crowbar circuit

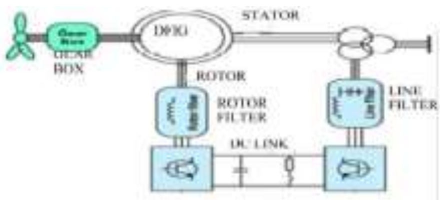

Fig.4: A Typical DC chopper circuit

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DC Chopper

DC chopper is also known as braking resistance which is linked in parallel with the dc link capacitor to limit the over voltage and current during abnormal condition. [Fig.4] shows the schematic diagram of DC chopper. The dc-link brake chopper shorts the dc-link through a power resistor when the dc-link voltage exceeds a fixed threshold level. The brake is used to uphold the dc-link voltage when transient rotor over current occurs[8]. There are six anti parallel diodes in the rotor-side converter that are extremely rated to endure short-circuit currents. The brake chopper works on a hysteresis band i.e., the turn-off voltage is set below the turn on threshold value.

The dc-link chopper has no effect on rotor over current. To limit this over current, a dynamic resistor is linked in series with the rotor. It is controlled by a power electronic switch.

Series dynamic braking resistor

The Series Dynamic Braking Resistor (SDBR) boosts the generator voltage and dissipates the active power[8]. At normal operation, the switch turns on and the resistor is bypassed. During the fault condition, the switch turns off and the braking resistor is connected in series with the circuit[9]. The DFIG rotor equivalent circuit with all protection schemes is shown in [Fig.5].

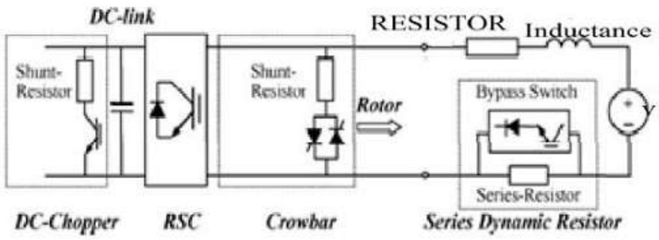

Fig.5: A Typical Series dynamic resistor circuit (SDR).

Reverse current tracking method

The proposal behind this control method is during the fault time an EMF is induced which exceeds the utmost output voltage of rotor side converter. The rotor current is controlled to track the stator current in the reverse direction. There by prevents the rotor current in a definite range with restricted RSC output voltage. No need of flux linkage or sequence component separation. This technique reduces the fault current with little torque oscillation [10].

Stator current feedback technique

Stator Current Feed Back method is presented in[13].This method aims to decrease the rotor current by varying the RSC control instead of installing additional hardware protection like a crowbar in the wind turbine system. When a fault affects the generator the exact and distorted stator currents are fed back as orientation for the rotor current controller. The purpose is to decrease the stator current oscillations and thus reduce the rotor current.[11].

Flux linkage tracking

LVRT control approach based on flux linkage tracking is intended for RSC to restrain the rotor current throughout grid faults. The essential attitude of the control approach is that, when a grid fault is detected the rotor flux linkage is prescribed to track a condensed fraction of the altering stator flux linkage by changing the output rotor voltage of the RSC. As long as the dissimilarity between ψs and ψr is kept small enough, the rotor current will be restricted within the maximum current allowed. This technique suppresses the rotor current with lesser torque oscillations, suitable for industrial applications.[1].

Wind turbine and drive train model

Wind turbines are systems that tie the kinetic energy of the wind for constructive power. Wind flow causes the shaft to spin. The resultant shaft power can be used for mechanical work, like pumping water, or to revolve a generator to produce electrical power. Two mass model of the drive train is accessible at this juncture. Wind turbine shaft is comparatively softer compared to the steam turbine shaft used in the conservative system [15].

Pitch Control

The pitch angle of the blade is controlled in order to optimize the power extraction from the wind. PI controllers are used to attain the pitch control. While the speed increases above the rated value, pitch angle increases by PI controllers to preserve the power output to its rated value. Pitch angle of the blade is prohibited to protect wind system from over rated power throughout the high wind speed.

Rotor side converter control

RSC control system presented in is used at this juncture. PI controllers are used for the regulation of reactive power control and rotor current. In order to decouple the electromagnetic torque, the induction generator is controlled in the stator flux oriented frame. ωref value is created by wind turbine. When a fault occurs, the incoming wind and power to the grid are unbalanced resulting a transient over current in the rotor circuit. During the fault period RSC will enlarge the generator rotor speed at the identical moment reducing the generator torque [15]. This method will not cause too much mechanical stress.

Grid side converter control

Converter control is operated in the grid voltage oriented reference frame to attain the independent control of active and reactive power [15]. PI controllers are used for the regulation of DC link voltage. During usual operation time, power flowing to the grid and RSC is balanced, at the time of fault extreme power flow between RSC and grid will lead the DC variation. To decrease the Pr/Vdc, the instantaneous variation of output power of RSC is set as the reference value[15].

The above existing methods discussed have few drawbacks, in case of crowbar method, significant power will be dissipated in the crowbar resistors during high voltage sags, thereby drawing more reactive power from the grid[2]. The dc-link chopper has no effect on rotor over current. The series dynamic braking resistor boosts the generator voltage and dissipates the active power. The reverse current tracking method reduces the fault current with little torque oscillation. In case of Pitch angle control, the blade is prohibited to protect wind system from over rated power throughout the high wind speed. All the available methods in existing system has its own difficulties to enhance the LVRT performance.

METHOD

Methods introduced in the past have certain boundaries for improving the performance of LVRT. Moreover it controls various parameters or it works only for certain type of liability. Here the scheme of energy storage and STFCL with a superior control on RSC and GSC is introduced to get better performance of system. The DFIG control includes the rotor side controller, grid side controller, STFCL and the super capacitor for improving the performance.

STFCL Control

Switch Type Fault Current Limiters (STFCL) have been planned with purpose of fault current control. SFCL has been presented at this juncture. It consists of fault current limiting inductors, isolation transformer, diode bridge, semiconductor switch and snubber capacitor. Snubber capacitor suppresses the transient over voltage when the semiconductor switch turns off. During the normal condition, semiconductor switch turns on and fault current inductors are bypassed. Semiconductor switch turns off during fault time, at first, fault current is limited by the fault energy absorption. The complete structure of SFCL with DFIG is shown in [Fig.6] [16].When the voltage Ca reaches the crest value, the fault current limiting inductors are completely inserted to stator to limit stator over current and thereby weaken the rotor back EMF. STFCL can protect not only the RSC from overcurrent and overvoltage but also the gear box from overtorque. The DFIG can ride through the most serious grid fault under well protection with the help of the STFCL.

Since overcurrent and overtorque are eliminated, the DFIG system can be well protected. The stator flux oscillations are much lighter than that without STFCL, which is because the rotor back-EMF voltage is weakened with the help of STFCL, and the RCS controllability is improved to counteract the stator flux oscillations. Moreover, rotor current and electromagnetic torque oscillations are fewer important, which is also due to the weakened rotor back-EMF voltage with the help of STFCL. The grid voltage also recovers quickly and smoothly than that of the without STFCL cases, which is due to the enhanced reactive power controllability provided by the STFCL [5].

Super capacitor

Super capacitor (SC) energy storage system improves the system stability. Super capacitor storage has big power concentration, long life cycle and good environmental performance makes feasible to balance the system power [14]. The DC-DC converter can work in three states [16].(a) Charging mode-SC charges up during this method, if surplus energy available in the grid due to light loaded condition. Converter works as a buck converter. (b) Discharging mode- SC deliver the energy to the grid to give back the voltage sag due to high load demand. Converter works as a boost converter. (c) Under normal operating condition, there is no real power exchange.

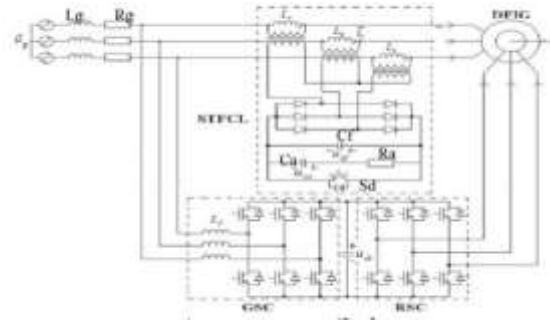

Fig.6: Switch Type Fault Current Limiter

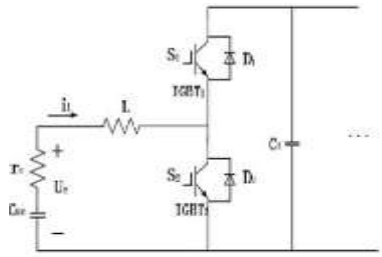

Fig.7: A Typical DC-DC converter.

DC-DC converter is controlled by two switches S1 and S2. During the increase in demand period S1 is controlled to cut off IGBT1 and branch of IGBT2 and D1 forms a boost converter. In light load period, buck converter is joined by IGBT1 and D2. By controlling the corresponding switches S1 and S2, DC-DC converter operates alternately. Vdc chooses the mode of operation of the DC-DC converter. When Vdc rises beyond the threshold value DC-DC converter works as a buck converter, When Vdc decreases below the rated value DC-DC converter works as a boost converter. In this method short-term energy storage device (SC) in a DFIG design was considered in order to smoothen the fast wind-induced power variations thereby enhancing its low-voltage ride through (LVRT) capability. A Typical DC-DC converter is shown in [Fig.7] [7]

Hence by combining STFCL with SC can effectively answer the issues of DFIG during fault. STFCL limits the fault current and rotor back-EMF. The torque oscillation is reduced and successfully suppresses the transient rotor current whereas SC is allowed to be charged during the high wind speed, and this stored energy can be used as an extra energy supply for DFIG to overcome low voltage sags during faults in the grid side. Thus the above combined method provides reactive power support to the grid[2,4,5].

ANALYSIS

For the purpose of analysis of the DFIG scheme throughout normal and faulted condition the following system is considered. DFIG of power 1.5 MW is considered here. The stator of DFIG is connected to a 575V bus. By using a step up transformer of 575V/25kV 4MVA the voltage is stepped up to 25KV. Connected to grid through a 20Km transmission line. A fault has occurred in the 20Km transmission line. The wind speed is set in to three different speeds. The fault is created at 0.2 sec and the equivalent wind speed at that time is 12m/sec. The whole system is developed and simulated in MATLAB/SIMULINK. The waveform in [Fig.8] shows the behavior of DFIG WT system during normal operation. The system parameters are represented in per unit value. The rotor voltage is 1 pu. The output waveform in [Fig.9] shows the behavior of DFIG WT system during symmetrical fault with no control on RSC and GSC. Exclusive of the appropriate control on DFIG scheme, at the time of voltage sag, system parameters are affected ruthlessly. Fault with duration of 100 ms is created here.

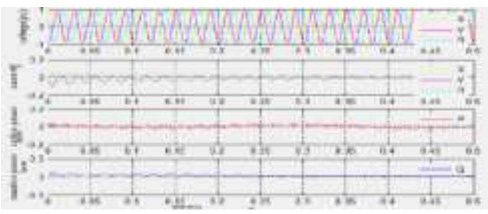

Fig.8: Waveform of DFIG during normal operation

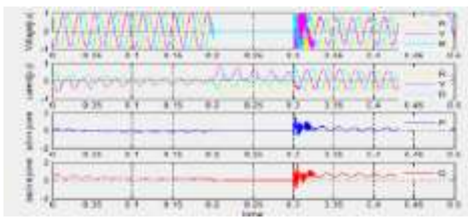

Fig.9: Waveform of DFIG during symmetrical fault with conventional method

The fault period is 0.2-0.3 sec. When the symmetrical three phase fault lacking enhanced control is detected, the grid voltage is decreased and the voltage becomes zero. The current is very high during this time. The real and reactive power is zero through the period of fault. [Fig.10] shows the LLG fault on the 20Km Transmission line. Here the rotor current is high and real and reactive power is almost zero with unpredictable nature. All parameters are represented in per unit value. By analyzing the waveform, throughout the fault period the voltage and current waveforms are extremely distorted. Also the real and reactive power waveform shows that throughout grid fault DFIG is disconnected from the grid. [Fig.11] shows the output waveforms of DFIG WT under the SLG fault with the proposed control method with fault at 0.2-0.3 sec, here the voltage, current waveform distortion is reduced. The preliminary variation is due to the rapid change in speed. Real and reactive power fluctuations are reduced with the proposed method.[Fig.12] shows the waveforms of DFIG WT with proposed control during LLG fault at 0.2-0.3 sec. The rotor current and voltage waveform gets improved. The rotor transient current is effectively controlled at this time. The fluctuation of real and reactive power is reduced. With the conventional method , the performance of DFIG under LLG fault is shown in [Fig.10]. Here voltage of faulted phase is zero while with the proposed method the voltage waveform is maintained in the fault period. Likewise the rotor current is suddenly increased with the conventional technique as shown in [Fig.10], but with the control, the unexpected increase in the rotor current at the time of fault is effectively reduced. The real and reactive power waveform is enhanced compared with the conventional system.

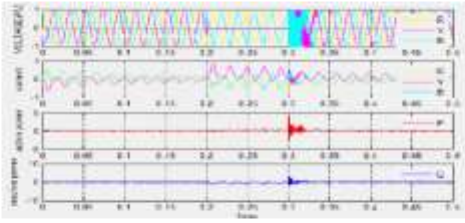

Fig.10: Waveform of DFIG during asymmetrical (LLG) fault with conventional method

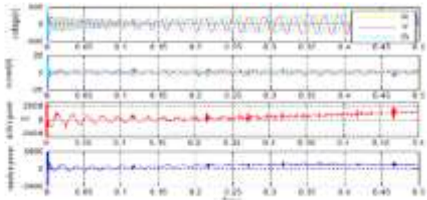

Fig.11: Waveform of DFIG during SLG fault with proposed method

[Fig.11] shows the waveform of DFIG WT under SLG fault with proposed control method. This technique is also suitable for the symmetrical fault. [Fig. 13] shows the output waveform under symmetrical fault. The rotor voltage and current waveform fluctuation is reduced. Also the real and reactive power does not dips to zero. Minute fluctuation occurs in the real and reactive power.Fig.9 shows the performance with conventional system, real and reactive power is zero throughout the time of fault, which means the scheme is disconnected from the grid. But proposed system with energy storage help to unite the machine at the time of fault and offers the reactive power support to improve the LVRT potential.

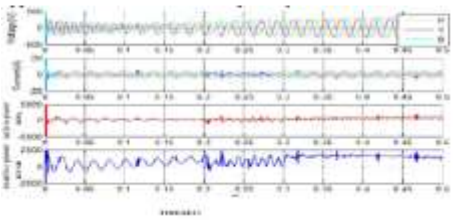

Fig.12: Waveform of DFIG during LLG proposed method.

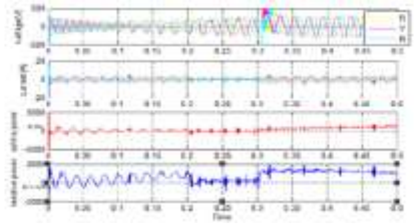

Fig.13: Waveform of DFIG during fault with symmetrical fault with proposed Method.

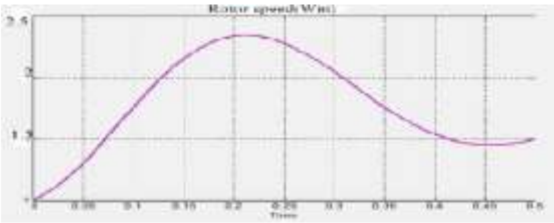

Fig.14: Rotor speed Vs output power.

The [Fig.14] shows the rotor speed waveforms with the proposed control technique. The torque value is almost constant with the proposed method. Proposed method can effectively control the rotor current, voltage, real and reactive power and contribute the grid permanence. Conventional method, the DFIG is disconnected from the grid, due to the over current in the rotor during fault and failed to contribute the scheme stability and reliability [12]. From the output waveform of conventional method, it is obvious that the real and reactive power grow to be zero and fluctuation of rotor voltage and current is large and it affects stability, will unfavorably affect the power electronic converter in the system. With the proposed system, by incorporating the idea of energy storage and STFCL with control on RSC and GSC the rotor voltage, current, real and reactive power remains within the secure operating limit throughout the period of fault. Even though there are fluctuations in real and reactive power, the control effectively controls the voltage and current. This control works for both symmetrical and asymmetrical fault.

IIOAB JOURNAL
ISSN: 0976-3104

CONCLUSION

Low Voltage Ride Through is a significant characteristic for wind turbine systems to complete the grid code requirements. DFIG is very sensitive to grid voltage variations. To overcome this, appropriate control must be implemented to protect the converter from tripping during grid voltage faults. High current transients cause voltage fluctuations, rotor current, torque variations and DC link voltage fluctuation. With the conventional crowbar method, the rotor circuit draws higher value of short circuit current at the time of voltage sag, thereby drawing more reactive power from the network. This method is not satisfactory when wind power generation is considerable. As the dispersion of wind turbine increases, wind turbines are necessary to stay connected throughout grid fault. From the analysis, it is found that conventional DFIG WT system faces troubles during grid voltage dip. The proposed control technique uses super capacitor combined with STFCL can effectively answer the issues of DFIG during fault at 0.2 – 0.3 sec. STFCL limits the fault current and rotor back-EMF on the other hand the SC is allowed to be charged during the high wind speed, and this stored energy can be used as an extra energy supply for DFIG to overcome low voltage sags during faults in the grid side.

This combined method enables DFIG to carry on the power production during fault and offers the reactive power support to the grid. With this scheme, rotor current and voltage waveforms are enhanced. The torque oscillation is reduced and successfully suppresses the transient rotor current. The only drawback of the method is bulkier compared to crowbar circuit, but considering the stupendous LVRT attractive potential the arrangement is very successful. This process protects the structure from over voltage, over current and over torque, and it works for both in symmetrical and asymmetrical fault.

CONFLICT OF INTEREST

There is no conflict of interest.

ACKNOWLEDGEMENTS

None

FINANCIAL DISCLOSURE

None

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