Fault Ride-Through Capability Improved by using Bridge-type Fault Current Limiter for Fixed-speed wind Turbine

Ishraque Ahmad, Prabodh Khampariya' Jaiprakash Tiwari

Abstract— **The relations between wind turbines and grid results in rising short-circuit level and fault ride-through (FRT) capacity problem throughout fault situation. In this paper, the bridge type fault current limiter (FCL) with discharge resistor is used for solve these trouble. For this FCL, a control system is planned, which use the dc reactor current as control changeable, to change the terminal voltage of induction generator (IG) without measure any parameter of scheme. In this paper, the wind energy conversion system (WECS) is a fixed-speed system able to with a squirrel-cage IG. The drive train is representing by a two-mass model. The analytical and simulation studies of the bridge-type FCL and proposed control system for restraining the fault current and recovering FRT ability are offered and compare with the force of the request of the series dynamic braking resistor (SDBR). Fault ride-through condition planned in recent transmission and distribution grid codes identify that wind-turbine generators (WTGs) must stay linked to electricity network. A particular problem about power converter-based WTGs is that measure controller planned for dependable process approximately nominal voltage levels will not work as planned throughout low network voltages that can happen during a fault. An effect of this is really improved converter currents, which may lead to converter breakdown. This paper present a nonlinear controller propose for a power converter-based WTG that ensure that current levels remain within design limits, even at really reduced voltage levels, thus attractive the WTG's fault ride-through capacity.**

Index Terms— **Modeling and simulation of power systems, Fault Current Limiter, Fixed speed wind Turbine, SDBR**

I. INTRODUCTION

Inter connection between grid and wind turbine has been extensively investigate in recent years. Two main problems during the fault condition are the short-circuit level increases and fault ride-through (FRT) capacity decreases. The relationship of wind turbines to the grid causes the fault current level increase outside capability of existing equipments in some points of grids. This not only capacity damage the series equipments but also can cause harmful effect on FRT capacity of wind turbines. The reaction of the wind industry to FRT requirements differ according to wind turbine technology. There are two main types of wind turbines used today: the fixed-speed wind turbine (FSWT) and the variable-speed wind turbine (VSWT). New wind turbine generation systems are regularly VSWT. But, over the past years, FSWTs have been installed in large size in power grids. Detailed technical developments, made in reaction to FRT requirements of both FSWT and VSWT, can be characterized as follows:

1) Dynamic reactive power compensation (RPC) by using FACTS device such as SVC and STATCOM
2) Pitch control
3) Rotor converter protection by crowbar resistor.
4) Brake resistor.

The simulation results concludes that a 0.05 per unit (p.u.) SDBR is equivalent to 0.4 p.u dynamic RPC. It means that the SDBR is more effective than RPC. An important design factor for SDBR is its quick incorporation and early switching out of the dynamic resistor. The bridge-type fault current limiter (FCL) with discharge resistor is used for solving problems of the relations of WECS and power grid. The addition of the fault current is partial by dc reactor without any wait. This quality of the bridge-type FCL suppress the immediate voltage drop and it is able to develop transitory performance of WECS in fault instant, which is the main advantage of the bridge-type FCL to other FRT improvement technique. On the other hand, the discharge resistor of the bridge-type FCL aim to add to the voltage at the terminal of the generator thereby mitigate the destabilize electrical torque and power during the fault. The WECS is considered as a fixed-speed system equipped with a squirrel-cage IG. [1]

The performance of wind generation systems in normal and fault conditions depends on the technology on which they are base. Changeable speed wind generators are able to manage the reactive power exchange with the grid (in a limited range) due to the power electronic devices that they include. It is necessary to protect this electronic procedure, much more responsive than the electrical device itself, from the over current and over voltage's that track any unexpected voltage difference. This is achieve by disconnect them and by linking power debauchery supplementary elements (crowbar), which are also used for speed up the machine demagnetization and decreasing the short-circuit current. During the fault improvement, and once the hardest transitory has been damp, fixed power electronic converters can give to voltage improvement by reactive power insertion. But, in some belongings it may not be enough and it may be required to add additional reactive reparation devices to undertaking the implementation of the fault ride-through requests. About fixed-speed generators, they do not have the capacity to control their reactive power replace because they always need to take in a particular amount of reactive power. [4]. Thus, they generally consist of fixed reactive power maintain policy (capacitors) meant at obtain a unit power factor in regular

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process situation. These devices are incapable to supply the functionalities demand by new interconnection requests, mainly in fault conditions due to the quadratic reduce of their power insertion capacity. Both normal and fault condition operation of wind farms can be optimized by using power electronic reimbursement devices such as SVCs (Static VAr Compensator) and STATCOMs (Static Synchronous Compensator).SVC systems are made up of Thyristor Controlled Reactors (TCR) and Thyristor Switched Capacitors (TSC). STATCOM devices are untainted power electronic systems made up of IGBT (Insulated Gate Bipolar Transistor), IGCT (Integrated Gate-Commutated Thyristor) or GTO (Gate Turn-off Thyristor) based converters. Compare to SVCs, STATCOMs are quicker, lesser, and have better performance at cheap voltages. As it can be seen the STATCOM can work with its rated current even at compact voltages. Hence, the inject reactive power vary linearly with the voltage. On the different the current inject by the SVC decrease linearly with the voltage and as a result the injected reactive power decrease quadratic ally. This quality makes the STATCOM better suitable for transients such as voltage sag and therefore for the application analyzed in this work. [4]

Therefore, in order to create an accurate model of a wind generator to be used in transient stability studies, Wind generators are mainly classified as fixed speed or variable speed. Among mainly fixed-speed units, the turbine drives an induction generator that is directly linked to the grid. The turbine speed varies very little due to the vertical angle of the generator's torque-speed characteristic; therefore, it is termed a fixed-speed system. With a variable-speed unit, the generator is linked to the grid using power-electronic converter technology. This allows the turbine speed to be forced to exploit performance (e.g., power capture). Both approach are regular in the wind industry. We centre of attention on model the fixed-speed part and an equal model of quite a few fixed-speed units in a wind park. The first-mode mechanical frequency of a classic wind turbine is in the 0- to 12-Hz range; this is also the array for electromechanical oscillations. As a result, the mechanical sensations of the wind turbine cooperate with the electromechanical dynamics. Therefore, in order to make correct model of a wind generator to be used in transitory immovability study, the first-mode mechanical turbine dynamics must be exactly represent. The wind-generator model existing here is copied by conduct model decrease on a thorough 650th-order finite-element model of a classic horizontal-axis turbine. smooth and mechanical dynamics are cheap resultant in a nonlinear 4th-order two-inertia turbine model mutual with a model generator . Simulation is obtainable to show the correctness of the model. [6]

Fixed speed induction generator (FSIG) wind turbine.This wind turbine uses a squirrel cage induction generator that is attached to the power system through a between transformer. As the stator voltage of most wind turbine electrical generators is 690 **V,** this transformer is necessary for link to the supply network and should be consider when model the electrical relations with the power system. Induction machines get through reactive power and so it is usual to give power factor improvement capacitors at each wind turbine. These are typically rated at around 30% of the wind farm capacity and are used to pay compensation the induction machine magnetising current. [7]

II. PROBLEM FORMULATION AND IDENTIFICATION

The relations between wind turbines and grid have been widely investigated in current years. some generator types are in use for wind power application nowadays. The main difference can be made between fixed speed and variable speed wind generator types. Variable speed wind power generation skill encompasses the operation of wind turbines at most favourable power coefficient for a wide wind speed variety. The two most widely used variable speed wind generator concepts are the converter driven synchronous generator and the DFIG.

The DFIG is a wound rotor induction generator with a voltage source converter connected to the slip-rings of the rotor. The stator winding is attached directly to the grid and the rotor winding is associated to the grid via a power electronic converter. For power system immovability study, model of a DFIG should be careful for steady state analysis as well as for large trouble dynamic investigation. Even though the wind turbines are circulated within the wind farm, the mass power from the latter is related to the grid at a lone substation. As a result, WTGs within the farm are aggregate into a single unit having an MVA rating equal to the outline of the MVA rating of the individual units. Also, as DFIG units have reactive power ability, the wind farm is modeled in a way parallel to the usual generator for steady state analysis and is represent as a PV bus with suitable VAr limits. Some components that give to the dynamic performance of a DFIG are outline as follows and included in the analysis conduct turbine aerodynamics;

a) Turbine mechanical control (also called pitch control) that controls the mechanical power delivered to the shaft;

b) Shaft dynamics model as a two mass shaft, one mass represent rotor/turbine blades and the second represent the generator;

c) Generator electrical characteristics—as the rotor side converter drives the rotor current very fast, the rotor flux dynamics is ignored and the model behaves as a controlled current source;

d) Electrical controls—three controllers are used to give controls for frequency/active power, voltage/reactive power, and pitch angle/mechanical power;

e) Protection relay settings. [2],

Two main problems throughout the fault condition are the short-circuit level increase and fault ride-through (FRT) ability decrease. There are two main types of wind turbines used today: the fixed-speed wind turbine (FSWT) and the variable-speed wind turbine (VSWT). Current wind turbine generation systems are usually VSWT. But, over the past years, FSWTs have been installing in large size in power grids.

Detailed technical development, made in response to FRT needs of both FSWT and VSWT, can be considered as follows. [1]

1) Dynamic reactive power compensation (RPC) by means of FACTS device such as SVC and STATCOM;

2) Pitch control;

3) Rotor converter protection by crowbar resistor;

4) Braking resistor. [1]

2.1 Dynamic reactive power compensation (RPC) by using FACTS device such as SVC and STATCOM:

The performance of wind generation systems in usual and fault situation depends on the technology on which they are base. Variable speed wind generators are able to control the reactive power exchange with the grid (in a limited range) due to the power electronic devices that they include. It is essential to save from harm these electronic devices, much more aware than the electrical machine itself, from the over current and over voltages that follow any rapid voltage difference. This is achieve by disconnect them and by linking power rakishness secondary elements (crowbar), which are also used for speed up the machine demagnetization and falling the short-circuit current. Throughout the fault improvement, and once the hardest transitory has been damp, fixed power electronic converters can add to voltage revival by reactive power insertion. But, in some cases it may not be enough and it may be essential to add additional reactive recompense devices to assurance the execution of the fault ride-through wants. About fixed-speed generators, they do not have the ability to rule their reactive power swap because they always need to attract a exacting amount of reactive power.
Consequently, they generally consist of fixed reactive power carry devices (capacitors) meant at obtain a unit power factor in standard process situation. These devices are not capable to supply the functionalities demand by new interconnection needs, particularly in fault situation due to the quadratic reduce of their power insertion ability. Both normal and fault condition operation of wind farms can be optimized by using power electronic compensation devices such as SVCs (Static VAr Compensator) and STATCOMs (Static Synchronous Compensator). SVC systems are made up of Thyristor Controlled Reactors devices are pure power electronic systems made up of IGBT (Insulated Gate Bipolar Transistor), IGCT (Integrated Gate-Commutated Thyristor) or GTO(Gate Turn-off Thyristor) based con-verters. Compared to SVCs, STATCOMs are faster, smaller, and have better performance at compact voltages. As the STATCOM can be operate with its rated current even at reduced voltages. Hence, the inject reactive power varies linearly with the voltage.This characteristic makes the STATCOM improved suitable for transients such as voltage sag and therefore for the application analyzed. [4]

2.2 FAULT RIDE-THROUGH CAPABILITY IMPROVEMENT OF FIXED-SPEED WIND TURBINES

.Short-circuits have a dual result on wind turbines: electrical and mechanical. The main electrical result is the demagnetization of the rotor while the most important mechanical one is the rotor speed increase. These effects are visible from the start of the fault until a few seconds after its clear.The terminal voltage drop provoke the demagnetization of the stator flux. However, the rotor flux can not decrease immediately and therefore the machine current goes through a hard transitory.Terminal voltage, stator RMS current and rotor speed of a wind turbine after a 0.1 s short-circuit. As the period of the transitory is quite short the generator can endure it without main problems. [4]
The active power export to the grid is considerably abridged throughout the fault while the input mechanical power from the wind turbine is approximately stable. Therefore, the generator will go faster during the short-circuit in order to mechanically store the energy excess. The most speed that is achieve depends on the outstanding voltage value, the apathy of the system, the period of the fault and the quantity of power extract from the wind. This speed must be lower than the greatest reasonable speed to avoid the separation of the generator.
After the fault clear, the generator consumes large amount of reactive power due to its magnetization and to the add to of the machine slip throughout the fault. This power use makes it not easy the revival of the terminal voltage. The most excellent way to avoid fault imitative problems on wind generators and progress their ride-through capacity is to control the relation point voltage by compensate voltage sags. This way the generator will be protected from any voltage defect. This being able to be done by using a series power electronic compensator Dynamic Voltage Restorer (DVR) which inject the essential voltage in the system in order to keep the generator voltage stable. However, this compensator requires active power combination ability during faults, and it may also need an active power handling capacity in normal operation conditions in order to avoid an excessive wind farm voltage modification. [4].

III. PROPOSED METHODOLOGY

The use of shunt FACTS controllers to improve the fault ride-through of induction generators (IGs) by RPC. The RPC method, which can be provide by STATCOM and SVC, can only control the reactive power after fault happening. Thus, the RPC method is able only to reduce voltage fluctuations of the IG after fault happening [5], [8]. The pitch control system is the cheapest key for the wind generator stabilization, but its reply is slow.

TABLE I
WIND TECHNOLOGY ENHANCEMENTS TO MEET FRT CHALLENGE

Type	FRT Enhancement
A	Dynamic reactive power compensation
B	As above +Pitch control
C	Rotor converter protection + pitch control
D	Pitch control + Braking resistance on D.C Link

As a result, the pitch control system cannot be considered as a useful stabilization means for wind energy conversion system (WECS). In [3], series dynamic braking resistor (SDBR) has been standard and used as a gainful calculate for the improvement of FRT. In [3], direct link of SDBR and dynamic RPC has been represent. The simulation results conclude that a 0.05 per unit (p.u.) SDBR is equivalent to 0.4 p.u dynamic RPC. It means that the SDBR is more helpful than RPC. A significant mean issue for SDBR is its quick addition and early switch out of the dynamic resistor. The bridge-type fault current limiter (FCL) with discharge resistor is used for solving trouble of the interface of WECS and power grid. The increase of the fault current is limited by dc reactor without any wait. This characteristic of the bridge-type FCL suppress the immediate voltage drop and it is able to develop transient performance of WECS in fault instant, which is the main advantage of the bridge-type FCL to other FRT improvement techniques. On the other hand, the discharge resistor of the bridge-type FCL aims to raise the voltage at the terminals of the generator, thereby justifying the destabilize electrical torque and power during the fault. The WECS is careful as a fixed-speed system able to with a squirrel-cage IG. The simulation results show that not only the fault current is limited but also FRT ability of WECS is improved. Also, a relative study of bridge-type FCL and SDBR for improving FRT ability is accepted out. [1].The wind industry has responded to the beginning of FRT needs in several ways according to wind turbine technology type. For the purpose of considering FRT response, it is suitable to classify commercial wind turbines in four main types,

A) fixed-speed wind turbines (FSWTs) with fixed pitch;
B) FSWTs with variable pitch (active stall);
C) variable-speed wind turbines (VSWTs) with doubly-fed induction generators (DFIGs);
D) VSWTs with fully-rated converters.

The purpose of this paper is to present detailed analysis and transient simulation results of its performance and assess its beneficial effects compared to state-of-art alternatives [3]. The SDBR idea aims to give directly to the balance of active power during a fault, thus displace or eliminate the need for pitch control. It does this by animatedly insert a resistor in the generation circuit, rising the voltage at the terminals of the generator and thereby justifying the destabilizing despair of electrical torque and power throughout the fault period.The schematic planning of SDBR is shown in Fig.1.SDBR is shown situated between the wind turbine(s) and the grid in Fig. 1.

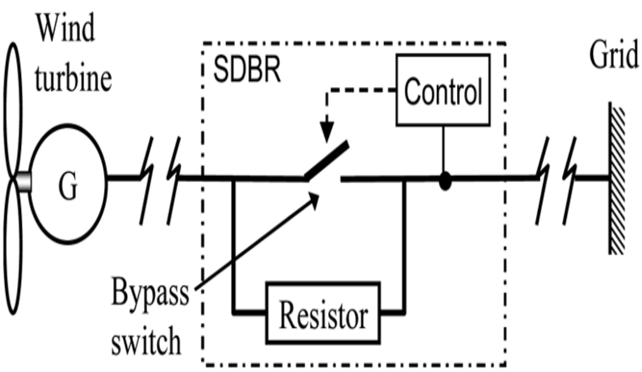

Fig. 1. SBDR schematic arrangement

The actual location of the device within an exacting wind farm topology will depend on the gap accessible to install it and the relation cost of switch at low, medium, and high voltage. The bypass switch could be mechanical, allow multi-cycle reply and isolated control, or static, and allow sub-cycle response and easily erratic control. A single-stage mechanical switching as the lowest cost and least complex option with possible to powerfully contribute to FRT fulfilment of FSWTs.SDBR would function with its switch closed under normal conditions, bypass the braking resistor. Voltage despair below a selected set-point would lead to near-instantaneous tripping of the switch. Current would then flow through the inserted resistor for the period of the fault and the initial post-fault revival. When voltage improved above a lowest reference level, the switch would close and the circuit would be restore to its usual state. During the short introduction period, the energy would be dissolute in the resistor, raise its heat. The resistor would be particular according to the warning high temperature of its resistive elements and the most energy dissipates during the insertion period. The advantage of series-SDBR over shunt-DBR is derived from the fact that its effect is related to current magnitude rather than voltage magnitude. SDBR is therefore most effective during the mutual high generation, low outstanding voltage conditions that are most difficult for FRT. We know generated power is transfer across the wind farm system, while surplus dynamic power is store in its drive train and heat is dissipate by SDBR. As we know that stator voltage is increased in magnitude by the voltage across SDBR. Since mechanical torque is proportional to the square of the stator voltage of an induction machine, it can be indirect that the attendance of SDBR will add to the mechanical power extract from the abstract advantage of SBDR under fault conditions. [3].

IV. 4. SIMULATION AND EXPERIMENTAL RESULT

4.1 simulated power system

A single line diagram of power system with FCL is shown in Fig.2. The parameter of this system is listed in Table I.

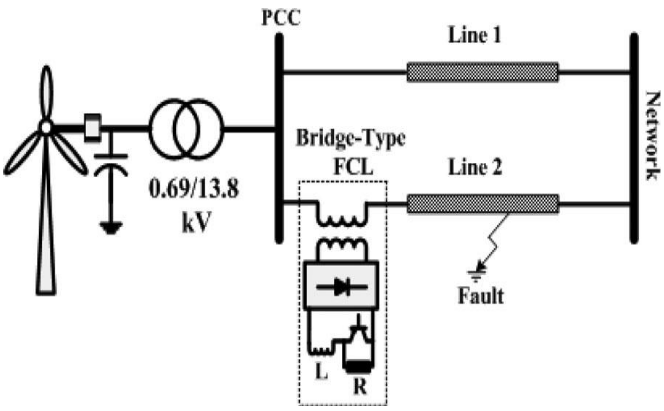

Fig.2. Simulated power system

A three-phase short-circuit fault is simulated on transmission line 2 (L2), which starts at t = 2 s. After 200 ms, the circuit breaker cut off the faulted line. The voltage verge of the terminal of the IG is equal to the 0.9 p.u. A capacitor bank of 200 kVAR is connected to the terminal of

the IG to balance the steady-state reactive power demand for IG. [1]

4.2 With and Without Using Bridge-Type FCL

The simulations are carried out for following cases:
1) Case 1: Without using any FCL
2) Case 2: By using the bridge-type FCL and resistor

TABLE 2
PARAMETERS OF TEST SYSTEM

Parameters		Value
Grid	Supply	13.8 kV
	Frequency	50Hz
	X/R ratio	5
	Transformer	0.69V/13.8 kV 1 MVA
Line	R	0.1(Ω/km)
	X	0.2(Ω/km)
	Length of Line1 (L_1)	20 km
	Length of Line2 (L_2)	20 km
Induction Generator	Power	500 kW
	Voltage	690 V
	Frequency	50 Hz
	Number of poles	4
	Slip	1/8 %
	Power factor	0.88
	Stator resistance	0. 00577 Ω
	Stator reactance	0.0782 Ω
	Rotor resistance	0. 0161 Ω
	Rotor reactance	0.1021 Ω
	Magnetizing reactance	2.434 Ω
FCL	DC reactor (L_d)	0.1 H
	Discharging Resistor (R)	20 Ω

4.3 SIMULATION RESULTS:

A single line diagram of power system with FCL is shown in Fig. 2. The parameter of this system are listed in Table 2. A three-phase short-circuit fault is simulated on transmission line 2 (L2), which starts at t = 2 s. After 200 ms, the circuit breaker cut off the faulted line. The voltage threshold of the terminal of the IG is equal to the 0.9 p.u. A capacitor bank of 200 kVAR is connected to the terminal of the IG to compensate the steady-state reactive power demand for IG With and Without Using Bridge-Type FCL .

The simulations are carried out for following cases:

1) Case 1: Without using any FCL;

2) Case 2: By using the bridge-type FCL and resistor.

Fig. 5 and 6 shows the fault current of the line 2 for both cases (1 and 2). In the case 1, the fault current increases to the peak value of 8 kA, approximately. By using the bridge-type FCL, the fault current is limited to the peak value of 6.3 kA.

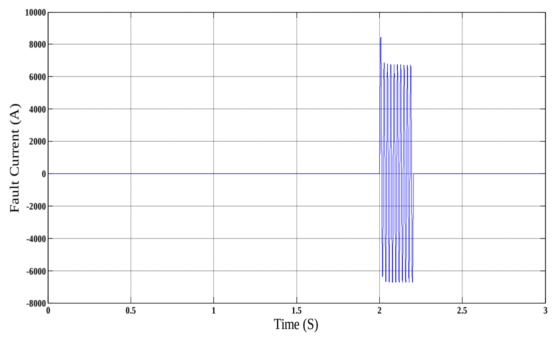

Fig.3 Fault current without FCL

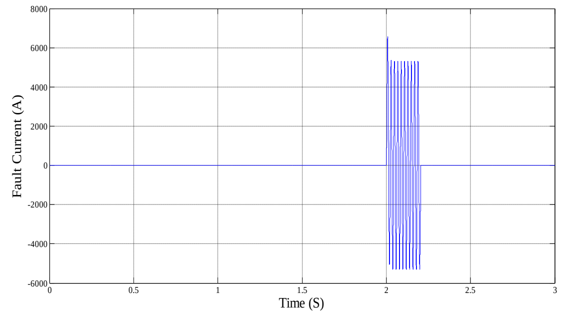

Fig.4 Fault current with FCL

Fig. 5 and 6 shows the rms value of the point of common coupling (PCC) voltage in both cases. It can be observed that in case 1 the PCC voltage decreases to zero approximately. The bridge-type FCL not only reduces the voltage sag to 0.9 p.u., but also prevents immediate voltage sag at the fault immediate and the voltage recovery process is superior.

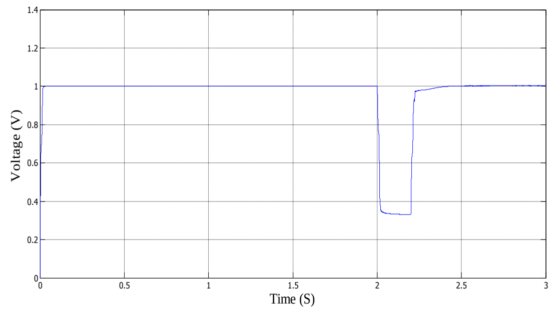

Fig.5 Fault voltage without FCL

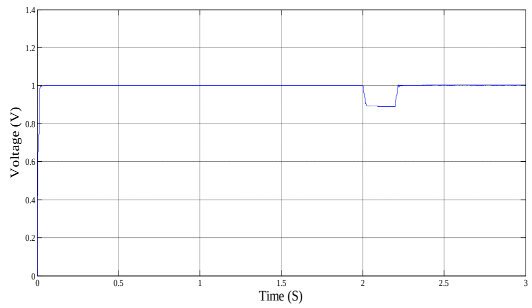

Fig.6.Fault voltage with FCL

Figs. 7, 8, 9 and 10 show the electrical torque and voltage versus rotor speed, respectively. It can be seen that FCL prevent from voltage sag and rotor increase of rate throughout the fault. According to the electrical torque is proportional to the square of the terminal voltage and inversely proportional to slip and rotor speed. Therefore, these results in decreasing the electrical torque and accelerate the rotor during the fault and thus getting better the stability of IG. Also, the simulation results verify the results of analytical studies in Section.Figs. 11,12 ,13 and 14 shows the rotor speed of the IG and the electrical torque, respectively. As shown in Fig. 13 and 14 the generator rotor speed swings are reduced in case 2 effectively.

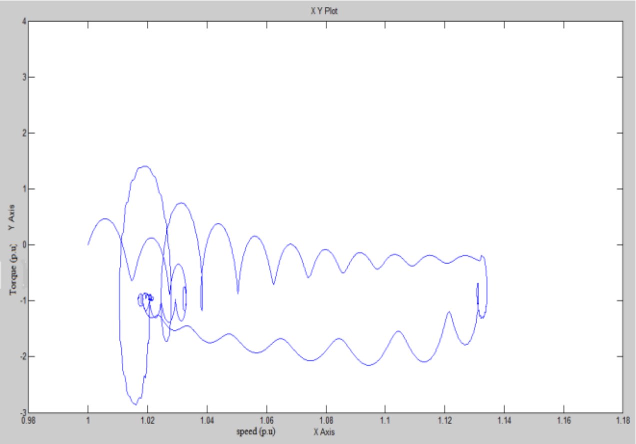

Fig.7 Torque verses speed without FCL

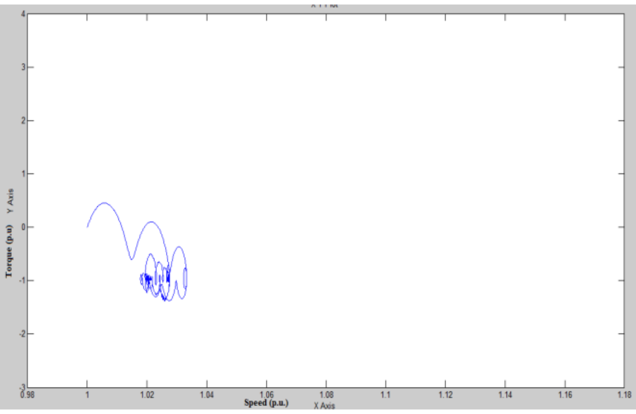

Fig. 8 Torque verses speed with FCL

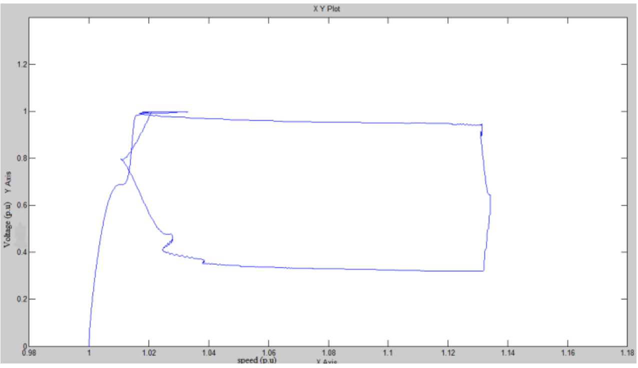

Fig.9.Voltage verses speed without FCL

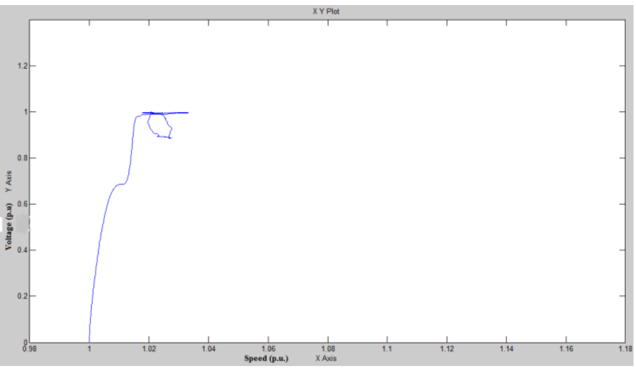

Fig.10.Voltage verses speed with FCL

Figs. 11,12 ,13 and 14 shows the rotor speed of the IG and the electrical torque, respectively. As shown in Fig. 13 and 14 the generator rotor speed swings are reduced in case 2 effectively. These results show that the bridge-type FCL with discharging resistor can provide an effective damping to the post-fault oscillations.shown in Fig. 7 and 8 the variation of the electrical torque is reduced in case 2. The bridge-type FCL is very effective in suppressing the variations of the electrical torque during the fault and swings after fault clearing.

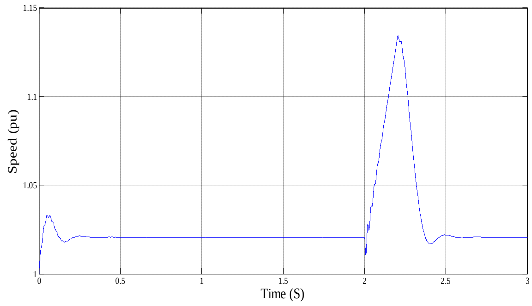

Fig.11.Speed verses time without FCL

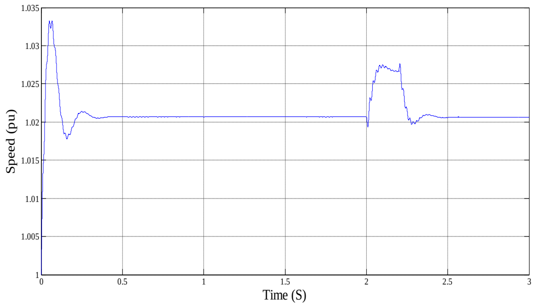

Fig.12.Speed verses time with FCL

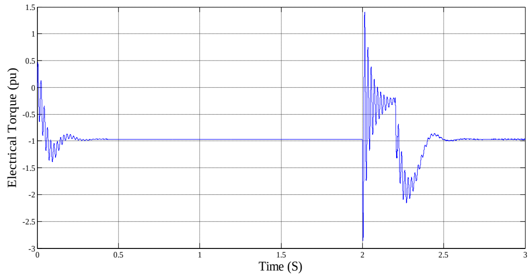

Fig.13.Torque verses time without FCL

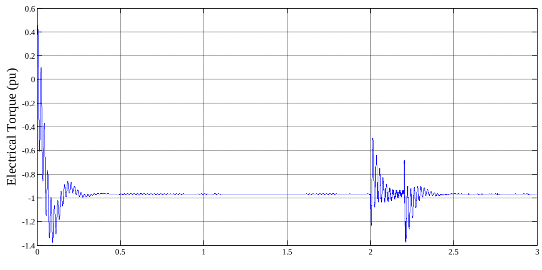

Fig.14.Torque verses time with FCL

Figs. 15, 16, 17 and 18 show the total active power generated by the induction generator and the total reactive power exchange between the Induction generator and the grid, respectively. During the fault (2 s < *t* < 2.2 s), the active power generated by the Induction generator is significantly reduced by using the bridge-type FCL, as shown in Fig. 17 and 18. Fig. 19 and 20 shows the total reactive power exchange between the Induction generator and the grid. After fault clearing (at *t* = 2.2 s), the absorbed reactive power from the grid is significantly reduced (negative values in Fig. 20). However, compared with the case 1, the IG delivers more active power to the power grid in case 2, and the reactive power absorbed by the Induction generator is reduced, which helps to avoid other problems such as voltage collapse and recovery process.

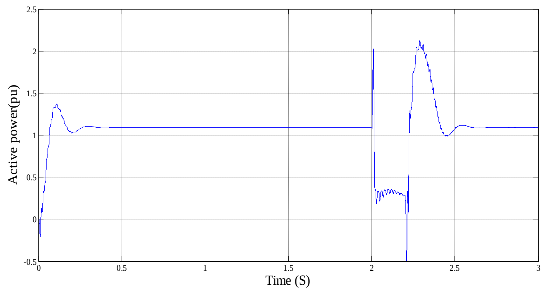

Fig.15 Active power (p.u)verses time without FCL

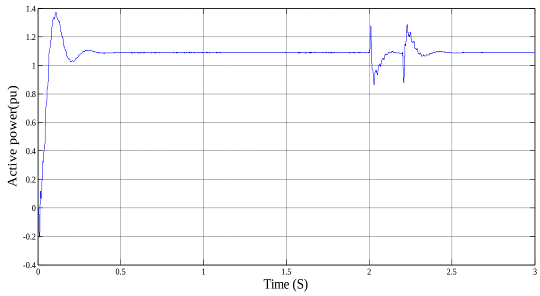

Fig.16 Active power (p.u)verses time with FCL

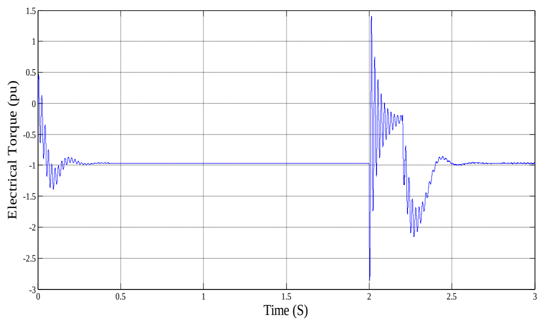

Fig.17 Reactive power (p.u)verses time without FCL

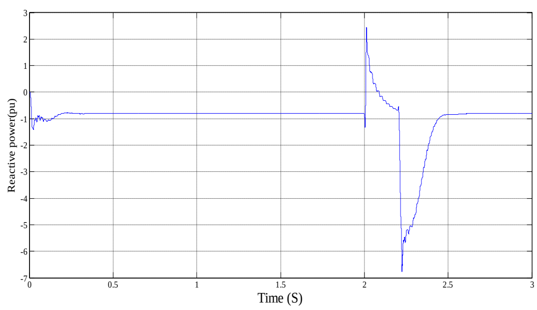

Fig.18 Reactive power (p.u)verses time with FCL

V. CONCLUSION

In this paper, the application of the bridge-type FCL, which has a control scheme based on dc reactor current measurement, has been proposed for improving the FRT capability of FSWT and limiting the fault current. Based on simulation results of a system with an FSWT and the bridge-type FCL, the following points can be drawn:

1) During the fault condition, the increment of the fault current
is limited by dc reactor without any delay and smoothing the surge current waveform and prevention from instantaneously deep voltage drop during fault. This characteristic of bridge-type FCL improves transient behavior of FSWT system in fault instant before inserting discharging resistor in series with dc reactor.

2) Then, by controlling the duration of ON and OFF periods of semiconductor switch generates a controllable resistor in order to control the terminal voltage of IG at threshold value during fault, which causes reducing the rotor acceleration and stabilizing the system by consuming the dc reactor energy over limiting fault current in acceptable level.

3) The comparison with SDBR shows that the bridge-type FCL is more effective for enhancement of FRT capability than SDBR.

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