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A Modified Bridge-Type Fault Current Limiter for Fault Ride-Through Capacity Enhancement of Fixed Speed Wind Generator

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Abstract:

Fault ride-through (FRT) is necessary for large wind farm in most power systems. Fixed speed wind turbines (FSWTs) are a fading but important sector in the fast-growing wind turbine (WT) promote. State-of-art technique applied to assemble grid needs for FSWT wind farm is blade pitching and dynamic reactive power compensation (RPC). Blade pitching is controlled by the difficult mechanical loads forced on a wind turbine during quick power re-establishment. Dynamic RPC is forced by its high capital cost. These present technologies can therefore be limiting, particularly when linking to smaller power systems. A new choice equipment is projected that insert series resistance into the generation circuit. The series dynamic braking resistor (SDBR) dissipates active power and boost generator voltage, potentially displacing the need for pitch control and dynamic RPC. In this project we use a delegate wind farm model to study the useful effect of SDBR. 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 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).

Index Terms:

Bridge-type fault current limiter (BFCL), fault ride-through (FRT), fixed speed wind turbine (FSWT), grid code, series dynamic braking resistor (SDBR), total harmonic distortion (THD).

1.INTRODUCTION:

Fault ride-through (FRT) is now required for connection of large wind farms in most power systems. The FRT-compliant wind farm must remain connected and actively contribute to system stability during a wide range of network fault scenarios.FRT is particularly important in securing stability in regions where wind is becoming a significant contributor to the power system's performance. FRT performance requirements differ according to the dynamic characteristics of the power system concerned. Smaller power systems, with little or no interconnection, are more prone to frequency instability, and hence, their Codes typically emphasize the provision of active power. Ireland, with a maximum system demand of 6 GW, represents a small, near-isolated national system with a challenging requirement to restore power within one second of fault clearance. Great Britain, with a maximum demand of 60 GW, represents a larger near-isolated system with similar requirements. In contrast, frequency stability in continental European countries such as Germany is strengthened by interconnections within the Union for the Co-operation of Transmission of Electricity (UCTE). [3] The wind industry has responded to the introduction of FRT requirements in several ways according to wind turbine technology type. For the purpose of considering FRT response, it is convenient to categorize 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.

Extensive investigation regarding interaction between wind turbines and power grid has been carried out in recent years [4], [5].

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Two main problems during the fault condition are, increase in short-circuit current level and decrement in fault ride-through (FRT) capability. As a result, circuit breaker interruption capacity surpasses the rated current and instantaneous voltage sag occurs. However, circuit breakers sometimes become incapable of handling the extreme level of fault current, so they fail to operate. Handling the increasing fault currents often involves costly replacement of substation components or alteration of coordinated control resulting in decreased operational flexibility and lower reliability. Even this replacement might be ineffective for some operation scenarios and FRT may not be ensured. To improve the FRT of WECS, both parallel and series types of compensation are used. Static synchronous compensator (STATCOM) [6], [7], thyristor switched capacitor (TSC) [8], static var compensator (SVC) [7], are used as parallel options, and series dynamic braking resistor (SDBR) [9], dynamic voltage restorer (DVR) [10], [11], magnetic energy recovery switch (MERS) [12], superconducting fault current limiter(SFCL) [13], and transformer coupled bridge-type fault current limiter (BFCL) [14], are among the series options.

The BFCL was used in [15] and [16] to improve the FRT of electric power networks. A separate configuration of BFCL was used in [13] and [14] to achieve the FRT of wind generator systems, but this configuration needs a special transformer with 12 lids for coupling the bridge to the system and primary end voltage rating of the transformer needs to be almost equal to line voltage to maintain desired level of voltage within fault duration. With this background, this paper proposes a new modified configuration of BFCL, which is different from those used in [13]–[16], to achieve the FRT of fixed speed wind generator system. It is important to note here that the dc reactor placed within the bridge of the proposed BFCL limits a sudden rise of fault current instantaneously. Thus sudden voltage drop at machine terminal is prevented during fault and thus it provides improved transient behavior. This unique feature of BFCL makes it favorable over other series FRT measures. A shunt bypass path helps maintain voltage at the point of common coupling (PCC) and machine terminal. In this way, it helps moderate that portion of electrical torque, which is responsible for instability and also increases the active power demand to machine during fault. Unlike [15] and [16], the shunt path of BFCL used in this paper consists of only resistor. Inductor is omitted because it discharges when the shunt path is disconnected.

In order to see how much effective the proposed BFCL is in improving the FRT of the wind generator, its performance is compared with that of the SDBR. Moreover, a harmonic performance improvement by the proposed method is also analyzed. Simulation was carried out by using MATLAB/Simulink software. In order to demonstrate the effectiveness of the proposed approach, a temporary three-phase-to-ground (3LG) fault was considered at one of the lines of the considered wind generator system.

II. FSWT MODELING:

To match with grid frequency, the SCIG-based WECS are made to rotate at a constant speed irrespective of the wind speed variation by some mechanical arrangement like pitch control and yaw drive system. Their rugged and simple construction, mechanical robustness, reliable operation with low maintenance cost, and longer lifetime are the reasons for their popularity

A. Wind Turbine Modeling:

The modeling of wind turbine rotor depends on various physical and geometrical aspects. For simplicity, considering only the electrical behavior of the system, a simplified method of modeling of the wind turbine blade and shaft is normally used. The commonly used mathematical relation for the mechanical power harnessed from the wind can be expressed as follows [17]:

$$P_w = \frac{1}{2}\pi\rho R^2 V_w^3 C_p(\lambda,\beta)$$

Where Pw is the extracted power from the wind, ρ is the air density, R is the blade radius, Vw is the wind velocity, and Cp is the power coefficient which is a function of both tip speed ratio λ, and blade pitch angle β. In this paper, the wind turbine MOD-2 model [4], [18] is considered, which is represented as follows:

$$\lambda = \frac{\omega_r R}{V_w}$$

$$C_p(\lambda,\beta) = \frac{1}{2}(\lambda - 0.022\beta - 5.6)e^{-0.17\lambda}$$

Where ωr is the angular mechanical speed. The relationship between Cp and λ is shown in Fig. 1 for different values of β. The wind turbine parameters used in this paper is given in Table I [2].

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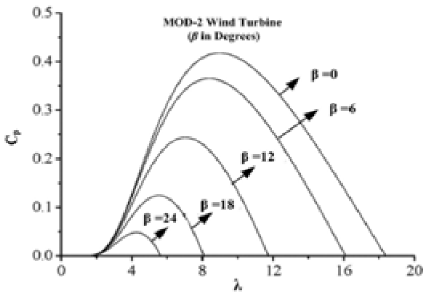

Fig 1 Cp – λ curves for different blade pitch angles (used in FSWT).

TABLE I
WIND TURBINE DATA

Characteristic	Value
Turbine Type	3 blade horizontal axis
Radius	46m
Rotor speed	18 rpm
Air density	1.225 kg/m3
Cut in wind speed	4 m/s
Rated wind speed	Approximately 12 m/s
Tower height	About 100m

TABLE II
WIND GENERATOR DATA

Generator characteristic	Value
Nominal Power (P)	2 MW
Rated Voltage (V)	690 V
Stator Resistance (Rs)	0.00488 pu
Stator Reactance (Xs)	0.09241 pu
Rotor Resistance (Rr)	0.00549 pu
Rotor Reactance (Xr)	0.09955 pu
Mutual Reactance (Xm)	3.95273 pu
Inertia Constant (H)	0.5 s

III. BRIDGE-TYPE FAULT CURRENT LIMITER:

The details of the configuration and operation of the proposed BFCL are as follows.

BFCL Configuration:

A modified configuration of BFCL, different from the one used in [15] and [16] is used in this paper. The BFCL is composed of two sections, namely, the bridge part and the shunt path. The first part is essentially the bridge part composed of four diodes D1 − D4 (Semikron SKNa 402) in bridge Configuration, a small value dc reactor Ldc equipped with a parallel

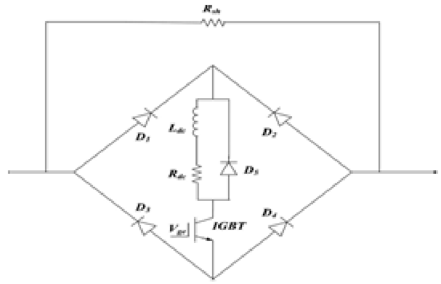

Fig 2. Modified BFCL configuration.

freewheeling diode D5 (Semikron SKNa 402) in series with an IGBT switch (CM200HG-130H) as shown in Fig. 2. The IGBT switches normally come in a package with freewheeling diode which is not shown here. Also, to include the inherited resistance of inductor, a very small value resistor Rdc is considered. The second part is a shunt branch composed of a resistor Rsh designed to meet the circuit criteria. The resistor and inductor in series were used in the shunt path [15], [16]. But here only the resistor is used. This is because when the shunt path is withdrawn after breaker opening; the reactor discharges the stored energy and results in rise of current. The BFCL is connected in series with transmission line, and placed in between the circuit breaker and transmission line.

BFCL Operation:

During normal operating condition of the system, the IGBT remains closed as its gate signal Vge is at high state. For one half cycle of electrical frequency, theD1 − Ldc − Rdc − D4 carries line current and for the other half it is carried by D2 − Ldc − Rdc − D3 . So, the current through the dc reactor Ldc flows in the same direction and the current at this brunch is dc. For this reason the dc reactor is charged to the peak current in that branch and acts as a short circuit. The dc reactor inherited resistance and IGBT turn-on resistance cause some voltage drop, as they are connected in series to line, but this voltage drop is quite negligible compared to line drop and has ignorable significance. That's why the bridge has no impact on steady-state operation. The impedance of the shunt path is high enough, so except very small leakage current, normal operation current is flown through the bridge fully.

At the event of fault, line current tends to increase but the reactor limits its increasing rate and the IGBT switch is saved from sharp di/dt rate at the starting of fault. As the line current through the dc path idc, crosses a predefined maximum permissible current ith ,

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the BFCL control system forces IGBT gate voltage Vge to low state and the IGBT is turned off. The bridge is withdrawn from the system and the bypass or shunt path takes over. The shunted path limits the fault current and consumes excess energy from the wind generator and FRT is achieved. During this period, the free-wheeling diode of the dc reactor and IGBT switch provide free path to discharge accumulated current in them. After the circuit breaker opening, the system starts to recover and voltage rises at the buses. As the voltage at the PCC reaches to some predefined reference value, Vge goes to high state turning on the IGBT switch, and the system is brought back to normal operating state.

BFCL Control Strategy:

There are handful parameters that can be used in the BFCL controller. The line current, line voltage, induction generator terminal current, active and reactive powers through line are probable candidates. Here the dc current through the dc reactor is used to control the IGBT switch. The dc reactor is charged to a certain current level at normal operation. At fault this current tends to go high and its rate of rise is faster than the line current or other parameters. So, by using this parameter, faster control is possible. When this dc current crosses a threshold value due to fault occurrence, the IGBT switches are turned off and current in the line is bypassed to the shunt path.

When the circuit breaker is opened, the system recovers and supposed to go to the normal steady-state condition. As the PCC voltage tends to cross 90% of the nominal value, the IGBT switches are closed and again current flows through the dc reactor. In a synchronous generator, fault current through line tends to be very high compared to line current and stays high until fault is isolated by breaker opening. But for an induction generator case, the fault current through line tends to fluctuate. That's why two different parameters are used for the BFCL controller.

IV.SIMULATION RESULTS:

Single line diagram of power system with FCL is shown in Fig 3. The parameter of this system is listed in Table I.

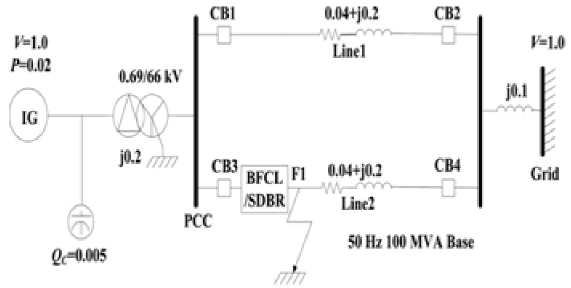

Fig.3simulated power system.

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.

4.1 With And Without BFCL, SDBR:

Simulations are carried out without using any fault current limiter and with fault current limiters like BFCL, SDBR.

4.1.1 Simulation Models:

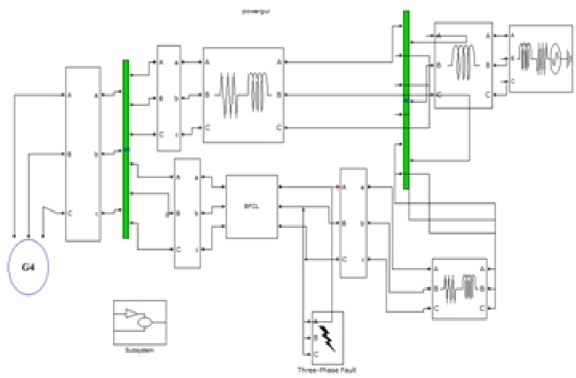

Fig.4 Simulink model without any fault current limiter

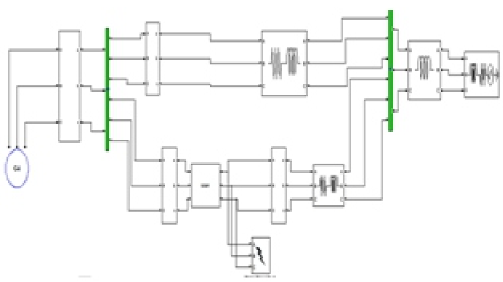

Fig.5. Simulink model using SDBR

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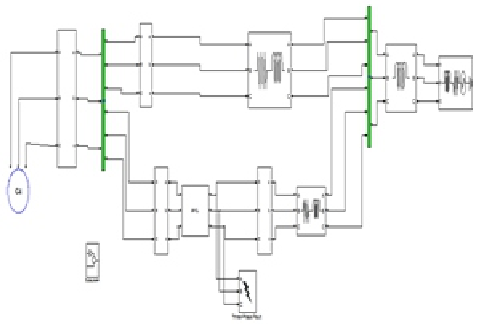

Fig.6. Simulink model using BFCL

RESPONSE FOR FAULT CURRENT SUPPRESSION:

The below figures 7,8,9 shows the fault current from line to ground in fault line. It is seen that the fault current reaches to around 8.0 pu calculated in machine base without any controller in the circuit, and it is suppressed around 3 pu. Fault current from faulted point of line toward ground is suppressed significantly by using BFCL. This ability enables using lower capacity circuit breaker.

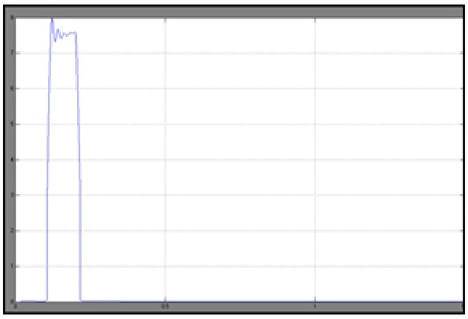

Fig.7. fault current from line to ground without any fcl

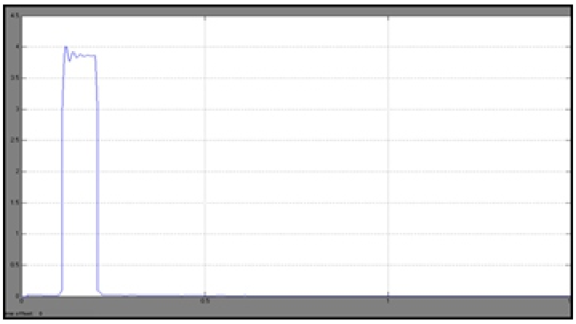

Fig.8. Fault current from line to ground using SDBR

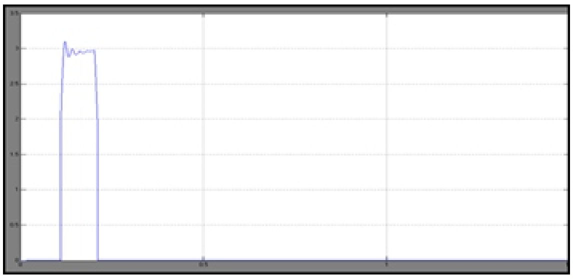

Fig.9 Fault Current From line To Ground Using BFCL

RESPONSE FOR CURRENT AT PCC:

The current from machine toward the PCC at fault is reduced to less than 1.2 pu using BFCL form around 3 pu without any controller as shown in below figures 10,11,12. The BFCL can also suppress fault current at the PCC. In both cases, the BFCL performs better than SDBR, and sudden jump in the current is also prevented.During fault i.e. the short circuit fault, the current delivered to the load is zero by using no controller. But by using BFCL, SDBR we can maintain some load current because they insert a resistance in the circuit.

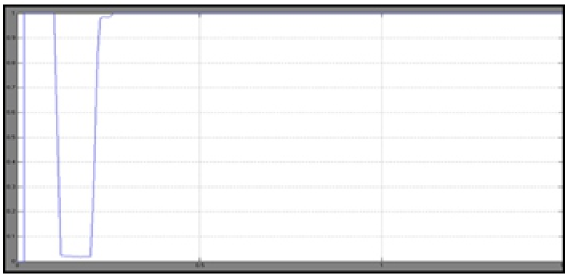

Fig.10 current at PCC without no controller

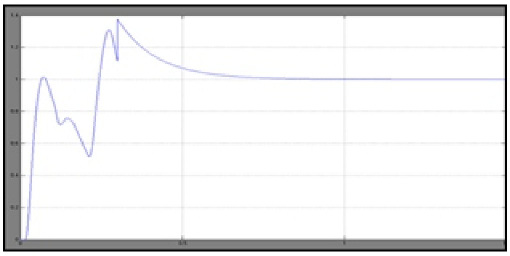

Fig.11 Current at PCC with SDBR

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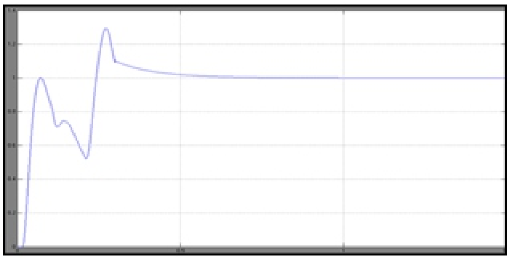

Fig.12 current at PCC using BFCL.

RESPONSE FOR VOLTAGE AT PCC:

In below Fig.13,14,15 the PCC RMS voltage response for the three cases along with the US grid code is shown. A larger timeframe is considered in this plot to incorporate the grid code. For the uncompensated system, the PCC voltage goes to almost zero and thus violates the grid code. With BFCL in action, the voltage is maintained over 0.8 pu. SDBR can also help maintain the voltage level but the BFCL keeps voltage level at the PCC higher than the SDBR during fault.

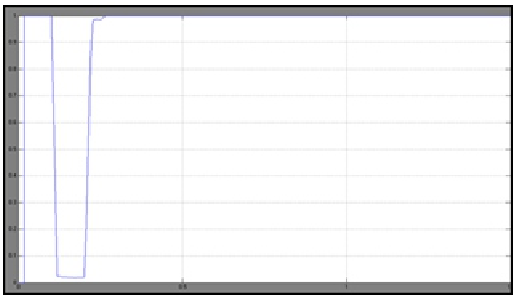

Fig 13 Voltage at PCC with No Controller.

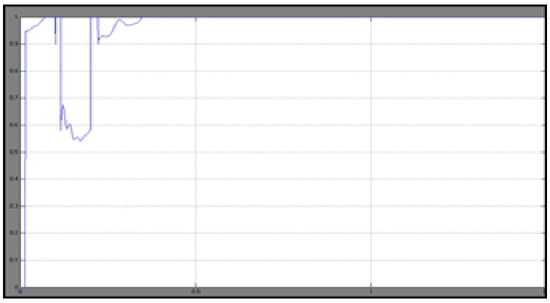

Fig 14 Voltage at PCC with SDBR

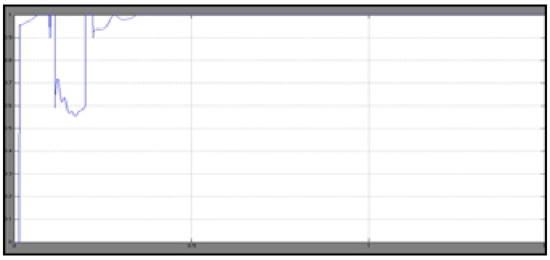

Fig.15 Voltage at PCC with BFCL

V.CONCLUSION:

This paper proposes the use of modified BFCL to improve the FRT capability and enhance power quality at the PCC of a FSWT. The modified BFCL is a very effective means to improve the FRT capacity of fixed speed wind generators. Suppression fault current is achieved by using the BFCL. Power quality of the system is improved and voltage harmonic code is maintained by inclusion of BFCL.

Moreover, harmonic current is reduced significantly that reduces stress on system components with iron core i.e., generator and transformer. The BFCL prevents huge instantaneous voltage drop at the faults instant, so the generator faces lower stress. The BFCL minimizes the fluctuation of machine speed and enhances stability. The BFCL works better than the SDBR in every aspect.

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