Analysis of MPPT Control Scheme and Grid Fault Mitigation Strategy for Current Source Converter based Offshore Wind Farm

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Abstract- **An interconnection scheme and maximum power point tracking algorithm for the current source converter (CSC) based offshore wind farm is presented in this paper. A fault mitigation strategy by utilizing the short circuit operating capability of CSC is also presented. Tip speed ratio control with speed control is used as MPPT technique. A three phase to ground fault, double line to ground fault and single line to ground fault are created very near to the grid connection point. The system is simulated using MATLAB/Simpower system toolbox with an inertia constant of 1s. It is found that the proposed fault mitigation strategy is more faster compared to other existing technique.**

Index Terms: Current source converter, Maximum Power Point Tracking, Tip Speed Ratio control, faults.

I. INTRODUCTION

The utilization of wind energy has increased over the past few years. It is possible to use either doubly fed induction generator or permanent magnet synchronous generator for transforming wind energy into electrical energy. PMSG is preferable as the wind generator as it doesn't need gear box and excitation. Therefore, the wind turbine operation will be more reliable and maintenance will be less. The wind farms can be onshore or offshore. Nowadays the trend is towards offshore wind farms due to the unavailability of sufficient onshore sites. Also the wind availability will be steadier and heavier in offshore located wind farms. Therefore, the power output will be more from an offshore wind farm.

There are two options for integrating an offshore wind farm to grid. Either we can go for HVAC or HVDC interconnection. As the power electronic technology is in the peak of its development, HVDC option has became more suitable and economical for integrating wind power to onshore grid. The HVDC link can be voltage source converter (VSC) based HVDC or CSC based HVDC.VSC HVDC will provide independent control of active and reactive power. But it require huge offshore substation. The step-up transformer and HVDC converters result in huge installation costs. Also the high dc-link voltage became a drawback for the VSC-HVDC converters.

The above said disadvantages of VSC HVDC based wind farms can be overcome by using pulse width modulated CSC based HVDC.PWM CSC based offshore wind farms have independent control of active and reactive power, black start capability etc. Popat et.al proposes a cascaded connection of PWM CSC [4]. By cascading the CSC it is possible to eliminate the bulky HVDC converter and step up transformer. Therefor the offshore substation needed can be eliminated.

Recently many articles presented the low voltage ride through techniques for VSC-HVDC base wind farms. C. Feltes et.al.[7] and Ramtharan et.al.[5] presented power set point adjustment method for active power reduction during grid faults. Akhamatov et.al.[6] and Ramtharan et.al.[8] presented an FRT method which utilizes a DC chopper and a dynamic resistor for dissipating the excess power as heat during fault conditions.

The main challenge for CSC based offshore wind farm is the protection from fault .Since the dc link inductance of the CSC based offshore wind farm is small compared with VSC based wind farm whose dc link capacitance has a relatively larger value, the CSC based offshore wind farm requires a fast fault ride through strategy. Popat et.al. presented an FRT method which uses the zero switching state operation of the CSC-HVDC based wind energy system. [9].

II. WIND FARM CONFIGURATION

The wind farm is integrated to the grid by using PWM Current Source Converter (CSC) based HVDC. The CSCs are cascaded on both generator and grid side [2]. By the cascaded connection of CSC on the generator side, the high voltage required for HVDC transmission can be achieved, without a step up transformer. For the present study we are considering two wind generating units which are connected in cascaded. The output of the two grid side CSCs are integrated to the grid by using a three winding transformer. The advantage of using three winding transformer is that, the major current harmonics will get eliminated. The wind farm configuration is shown in fig.1.

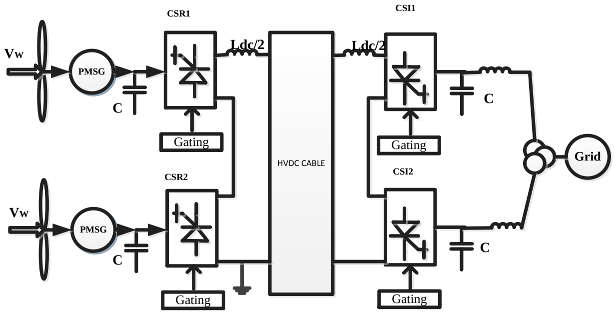

Fig. 1 Wind farm Configuration.

Figure 2 shows the topology for the current source rectifier which is used for the simulation. The input capacitance are meant for commutation and also for filtering purpose. FD is the freewheeling diode.

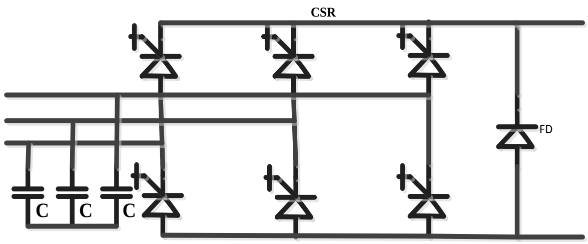

Fig. 2 Topology for current source rectifier.

III. GENERATOR SIDE CONTROL SCHEME

As the wind speed is varying widely it is very important to extract the maximum possible power from the wind corresponding to the available wind speed. There are mainly two types of Maximum Power Point Tracking (MPPT) methods are available. Methods which needs wind speed measurement and methods which doesn't need wind speed measurement. Although the Anemo meters which is needed for wind speed measurement is expensive, MPPT with wind speed measurement will give faster control response. Therefore this method is preferable for large capacity systems. A Maximum Power Point Tracking control which is based on Optimum Tip Speed ratio, with speed control is used in this study. The system configuration and control scheme of generator side converter control [3] are shown in figure 3 and 4.

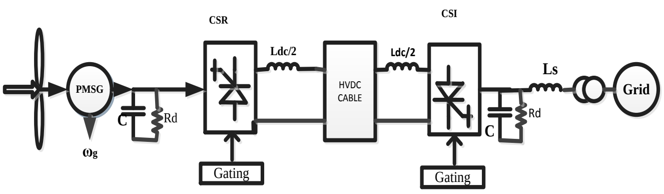

Fig. 3 System configuration.

Where Rd is the damping resistor whose value is normally chosen as 1.5 pu. The purpose of damping resistor is to damping out the resonant oscillations created by the commutation capacitance and PMSG inductance.

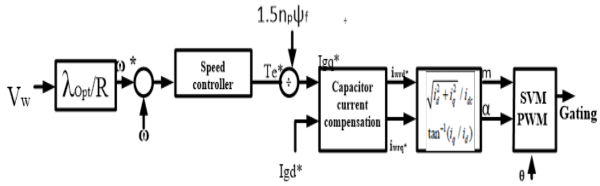

Fig. 4 Control scheme.

It will be easy to obtain the optimum rotational speed of the turbine corresponding to a given wind speed if we know the optimum Tip Speed ratio.

The relation between them is given as:

$$\omega_{ref} = \omega_{m\_opt} = \frac{\lambda_{opt} v_{wind}}{R} \quad (1)$$

The output of the speed controller will be the torque reference. From the torque reference we will get the quadrature axis component of generator current i_{qg}. The direct axis component of generator current i_{dg} is fixed as zero.

The PWM generator current can be obtained after subtracting the capacitor current from the d and q axis component of generator current as given below.

$$i_{wrd}^{*} = i_{gd}^{*} - i_{crd}$$

$$i_{wrq}^{*} = i_{gq}^{*} - i_{crq} \quad (2)$$

Where the capacitor current can be found as follows:

$$i_{crd} = -\omega_g C_r v_{gq}$$

$$i_{crq} = -\omega_g C_r v_{gd} \quad (3)$$

IV. GRID SIDE CONTROL SCHEME

It is assumed that the grid voltage vector is in line with the direct axis component of synchronous frame. Therefore the grid voltage will have only d axis component V_{sd} but the q axis component V_{sq} will be equal to zero

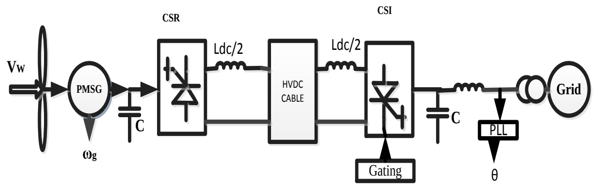

Fig. 5 System configuration.

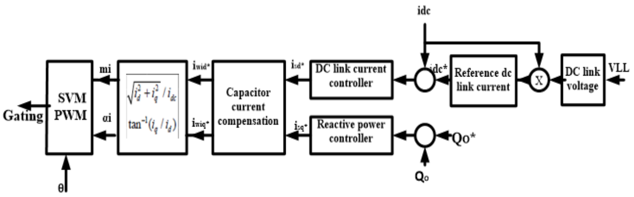

Fig. 6: Control scheme.

Therefore, it will be possible to achieve independent control of active and reactive power output to grid by regulating the current output to grid as given below.

$$P_o = \frac{3}{2}\left(v_{sd}i_{sd} + v_{sq}i_{sd}\right) = \frac{3}{2}v_{sd}i_{sd}$$

$$Q_O = \frac{3}{2}\left(v_{sq}i_{sd} - v_{sd}i_{sq}\right) = -\frac{3}{2}v_{sd}i_{sq} \quad (4)$$

The main objective of grid side control scheme is to regulate dc link current. The dc link current error will be minimised by a current PI controller. The output of current controller will give the d axis component of grid current i_{ds}. The dc link current reference can be found by the following formula.

$$i_{dc}^{*} = \sqrt{(1-\omega_s^2 L_s C_i)^2\left(\frac{2P_{dc}}{3v_{sd}}\right)^2 + \left(\omega_s C_i v_{sd} - (1-\omega_s^2 L_s C_i)\frac{2Q_o^{*}}{3v_{sd}}\right)^2} \quad (5)$$

Where Pdc=Vdci*idc

$$v_{dci} = \sqrt{1.5}V_{LL}m_i\cos(\alpha_i) \quad (6)$$

The other control objective of the grid side controller is the reactive power regulation. The reactive power error will be minimised by using reactive power controller, which is a PI controller. The output of the reactive power controller will give the q axis component of grid current i_{qs}.

The PWM grid current can be obtained from the d and q axis component of grid current after subtracting the the d and q axis component of capacitor current a follows.

$$i_{wid}^{*} = i_{sd}^{*} + i_{cid} = i_{sd}^{*} - \omega_s C_i v_{ciq}$$

$$i_{wiq}^{*} = i_{sq}^{*} + i_{ciq} = i_{sq}^{*} + \omega_s C_i v_{cid} \quad (7)$$

Where the capacitor voltage can be expressed as:

$$v_{cid} = R_s i_{sd} - \omega_s L_s i_{sq} + v_{sd}$$

$$v_{ciq} = R_s i_{sq} + \omega_s L_s i_{sd} \quad (8)$$

Where Ls is the grid-side line inductance, while Rs represents the transformer and line losses together. The system configuration and control scheme of the grid side converter control are shown in figure 5 and 6.

V. FAULT RIDE THROUGH SCHEME

Many nations enforce grid code specifications for FRT capabilities inorder to avoid disconnection of wind farm on the incidence of grid faults. The present study has been carried out based on E. ON grid code as shown in the figure 7 [1]. The curve shows that grid voltage drops to zero for 150 ms due to a short circuit fault and then recovers gradually back to its lower voltage level. The wind farms should remain in operation as long as voltage at the grid is above the solid line [1]

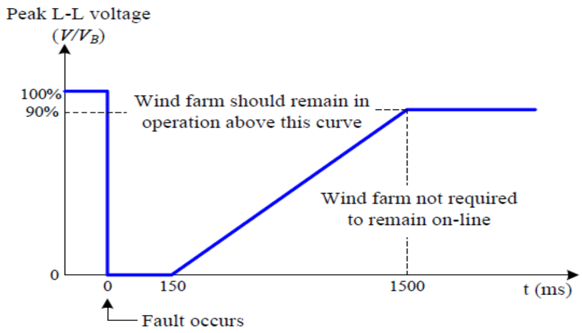

Fig. 7 Grid fault ride-through requirement in E.ON grid codes.

During grid faults the grid side inverter loses its control ability. The power flow will become unbalanced. Therefore the dc link current will rise above the normal value. This will lead to the destruction of the converter units. To avoid the quick rise of dc link current, the power output to the dc link from the wind generation system must be reduced.

When the dc link current rises above the normal operating range, the generator side control will be switched to fault ride through scheme. In this control scheme CSCs are fired by its zero switching states. In zero switching state the two switches in the same leg will conduct together, there by act as a short circuit across the wind turbine generator unit, as shown in figure8.As a result the power output of that permanent magnet synchronous generator will be dropped to zero, thereby protecting the wind turbine generator unit from the faulty grid.

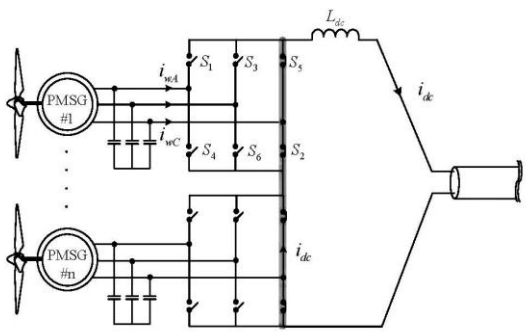

Fig. 8 Zero switching state operation of CSC.

VI. SYSTEM PERFORMANCE INVESTIGATION BY SIMULATION

In order to investigate the performance of the wind generation system under the control schemes discussed above, two cascaded wind turbine generator units are considered. Direct driven wind turbine is considered for the study. A variable speed permanent magnet synchronous generator with multiple poles is considered as the wind generator. The simulation is performed using Matlab/Simulink with the SimPowerSystem toolbox. The main simulation parameters are listed in Table1. For the present study, the turbine-generator inertia constant is assumed to be 1 sec. Both generator and grid side converter are fired by space vector modulation (SVM) technique. Switching frequency is assumed to be 540 Hz. The performance of the system under steady state is given in fg.9. In order to verify the dynamic behaviour of the system a step down change and step up change of wind speed is applied to the system. The results are shown in fig 10 and 11.

A. Generator and DC Link Response Under Steady State

It is found that under rated wind speed of 12m/s the rms generator voltage is 3200V,rms current is 300A and the DC link current is 500A as shown in figure 9.

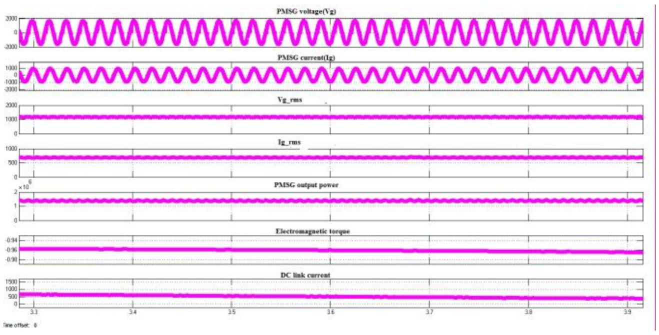

Fig. 9 PMSG voltage, current, rms voltage, rms current output power ,Electromagnetic torque and DC link current response at wind speed of 12m/s..

B. Generator and Dc Link Response to a Step Change in Wind Speed from 12m/s to 8 m/s

Corresponding to a step change in wind speed from 12m/s to 8m/s the dc link current will change from 500A to 200 A. figure 10 shows the corresponding waveforms.

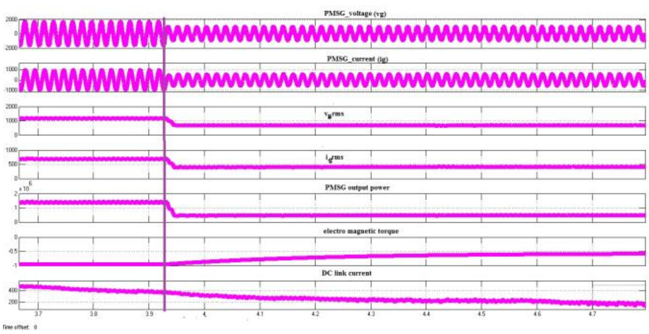

Fig. 10 PMSG voltage, current, rms voltage, rms current output power ,Electro magnetic torque and DC link current response to a step change in wind speed from 12m/s to 8m/s

C. Generator and DC Link Response to a Step Change in Wind Speed from 8m/s to 11m/s

It is seen that when the wind speed changes from 8m/s to 11 m/s the dc link current will change from 200A to 400A.Figure 11 shows the corresponding waveforms.

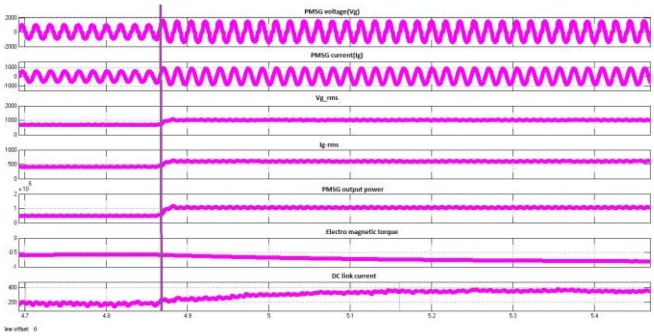

Fig. 11 PMSG voltage, current, rms voltage, rms current, output power , Electro magnetic torque and DC link current response to a step change in wind speed from 8m/s to 11m/s.

D. Torque and speed response to a step change in wind speed

Figure 12 shows the torque and speed response for a step change in wind speed from 12m/s to 7m/s. When the wind speed change from 12m/s to 7m/s, the generator speed is changed from 16rad/s to 10rad/s.

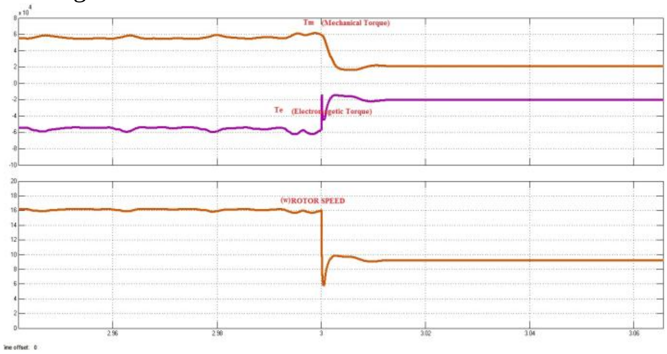

Fig.12 Mechanical torque, Electromagnetic torque and generator speed response to a step change in wind speed.

E. Power output corresponding to different wind speed

Figure 13 shows the active and reactive power output of wind farm at different wind speed

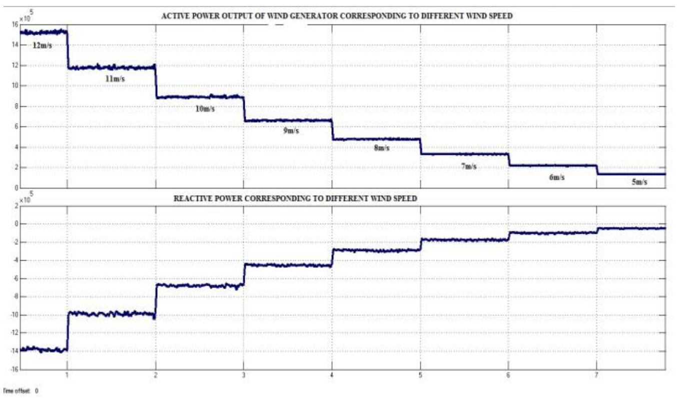

Fig. 13. Active and Reactive power output corresponding to different wind speed

F. Verification Of Mppt Control Scheme

Tip speed ratio (TSR) control with speed control is used in this study. The TSR control will give the optimum rotor speed which will give the maximum power corresponding to each wind speed. The speed error will be processed by a PI controller. The power and rotor speed for different wind speed are given in table1. Figure 14 shows the wind turbine power characteristics that is wind power versus generator speed for different wind speed. The maximum power versus wind speed curve is give in figure 15.

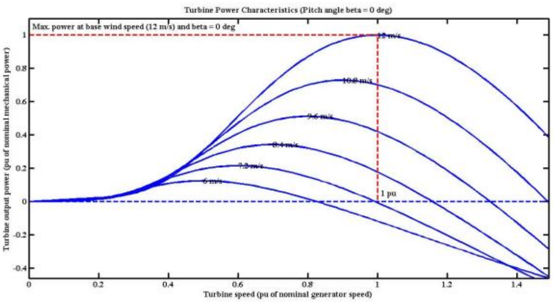

Fig.14 wind turbine power characteristics

Table.1Maximum power and optimum rotor speed for different wind speed

Wind speed(m/s)	Pmax (Theoretical)	Pmax(Actual)	Optimum Rotor speed(theoretical)	Optimum Rotor speed(Actual)
16	1.642	1.7	14.83	15
15	1.672	1.62	15	16
14	1.482	1.6	14.51	15.3
13	1.531	1.56	14.93	15.5
12	1.501	1.5	14.89	15
11	1.419	1.17	14	14
10	1.221	.89	12.84	12.5
9	1.003	.66	11.32	11
8	.7544	.47	10.8	10
7	.506	.33	8.68	8.5
6	.31	.22	7.466	7.5
5	.1835	.13	6.345	6

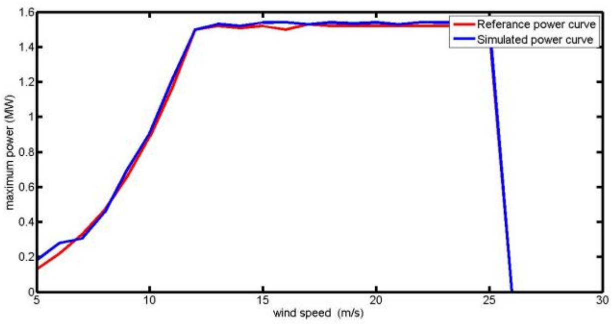

Fig.15 maximum power versus wind speed

VII. ANALYSIS OF GROUND FAULTS

The system performances with the discussed fault ride through scheme against three phase fault, double line to ground fault, and single line to ground fault are investigated by simulation .The ground faults are assumed at the grid connection point of the wind farm. The fault lasts for 120 ms from 3.6s to 3.72s as shown in Fig 16 to 18. On the occurrence of the fault, due to the power difference between the generator side and grid side converter the dc link current will rise to a high value. Whenever the dc link current rise above the normal operating range the generator side converter control will switch to the fault ride through mode. The generator side converter will be operating in the zero switching state. dc link current will bypass through shorted leg of the CSC. Also the generator output power will drop to zero, and the wind turbine generator unit will get isolated from the grid. It is seen that in all the faults the under this protection scheme the dc link current under fault conditions is limited to 2pu.When the dclink current rises above this value protection system will be active and the wind farms will be isolated.

A. Double Line To Ground Fault

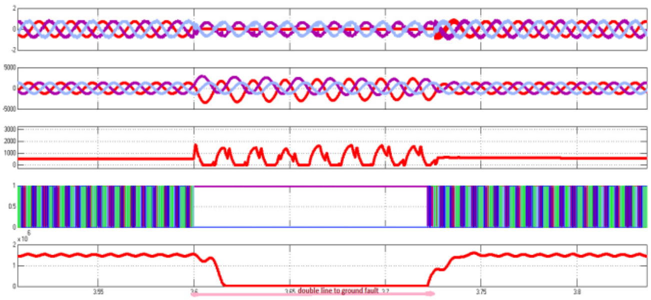

Fig. 16 Grid voltage, grid current, dc link current, by pass signals for CSC and generator output power during double line to ground fault.

B. Single Line To Ground Fault

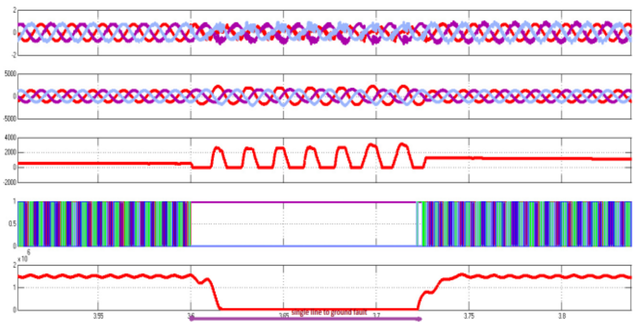

Fig. 17 grid voltage, grid current, dc link current, bypass signals for CSC and generator output power during singe line to ground fault.

C. Three Phase to Ground Fault

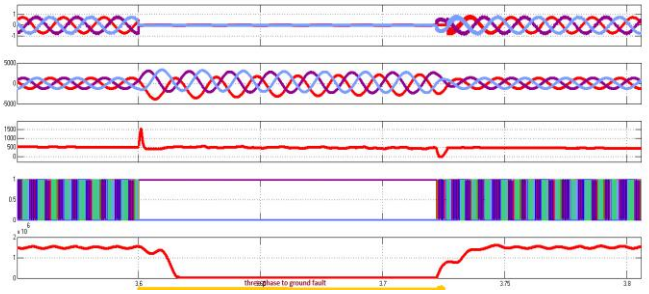

Fig. 18 grid voltage, grid current, dc link current, bypass signals for CSC and generator output power during three phase to ground fault.

VIII. CONCLUSION

In this paper the application of CSC for the offshore wind farm is presented. The generator and grid side converter control schemes are discussed and verified through simulation. Due to the low dc link inductance CSC based wind farms requires a fault ride through scheme which must be faster than that is required for VSC based wind energy conversion system. A fault ride through scheme, which is developed based on the zero switching state operation of the CSC is discussed and verified through simulation.

TABLE 2
SIMULATION PARAMETERS

System parameters	
Power	1.56MW
Voltage	3200V
Current	300A
Frequency	60Hz
Generator parameters	
Frequency	60Hz
Synchronous inductance	0.4pu
Stator resistance	0.01pu
Number of poles	32
Converter parameters	
Generator side capacitance	0.3pu
Grid side capacitance	0.5pu
Grid side line inductance	0.1pu
DC link inductance	1pu
Device switching frequency	540Hz

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