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Fault Ride through ability of Cascaded Current Source Converters

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Abstract

This paper presents a Fault Ride ThroughTechnique for Permanent Magnet based offshore wind farms. Here the cascaded current source converters are active at the generator side and grid side. The short circuit operating capability of Current Source Converter is used to improve the Fault Ride Through capability. Simultaneously grid side converters satisfy the reactive power forced by grid codes. Faulty turbine-generator can be easily removed from the system without affecting the healthy system.

Index terms: *Current Source Converters (CSC), Fault Ride Through (FRT), Wind Energy Conversion System (WECS) and Permanent Magnet Synchronous Generator (PMSG).*

1. Introduction

To avoid the interruption of wind farm during grid fault many countries force the grid code requirement for Fault Ride Through(FRT) capability. As shown in figure 1 wind farms should stay in operation providing voltage at the grid connection point remained above the solid line. Also wind farms should provide reactive current to support grid voltage recovery throughout voltage dip. For every 2% of reactive current compensation it has to provide 1% of voltage dip for 100% of rated current.

In recent times many scholars have addressed Fault Ride Through (FRT) for wind farm connected through Voltage Source Converters (VSC) based HVDC (High Voltage DC) [1-6]. In [1] and [2] active power reduction at each wind turbine is achieved by power set point achievement. In [5] and [6] the dc chopper is used to dissipate extra dc link power in the breaking resistors. In this technique the wind farm is not affected by fault.

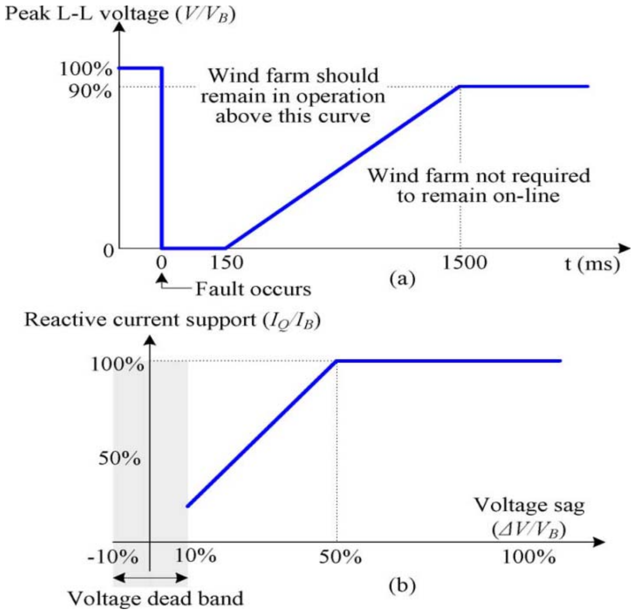

Fig. 1. (a) grid fault requirement, (b) reactive current support during network fault

But the main disadvantage is the larger cost of choppers. This paper presents a fault ride through method for cascaded current source converter based offshore wind farm. This method has advantages like active and reactive power control, black start capability, etc.., [7] and also it eliminates HVDC converters and offshore step up transformers. So this configuration is possible with small number of sub stations.

But the disadvantage is the distance between the generator and grid side converters is very long which causes a voltage dip that cannot be identifiedand also the dc link inductance in CSC is very small in the order of 0.7 to 1 pu when compared to dc link capacitance of 3 to 5 pu of VSC. This applies a challenge for FRT capability of CSC based system. So this method cannot be used for this system. Hence to overcome this problem FRT technique using short circuit operating capability of CSC is developed.

The other challenges for cascaded CSC are to provide constant operation of wind farm when one or more turbines fail to work. This problem is not serious for VSC HVDC based offshore wind farm in which the generators are connected parallel.

2. Challenges in existing FRT

During grid fault the voltage dip is significantly reduced due to the active power transfer capability of grid side converter. All together the increase in dc voltage/current in voltage/current source based wind farm the power fed to the dc link from generators should be reduced.

2.1 Active Power Reduction At Wind Turbine Through Power Set Point Adjustment

For communicating the reference signals in large offshore wind farms the communication signals are used between wind farm controller and turbine controller.

From the grid voltage measurement the fault is detected and the maximum transferrable active power from the grid side VSC is measured. Through the communication link the active power reduction factor is sent to the turbine-generator. But the main disadvantage of this technique is between each grid side converter and generator unit there should be communication link. The speed of power reduction will be affected because there will be a delay in sending the power set point by communication link. This communication delay will create a problem in the CSC based offshore wind farm because for CSC the dc link inductance is very small when compared to dc link capacitance in VSC.

Usually in VSC, the grid side converter will control the dc link voltage. The dc link voltage in VSC based WECS can be derived as [8]

$$v_{dc} = \sqrt{2 / C_{dc} \int (P_{WF} - P_{grid}) dt}. \quad (1)$$

The above expression is the power difference between the generator and grid side converters which determines the dc link voltage. In the same way for dc link current in CSC based WECS is derived as [9]

$$i_{dc} = \sqrt{2 / L_{dc} \int (P_{WF} - P_{grid}) dt} \quad (2)$$

Where

P_{WF} is total wind farm power injected to the dc-link from generator-side converters
P_{grid} is output power injected to the grid from grid-side converters
C_{dc},v_{dc} is dc-link capacitance and voltage for VSC-HVDC-based wind farm;
L_{dc},i_{dc} is dc-link inductance and current for the cascaded CSC-based wind farm.

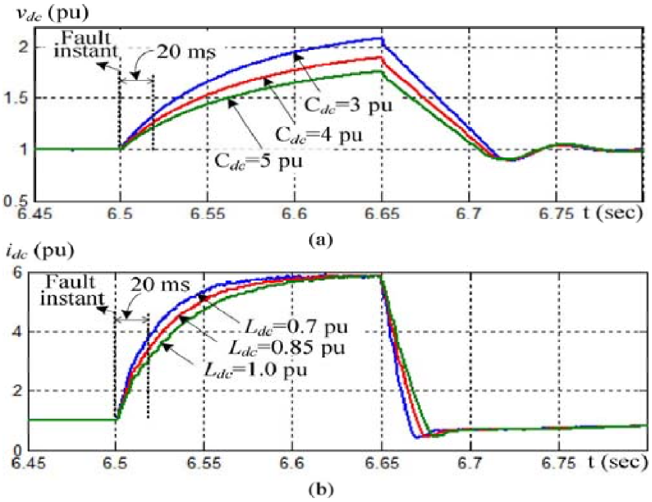

Fig.2. DC link responses during grid fault (a) VSC based WECS; (b) CSC based WECS

From fig 2 the dc link parameters for VSC and CSC are 3-5 pu and 0.7-1.0 pu respectively. In normal condition both the systems are working at rated conditions. But when the fault occurred at 6.5 sec the voltage has reduced to 0 pu at 150ms and then improves to 1 pu. When compared to dc link current of VSC the CSC has increase in dc link voltage. Therefore this technique is not possible for proposed CSC based offshore wind farm.

2.2 Active Power Reduction through Offshore Grid/Frequency Control

In [3] during grid faults the grid frequency is increased by VSC. So the output of generator is minimized. The offshore grid frequency/ voltage is controlled by the WFSC.

In both the cases the onshore fault is detected by the communication link between the grid side VSC and WFVSC. But for these methods an offshore grid and HVDC converter. In the proposed method these components are eliminated.

3. ProposedMethod

Fig 5 shows the block diagram of wind farm structure. The control module consists of wind farm supervisory control, control units and grid side converter control. The normal operation of wind farm is as follows:

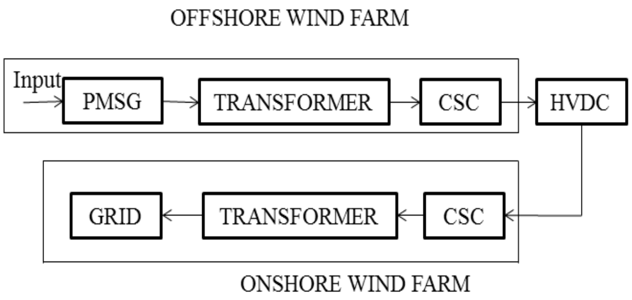

Fig. 3.Proposed system configuration of cascaded CSC

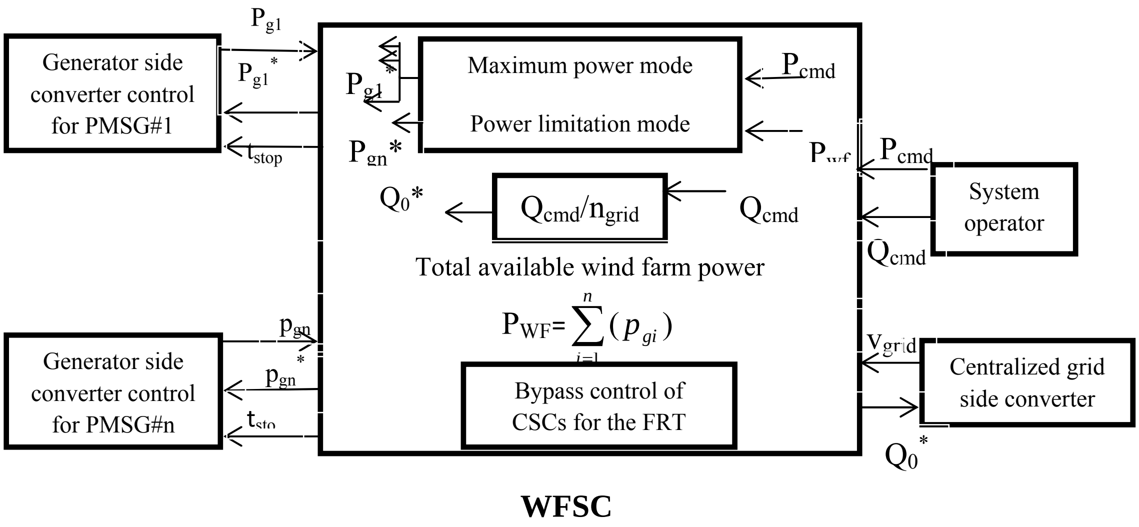

Fig.4. Block diagram of cascaded CSC based offshore wind farm.

3.1 Normal Operation

According to system operator demand WFSC operates in two modes as maximum power mode and power limitation mode. In maximum power mode all wind turbines work with their own possible power. But in power limitation mode WFSC produces active power reference (P^*_{g1}, P^*_{g2}, P^*_{g3},…,P^*_{gn}) for every turbine-generator controller.

Fig 7 shows the normal operation of generator and grid side controller. In the fig a speed controller obtains the reference speed ω^*_n from the maximum power point tracking and controls the speed of PMSG respectively. The output of the reference speed controller is given to the torque producing current i^*_{qgn}. The zero d axis current which is set to zero is applied to the capacitor current compensation. Then the modulation index and firing angle is obtained by the converter reference current. Using the SVM the gating signals are generated.

The function of grid side converters is to transfer the active from the generators to grid while keeping the dc link current at the preferred level. To maintain the power factor at the desired level the grid side converters adjust the reactive power. The identical distribution of active and reactive power can be easily attained through the series connection through the gating signals [10]. For grid side converter control WFSC generates a dc reference $i^*_{dc.}$ In the same way the from the system operator WFSC accepts the reactive power demand Q_{cmd}. From this the reactive power reference Q^*_o for grid converter is created based on equal sharing of reactive power is given by

$$Q_O{}^* = \frac{Q_{cmd}}{n_{grid}}$$

Where

n_{grid} is number of grid side converters in process

The d axis grid current reference (i^*_{ds}) and the q axis grid current reference (i^*_{qs}) are the outputs of dc link current and the reactive power controllers. The converter capacitor current compensation yields converter reference current (i^*_{dwi}, i^*_{dqs}). From the grid side converters the modulation index and firing angle are designed. Using the SVM the gating pulses are produced.

3.2 Fault Ride Through Operation Mode

The CSC based system needs FRT capability because of low dc link inductance. In the forthcoming section the FRT method is discussed.

3.2.1 Short Circuit Operating Capability Of CSC

The switching pattern for PWM should satisfy the condition as at same time only two switches can conduct one from upper leg and another from lower leg. Three zero switching states are possible are $i_{\omega a}= i_{\omega b}=i_{\omega c}=0$ (Fig 5). During this condition the generator is isolated from the system. FRT used this feature toovercome the fault

3.2.2 Fault Detection

The grid fault can be detected by the measurement of the dc link current. In the presence of fault the dc link current will not be in the limit. It exceeds the operating range. . Due to less powertransfer capability the dc linkcurrent exceeds the operating range.Since the converter is used here the communication links are eliminated which also reduces the cost

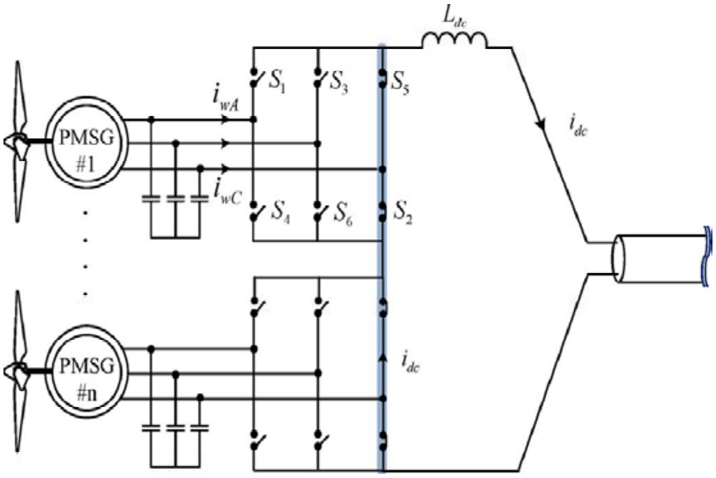

Fig. 5.Zero switching state operation of generator side converter during grid fault

1.2.3 Generator Side Converters

The fault can be detected by measuring the grid voltage and grid current. The generator will be moved from normal operation to the FRT mode. In this mode by zero switching state the generator side converters are bypassed. The generator will be separated from the system in the presence of fault. Depending upon the measurement of dc link current the severity of fault is found. If the fault is less severe then 50% of generators are separated and if the fault is highly severe then all the generators are separated from the system. When the fault is cleared the WFSC finds grid voltage recovery and sends the deactivate bypass (t_{stop}) signal to change from FRT mode to normal mode.

3.2.4 Grid Side Converters

To support grid voltage recovery during grid fault the grid side converters should provide necessary reactive current support. The current ratings of the grid side converters limit the reactive power support. Assuming maximum steady state operating current at the grid terminal the grid reactive current output is as follows:

$$i_{qs}^{*} = \begin{cases} 2I_b(V_b - v_{ds})/V_b, if\ |(v_{ds} - V_b)| \le 0.5pu \\ I_b, if\ |(v_{ds} - V_b)| > 0.5pu \end{cases} \quad (4)$$

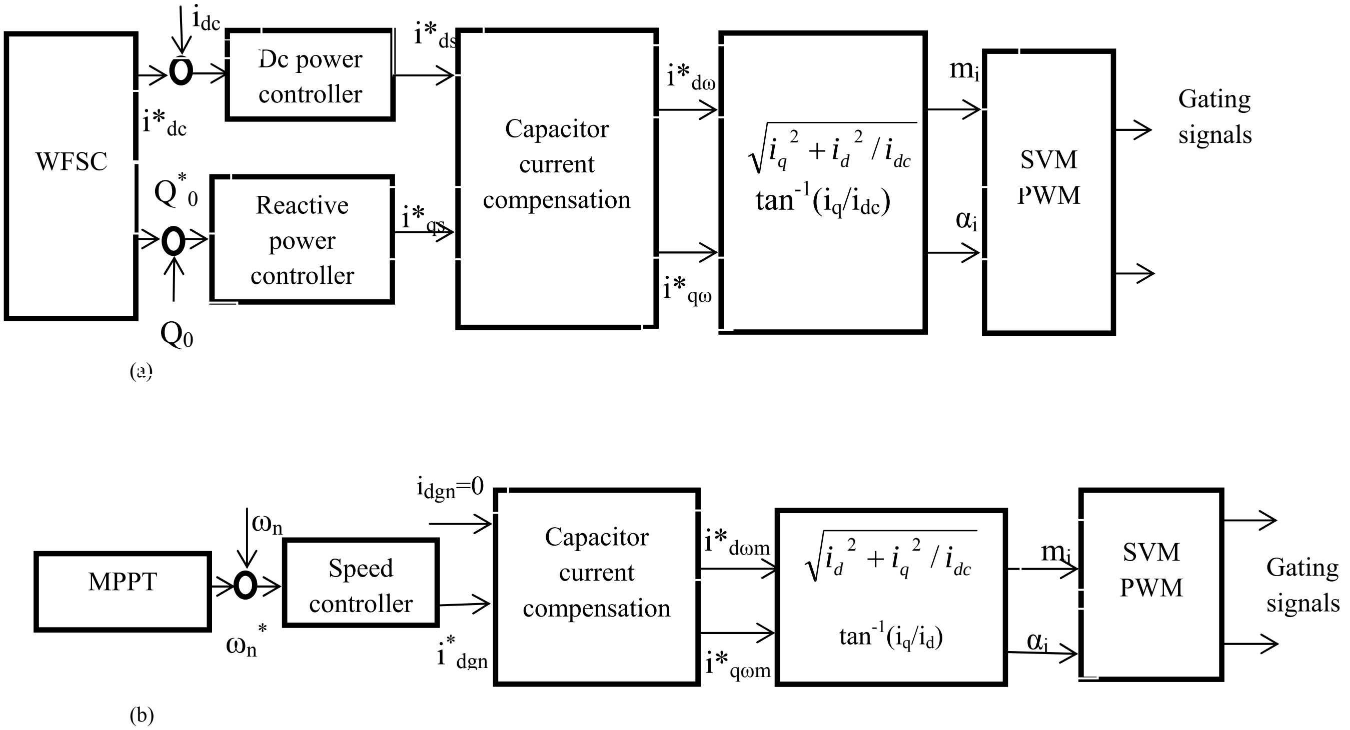

Fig.6. (a) Centralized grid side converters (b) Grid side converters

Where
V_b is magnitude of the rated phase voltage;
I_b is magnitude of the rated phase current;
v_{ds} is d-axis grid voltage;
i^*_{qs} is q-axis grid current (reactive component).

The grid side controller is considered to give importance to reactive current and the left over current carrying capacity of converter is used for active current which is given by

$$i_{ds}^{*} = \sqrt{I_b^{2} - i*_{qs}} \quad (5)$$

The maximum active power transferrable from grid power is given by

$$p_{grid} = v_{ds}\sqrt{(I_b^{2} - I_{qs}{}^{*2}} \quad (6)$$

4. Flexible Operation Of Wind Farm

The main task of cascaded CSC is continuous operation of wind farm in any condition. The following conditions should be considered. They are:

- Failure of turbine generator unit
- Failure of converter switching devices

And the main aspect is the wind turbines facing wind speed less than the cut in speed should be separated from the system without disturbing the other turbines. Using the zero switching state the generator fault can be cleared and CSC is separated.

5. Simulation

The simulation is done in MATLAB using sim power system. The generators are connected seriously such that if one generator is failed means the other system will not operate. The Simulink block is shown in fig 8.

5.1 Normal Operation

In normal operation mode the generators will be operating in giving the maximum power. The generator used here is a PMSG. The negative feedback is given to the generator. The input to the converter is SVM pulses. In this system the MPPT technique is used in which the input given is velocity. The reference speed is given to the pi controller in which it increases the speed of the system and at the same time it is used to increase the stability. The output from the controller is given to the capacitor banks in which it is used to control the reactive power and also acts as filter. The output from the capacitor bank is given to the function parameter. The output from the function parameter is the modulation index and the firing angle.

Fig 7 shows the power output. In grid the maximum power is obtained at 3.8 is power is 1.5 sec. At 1.8 pu the grid starts to deliver the power. The power is delivered constantly from 2.5 sec at 2 pu. The next output is the source power in which the maximum power is attained at 4.8 pu respectively. At 1 sec the maximum power is obtained. The constant power is delivered at 2.2 sec at 2 pu. But due to some losses the generated power is not transferred fully. The next output is the inverter output in which it delivers the power only in fault condition. In normal condition the inverter will be charged. During charging period the curve is obtained at the negative region.

Fig 8shows the output of powers in the fault condition. The fault is occurred at 6 sec and the fault is cleared at 6.3 sec respectively. In normal opeartion the power is generated and is delivered to the grid. But in the presence of fault the power cannot be generated and the inverter will be delivering the power.

5.2 Fault Condition

At 6 sec the grid power and the source power will be zero because the fault is occurred. At that time the inverter will be delivering the power. When the source power reaches zero the inverter will be delivering the power respectively.

6. Conclusion

Thus a FRT technique is proposed for the offshore wind farm. Simulation results shows that the fault is created.It is shown that the low dc-link inductance of the current-source-based system causes very rapid rise of the dc-link current during grid fault.In order to overcome the problem, inherent short-circuit operating capability of the CSC is used to develop an FRT strategy without relying on the communication link. As a requirement of the current source-based

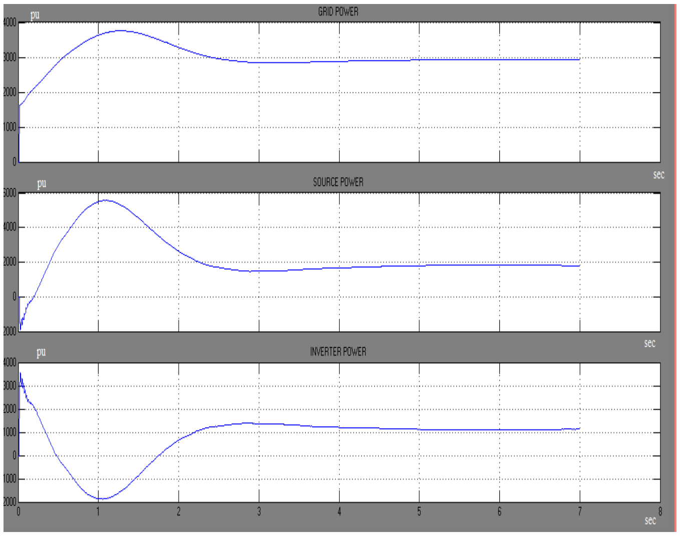

Fig. 7.Power outputs in normal condition

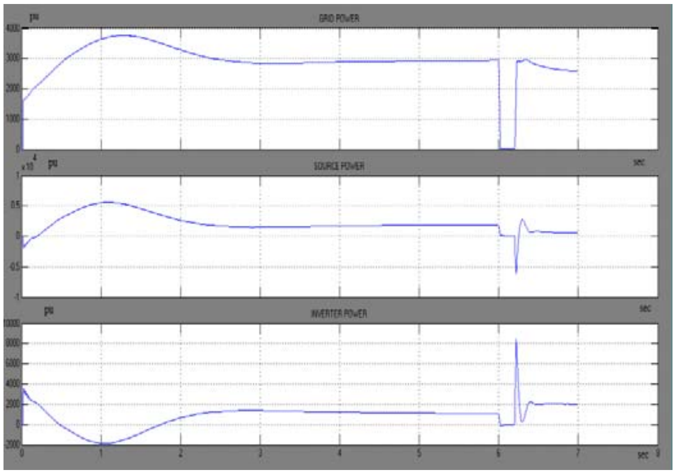

Fig. 8Power output in fault condition

system, this approach allows very fast power reduction during the grid fault.So the short circuit operating capability of the cascaded CSC is used to develop FRT. Since here CSC is used the grid fault is cleared within a short period of time. Simulation resuls shows the accuracy of clearing the fault and the duration of fault occurred.

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