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On the Enhancement of Fault Ride through Capability of Wind Farms

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Abstract

The capacity additions to wind power generation are taking at regular interval all over the world and have exceeded 300GW. Most of these plants are vulnerable to grid faults and other abnormal conditions and may certainly trip. Reconnection results in severe transients causing deep sags and sustained interruptions. Such a situation must be avoided by keeping wind generator synchronised to the grid. This is possible if generators are employed with fault ride through capabilities. Fault ride through capability is one of the mandatory requirements for wind generators and has been specified in many National grid codes including that of India. The inherent capability of wind generators to safely glide during grid fault condition is limited. The ride through capability of wind generators need to be enhanced by different mechanisms. The controllable devices used to limit fault current magnitude by introducing dynamic impedance or using by-pass switches. This paper deals with fault ride through capability enhancement by using different apparatus such as STATCOM, Pitch angle Controller and DC link voltage controller. These are demonstrated through simulation case studies.

Keywords: Grid Codes, Fault Ride through Capability, STATCOM

1. Introduction

Wind power has huge potential of 400GW across the world[1]. Many favourable locations have been brought into use by implementation of standalone wind power plants which are grid connected. The benefits of such schemes are reduced emissions, reduction in transmission loss and line cost. However these plants are also likely to introduce instability of the system due to increased penetration level, rise in terminal voltage violating specified norms, possibility of tripping of voltage sensitive loads and power quality issues[2–4]. In addition peculiarity of wind power such as limited predictability, randomness and intermittence aggravate the operation of integrated power system.

Different Wind Turbine Generator (WTG) configurations have been developed and are in use. International standards organisations such as IEEE/IEC have classified WTGs based on speed and/control of power as Type A to Type D (Type1 to Type 5). For more energy capture WTGs based on variable speed are preferred and deployed on wide scales for power generation[4,5]. Besides these, other configurations employing permanent magnet synchronous generator, switched reluctance generator, synchronous reluctance generator, brushless doubly fed reluctance generator are gaining importance due to variable speed operation and higher efficiency[6–8]. Most of these generators are connected to the grid through power electronic converters and grid voltage itself is taken as reference and synchronisation signal. With distorted voltage or absence of voltage, mis-operation takes place resulting in tripping of units. Further due to insufficient inertia/no inertia associated with wind generators they may even trip during transient faults[9]. Tripping of large wind generators can cause large transients in the power system which must be avoided at any cost. Such a stringent requirement is specified in many grid codes which are

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denoted as fault ride through capability of wind generator. WTG with adequate fault ride through capability will not trip. Therefore this paper studies the use of different mechanisms such as STATCOM, Pitch Angle Controller (PAC) and DC Link Voltage Controller (DCLVC) to provide fault ride through capability. The capabilities of these controllers are demonstrate though simulation study for single line to ground fault as they occurs frequently[10]. This paper is organised as given below. Section 2 deals with fault ride through capability, Section 3 elaborates STATCOM, and Section 4 discusses a simulation case study for enhancement of ride through capability of wind generator by using STATCOM, PAC and DCLVC. A comparative study of these controllers is presented in Section 5 followed by conclusion.

2. Fault Ride Through Capability

Capacity addition along with increased rating of individual wind generators does affect the grid operation. Under worst situations, like severe fault, wind generators must not trip. Many grid codes have exclusively addressed this issue and prescribed regulations which are similar to those of conventional power plants that is wind generator must not trip for a specified duration of voltage dip and interruptions. The reactive power support that is required for wind generator for maintaining synchronism during fault condition or abnormal condition is called as Fault Ride Through capability requirement (FRT)[11]. FRT can be provided either on low voltage side of the wind generator or on high voltage side. Accordingly these can be designated as Low Voltage Ride Through (LVRT) or High Voltage Ride Through (HVRT) capabilities respectively. The voltage support required during the fault conditions is dependent on fault. The magnitude of fault current depends on type of fault and its location in the network. The fault current causes excessive voltage drop over healthy part of the network resulting in deep sags. The duration of sag is determined by type of fault, the response time of protective switchgears and facility of auto reclosing (fast or delayed) etc. Reduction in voltage magnitude and phase angle jumps is responsible for mis-operation of power electronic control of wind generators resulting in tripping of units.

Indian Electric Grid Codes (IEGC) has specified that the requirements of a FRT are met if the minimum voltage during the fault condition (Vf) is 15% of nominal system voltage and maximum post fault voltage (Vpf) is 80% of system nominal voltage i.e. wind generator must not trip during the fault for voltages in range Vf to Vpf as indicated in Figure 1.

The fault ride through requirement of German and Irish systems are also indicated in Figure 1[12–14] from which it can be seen that German system has more stringent requirement i.e., even at zero voltage wind generator must not trip. With latest amendments in German grid codes wind generators may trip at 1.5s and 1.8s[15] or at other time intervals as seen from Figure 1. However resynchronisation time has to be the same.

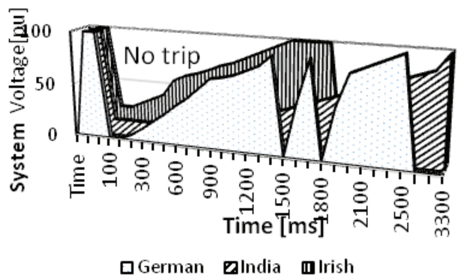

Figure 1. Complete fault ride through capability characteristic for German, Indian and Irish systems.

To avoid disconnection of wind generation in "No Trip" zone (Figure 1) it is essential to provide additional auxiliary mechanisms which will enhance ride through capability of wind generator. The commonly used mechanisms include crowbar circuits, buck-boost converters, choppers, DC link capacitor control, pitching of blades, advanced mechanisms like controllable series braking resistors, modulated series dynamic braking resistors, reactive power support, use of FACTS devices etc[16–21]. The main role of these mechanisms is to restrict power flow under safe limit or to bypass the power converters or to maintain voltage profile so as to avoid disconnection of wind generators.

3. STATCOM

Static Compensator (STATCOM) is a shunt type controller from the FACTS family. The STATCOM is analogous to the rotating synchronous condenser but without any rotational parts. It can generate or absorb reactive power at a much faster rate than its traditional counterpart. It employs a Voltage Source Converter (VSC) for reactive power injection into the system. The STATCOM can be built by any one of the different converter topologies depending upon the requirements of the system. The basic aim of these topologies is to reduce switching frequency of the power electronic switches of the VSC and produce harmonic free sinusoidal voltages. The STATCOM based on VSC is represented by single line diagram shown in Figure 2.

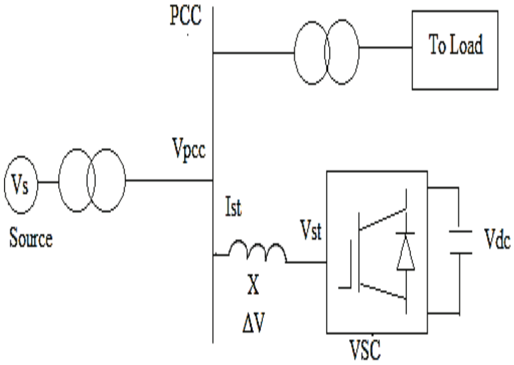

Figure 2. Single line diagram of VSC based statcom.

The STATCOM is connected to the source through a three phase transformer. In principle the magnitude (Vst) and its phase of VSC are controlled by taking reference signal as Point of Common Coupling (PCC) voltage Vpcc. The voltage drop ΔV across the transformer leakage reactance referred to PCC bus side (neglecting resistance of winding) is connected to a continuously controllable Voltage (Vst). The resulting control action by STATCOM is shown with space phasor diagram shown in Figure 3 at fundamental power frequency. Figure 3(a) represents compensation in a leading zone and Figure 3(b) indicates the control action in lagging zone.

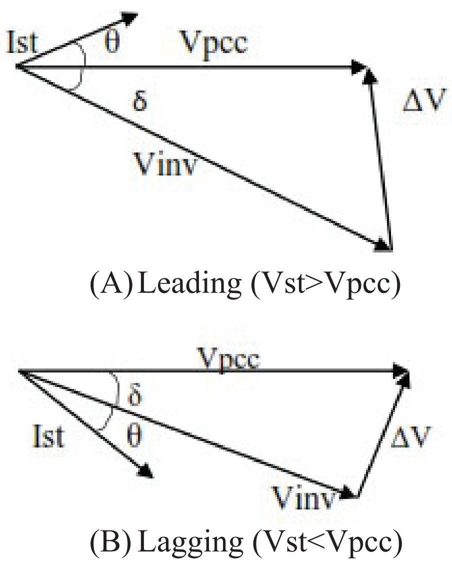

Figure 3. Space phasor representation of var compensation.

From Figure 3 it can be seen that reactive power can be controlled in leading as well as lagging mode. The current flowing into STATCOM is given by Equation (1)

$$I_{St} = \frac{V_{pcc} - V_{St}}{X} \quad (1)$$

The input voltage(V_{dc}) in VSC is provided by charged capacitor. VSC produces a symmetrical set of controllable three phase voltages with frequency same as that of grid. Each output voltage is coupled to corresponding grid voltage through coupling transformer or a reactor having small inductance. The amount of reactive power can be controlled by varying the magnitude of Vst and its phase with reference to PCC voltage. The magnitude of V_{inv} decides the direction of current as shown in Figure 3. Fundamental power exchanged are given by Equation (2) and (3) respectively.

$$P = \frac{V_{\text{pcc}} C_{\text{inv}}}{X} \sin\delta \quad (2)$$

$$Q = \frac{V_{\text{pcc}}^2 V_{\text{inv}}}{X} \sin\delta \quad (3)$$

It can be noted that Vst lags behind source voltage Vpcc by an angle δ and Ist lags behind voltage drop over reactor by 90^0. The flow of active power between source and STATCOM is regulated by angle δ. The active power flow can be on either side depending on δ (positive or negative). The reactive power flow is governed by magnitude of voltages Vpcc and Vst. If Vpcc>Vst STATCOM absorbs reactive power and delivers reactive power if Vst>Vpcc. There is always flow of some active power into STATCOM from PCC bus to meet the VSC losses and charging of dc capacitor. Therefore value of δ is higher than zero and is around 4-5 degrees.

The demand of reactive power is determined from the power frequency voltage and current through the line. A synchronisation unit decides that it remains synchronised with the system. For controlling output voltage of STATCOM system voltage, current and dc voltages are sampled and measured by A/D convertor. These signals are compared with reference signals to generate error signal. This error signal is modulated with gain of PI regulator to develop signal for Modulation Index (MI) which is fed to a PWM generator. Another controlled input to PWM generator is through PI regulator used for controlling dc bus voltage. Hence PWM generator produces desired gate signals and is fed to a driver circuit of VSC.

The DC voltage can be controlled looking into aspects such as MI, harmonic generation response time, stresses on power electronic switches etc. Three common methods are used for the control of DC bus voltage. These are described below.

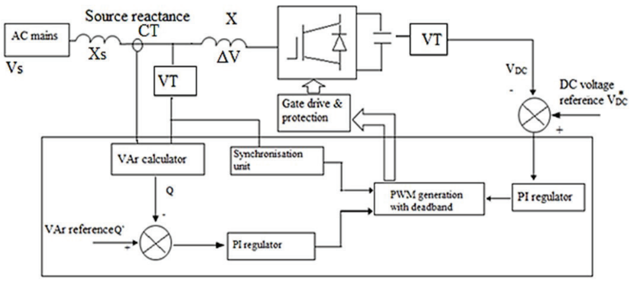

Figure 4. Basic control structure of STATCOM.

3.1 STATCOM Control

A simplified control structure[22] of STATCOM based on magnitude and phase angle control method is shown in Figure 4. Any advanced processor or controller can be used to develop gating signals for power electronic switches of the VSC by way of comparing reference signal of reactive power and dc bus voltage.

a) Constant DC bus voltage- This scheme employs simpler control. Same DC voltage is used for the generation of lagging and leading VArs which affects MI. During lagging VAr generation MI is poor leading to high distortions in output voltage of VSC.
b) Variation of DC voltage- This scheme employs variable dc voltage according to VAr requirements. The MI can be maintained reasonably high closer to 1 which minimizes distortions in output voltage of VSC. However frequent changes in dc voltage levels lead to slow response.
c) Use of two different references for dc voltage- This scheme employs a higher value for leading VArs and a lower value is used for lagging VArs. This results in higher MI for both compensations. This method combines the advantages of methods stated in (a) and (b).

High and low dc voltage reference can be obtained by Equation (4) and (5) respectively

$$V_{dc(h)} = 2\left[V_{PCC\ max} + \frac{Q.X}{\sqrt{3}.V_{S\ max}}\right] \qquad (4)$$

$$V_{dc(l)} = 2.V_{pcc\,max} \qquad (5)$$

Where Vpccmax- peak magnitude of PCC voltage source (system) voltage and Q rated reactive power exchange

The lower values of modulation indices for leading and lagging VArs are given by Equation (6) an (7) respectively.

$$MI_{min\,(lead)} = \frac{2V_{pcc\,max}}{V_{dc(h)}} \qquad (6)$$

$$MI_{min\,(lag)} = \frac{2\left[V_{pcc\,max} - Q.^{X}\Big/\left(\sqrt{3}\,V_{pcc\,max}\right)\right]}{V_{dc(l)}} \qquad (7)$$

There is always a minor requirement of active power to supply power losses in VSC. This requirement is fulfilled by the dc voltage control circuit generating a phase shift angle δ between Vpcc and Vst through a PI regulator.

4. Implementation of Fault Ride Through Capability

This section deals with implementation details of FRT through case studies. Basic role of FRT capability is to keep wind generator synchronised even under abnormal conditions with adequate voltage support. After detailed discussion on operation and control of STATOM it is implemented under MATLAB environment in conjunction with wind generator or wind farm. Along with STATCOM other mechanisms such as pitch angle control and DC link voltage control methods are also presented for providing ride though capability.

4.1 Application of STATCOM for FRT

The dynamic reactive power support can be provided using STATCOM. Performance of grid connected WTG under fault conditions is illustrated without and with STATCOM in this case study. A typical radial power network is used for study[23] whose details are shown in Figure 5.

Table 1. Specifications/rating of system components

Grid generator	120kV, 2500MVA	Connection Yg
Transformer1	120/25kV, 47MVA	Ynd11
Transmission line 1	Z_0 = 0.1147pu	
Transformer2	25kV/575V, 12 MVA	Dyn11
Wind farm	575V, 9MVA	
Load 1	25kV, 2 MVA	Y
Load 2	575V, 500kW	Y

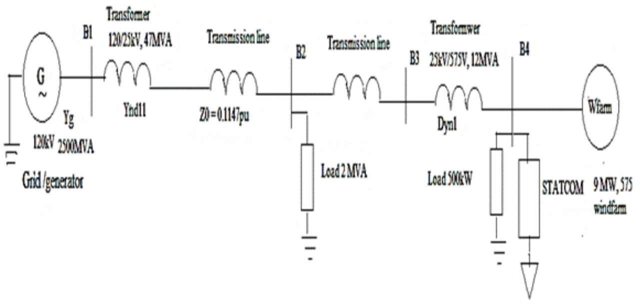

Figure 5. Single line diagram of radial transmission network with wind farm.

The circuit shown in Figure 5 is simulated in MATLAB-Simulink environment to study circuit behaviour for Single Line to Ground (SLG) fault at bus B2 and bus B4 is examined one at a time. The specifications of system components are given in Table 1. Simulation time is taken as 4s. After ensuring that system has reached steady state a SLG fault is created suddenly at bus B2 on phase A, the duration of fault being 0.5s ≤ t ≤3.6s. The SLG fault is cleared at 3.6 sec. The R.M.S. voltage variation during the fault at B2 is shown in Figure 6(a). It is seen that at B2 faulted phase voltage has reached zero immediately after the fault and other two phase voltages are observed with a momentary voltage swell. This swell is predominantly due to voltage drops across zero sequence impedance of the network. If these voltage drops are removed from phase to ground voltages the other two phases also show voltage sag[24]. Figure 6(b) shows voltages at bus B4 during the same duration. Note that there is no effect on phase C and other two phase voltages display sag of nearly 40%. It may be due to fault current contribution from WTG, which is flowing over the line impedance to cause a large voltage drop. Further it is noted that due to drop in voltage at B4 the power output of wind generator, after some oscillations, has reduced to zero at t = 2.6s due to tripping of circuit breaker. The variation of output power of wind generator during fault is shown in Figure 6(c). The reactive power developed by the wind generator is also shown in Figure 6(d). It is seen that there is a sudden change in reactive power due to rapid decay of bus voltages at the instant of fault inception; but subsequently there is no reactive power support for the duration of fault.

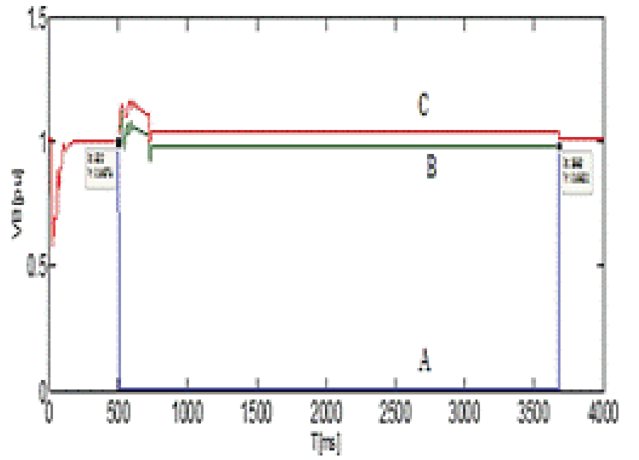

Figure 6(a). Voltage variation at BUS B2 during SLG fault at BUS B2.

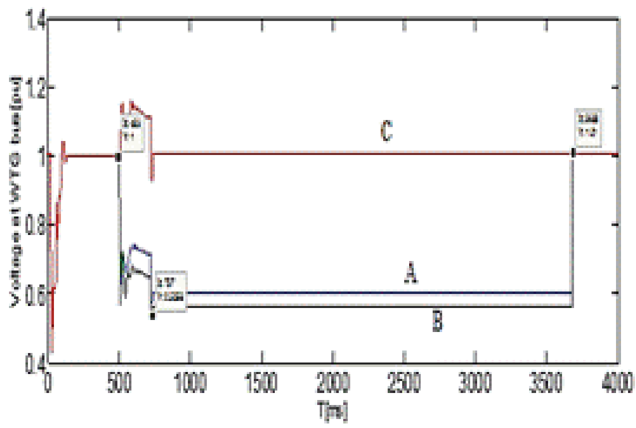

Figure 6(b). Voltage variation at BUS B4 during SLG FAULT at BUS B2.

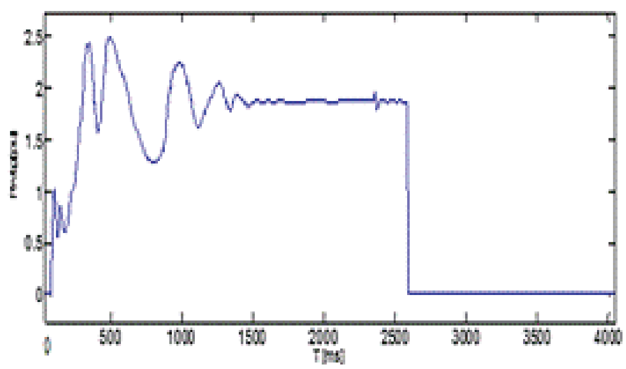

Figure 6(c). Power output of wind generator.

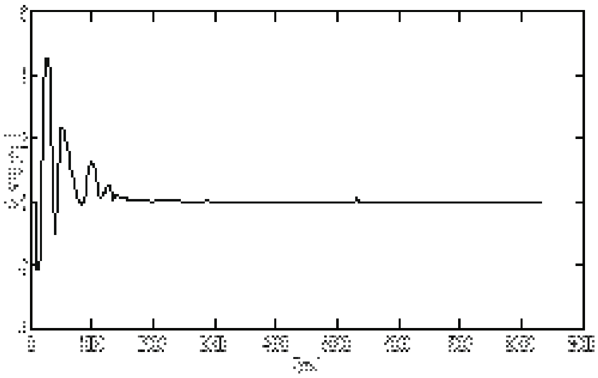

Figure 6(d). Reactive power developed by wind generator.

During the fault the STATCOM connected to bus B4 provides necessary reactive power keeping WTG connected to the grid. The STATCOM works in reactive power control mode and provides suitable compensation with necessary correction. The corrective action taken by STATCOM for maintaining voltages at B2 and B4 is shown in Figure 6(e) and Figure 6(f). As bus voltage is maintained by STATCOM the power developed by wind generator does not reduce to zero; but it remains on the higher side and continues to contribute to fault and healthy part of the system.

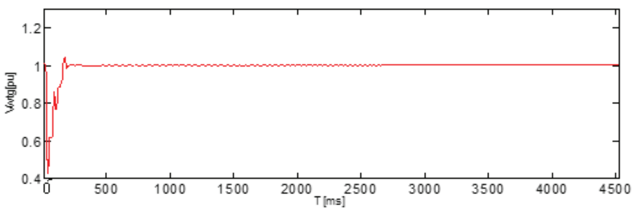

Figure 6(e). Correction in voltage at B2 during SLG fault with STATCOM connected at B4.

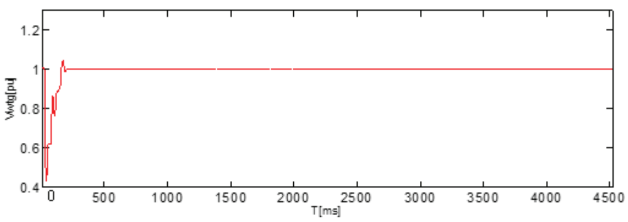

Figure 6(f). Correction in voltage at B4 by STATCOM

The profile of active power generated by wind generator is then investigated. During fault active power generated by wind generator increases due to higher mechanical input and this is shown in Figure 6(g). It is therefore necessary to restrict active power near about rated value so that wind generator will remain connected to system. For this, control settings of active power needs to be modified by incorporating additional control. The modified active power characteristics are shown in Figure 6(h). It can be inferred upon from Figure 6(g) and Figure 6(h) that wind generator has gained enhanced fault ride through capability and has remained connected during fault. The reactive power developed by the wind generator is shown in Figure 6(i) and it shows transients before falling to zero.

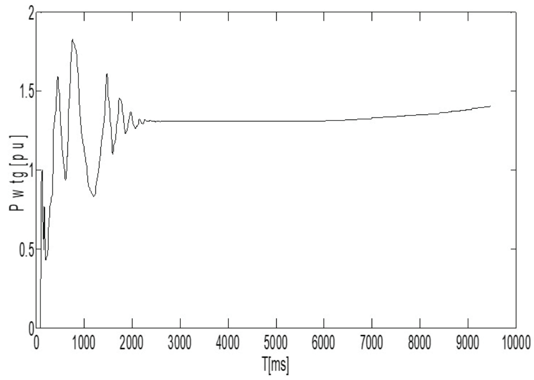

Figure 6(g). Power developed by wind generator under fault condition.

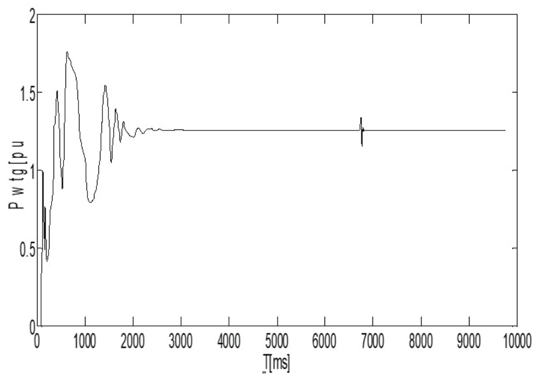

Figure 6(h). Power developed by wind generator with active power control action initiated.

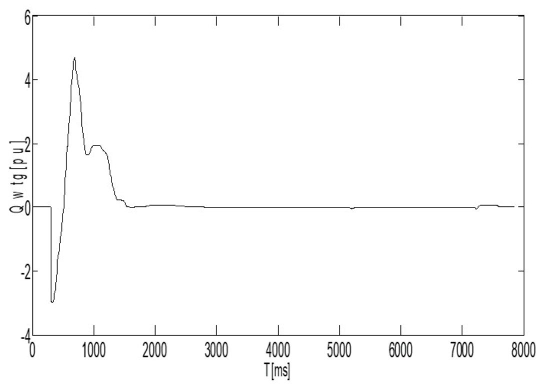

Figure 6(i). Reactive power developed by wind generator.

Similarly, a SLG fault on 'phase A' at B4 is created for a duration of 0.474s ≤ t ≤ 1.274s. The corresponding variations in voltages at buses B4 and B2 are shown in Figure 6. It is observed from Figure 7(a) that faulted phase voltage (v_A) is zero during the fault condition, whereas other phase voltages observe temporary swell for very short duration due to the transient voltage drop over zero sequence impedance. It can be seen that the voltage at the point of fault sharply reduces resulting in tripping of generator units connected at that point or nearby faulted bus. Figure 7(b) indicates that the voltage at B2 is not affected by the fault at B4. The corrective actions taken by STATCOM are shown in Figure 7(c) and Figure 7(d) respectively. The employment of STATCOM instantaneously corrects voltage dips and avoids disconnection of wind generator.

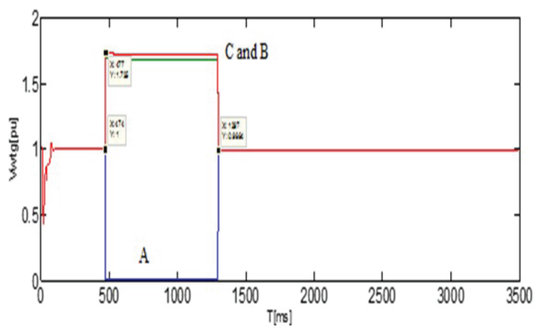

Figure 7(a). Voltage variation during SLG fault at B4 BUS without STATCOM.

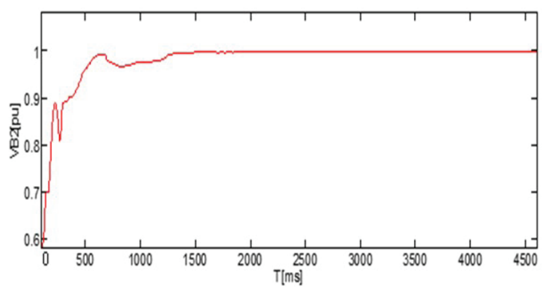

Figure 7(b). Voltage variation during SLG fault at B2 without STATCOM.

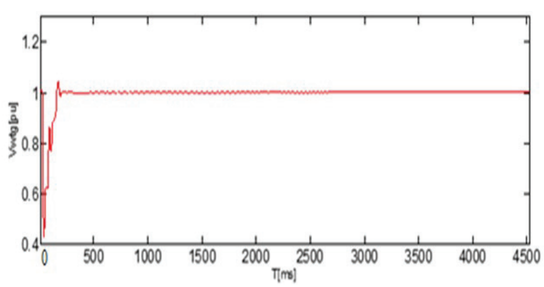

Figure 7(c). Voltage AT B4 BUS during SLG fault in presence of STATCOM.

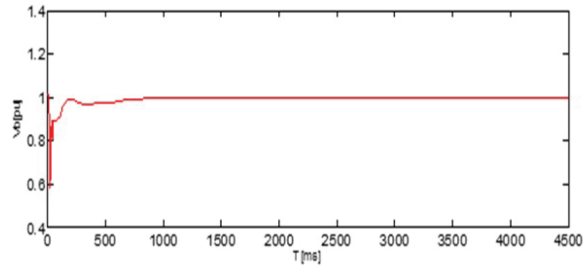

Figure 7(d). FIG. 7(D) Voltage At B2 during Slg fault in presence of Statcom.

It can be observed from the simulation study that during wind generator got disconnected during SLG fault in absence of STATCOM whereas they remained connected due to adequate reactive power support provided by STATCOM.

4.2 Pitch Angle Controller (PAC)

The power output of wind generator can be is controlled either by control of pitch angle of turbine blades or shifting the operation from best operating point in power vs wind speed characteristic. The control scheme for pitch angle control of WTG is shown in Figure 8(a).

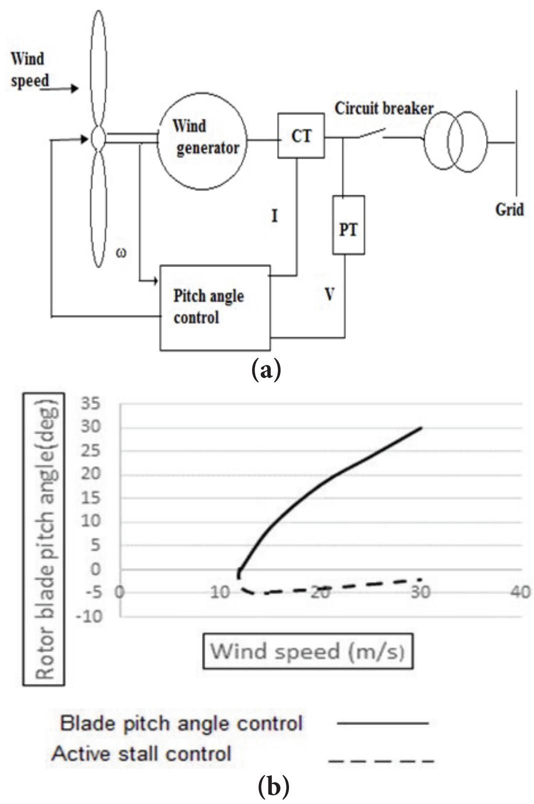

Figure 8. Pitch angle control of wind generator. (a) Pitch angle control of wind generator; (b) Pitch angle(β) Vs wind speed.

Another effective method of controlling power output from wind turbine is to change angle of attack. This is achieved by moving the blades of wind turbine along the longitudinal axis by electric actuators. The blade angle is adjusted to critical aerodynamic angle of attack at which air flow separates over rotor blade to reduce aerodynamic power input. The blade pitch angle control reduces aerodynamic efficiency thereby avoiding uncontrolled speeding of rotor.

The torque developed by the wind turbine is dependent on wind speed and pitch angle of blades. The decision of setting up of pitch angle is taken by incident wind speed and demand of active power. The operation of pitch angle control is also coordinated with protective relays. In the event of voltage dip or sag, pitch angle control system is actuated. Usually the power production is maximum with zero pitch angle (β). During abnormal condition or fault, pitch angle control avoids speeding of WTG by increasing pitching angle. However modern wind turbine uses heavy blades that put restrictions on the rapid change of pitch angle. As the size of blade actuators is reduced for economic reasons the rate of change is usually around 3-10 deg/s[15]. The variation of β Vs ω is shown in Figure 8(b). The horizontal axis wind turbine generator schemes are provided with pitch angle control mechanisms. Hence certain control over generator speed can be regained by changing pitch angle of the rotor blades.

4.2.1 PAC for Enhancement of FRTC

The blade pitch angle control scheme is shown in Figure 9. Under normal condition the pitch angle is zero. It increases to a higher value when higher wind speeds are prevalent or at any other abnormal condition. This helps to keep the acceleration of WTG to a minimum value and avoids the increase in power developed.

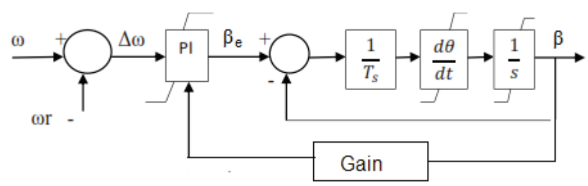

Figure 9. Pitch angle controller for wind generator.

This scheme directly controls the speed of WTG by comparing actual speed with reference speed. The speed error (Δω) undergoes modulation by the PI controller. This initiates the action of servomechanism to change the pitch angle of blade. In closed loop system actually value of pitch angle is compared with reference value which triggers the servomechanism. Additionally rate of change of pitch angle is also kept within acceptable limit. The action of pitch angle maintains balance between electrical power developed and mechanical input power to the wind turbine. A damping controller is also be added to damp any low frequency oscillations arising due to drop in electrical output and acceleration of wind turbine generator.

4.2.2 PAC with SLG Fault

Case study for FRTC considers only SLG fault for the power network shown in Figure 5 without STATCOM. The studies are carried out for pre-fault conditions with pitch controller disabled. The pre-fault results are presented in Figure 10(a) to Figure 10(c) for bus voltage, generator speed and variation of pitch angle control respectively.

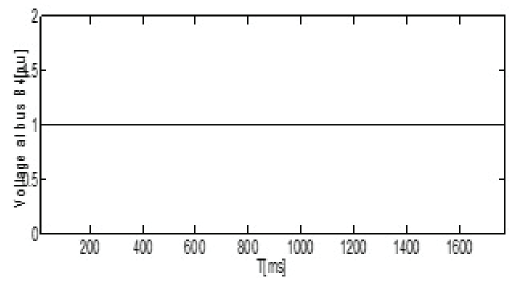

Figure 10(a). Pitch angle controller for wind generator.

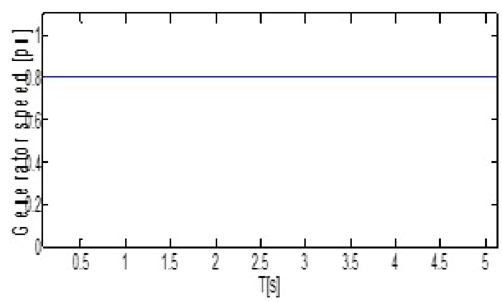

Figure 10(b). Pre-fault speed of wind generator.

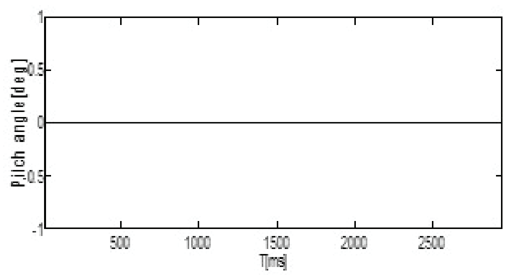

Figure 10(c). Pre-fault pitch angle control.

Now suddenly SLG fault is created at 0.47s at bus B4 and fault lasts upto 1.27s (Figure 10(a)). The variations in the different variables under this situation are shown in Figure 10(d) to (f).

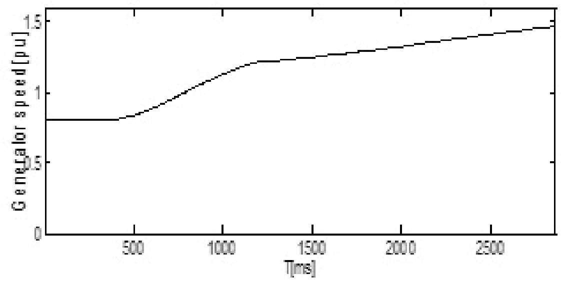

Figure 10(d). Variation of speed of wind generator.

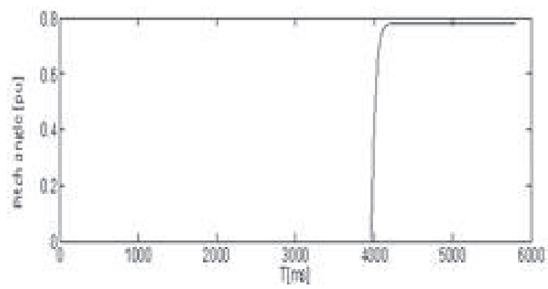

Figure 10(e). Variation of pitch angle of wind generator.

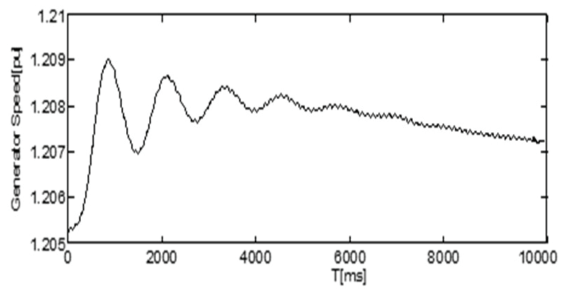

Figure 10(f). Variation of speed of wind generator.

The set will accelerate due to reduction in power requirement as shown in Figure 10(d). and generator speed may go beyond set limit. This will initiate automatically pitch angle controller to control speed of wind turbine. The control action is shown in Figure 10(e). This control enables blades to change angle of attack for reduction in aerodynamic forces and increase pitch angle which reduces power generation. The variations in generator speed are shown in Figure 10(f). It is observed that speed of set is limited to safe value. This also restricts active power generation during machine acceleration.

4.3 DC Link Control for FRTC

This scheme employs synchronous generator or induction generator or even permanent magnet synchronous generator for power generation. This generator is connected to the local grid through power electronic converter useful for variable speed operation of WTG. In this case study permanent magnet synchronous generator replaces DFIG shown in Figure 5. In this case PMSG is connected to the rest of the system through full capacity back to back converter. Under normal condition grid side converter maintains voltage and frequency within acceptable limits. The role of generator side converter is to regulate speed of the set and to stabilize the dc link voltage. This also helps in shedding additional load on the system. The control scheme employed keeping dc link voltage fairly constant which includes a buck-boost controller after generator side converter. The operation of buck boost converter is controlled by the speed reference signal. The schematic of this scheme is shown in Figure 11(a). During a fault or any abnormal condition there is large requirement of active power. This requirement can be partially fulfilled by wind generator. As the active power demand of wind generator increases the DC link voltage observes dip in magnitude. The reduction in dc link voltage prompts the protective systems to disconnect the WTG. The active power support given by dc link controller under abnormal condition is insufficient and may set trip command.

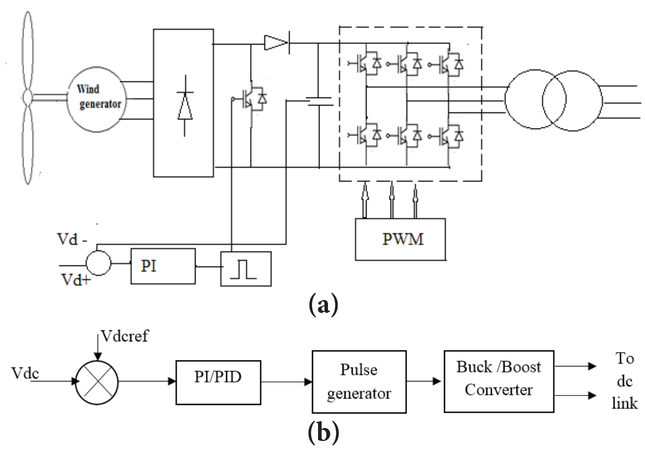

Figure 11. DC link control for wind generator. (a) DC Link Control; (b) Control scheme for dc link

The dc link control scheme is shown in Figure 11(b). In this DC link voltage is sensed and compared with reference signal. The comparator *generates* error signal which is modulated by PI controller to generate gate pulses either for chopper circuit or for buck boost converter. The buck-boost converter controls the dc link voltage to desired level.

Now SLG fault is created on phase A at bus B4 at t = 0.47s and it lasts till 2.7s. The variations of bus voltage, active power, reactive power, dc link voltage and speed during fault are presented in Figure 12(a) to Figure 12(d)

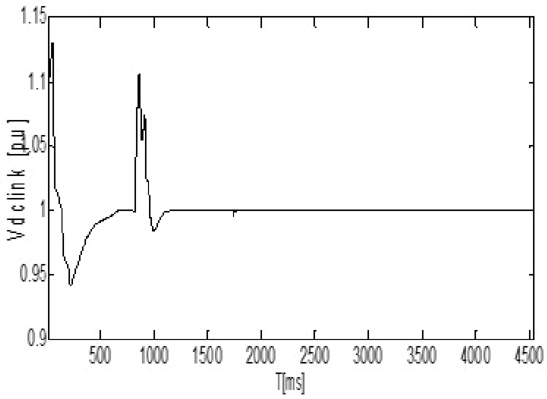

Figure 12(a). Variation of DC LINK voltage during fault.

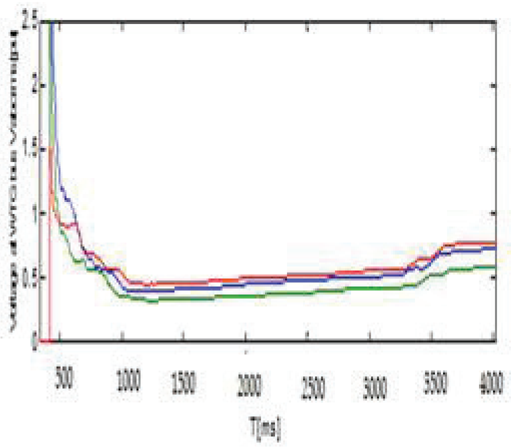

Figure 12(b). Variation of voltages at B4 BUS during SLG fault at B4 with DC link control.

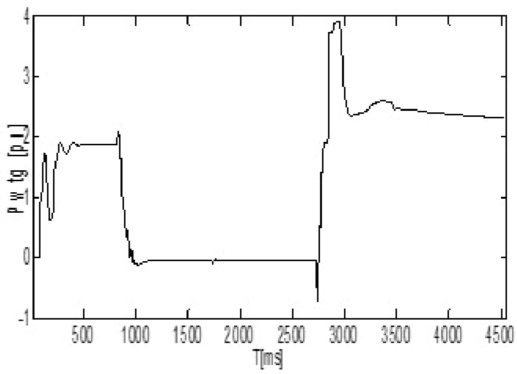

Figure 12(c). Variation of active power injected by wind generator at BUS B4.

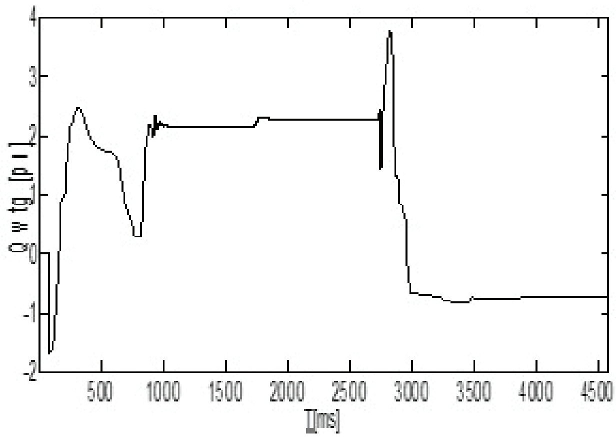

Figure 12(d). Variation of reactive power developed by wind generator.

During SLG fault at bus B4 (Figure 6(a)) the bus voltage variation is as shown in Figure12(a). At the instant of fault, DC link controller is initiated and tries to keep the dc link voltage constant after initial transients. This is shown in Figure 12(a). The resultant voltage at WTG bus has initially reduced to a lower value as shown in Figure 12(b) and subsequently improves due to the action of dc link controller. The power developed by the WTG is shown in Figure 12(c). Here also after initial transients the active power improves to a constant value. The reactive power developed by WTG is shown in Figure 12(d) which is close to zero after initial transients. The active power developed by wind generator reduces to very low value during fault. The reactive power production by WTG has increased immediately after fault inception and almost remaining constant till fault lasts to give voltage support. There is a sudden increase in active and reactive power developed by WTG immediate after the fault is cleared. This will help in maintaining system voltage and active power support. The transients at point of fault recovery are dependent on system parameters.

5. Comparison of STATCOM, Pitch Angle and DC Link Voltage Control

The performance of above mentioned control methods for enhancing fault ride through capability is compared for effectiveness in Table 3.

Table 2. Comparison of the schemes

Apparatus Description	STATCOM	Pitch Angle Controller	DC link controller
Mechanism employed	Controllable VSC	Electric actuators	Buck Boost converter/chopper
Controlling parameter	Magnitude and phase of injected current	Angle of attack of wind on blades(alignment of blades with incident wind)	Controlled switching of power electronic switches (Switching frequency)
Controlled parameter	Grid voltage by way of injection/absorption of reactive power	Mechanical drag to control aerodynamic power input to the turbine	DC link voltage by buck-boost action
Sensing parameter	System Voltage	Wind speed, turbine speed	Wind speed,
Reference signals	System Voltage and reactive power demand of the network	voltage and current of wind generator	DC link voltage and current
Response time	Fast, Typically microseconds (300microsec)	Slower response typically in seconds (4s)	Reasonable, Typically milliseconds (1ms)
FRT capability limited by system voltage	System voltage upto 10% of nominal value	System voltage upto 50% of nominal value	System voltage upto 30% of nominal value
Additional capability	Power factor control according to grid requirement	Helping in stall mechanism	Sometimes help in isolating machine side converter
Cost	Highest @ 24.8M$/MVAR (as external hardware required)	It is already included in turbine control; hence no additional cost	Moderate (As additional circuitry required)

6. Case for Adoption of STATCOM in India

In India many WTGs commissioned prior to 2014 were installed without fault ride through capabilities as it was not mandatory at that time. These WTGs are controlled by either stall mechanism or pitch mechanism or active stall control. An amendment in IEGC in 2015 has specified that WTGs installed after 2014 must have FRT feature embedded into the system. For old turbines which were not designed for LVRT, provision of LVRT would add substantial load on the drive train mechanism and associated circuitry. It can bear this load only with increased size or with higher factor of safety in design. Provision of LVRT as a retrofit for old wind turbine generators is a challenge as these turbine units are manufactured by different manufacturers and many of whom are not in this business now and it is difficult to get a supplier for LVRT retrofit.

The survey conducted by Indian Wind Turbine Manufacturer Association (IWTMA) estimates that around 25000 wind turbines were installed prior to 2014 and around 14000 machines are above 700kW who are awaiting LVRT retrofit and certification. From IWTMA statistics there exists 11% of stall type WTGs in India and every year 2% of such machines get added to this block[24]. Provision of LVRT is not feasible for such machines either technically or commercially. For the remaining units some manufacturers have shown their inability for support to LVRT. As per the estimates of IWTMA the cost of LVRT retro-fit for single turbine fitting is considerably high to the tune of Rs. 20 to 50 lakh irrespective of the rating of turbine[24]. In addition, the cost of type testing of LVRT retrofit and certification will be round Rs. 3 Crore per certification. Totally the average cost of retrofit including certification will be around 55440 Crore which is exorbitant.

In view of above mentioned remarks provision of external mechanism for fault ride through capability will be useful. STATCOM will be a good option for achieving this. Provision of STATCOM will substantially reduce the retrofit cost to reasonable value and future ready.

7. Conclusion

IEGC has been amended in 2015 to make provision of FRT mandatory for all WTGs. For implementation of FRT various alternatives can be used. The capabilities of three controllers' viz. STATCOM, PA controller and DCLVC are demonstrated through simulation studies for single line to ground fault and it can be observed that the performance of STATCOM is better than other controllers and keeps the WTG connected to the grid even under severe fault condition. STATCOM takes a minimum time for the corrective action and supply of requisite reactive power to provide ride through capability and ensuring delivery of rated active power as per the requirement of IEGC. The other controllers operate at reduced active power to avoid tripping of generators. The use of STATCOM can bring down the cost of retro-fitting of old wind turbines still in use.

8. References

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