UPFC and its Effect Under Fault Conditions on Wind Power Integration with the Power Grid

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Abstract: Due to the competition in the existing electrical market, it isvery necessary to enhance the transmission performance of the power system through the existing transmission lines also Reactive Power flow control is a major concern in the operation and manage of power systems.The FACTS devices have been designed as excellent controllers in a power system for superior reliability and transmission capacity on a long-term and economical basis. This Paper describes a unified power flow controller (UPFC) model developed for performing system reasonableresearch.In the condition of any fault , the voltage at the Point of Common Coupling (PCC) decrease under eighthy percent instantly and the rotor speed of induction generators ends up noticbly unstable. This paper the low voltage ride-through (LVRT) of wind energy conversion system (WECS) isenhanced by the application of an UPFC and further at the time of fault to damp out the rotor speed oscillations of induction generator.The wind turbine has a noteworthy issuerelated with it which is high variation in volatge of the grid amid power gerenrationwith, an increase of large wind farms. The wind turbine's performance normally worsen during voltage variations, which could be either over voltage or voltage drops. Over voltage, withstanding capacity of the wind turbine is typically known as High Voltage Ride Through (HVRT) and on the other hand, the capability of wind turbines amid voltage drops is known as Low Voltage Ride Through (LVRT). The issues because of sudden over-voltage and voltage plunges are typically related with the power electronic converters fed wind turbines and are being affected by the poor grid situations. The simulation results demonstrates that UPFC can enhance the LVRT of DFIG-based WECS and hence maintain wind turbine connection to the grid during certain levels of voltage variation at the grid side.

Keywords: LVRT, Indian Electricity Grid code, UPFC, DFIG-WECS

1. INTRODUCTION

As from several years the use ofelectrical power is increasing, the sources of electricity generation which are used conventionally are decreasing. Recently, wind energy is the most applicable & reliable energy source and is also rising with time. The rate of rise of wind energy generation in the year 2012 was around 28 percent and by the end of 2015 it reached 60000 MW which is also expected to increase with the time and reach up to level of 150 000 MW by the year 2020. The government has permitted to cut off the WTGs rating fron the grid during the time of grid disturbances for the purpose of by passing the wind turbine damage. Because of the significant improvement in the WTGs and the world wide trends for creating the smart grids, to give support to the grid during the fault conditions the operators of transmission system require to have connection of WTGs with the grid for maintaining the level of faults.

As the variation in voltage is considred as a common quality issue, many of the studies now days are paying attention on the performenaces of the WTGs during the time of voltage sag. Though it is low power quality issue, voltage swell may lead towards the extrication of the WTGs from the grid. Voltage swell is basically developed by switching off the larger loads, energizing the capacitor banks and voltage improvement in the un faulted phase at the time of single line ground fault and is also explained as an improvement in voltage level in range of 1.1 putp 1.8 pu for the timing of 0.5 cycles in minute. On the other side, voltage sagis is considered as a reduction in voltage level within the the range of 0.9 pu to 0.2 pu of the nominal steady level for 0.5 cycles

Wind farms are required to balance voltage deviations at the connection point by adjusting their reactive power exchange and moreover, by setting up predetermined power factors. Wind farms needs to capable of operating at power factor which varies in between 0.9 lag to 095 lag. The above performance shall also be achieved with a voltage variation of ±10% of nominal, frequency variation of +1.6% and −0.06%.

Wind farms are required to have sufficient reactive power compensation to be neutral in reactive power at any operating point. In India, the State Load Dispatch Centre (and users), ensure that the grid voltage remains within the operating limitsand hence it is required from the wind turbine to remain connected and deliver power for the specified voltage ranges and put efforts to maintain it. Also, wind farms shall make available the up-to-date capability curves indicating restrictions to the State Load Dispatch Centre/Regional Load Dispatch Centre, to allow accurate system studies and effective operation of the state transmission system [1].

The reactive power output of the wind farm must be controllable in one of the two following control modes according to (State Utilities) SU specifications:

- The wind farm shall be capable to regulate the reactive power transfer with the system at all active power production levels. The control shall operate automatically and on a continuous basis [2].
- The wind farm must be capable to automatically control its reactive power output as a function of the voltage at the connection point for the purpose of controlling the voltage [3].

The wind farm is required to posses the sufficient capacity of reactive power to operate with the zero recative exchange with the network that is measured at point conncetion when the voltage and the frequencies are within the normal limits of operations.

FRT usually known as Fault ride through is fundamentally imposed on the generator of wind power so that it fundamentally remains stable and stays connected with the network during the faults of network. Any kind of disconnection from the grid may get more worse and can also threaten down the standards of security at high penetration rate [4]. The wind farm is required to operate in satisfactory manner throughout and later than the instability in the transmission network and also leftovers connected with the grid without tripping from the grid for set time period during the voltage drops at the Point of Common Coupling [5]. The timings and strength of the fault ride mainly dpends on the parameters like:

- The drop of voltage magnitude at the time of fault
- Time taken by the grid system to recover to the normal state [2]

This requirement applies under the following conditions:

- The wind farm and the wind turbines must be capable to stay connected to the system and to maintain operation during and after clearing faults in the distribution/transmission system.
- The wind farm may be disconnected momentarily from the system if the voltage at the connection point during or after a system disturbance falls below the certain levels [4-5].

During a fault that causes a voltage drop at the wind turbine terminals, the active power demand of induction generators increases, as a result of which the reactive power will be drawn from the grid unless active power support is available at the generator terminals, which further cause's instability.

Flexible AC transmission devices have been utilized for the objective of maintaining the WTGs penetration towards the electricity grids. the important and essential application of the unified power flow controller is basicalay to enhance the wind turbine system in association with the grid codes. The continuous development of the high power semi conductors technology has made it possible to eventually control the electricity system by means of electronic devices. Such devices mainly constitutes emerging technologies which are populary known as FACTS (flexible alternating current transmission systems). This technology has manybenefits like the greater power control flow, improved secure loading of the existing circuit transmission, dampning of the power systems and less cost than varied other alternative technologies relted with the reinforcement of transmission system.

UPFC is considred as the most versatile device. It can basically perform the varied functions of the static synchronous compensator and also offer additional flexibilities with the help of combination of the functions of the above controllers [8].

The important function of the UPFC is mainly to control the flow of the real power by injecting the voltage in series with the line of transmission. Both the magnitudes and the angle phase can vary at independent level. Real power flow can allow the power flow in prescribed routes for the purpose of loading the lines of transmission that are closer to thermal limits.

Apart form it,it can be used for the purpose of improving the transient and small stability qualities of the system of power. The schematic of the UPFC has been depicted in the figure 3. The UPFC comprises of mainly two branches. The series of the braches comprises of converters of voltage sources, that mainly injects the voltage through transformers. At the input end of UPFC there is converter 1 is connected in shunt to power system AC and the second converter at the output end of the UPFC which is connected with in varied series with the transmission circuit.

2. SYSTEM UNDER STUDY

Fig.1 depicts the system which is under examination for investigating the effect of the UPFC on the stability of the system of power with the wind generation system.

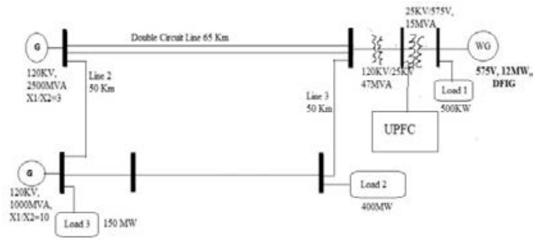


Figure.1: Single line diagram of the system under study.

Since the goal of the research study is to know the effect of the integration of the wind power in our offered system of power,so for that we have basically considered varied sources as the main ideal source that are capable of contribution the power towards the grid at constant frequencies and levels of voltage [8]. There are basically two kinds of sources which are ideal in the system each of which is considred to be around 120 KV which is located at the station 1 and 2 that are away from one another and the two of the stations are quite connected through the line of 50 km. DFIG wind generator of the 12 MW which comprise of 2MW each of which has 6 units that has rated output voltage of 575 V, and supplies the grid coonction towards station 1 through the 65 Km and towards station 2 through 50 Km line with the 25 Kv feeder of distribution system and power of exports towards 120 kV grid. So now the complete system forms a complete loop of 5 buses as depicted in the figure no. 1. The DFIG generation system of wind comprise of 6 inidvidual units which are of 2MW and has capability of supplying local resistive load of around 500 KW and infact a filter 0.9 Mvar(Q=50)isalso connected towards the wind generator bus.

Varied ratings of the parameters of the wind turbines has been depicted below in the figures. The singular simulated DFIG type of the wind generator has been shown in the figure wich comprises of 6 kinds of wind turbine farm, however there is Simulink model which has been gained from multiplying the varied parameters of *UPFC*.

With UPFC the single turbine by 6. Some of the parameters of the single turbine have been depicted below:

- Nominal mechanical power output of the single wind turbine of mainly : 2×10^6 watts,
- The DC bus capacitor per turbine is considered as: 10000 microfarads.
- Power generation output: 2/0.9 MVA (at 0.9 PF) and
- Mode of operation: Voltage regulation.

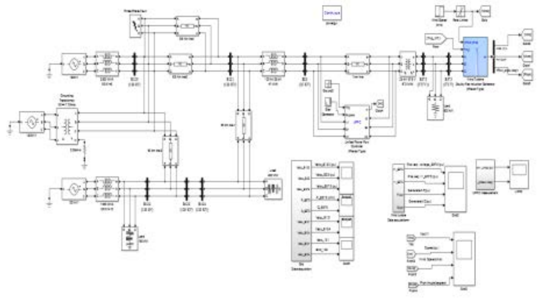


Figure 2: Simulink model of compensated system

The converter controller tries to keep the output terminal voltage equal to 1 pu. *i.e.* the reference voltage with the voltage-time characteristics slope of 0.02 pu.

The system performance has been observed for duration of 50 seconds, as the wind turbine model that we have used here is a phasor type model, which permits analysis of transient state stability in long duration simulation only.

Here wound rotor induction generator has been employed in the doubly fed induction generator type wind turbine. For conversion of Ac to DC and back to AC at power frequency, we have employed a voltage source converter consisting of IGBT devices as a switch and controlled by pulse width modulation techniques. The output from the stator winding supplies the AC/DC/AC converter, which directly supplies the wind-generated power at power frequency to the grid. So the rotor generated wind speed dependent AC power at variable frequency fed to grid at fixed power frequency. So by optimizing the turbine speed using the DFIG technology, it is possible to extract energy from the wind even at low speeds while keeping the mechanical stresses minimum on the turbine during wind’s gusts. For a given wind, speed the optimum speed of turbine to develop mechanical energy at maximum value is directly proportional to the speed of the wind.

Here for our experimental model the wind speed is kept constant at a value of 15 m/s and torque controller maintain the torque developed by a wind turbine at 1.09pu of rated torque for all wind speed above rated value. During steady state operation, the reactive VAR’s generated by wind generator are being regulated to zero. For 1.09pu torque, the wind generates an electrical output of 1pu.

3. UNIFIED POWER FLOW CONTROLLER

With the rising growth of the demand of the electrical power system, there has been great challenge of delivering the needed electrical power in consideration with the sustainability system of quality and reliability of the power delivery. For the purpose of achieveing this objective, it is important to mainly control down the current system of transmission for effective use and even for avoiding the new cost installation.[9] The technology of FACTS plays an effective role in improving the use of the current system of electrical power as it can offer adequate solution for improving the systems of power [10]. As a flexible ac transmission system device, unified flow control allows the system of power to be flexible by utilizing the high speed responses and decoupled the active and recative powers compensation and also by installing the UPFC at specificpoints of the system of transmission, the dispatch of power can be enhanced up to the rating of generators, transformers and thermal limits of line conductors, by improving the margin of stability. Both the active and recative powers in the four quadrants in smooth and rapid manner can basically controlled by Shunt & Series converters of the UPFC[11].

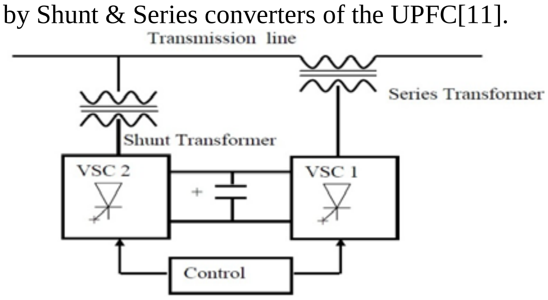


Figure 3 UPFC configuration

4. MATLAB SIMULATION RESULTS

The Unified Power Flow Controller is basically connected with the Point of Common Coupling bus for improving the Wind Turbo Generator damping and also to offer the support towards the system during the conditions of fault. The model of the scheme of the power system for the study of case is illustrated in the figure 1 which includes the controllers with the strategy of control, which is teherafter constructed using the Matlab software. The recative powers that are produced by the turbines of wind is regulted at 0 Mvar for achieving the unity power factor operation. In this research study, average wind speed of the 14m/s is utilized,the output of the turbine is 1.0 pu and the speed of the generator is 1.0 pu. The UPFC is utilized for the purpose of improving the faults ride through with the capability of WTGs, by basically controlling the active powers and the recative powers at the bus thorugh which it is connected. Numercial simulations are performed for the purpose of analyzing then compensating the fluctauations of voltage due to wind power variations and regulation of vaoltage issues because of sudden load connections.

Matlab simulation result of uncompensated system under study.

Effect of variation of wind speed

The fig. 4 shows the output real and reactive power of wind farm at constant rated wind speed without compensation.

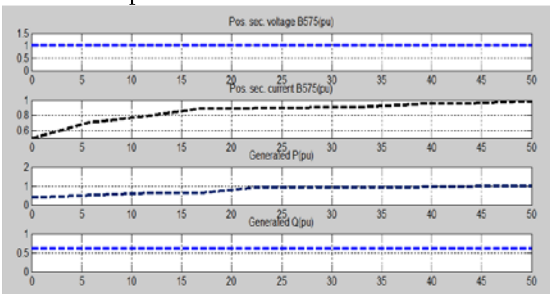
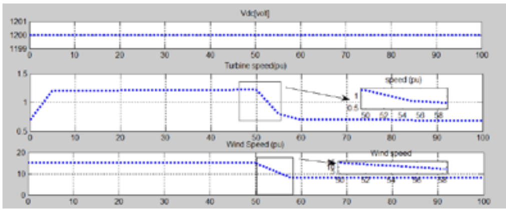


Figure. 4 : PCC voltage, real and reactive power with constant wind speed from wind farm without compensation.

From fig 4 it seems that operating power factor of wind farm is less than 0.95 leading. To study the effect of variation of wind speed we have simulated the test system to run initially at wind speed 15 m/s, then at t = 50 s, wind speed is decreased to nearly half of its value to 8 m/s as shown in fig 5



Figue 5: Initially, wind speed 15 m/s, then at t = 50 s, wind speed is decreased to nearly half of its valueto8 m/s with wind farm without compensation.

The following parameter signals are observed /monitored to study the effect of variation of wind speed on the “Wind Turbine" scope and represented in fig. 6. The output generated active & reactive powers, ac output voltage, current, DC bus voltage and turbine speed. With an initial wind speed of 15m/s the real power generation starts increasing gradually with time and a constant wind speed reaches to 0.9pu of rated real power in 18 seconds, but same time generated reactive power follows an inverse relation with real power. Generated reactive power initially is 0.6 pu when real power is only 0.25pu initially. With the increase in real power generation up to 0.9pu, reactive power reduces to 0.5 pu. As per Indian electricity grid code for wind energy, generation system interconnection a wind generator should operate with a power factor limit of ±0.95 during steady state.

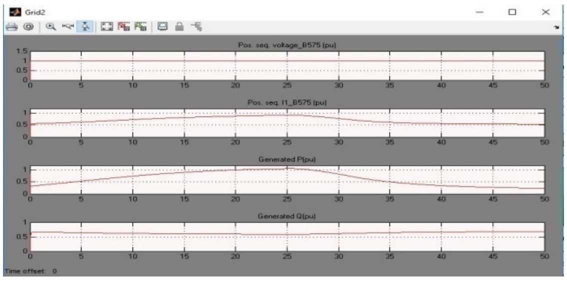


Figure. 6: Variation of the output voltage, real and reactive power with a variation of wind speed from the wind generator.

In our case, the power factor at start remains within the limit of 0.65 to 0.89 leading. Even when the system has achieved steady state at rated wind speed, the power factor is cos $(\tan^{-1}(0.5/0.9))$ = 0.874. Now this condition is a violation of grid codes so reactive power generation is required to be compensated or wind system has to be paid a penalty for not maintaining the *pf*. Again, as wind speed falls to half of its rated value suddenly the real power generation reduces drastically and power factor falls down below 0.24. Under this situation, a wind generator is not allowed to remain connected to the grid as per Indian electricity grid codes.

Performance Under fault in120-kV Grid system

Inthis section the impact of a single phase-to-ground fault occurring on the 120-kV line atB120 bus is observed. Now when we open the "Fault" blocks menu and "Phase A Fault" is selected. The fault is programmed to apply a 9-cycle, single-phase to ground fault at t = 50s when the system has already achieved steady state.

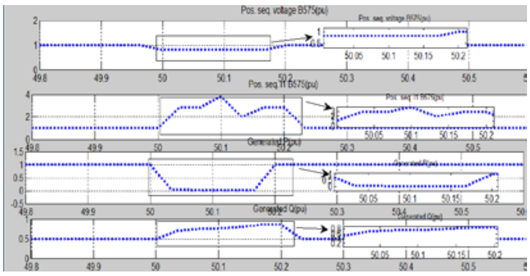


Figure. 7: Power and voltage profile of PCC pre-fault, during and post-fault conditions without compensation device.

From the above fig. 7 we observe that when an LG fault occurs on the high voltage transmission system&"Voltage regulation" mode is sected for the wind turbine , the positive-sequence voltage at wind-turbine terminals (V_B575) drops to 0.81pu at the time of fault, which is above the under-voltage protection threshold (0.75 pu for a t> 0.1 s). The wind farm, therefore,remains in operational condition. But the real enegy support for the system from the wind farm is zero amid the fault. As per the IEGC, wind farm must have the capacity to support, the grid during fault ought to produce real energy to the system to enhance the transient stability of the system. As in the case due to fault if some conventional unit is lost system will require spinning reserve support to cover the loss. The wind farm must be operate as a spinning reserve at the time of fault situation if system voltage has not fell, i.e.FRT capacity. Further, at the time offault, if there occurs under voltage, for proper function wind generator requires reactive power, that is drawn by generators from the grid in the absence of reactive power support. A state of over current is reached and thermal limit of the transmission line would be crossedinterfacing the wind farm to the grid. So disconnection of the wind farm from the grid would be required. Thus, the transient stability of the overall systemwould bereduced.Themagnitude of the voltage drop at the point of connection and time required to clear the grid fault are disiding factors for duration of Fault Ride Through.

Fault voltage and current profile at load bus away from a wind farm

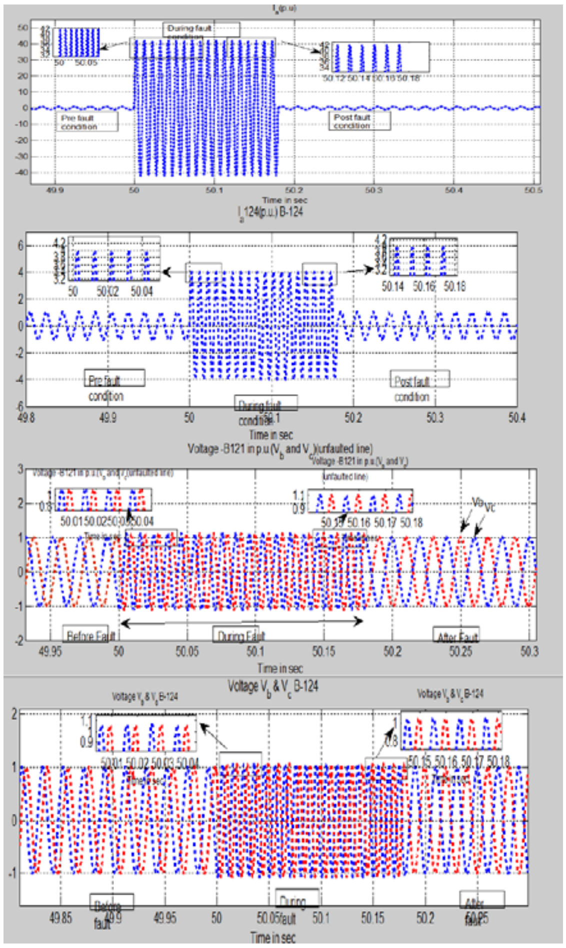


Figure 8 :(a) Current profile ia_121 during fault; (b) Current profile ib_124 during fault; (c)voltage profile v-bc_121 during at far buses in uncompensated system; (d) voltage profile V_bc_B124 during at far buses in uncompensated system

Fig. 8 shows the voltage and the change during the fault in the high volt network. It comprises of the vo1ltage and the variation in current at two buses which are named as bus_121 and bus_124. Here we have been able to conclude that during the time of fault voltage drop at mainly 0.6 in faulty phase, then the fault current is noted as 43.5 pu.

Matlab simulation result of compensated with upfc system under study

Without any kind of compensation, the system mainly ha sthe issue of the operations at the power factor, which is considered out of allowablelimit yetin service at the rated steady input wind speed and the voltage of output at the connection points. In the system of UPFC the common connection performance is drawn in fig. 11.

The result with & without UPFC has been shown. At constant wind speed as well as during the sudden wind transition and after geeting settled at the low level wind speed the magnitude of the voltage bus is common.

However, without the compensation of UPFC, the generation of reactive power is quite large for the under arted speed so that wind farm is operated at the leading pf which is less than 0.95. Even during the time of rated speed, the factor of power is +0.91 which basically should be in between ±0.95 which is the the range as per the instructions of IEGC.

Nowdays, the systems compensated with the UPFC at the common connection points the recative power generations is maintained at zero irrespective of the speed of the wind.

So, the generator of wind mainly operates at the factor of unity power at all kinds of speed.

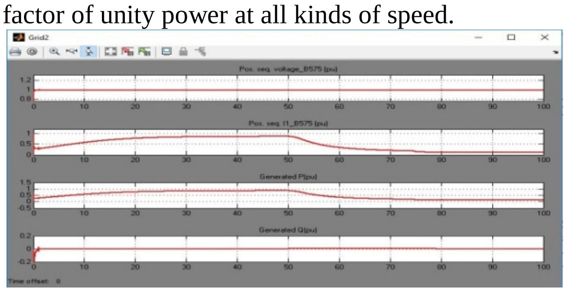


Figure. 9 : With the help of this graph we can show the real power (P) & reactive power (Q)at point of common coupling with variable wind speedwith UPFC.

Performance under fault in 120-kV grid system

Simulation is basicaaly carried with the fault at the grids side which causes the voltage sag at the bus of PCC at t= 50 s for the time cycle of mainly 9 cycles of ac. The performance of voltage at the points of common couplings is mainly examined at the time of fault without and with the connections of the UPFC towards the bus of PCC. The figure below depicts the voltage and reactvie power profile at the PCC at the pre fault during and even after post fault in the grid system compensation with the UPFC

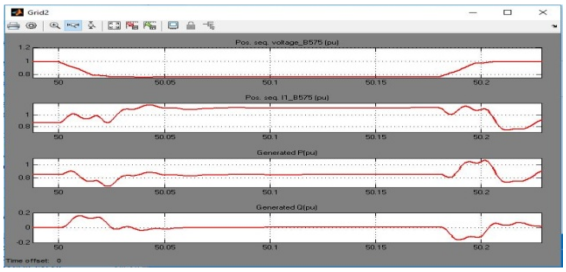


Figure 10 : Voltage, real and reactive power at PCC pre-fault, during and post-fault in UPFC compensated system.

As seen in the figure above the voltage at PCC drops to the level of 0.76 pu during the time period of LG fault in the grid, but the main real power support is regulated towards the grid from the wind farm which does not fall to the level of 0 as it can happen in the system of which are uncompensated system. During the timeing of the fault in the grid real power, basically all the support from wind falls to 0 from wind farm, but now when the system has been provided UPFC for compensation. The wind farms are offered the real powers towards grid thus improving the stability of the transient of the systems.

Figure no. 11 and Figure no. 12 reveals the voltage across the capacitor of DC link of the WTG (V_{DC}) without and with the compensation of UPFC respectively. With the connected UPFC towards the system, the overshooting and the time of settlement are mainly reduced in comparison to the systems without the connections of the UPFC.

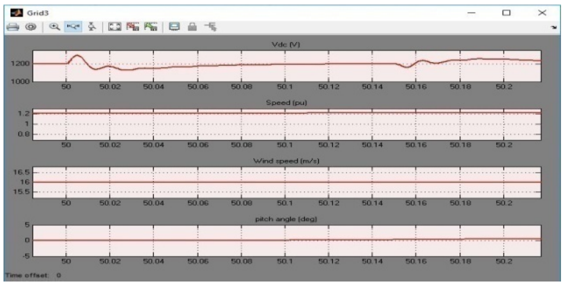


Figure 11: Voltage across the DC-link capacitor of the WTG at pre-fault, during –fault and post-fault in theuncompensated system.

As can be seen thorugh the DC volatge overshooting in the WTG is 1300 Vduring the faults and even falls down towrads the 1150V even when there is no compensation which is provided. In comparison to it, the maximum voltage attained is not more than 1275V and even falls to the level of 1190V only in the case of compensated system.

It is quite noticeable that during the normal conditions of operations, there is no such recative power exchanges in between the UPFC and the system of AC and the generation of power is also mainatned at level 0 for the purpose of achieving the unity power factor operations for the WTG.

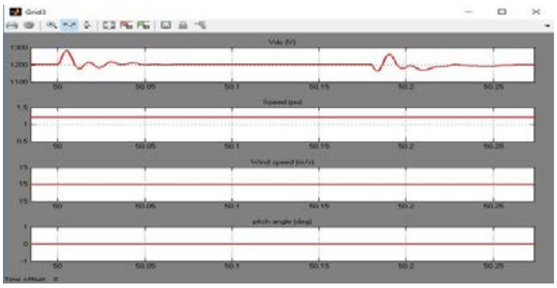


Figure 12 Voltage across the DC-link capacitor of the WTG at pre-fault, during –fault and post-fault in compensated system.

Fault voltage and current profile at high voltage system from wind farm in compensated system

The figure below reveals the voltage and the profile at the time of fault in the system of compensation.

From fig. no. 10. it is visible that during the time of fault the voltage level drops at mainly 0 level in faulty phase during fault however the currnt level decaresesconsiderably.These all effects increase the transient stability of the system overall.

5. CONCLUSION

It is concluded that the UPFC has significant impact in the situations where the fault location is changed.FRT will be improved at PCC in all conditions. If the fault location is very far to the UPFC, its impact is reduced. However, the fault current is also reduced. In our case, we will consider the single line to ground fault when the alternator is solidly grounded because this fault is not only the most severe fault but also frequently occurs in the power system.

The application of an UPFC has been investigated in this study to improve the Fault ride through (FRT) of wind energy conversion system in accordance to the grid codes of Indian and the United States Electricity. The outcome demonstrates that. In the absence of an UPFC, in order to protect the turbines from being damaged, there must be disconnected between the WTGs and the grid, amid voltage sag or swell conditions, since there might be some violation of a safety margin requirement of voltage at the PCC . To solve this particular problem, UPFC has significant importance as its presence can improve the FRT capacity, thus the connection between the grid and WTGs can be established and maintained during any such fault conditions. It also ensures the power delivery to the grid.

This paper utilizes and talks about the above control procedure for stifling undesirable electromechanical motions in power system with a Unified Power Flow Controller .This study investigates the improvement in the voltage stability margin and the power transfer capacity of the system with the consolidation of an UPFC.

A five-bus power system has been simulated using the MATLAB / SIMULINK software.The outcomes resulted from the load flow are captured for an uncompensated system and then subsequently voltage and the reactive power profiles are investigated.

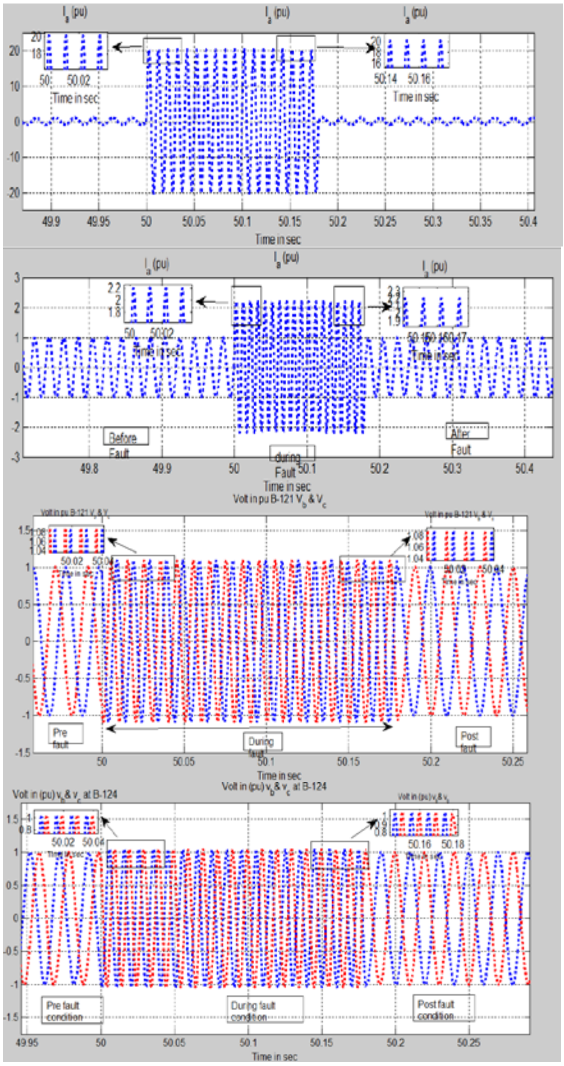


Figure 13 (a) Current ia_121_with_upfc profile during fault (b) Current ia_b124_with_upfc profile during fault (c) voltage voltage_b121_with upfc profile during at far buses in compensated system(d) voltage Vb124_with upfc profile during at far buses in compensated system

In the circuit, a diagram of fact solution the connection of the UPFC to the wind\ farm to provide voltage support.

The Unified power flow controller providing voltage control and a 'ride through' solution is presented in this work by a simple model of a stable speed wind farm with UPFC in MATLAB. The wind farm consists of 6x2MW fixed-speed, stall regulated wind turbines. The 'equivalent' turbine is assumed to respond in a coherent manner to the system disturbance. The short-circuit ratio at bus B575 is 10. For the simulation results, it was assumed that the 120 kV network was subjected to a three-phase fault along one of the parallel circuits, of 150 ms duration at 50 seconds. The faulty circuit is disconnected after the fault clearance. The main simulation results were produced by using MATLAB.

The voltage at the high-voltage point of connection of the wind farm (B575) is not able to recover the pre-fault voltage level after the clearance of the fault. That shows, the wind farm does not have the capacity to ride through the fault. However, with UPFC’s support,the responses show that the wind farm overcomes this weakness. The UPFC provides the required support to ride through the fault.

The voltage recovery of the wind farm because of the voltage support and reactive power compensation given by the UPFC. It can be watched that the UPFC provides certain reactive energy to the wind farm under normal operational conditions. Amid the fault, the reactive energy provided by the UPFC is generally reduced and then instantly after the fault, to compensate the margin requirement, the UPFC supplies an additional amount of reactive energy to the wind farm .Which helps the system recover and ride through this fault scenario.

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