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Grid Integration of Renewable Energy: A Case Study

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Abstract: India is considering renewable energy resources (RES) like solar and wind as alternative for future energy needs. As on March 31, 2012 the grid interactive power generation from RES is 24914 MW i.e. around 12.1 % of the total installed energy capacity. Further Ministry of New and Renewable Energy (MNRE), Government of India is targeting to achieve 20000 MW grid interactive powers through solar and 38500 MW from wind by 2022. However there are various issues related to grid integration of RES keeping in the view of aforesaid trends it becomes necessary to investigate the possible solutions for these issues. This paper presents the some issues and challenges encountered during grid integration of different renewable and how to overcome them.

I. INTRODUCTION

Out of the total generation of power, a large part of it is being met by the Conventional power sources like thermal, hydro, and nuclear. However, due to some inherent disadvantages like increased environmental impact, decreased water availability and radiation hazards of the conventional power sources more emphasis is being given to tap the non-conventional resources like solar, tidal, geothermal and wind energy in the present time.

Transient stability [1, 3] entails the evaluation of a power system's ability to withstand large disturbances and to survive the transition to another operating condition [2]. These disturbances may be faults such as a short circuit on a transmission line, loss of a generator, loss of a load, gain of load or loss of a portion of transmission network [4, 5].

Sequential method is used to determine the location of placing the static synchronous compensator. For distances over km, HVDC transmission offers several advantages over HVAC connection [9], i.e. the power flow is fully controlled, cable power losses are much lower and sending and receiving end frequencies are independent.

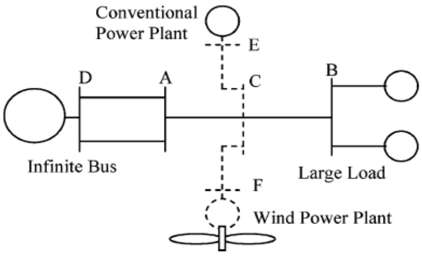

Fig1: Grid integration with wind power plant

II. PROBLEMS RELATED TO GRID CONNECTIONS

1) Voltage unbalance
2) Poor grid stability
3) Impact of low power factor
4) Power system Faults
5) Reactive power

III. HOW TO SOLVE ALL THESE PROBLEMS

Using doubly fed induction generators (DFIG) and constant speed wind turbine (CSWT) in wind resource can result in:

1) Enhancing transient stability
2) Damp out alternator output voltage
3) Minimize rotor angle variation
4) Reduction in time for clearing faults

IV. GRID CONNECTION OF WIND GENERATORS

The fixed-speed, squirrel cage induction generator (SCIG) is connected directly to the distribution grid through a two winding transformer. There is a gear box which maces the generator's speed to the frequency of the grid. During high wind speeds, the power extracted from the wind is limited by the stall effect of the generator. This prevents the mechanical power extracted from the wind from becoming too large. In most cases, a capacitor bank is connected to the fixed-speed wind generator for reactive power compensation purposes. The capacitor bank minimizes the amount of reactive power that the generator draws from the grid. Similarly, the doubly-fed induction generator

(DFIG) [6] has a gear box, but it is much more complex than the fixed speed generator. The generator is connected to the grid through a three winding transformer as opposed to a two winding transformer of the fixed speed wind generator. The stator is directly connected to the grid and the rotor through a Pulse-Width- Modulated converter. This converter decouples the generator from the grid and therefore allows variable speed operation. In high wind speeds, and fluctuating wind, the output power is kept relatively constant, but close to the rated power of the generator. The variable speed converter driven synchronous generator has a gear box and a low number of pole pairs, usually in the range of four to six as compared to the direct drive which has around eighty pole pairs. Similarly to the DFIG, the variable speed converter driven synchronous generator is coupled to the grid through a back to back converter. This converter can either be a voltage source or a diode rectifier and voltage source converters [7]. The power extracted from the wind is limited by the pitch control especially during high wind speeds.

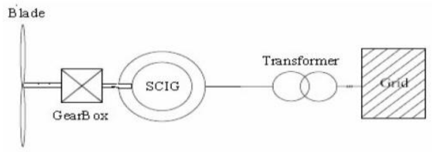

Fig 2: Schematic representation of the fixed speed induction generator

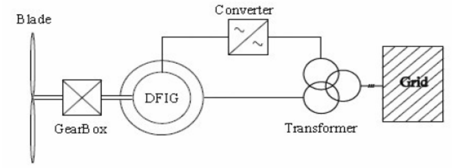

Fig 3: Schematic representation of the DFIG

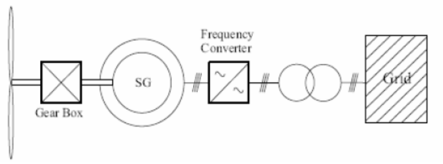

Fig 4: Schematic representation of the converter driven synchronous generator.

V. OTHER COMPONENTS INVOLVED IN GRID INTEGRATION

An automatic voltage regulator (or AVR for short) consist of several components such as diodes, capacitors, resistors and potentiometers or even microcontrollers, all placed on a circuit board. This is then mounted near the generator and connected with several wires to measure and adjust the generator. In the first place the AVR monitors the output voltage and controls the input voltage for the exciter of the generator. By increasing or decreasing the generator control voltage, the output voltage of the generator increases or decreases accordingly. The AVR calculates how much voltage has to be sent to the exciter numerous times a second, therefore stabilizing the output voltage to a predetermined set point

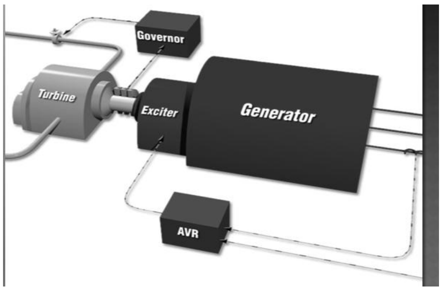

Fig 5: Automatic Voltage Regulator

Power system stability is the ability of an electric power system, for a given initial operating conditions, to regain a state of operating equilibrium after being subjected to a physical disturbance [6,8]. PSS are generator control equipments which are used in feedback to enhance the damping of rotor oscillation caused due to small signal disturbances. It enhances dynamic stability of the system, reduced power loss, and improved damping of the system.

Statcom: Electrical loads both generate and absorb reactive power. Since the transmitted load often varies considerably from one hour to the next, the reactive power balance in a grid varies as well. This can result in unacceptable variations in voltage amplitude, including voltage depression or even voltage collapse. Like an SVC, the STATCOM instantly and continuously provides variable reactive power in response to voltage transients, supporting the stability of grid voltage.

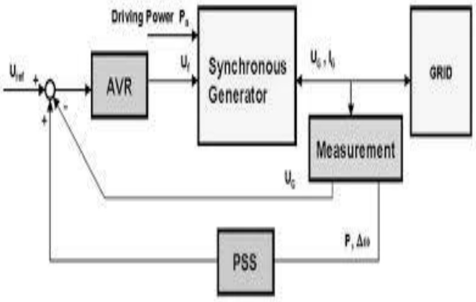

Fig 6: Static Compensator

VI. CASE STUDIES

Case 1.

The transient stability of the power system presented in Fig is attempted in this case. The parameters of the system have been taken [10]. The system consists of four machines and eleven buses divided into two areas. A three phase symmetrical fault is considered to occur at F as shown in the Fig. 3.1.

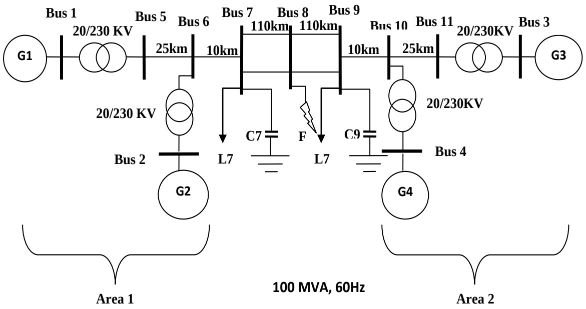

Fig 7: Basic power system with fault for transient

The fault is considered to occur from t=1sec to t=1.05sec. No power is transmitted to infinite bus during faults. The short circuit current flows through pure reactance to the fault. Hence, only reactive power flows and the active power P_e at the air gap is zero during the fault. It is also mentioned here that that the maximum power transfer occur when $\delta = 90^{O}$, beyond this limit the system is unstable.

The simulation results for this system are as shown in Fig. The rotor angle stability curves for all the alternators diverge into instability due to the fault which occurred in the system. The reason for the divergence of rotor angle is the acceleration of the rotor due to the fault taking place in the system.

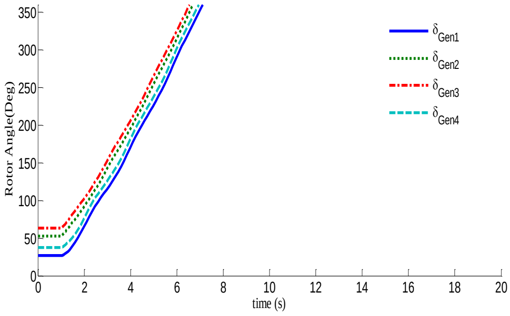

Fig 8: Rotor angle vs. time curve

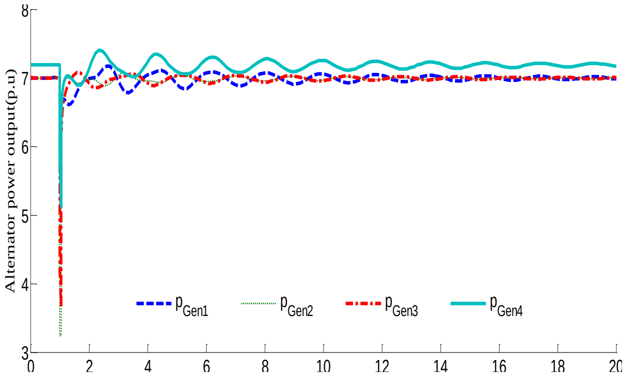

Fig 9: Alternator power output

The alternator power variation with time is presented in Fig. The power curves of all the alternators show a rapid power swing after the occurrence of a fault. These oscillations in power levels mainly are due to the rotor angle instability caused by the fault in the system [11].

The oscillations damp out after several seconds (20 secs or more). However, the power swings leads to undesirable tripping of protective relays even after the clearance of the fault. These power swings may lead to the variations in supply frequency. The voltage stability curves obtained by the time domain simulation are shown in Fig. The alternator terminal voltage variations show the voltage levels to lie well within the limits. However, there exists a small but persistent oscillation in the voltage levels. The oscillation in the voltage levels is due to oscillation in reactive power flow [12]. The oscillations in the voltage levels damp out after a few seconds (10 to 12 secs). However, the presence of oscillations can result in poor regulation and lead to a poor quality of suppl

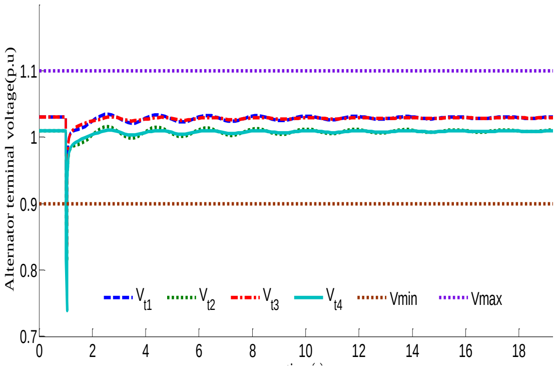

Fig 10: Oscillations in voltage level

Case 2

The power system presented in case 1 is investigated for the transient and voltage stability with embedded wind generation along with the conventional generation. The new system has same load conditions as in case 1. Fig. shows the wind integrated power system. The wind generator W is considered to be of doubly fed induction generator (DFIG) which gives a variable speed operation [13]. It also avoids the requirement of separate reactive power compensation using capacitor banks. The data for the DFIG are as given below.

Rating: 30 MVA, 20 KV.

Stator and rotor resistances and reactance’s are in p.u. of base 100 MVA.

$$R_s = 0.01 p.u.\ X_s = 0.1 p.u\ R_r = 0.01 p.u\ X_r = 0.08 p.u\ X_m = 3 p.u$$

$$H = 3\, {}^{kWs}\!/_{kVA}\ \text{No of poles P=4.}$$

The fault is considered to occur from t = 1sec to t = 1.05sec. The simulation results of the power system in Fig show the rotor angle variation with time.

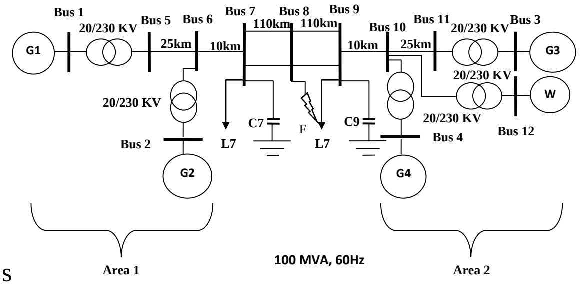

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Fig 11: Single Line Diagram of prototype model

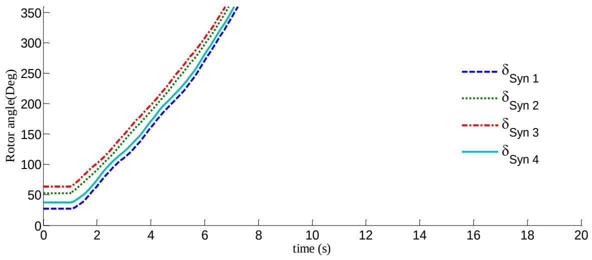

Fig 12: rotor angle variation

It is inferred from Fig that the wind integration into a power system deteriorates the rotor angle stability. However, the rate of deviation from stability limit is less for DFIG compared to the traditional constant speed wind turbines (CSWT).

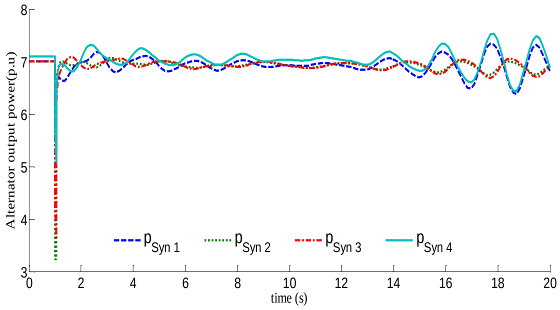

Fig 13: output power variation with time curves of the alternators in the power system.

It is seen that the oscillations in output power is more pronounced and is diverging when wind generation is considered. This diverging characteristic is owing to the diverging rotor angle and voltage levels. There exist rapid power oscillations which is following an un damped characteristic. These rapid power swings can cause an increase in wear tear of the alternator. It also causes rapid frequency oscillations. The variation in power levels and frequency levels can cause tripping of protective devices even after the fault is cleared.

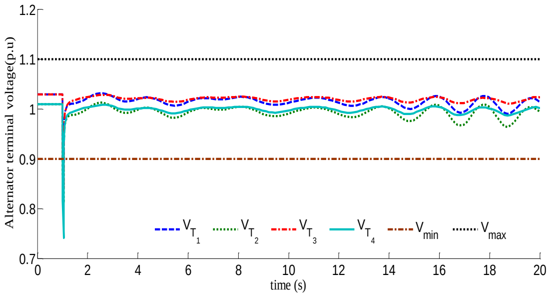

Fig 14: output power variation with time

It be inferred from Fig that there are oscillations in all the output voltages of all the alternators in the system. Also, these oscillations persist without any damping. The presence of these oscillations causes an oscillatory instability and subsequent tripping of voltage relays. Fig shows the terminal voltage of the DFIG wind farm. Due to the voltage control action of the converters associated with the DFIG it is seen to have a stable terminal voltage. There exists a small but persisting oscillation. However, due to the pitch angle control action by the DFIG the output power attains a stable value.

Case 3

The power system in case 2 is modified by adding excitation controllers namely automatic voltage regulator (AVR) and power system stabilizer (PSS). Fig. shows the modified power system.

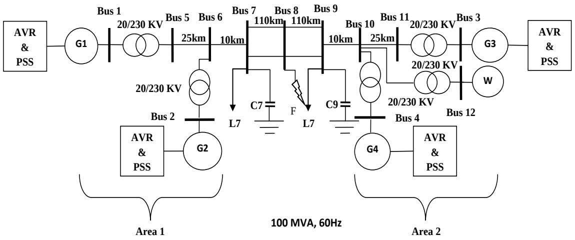

Fig 15: Analysis of output variation with time.

The excitation controller parameters are as quoted below. The fault is considered to occur from *t*=1 sec to *t*=1.05 sec. It is mentioned here that AVR regulates the terminal voltage of the alternator and PSS damps out the oscillations in the rotor speed. The simulation results are as given in Fig. shows the variation of rotor angle with time. It can be inferred from that the rotor angle shows a stable characteristic by reducing to a stable level below the critical limit $\delta=90^0$. It is due to an appropriate excitation control of the alternators. Further, it reduces the deviations from the stability limits and damp out the oscillations present in the alternator output.

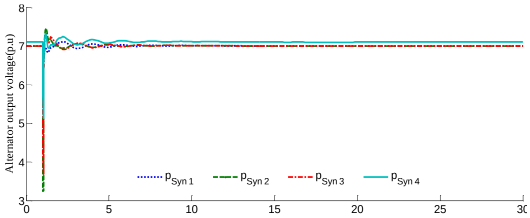

Fig 16: variation of output

It can be seen that the output power shows a constant rated value. The first swing oscillations are damped out early by the effect of PSS. Hence the reliable operation of the power system is ensured.

It is observed that initially the output power shows a high value compared to the stable value which is nearly 0.3 as shown in Fig. But due to the influence of pitch angle control of DFIG the power level is soon restored to the stable limits.

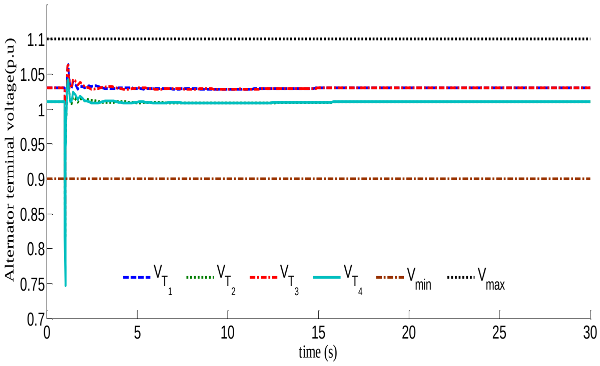

Fig 17: terminal voltage vs. time curve of the alternator.

VII. CONCLUSION

Various problems related to transient stability and voltage stability studies have been carried out for wind fed power system under various conditions. It has been established that with the integration of wind farm the transient and voltage stability problem are aggravated. However, with the addition of excitation controllers like AVR & PSS the stability and fault ride through of the system can be improved to a significant level.

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