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Stabilization of a Fixed Speed IG Based Wind Farm using Variable Speed PMSG

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Abstract

To optimize the output power and reduce the frequency fluctuation in conventional fixed speed Induction Generator (IG) based wind farm, various controlling devices are used. But, this paper proposes that Permanent Magnet Synchronous Generator (PMSG) can work both as a power producing device and as a controlling device for IG. In this paper a more practical case has been considered where a wind farm is operated with a set of Synchronous Generators (SG). Thermal, Hydro and Nuclear Governors have been used for SGs. Wind farm has a capacity of 20% of the total SG's capacity. Both two-level and three-level converter-inverter based PMSG have been considered. Comparative results between IG and IG with PMSG are shown. Simulation results prove the effectiveness of the proposed system. Simulations have been carried out by using the laboratory standard power system software package, PSCAD/EMTDC.

Keywords: frequency fluctuation; synchronous generator; governor; three-level converter; three-level inverter.

INTRODUCTION

Among the renewable energy sources, wind energy is one of the fastest growing sources. In 2010 wind energy production was over 2.5% of total worldwide electricity usage and it is growing rapidly at more than 25% per annum, the monetary cost per unit of energy produced is similar to the cost for new coal and natural gas installations [1]. Worldwide there are now over two hundred thousand wind turbines operating, with a total nameplate capacity of 282,482 MW as of end 2012 [2]. For a long time, Induction Generator (IG) has been the mostly used generator types for wind farm as a fixed speed wind generator. But the main disadvantage of IG is that, its output power, voltage and frequency fluctuates randomly with the varying wind speed. In most cases, capacitors are connected in parallel to the IG to compensate the reactive power consumption. But it cannot maintain the wind generator terminal voltage constant under randomly fluctuating wind speed [3]. Voltage or current source inverter based Flexible AC Transmission System (FACTS) devices such as Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), Dynamic Voltage Restorer (DVR), Solid State Transfer Switch (SSTS), and Unified Power Flow Controller (UPFC) have been used for flexible power flow control, secure loading and dumping of power system oscillations [4]. These FACTS devices are non-producing elements; moreover they increase the overall system costs of the fixed speed wind generator based wind farm.

In our previous work [5-6] it is seen that the performance of IG can be made better by using PMSG with it. But, this paper considers a more practical case. Here, a wind farm of a capacity of 20 MVA is operated along with a set of 4 SGs which has a total capacity of 100 MVA. Three types of governors are used for SGs, they are, thermal governor, hydro governor and nuclear governor. SG with thermal governor has a better response than hydro governor [7-8]. When different governors are used for SG, the condition becomes more critical since the different governors cannot respond so quickly with the response of the wind farm [8-10]. In [8] it is reported that though the thermal governor can control system frequency, but it cannot be maintained to the acceptable level when wind power capacity become 10% of total capacity. It is also presented that when several SGs with same total capacity are connected to the network, system frequency becomes more severe for 10% capacity of wind power. And this critical condition has been considered in this study and it is shown that a wind farm consisting of IG having a capacity of 20% can have a stable response if a PMSG of 1% is included with IG. It is shown that PMSG helps the fixed speed IG to reduce its output fluctuations and to provide necessary reactive power so that the set of SG with their different governors can respond even in this difficult condition and can have an allowable frequency deviation. Two types of combinations have been used for PMSG, both two-level and three-level converter-inverter set has been used and their performances have been compared.

SYSTEM LAYOUT

Three case studies have been considered in this paper. The cases are explained in the following paragraphs.

A. Case-1, A set of SGs along with an IG based wind farm

In this case an IG of 20 MVA has been connected with a set of four SG's having a total capacity of 100 MVA. Fig. 1(a) shows the schematic diagram of this case.

B. Case-2, A set of SGs along with an IG and PMSG (2-level converter-inverter set) based wind farm

In this case an IG (20 MVA) along with a PMSG (1 MVA) is connected with a set of four SGs (100 MVA). Here 2-level IGBT converter-inverter set has been used for PMSG. Fig. 1(b) shows the schematic diagram of this case.

C. Case-3, A set of SGs along with an IG and PMSG (3-level converter-inverter set) based wind farm

In this case an IG (20 MVA) along with a PMSG (1 MVA) is connected with a set of four SGs (100 MVA). Here 3-level IGBT converter-inverter set has been used for PMSG. Schematic diagram similar to Fig. 1(b) is used for this case.

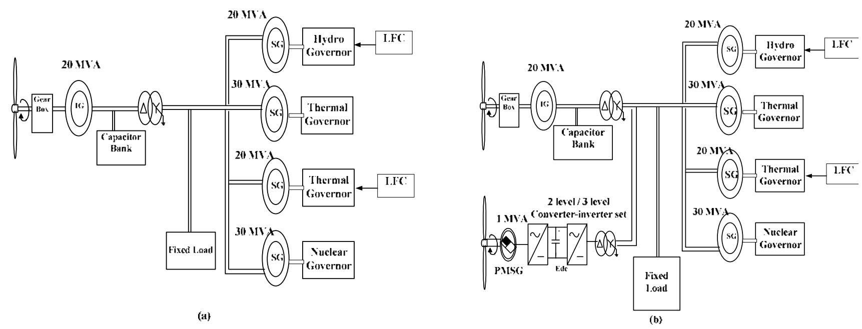


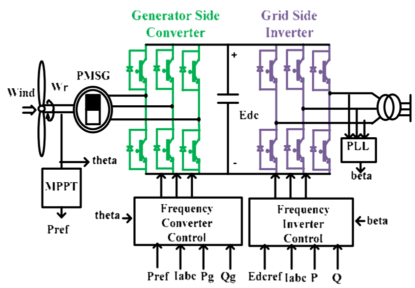
Fig. 1 Schematic diagram of (a) Case-1 and (b) Case-2 and Case-3.

PMSG MODELS

Two models of PMSG have been used in this study. Fig. 2 and Fig. 3 shows a VSWT-PMSG system which is modelled with two-level and three-level converter-inverter set respectively. The PMSG model available in the package software PSCAD/EMTDC is used [11]. The frequency converter consists of a generator side AC/DC converter, a DC link capacitor and a grid side DC/AC inverter. The converter/inverter used are standard three phase two-level unit, composed of six insulated gate bipolar junction transistor (IGBTs) and anti parallel diodes and three phase three-level unit composed of twelve IGBTs and anti parallel diodes. These full-rating power converters (generator side converter and grid side inverter) are linked by a DC bus. In both models the three phase AC output of the generator is rectified and the DC output from the rectifier is fed to an IGBT-based grid side inverter. Its output is fed to a step-up transformer and then to the grid. In both the converter and inverter, triangle signal is used as carrier wave of Pulse Width Modulation (PWM) operation. The carrier frequency is chosen 1000Hz. The DC link capacitor value is 50,000 μF. The rated DC link voltage is 1 pu. The grid side inverter control works to maintain the DC-link capacitor voltage at the set value, so that the active power can be exchanged efficiently from PMSG to the grid. It also controls the reactive power output to the grid in order to control the grid side voltage.

SYNCHRONOUS GENERATOR MODEL AND GOVERNOR

The governor is such a device which automatically adjusts the rotational speed of the turbine and the generator output. The turbine is operated at a constant rotational speed, when the generator load remains constant. However, when the load changes, balance between the generator output and the load is not maintained, and the rotational speed changes. When the load is removed, the governor detects the increase of the rotational speed, and then, the valve is closed rapidly so that an abnormal speed increase of the generators is prevented. The governors of [8] and [12] are considered in this study. The synchronous generator and Load Frequency Control (LFC) model used in [8] has also been used in this study.



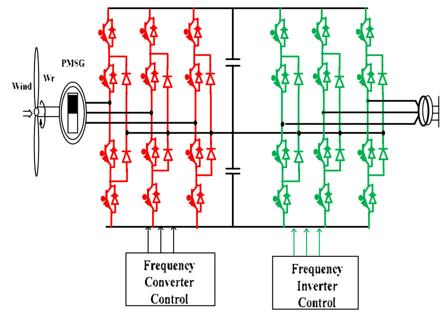
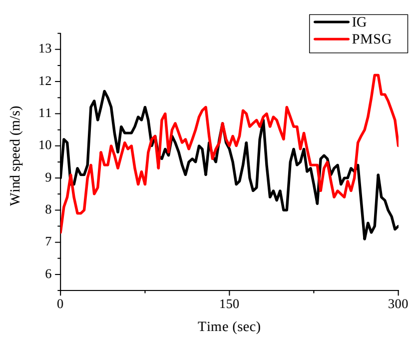


Fig. 2 Schematic Diagram of PMSG with 2-level IGBT converter-inverter set.

Fig. 3 Schematic Diagram of PMSG with 3-level IGBT converter-inverter set.

SIMULATION RESULTS

Simulations have been done by using the software PSCAD/EMTDC [11] for 300 seconds. Fig. 4 shows the wind speeds used for IG and PMSG in this simulation. Fig. 5 shows the real power response at the wind farm terminal. It is shown that, the response of IG is improved by using PMSG with 3-level converter-inverter set, while 2-level converter-inverter cannot provide good response. Fig. 6 shows the frequency response at the wind farm terminal. PMSG with 3-level converter-inverter maintains the frequency within the allowable range. Fig. 7 shows the terminal voltage of the wind farm. Here also 3-level converter-inverter PMSG provides the better response.



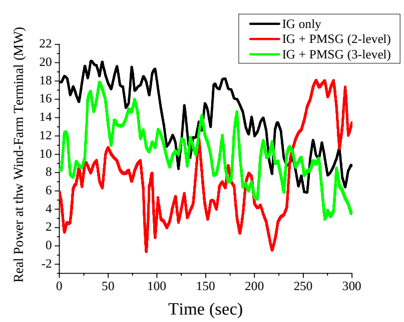


Fig. 4 Wind speeds used for IG and PMSG.

Fig. 5 Real power response at the wind farm terminal.

So, it is seen that for different combinations of governors of SG, a fixed speed wind farm of 20% capacity can have a stable response if a PMSG of 1% is included with it. A three-level converter-inverter set can provide this response. In this case the real power of the set of SGs can respond with that of the wind farm, i.e. when the power from the wind farm tends to decrease, the power of SG tends to increase and vice versa in order to maintain a constant power at the load side. Thus the system remains stable. This can be seen from Fig. 8. So, the power supplied to the load remains almost constant, as can be seen from Fig. 9.

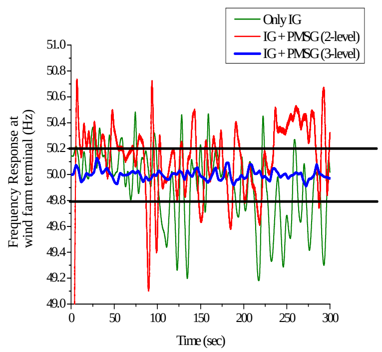


Fig. 6 Frequency Response at the wind farm terminal.

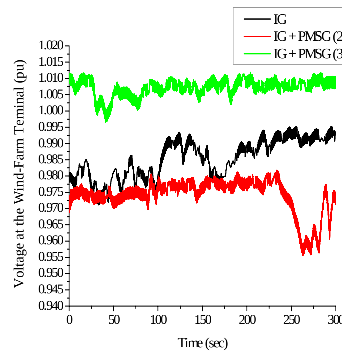


Fig. 7 Terminal Voltage at the wind farm.

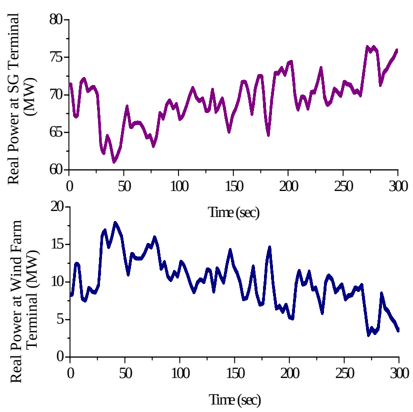


Fig. 8 Real power response at the SG terminal and wind farm terminal.

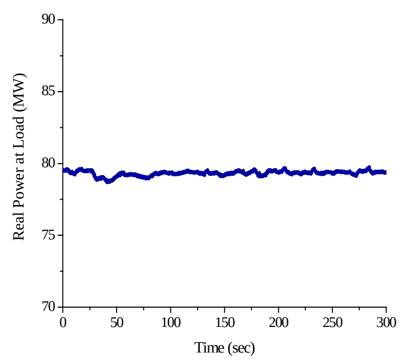


Fig. 9 Real power available at the load.

Hence, a wind farm consisting of PMSG with a three-level converter-inverter set along with IG is able to provide a stable and reliable output when connected to a set of synchronous generators with different governors. This model works not only in the steady-state condition, but also it is equally good in transient conditions. The voltage response during the transient condition follows the grid code set by Federal Energy Regulatory Commission (FERC) [13] shown in Fig. 10.

The transient response of the proposed model can be seen from Fig. 11-13. It can respond to a fault of the system quickly and can return back to the normal operating condition as soon as possible. In this simulation, a three line to ground (3LG) has been considered at 350th second and it is cleared within 0.05 seconds. The dynamic wind speed data shown in the Fig.4 has been considered for the transient condition to make the response of the proposed system more practical. Fig. 11 shows the voltage response which follows the grid code shown in Fig. 10. In Fig. 12, it is seen that the frequency fluctuation along the load side remains well within the limit (0.02Hz). Fig. 13 shows the real power at the load. Here also the response of the proposed model is reliable.

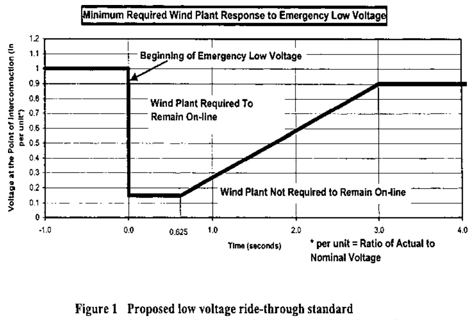


Fig. 10 Low voltage ride-through standard set by FERC, U.S. [13].

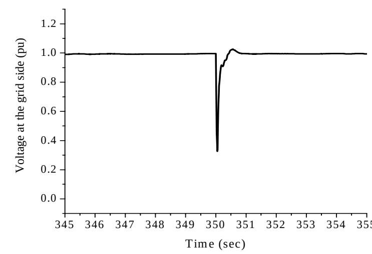


Fig. 11 Voltage at the load side (pu) during fault.

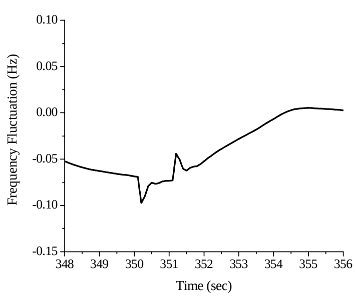


Fig. 12 Frequency fluctuation (Hz) at the load during fault.

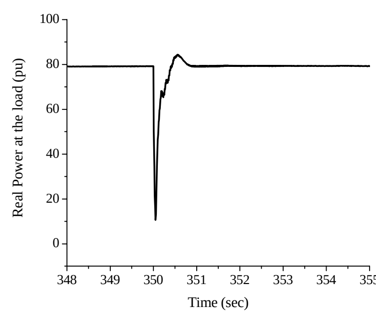


Fig. 13 Real power (pu) at the load side during fault.

CONCLUSION

The response of the wind farm connected with a system consisting of SGs with different governors becomes more critical. This critical case has been considered in this study and it is shown that an IG of capacity of 20% of the total system can provide a stable response if a PMSG of 1% is included with IG. PMSG consisting of a three-level IGBT converter-inverter set gives the best response. Simulation results prove the ability of the proposed model. SGs with their thermal, hydro and nuclear governor can respond with the output of the wind farm and provides a stable and maintained power at the grid. Moreover this model is also capable of providing a better response during transient condition, that is, during a severe fault. It can respond to the fault quickly and can return back to the previous state very within an allowable time as defined by the grid code. Thus the system becomes stable. Therefore the system has proved its better quality and improved reliability.

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