SVC, STATCOM, and Transmission Line Rating Enhancements On Induction Generator Driven By Wind Turbine

Janmejay vyas[1]
[1]Department of Electrical Engineering
[1]RMS Polytechnic

Abstract — Multi-megawatt wind-turbine systems, often organized in a wind park, are the backbone of the power generation based on renewable-energy systems. This paper presents the effect of some system parameters like rating of capacitor bank, static var compensator SVC rating, static synchronous compensator STATCOM rating and transmission line length, on performance of induction generator driven by wind turbine. Also, the most-adopted wind-turbine systems, the adopted generators the topologies of the converters, the generator control and grid connection issues, as well as their arrangement in wind parks. This study is based on the SimPowerSystems for use with Matlab/Simulink.

I. INTRODUCTION

Most of the electricity generated today uses non-renewable sources of fuel such as coal, oil and gas. These contribute to large quantities of CO_2 to the atmosphere, and cause an enhanced greenhouse effect, leading to the warming of the earth's atmosphere. The increasing rate of depletion of conventional energy sources has increased emphasis on renewable energy sources to provide the growing demand. The adverse effects of conventional systems have given rise to a shift in focus towards renewable energy sources such as wind, solar, hydro, tidal wave, biomass, and so on. As already known, renewable energy sources have virtually no adverse effects on the environment. The Global Wind Energy Council GWEC [1] states that wind energy developments have occurred in more than 70 countries around the world.

Induction machines are mostly used as generators in wind power based generations. Since induction machines have a performance problem as they draw very large reactive currents during fault condition, reactive power compensation can be provided to improve performance. This part presents general review and previous work of wind turbine and wind generators [2-4]. Also, it is intended to provide an overview of Static VAR Compensator SVC and Static Synchronous Compensator STATCOM in order to provide the merits and applications of Flexible AC Transmission System FACTS to the operations of transmission and distribution systems [5-9]. In the present work, three applications of SVC, and STATCOM, and transmission line length variations of rating are studied, on performance of Induction Generator IG driven by wind turbine. The simulation studies of the wind turbine system connected to grid are performed using MATLAB/SIMULINK SimPowerSystems toolbox.

II. WIND-TURBINE SYSTEM OVERVIEW

The most-common wind-turbine systems and the control issues are reviewed here [10-13]. Wind-turbine systems directly coupled to the grid and/or without any power converter directly or indirectly controlling the rotor speed will not be taken into consideration. The electrical generators currently used for the implementation of multi-MW Wind-Energy Conversion System WECSs are the doubly fed induction generator DFIG, the cage induction generator IG, and the synchronous generator SG. The DFIG is widely used for variable-speed generation and is one of the most important generators for wind-energy applications [12-15]. Nowadays, this topology has a fraction of the wind-energy market, which is close to 50%. For a typical DFIG, the power converters are connected to the rotor and, for a restricted speed range, are rated at a fraction of the machine nominal power [14], i.e., typically 30% of this value. The speed range is limited, and slip rings are required in order to connect the machine-side converter to the rotor. For WECSs based on DFIGs, gearboxes are still required because a multi-pole low-speed DFIG is not technically feasible [12]. The WECS speed is regulated, adjusting the electrical torque via the rotor-side converter. The speed regulation is mostly used to optimize the power extraction from the wind. However, the possibility of controlling the active power and the reactive power gives to this system the rolling capacity on the grid [16-17] because the active-power injection is controlled not only with the pitch or active stall but also via the machine-side pulse-width-modulation PWM converter.

The squirrel-cage induction generator SCIG is a very popular machine due to its mechanical simplicity and robust construction [12]. The rotor is provided by metallic bars, which are resistant to the effects of dirt and vibration. Unlike the DFIG, no brushes are required for the operation of this machine, and little maintenance is necessary, mainly bearing lubrication only. The SCIG was widely used in fixed-speed WECS, and it is still used for variable-speed wind-energy generation [12]. The IG with a frequency converter is completely decoupled from the grid, and as a consequence, this system has a complete rolling capacity. The control system of a WECS based on a SCIG and on back-to-back converters could be designed to avoid increasing the short-circuit power because the control loops limit the fault current at the grid-side converter output. The main drawbacks of the SCIG are in the fact that two full power converters are required for the operation of this machine and that a multi-pole direct-drive operation is not technically feasible [12]. Therefore, SCIGs do not have the advantage of variable-speed operation using reduced-size power converters, SCIGs can neither be used in direct-driven WECS.

The two subsystems, the electrical and mechanical ones that compose the WECS are characterized by different control goals but interact in view of the main aim, the control of the power injected into the grid. The electrical control system regulates the supply of the active/reactive power to the grid [16-17]. The electrical system also provides overload protection. The mechanical subsystem is responsible of the power limitation, the maximum energy capture, the speed limitation, and the reduction of the acoustical noise [18-19]. The power has to react based on a set point given by the power-grid dispatch center or locally with the goal to maximize the production based on the available wind power [19]. The control of the WECS electrical subsystem can be divided into three different stages. The first stage includes the basic functions that guarantee the proper operation of the power converters, hence taking care of voltages and currents on the generator side, in the intermediate direct-current dc link if present, and on the grid side [11]. The second stage includes the WECS specific functions, hence the maximization and the limitation of the power. The control of the WECS is organized such that below the maximum power production, the wind turbine will typically vary the speed proportional to the wind speed and keep the pitch angle fixed [18]. At very low wind, the speed of the turbine will be fixed at the maximum allowable slip in order not to have overvoltage. A pitch-angle controller will limit the power when the turbine reaches the nominal power. The third stage includes extra functions that will become crucial in the future power system, characterized by a significant inflow of the distributed power generation. The WECS is expected to contribute and improve the power quality, to offer energy storage to buffer the energy production, and to contribute to the grid stability with the inertia-emulation functionality. In this sense, the transmission-system operator may also provide a supervisory command to take advantage of these extra functions when required.

III. SVC AND STATCOM OVERVIEW

Induction generator based wind parks usually draw a large amount of reactive power that leads to problems of stability both in steady-state and during transients. In addition, transmission system operators TSO nowadays put strict requirements on ride-though capability. The wind parks themselves cannot fulfill these requirements without reactive power support devices. Recent technology gives several solutions for this, of which conventional switched capacitor CAP, static var compensator SVC, and static compensator STATCOM are usually applied. Many studies on low voltage ride-through capability RTC of wind parks with these support devices have been performed. For example, the influence of STATCOM on the transient stability margin of squirrel-cage generator based wind parks has been studied in [20]. Applying a STATCOM to an existing wind park with fixed-speed induction generators to prevent voltage collapse caused by serious network disturbances has been conducted in [21]. Reference [22] presents a method to compare the performances of STATCOM and SVC on RTC. In earlier works, STATCOM has been identified as the fastest responding device that can assist in improving power quality and fault ride through of wind farms [23]. It has been also shown that it is technically practical to apply electricity storage to wind generation that may be installed on the grid to improve throughput of existing grid infrastructure, reduce system loss and improve power factor [24]. Battery energy storage is an extremely well proven storage technology with low losses [25].

Different solutions are found to support the transient behavior of cage induction generators in case of changes in the grid voltage. Mechanically switched capacitors, SVC, synchronous condensers and voltage source SVC such as the STATCOM can be used to regulate voltage as shunt compensator to improve the grid interface of directly connected

IV. STUDIED SYSTEM AND MODELING

The mathematical models of wind turbine, and wind generators are presented in this section. The general concepts of FACTS controllers modeling are explained in steady-state. The wind farm using Induction Generators IG driven by variable-pitch wind turbines test system is utilized.

A. Wind Turbine Model

The wind turbine model employed in the present study is based on the steady-state power characteristics of the turbine. The stiffness of the drive train is infinite and the friction factor and the inertia of the turbine are combined with those of the generator coupled to the turbine. The wind turbine mechanical power output is a function of rotor speed as well as the wind speed and is expressed as:

In this studied a constant pitch angle β is used and its value is assigned as zero, the based speed is selected at 9m/s. The turbine power characteristics of the model are shown in Fig. (1), and it shows how PWT varies with rotor speed for different wind speeds. The optimum tip speed ratio curve gives the highest efficiency points for PWT. As seen from figure, rated power 3MW (1pu) occurs at rated wind speed of 9m/s.

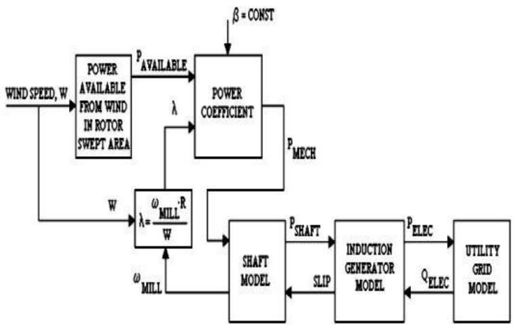

Fig. 1

B. WTIG

The block diagram of WTTIG is shown in Fig. (4), and the stator winding is connected directly to the 60Hz grid and the rotor is driven by a variable pitch wind turbine. The power captured by the wind turbine is converted into electrical power by the induction generator and is transmitted to the grid by the stator winding. The pitch angle is controlled in order to limit the generator output power to its nominal value for high wind speeds. In order to generate power the IG speed must be slightly above the synchronous speed. The pitch angle controller regulates the WT blade pitch angle β, according to the wind speed variations. Hence, the power output of WTIG depends on the characteristics of the pitch controller in addition to the turbine and generator characteristics. This control guarantees that, irrespective of the voltage, the power output of the WTIG for any wind speed will be equal to the designed value for that speed.

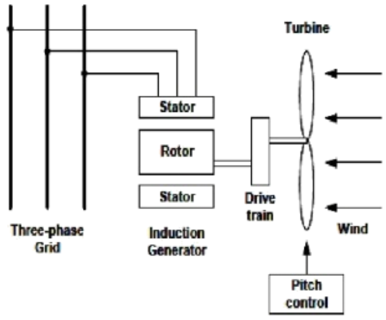

Fig. 4: WTIG block diagram

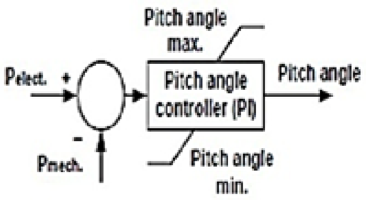

Fig. 5: Pitch angle control

The pitch angle β is controlled in order to limit the generator output power at its nominal value for winds exceeding the nominal speed. β is controlled by a Proportional-Integral PI controller in order to limit the electric output power to the nominal mechanical power. When the measured electric output power is under its nominal value, β is kept constant at zero degree. When it increases above its nominal value the PI controller increases β to bring back the measured power to its nominal value. The pitch angle control system is shown in Fig. (5).

C. SVC Modeling

The primary task of an S VC is to maintain the voltage at a particular bus by means of reactive power compensation.

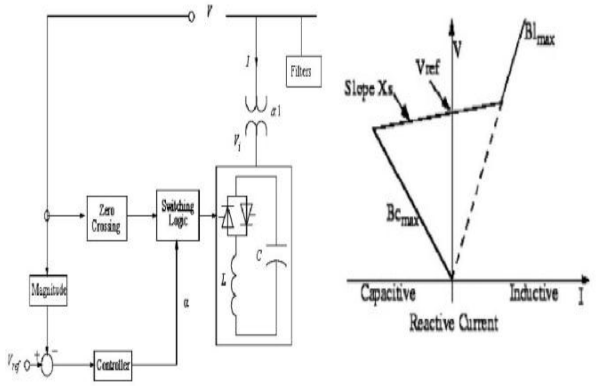

Fig. 6: SVC voltage control system

SVC is basically a shunt connected Static Var Generator SVG whose output is adjus ted to exchange capacitive or inductive current so as to maintain or control specific power system variables. Figure (6) shows the single-line diagram of a SVC and a simplified bloc k diagram of its control system. A typically, the power system control variable controlled by SVC is the terminal bus voltage, and tota l susceptance of SVC can be controlled by firing thyristors. Consequently, it represents the controller with variable impedance that i s changed with the firing angle of TCR. The terminal or V-I characteristics of SVC is illustrated in Fig. (7).

V. CONCLUSIONS

Three applications of FC, SVC, and STATCOM to wind farm are studied to improving the performance of WTIG. In both cases the system behavior was analyzed and is discussed using steady state phasor simulation and results are confirmed. The performance study considered active power from each WTIG, and active power injected to the network. Also, reactive power to each WTIG, and reactive power absorbed from network, reactive power compensation, Wind Turbine speed, and Voltage at feeder bus. This paper presents the choice of the best parameters to improve the performance of WTIG, these parameters such as FC rating, SVC rating, STATCOM rating and TL length.

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