Study on Hybrid Solar Wind Power System with PMSG for Power Enhancement Using Ai Technique

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ABSTRACT

This paper reviews different permanent magnet synchronous generator (PMSG) operated in wind energy systems and solar energy systems. A complete survey has been made towards the new contributions for harmonic compensation and new efficient topologies in the last five years to improve the efficiency, reliability and cost of the wind energy system. Different power electronic converters, which are connected between generator and the load/grid, have been investigated on based on harmonic compensation, efficient working, and high power rating conversion. The wind generation system is still a challenge to extract smooth power from wind. To improve the power quality of the system such as islanding problem and power variation, different renewable storage systems are discussed and compared. Finally, discussion about the different controller is presented to fulfill the load or grid requirement.

I. INTRODUCTION

The power supply from mere conventional sources is unable to cater to modern power demand and thus raising the issue of power reliability and security while the huge amount of pollutants pose serious environmental issues. In last two decades, renewable and distributed energy sources have emerged as a supplement to conventional energy sources and are foreseen by utility engineers as a potent solution in fulfillment of load demand in successfully overcoming the power issues. Hybrid Renewable Energy Systems based Distributed Generation (DG) is the recent trend in the renewable energy system as it has shown to improve the overall performance and reliability. Numerous opportunities have been put forward for effectively exploiting several renewable energy sources for electricity generation. Among all the trending renewable energy resources, wind and solar energy sources combined together have been used efficiently in diverse hybrid systems. Recently, Solar PV-Wind hybrid systems received significant attention from the utilities worldwide. Wind and solar energy systems complement each other during a day cycle. Solar energy, having a potential of even providing as high as four times the total global energy demand in a certain region of North Africa, is present throughout the day while strong winds mostly occur during nocturnal period. Usually, strong winds are observed in the course of the night time as well as cloudy days in contrast to weak winds occur during bright days. Irrespective of their intermittent behavior and inherent drawbacks, Wind-PV hybrid energy systems are used to supply energy to load with greater reliability and continuity of supply.

II. LITERATURE REVIEW

F. Mazouz et al. [1] In this paper, we propose a vector control of a doubly fed induction generator (DFIG) for variable speed wind power generation. The model is developed based on the dual powered generator for the control of the active and reactive powers. Several studies are carried out to test their operation under different wind conditions. The results have shown good performances of the wind energy converter system operate under wind variations with indirect vector control strategies.

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S. Engelhardt et al. [2] This paper discusses the steady-state reactive power loading capability of DFIG-based WTs by taking into account the most important physical phenomena restricting the reactive power supply of DFIG-based WT systems. The active-reactive power diagram is systematically derived by considering the typical power-speed relationship and converter loading limits. The authors discuss also some special operating modes limiting the reactive power capability together with aspects of modeling and control that give rise to these limitations.

T. Lund et al. [3] The aim of the work is to derive a steady state PQ-diagram for a variable speed wind turbine equipped with a Doubly Fed Induction Generator. Firstly, the dependency between optimal rotor speed and wind speed is presented. Secondly, the limitations in reactive power production, caused by the rotor current, the rotor voltage and the stator current are derived. Thirdly, the influence of switching from Δ to Y coupling of the stator is investigated. Finally, a complete PQ diagram for a wind turbine is plotted. It is concluded that the limiting factor regarding reactive power production will typically be the rotor current limit, and that the limit for reactive power absorption will be the stator current limit. Further, it is concluded that the rotor voltage will only have a limiting effect at high positive and negative slips, but near the limitation, the reactive power capability is very sensitive to small changes in the slip.

D. Santos-Martin et al. [4] In this paper present synchronous generator reactive power capability has been extensively treated in the bibliography, reactive capability of doubly fed asynchronous generator (DFAG) has not yet been studied. This kind of generator is widely used in wind energy, and its reactive power capability must be known in order to plan the reactive capability of wind farms as required by grid codes. Active and reactive power output of DFAGs can be expressed as a function of the terminal voltage and the internal voltage, allowing the graphical representation of the power capability limits in a similar way as the synchronous generator.

III. GRID STABILITY IMPROVEMENT BY REACTIVE POWER

Several measures can be taken to improve static and dynamic reactive power reserves in the power grid. Usually it is achieved by deploying reactive power support devices, such as on-load tap changing (OLTC) transformers, excitation control, switchable and non-switchable shunt capacitors/ reactors, synchronous condensers, and flexible AC transmission system (FACTS) devices (e.g. static synchronous compensators (STATCOMs)) [5]. Various techniques have been employed by researchers using these elements to stabilize the power grid, and provide adequate reactive power support to network. Some wind generators based on asynchronous machines (e.g. squirrel-cage induction machines (SCIMs) in fixed speed wind generators (FSWGs)) cannot contribute to the voltage regulation as they absorb reactive power during steady-state operation [6]. However, variable-speed wind generators (VSWG) with PEC interface, such as the doubly-fed induction generator (DFIG) can provide reactive power. Unfortunately, rotor converter rating of the DFIG is limited to only steady-state requirements to keep this technology within a reasonable cost margin. Therefore, the reactive power capability of the DFIG is not adequate as the primary safeguard during transient conditions. Similar limitations could be experienced with the full-converter wind generators (FCWGs). Hence, FACTS devices are used in wind farms to improve voltage stability using their dynamic reactive power capability. Excitation controllers also play an important role in reactive power compensation in power systems. Yet this type of controllers lack accuracy as they are designed considering static load models. Although VSWG technologies, such as DFIGs are more widely used due to their superior control capabilities, they have very limited dynamic reactive power reserve in comparison to the synchronous generators. Nevertheless, PEC interfaced STATCOM devices could be used to improve the dynamic reactive power capability of wind farms to comply with grid-codes.

IV. GRID CODE REACTIVE POWER COMPLIANCE REQUIREMENTS FOR REGS

With the increasing renewable power penetration levels in power networks, the grid operators (e.g. transmission system operators (TSOs) and distribution system operators (DSOs)) have started to stipulate strict grid-codes for REGs on fault ride-through (FRT), reactive power management and voltage control. Aforementioned, reactive power strongly influence on network steady-state voltage, and voltage recovery...
during system contingencies, hence grid-codes specify both steady state and dynamic reactive power capabilities for REGs. The grid-code specifications for FRT and voltage control are also closely related with the static and dynamic reactive power requirements for REGs. Therefore, reactive power grid-code requirements set for the wind generators and PEC interfaced generators (e.g. solar PV) are discussed in following subsections [7].

![Diagram of wind generator configurations]

**FIGURE 1.** Typical wind generator configurations: i) Fixed-speed wind generator (FSWG); ii) Limited variable-speed wind generator; iii) Doubly-fed induction generator (DFIG); iv) PEC interfaced fully-fed AG based FCWG; v) Electrically excited synchronous generator based FCWG; and vi) Permanent Magnet synchronous generator (PMSG) based FCWG

**V. REACTIVE POWER CAPABILITY OF WIND GENERATORS**

Wind generators are typically categorized into four (4) types: 1) Type-1: Fixed-speed wind generator (FSWG) (based on SCIG), 2) Type-2: Limited variable-speed wind generator (based on wound rotor induction generator (WRIG)), 3) Type-3: Doubly-fed induction generator (based on WRIG), and 4) Type-4: Full-converter wind generator (FCWG). The FCWGs can be further subdivided depending on the generator type (e.g. permanent magnet synchronous generator (PMSG) and electrically excited synchronous generator). Figure 5 shows typical wind generator configurations. It must be noted that both the SCIG and the WRIG machines are also known as the asynchronous generator (AG). The first and most simple configuration is the FSWG, which directly connects the SCIG to the grid, and a gearbox is used in the drive-train to maintain the constant rotational speed [8]. This type of wind generators produce real power when the shaft rotational speed is greater than the electrical frequency of the grid (i.e. when producing a negative slip), however these generators consume reactive power. For a given wind speed, the operating speed of the turbine varies linearly with the torque. The mechanical inertia of the drive-train limits the rate-of-change of electrical power output under varying wind conditions. This configuration is depicted in Figure 1 (i). There is no active or reactive power control scheme, except the pitch angle control (PAC) scheme maintains the maximum power point (MPP) and curtails the wind power extraction at high wind speeds. To avoid high transient starting current, a soft-start device is used in FSWGs. Figure 1(ii) shows a limited variable-speed wind generator (Type-2), which is almost similar to the FSWGs. However, variable resistors are connected to the rotor circuit of this type of wind generators to provide limited variability in rotational speed. The variable resistors can control the rotor current depending on the wind gust conditions, and can also improve the dynamic response during grid disturbances. The Type-3 wind generators are commonly known as the doubly-fed induction generators (DFIGs), and the configuration of the DFIG is illustrated in Figure 1(iii). In this type of wind generators, the stator circuit is connected to the grid directly, and the rotor is connected via a back-to-back PEC interface, by making it a doubly-fed machine. Because of the superior active and reactive power controllability of the DFIG, this wind generator type is heavily being used in the wind power industry, and hence substantial research has been conducted on DFIGs during last 15 years to improve their performance [1]–[3]. The Type-4 wind generators (also known as the FCWG) use a fully-rated PEC interface to connect with the grid, and three different configurations are shown in Figure 1(iv)-(vi). The Figure (iv) shows a FCWG based
on the AG, and the WRIG is mostly used as the AG. The FCWG configurations based on synchronous generators can either be excited electrically via slip rings as shown in Figure 1(v), or they can be self excited permanent magnet synchronous generators (PMSGs) as shown in Figure 1(vi).

**VI. REACTIVE POWER CAPABILITY OF SOLAR-PV GENERATORS**

Having no rotating magnetic field or coil arrangements, the solar-PV systems supply power through an inverter.

Solar-PV panel itself does not have any reactive power support as it produces electricity using photovoltaic effect. However, the inverter used for DC/AC conversion can provide significant amount of reactive power support during normal operating conditions or even in fault conditions. The solar inverter also provides other ancillary services, such as MPPT control, LVRT etc [9]. Although, reactive power support is not yet mandatory for solar-PV systems in most grid codes, as the penetration level increases more controllability over active and reactive power will become a necessity. A typical single-phase grid connected solar-PV system is illustrated. There are several reactive power compensation techniques implemented by researchers for solar-PV systems. Traditionally, this is done by employing a control scheme in the inverter control circuit. These techniques along with some others are discussed in the following subsections.

**VII. STATCOM**

Hingorani first proposed the concept of STATCOM in 1976. A STATCOM is a FACTS device usually consisted of a VSC, a controller, and a step-up transformer or coupling reactor as shown in [Fig. 3]. It is typically used at the PCC of a wind farm or solar-PV generator for reactive power compensation and voltage control. By turning on/off the VSC switches (e.g. IGBTs) of the STATCOM, the output voltage of the VSC is regulated, and hence the output current can be controlled. The current and power equations of the STATCOM are given in equation.

\[
I = \frac{V_o - V_{pcc}}{X_c}
\]

\[
P = \frac{V_o V_{pcc}}{X} \sin(\alpha - \theta)
\]

\[
Q = \frac{V_o (V_o - V_{pcc} \cos(\alpha - \theta))}{X}
\]

It is evident from the above equations that, either capacitive or inductive current can be achieved by regulating the VSC output voltage, Vo. For the values of Vo larger than Vpcc, the STATCOM will operate in the capacitive mode, whereas for the values of Vo smaller than Vpcc it will operate in inductive mode. The active and reactive current characteristics of a STATCOM are illustrated. STATCOM has been extensively used along with REGs for reactive power.

**VIII. ARTIFICIAL INTELLIGENCE**

Artificial intelligence (AI) is the simulation of human intelligence processes by machines, especially computer systems. These processes include learning (the acquisition of information and rules for using the information), reasoning (using rules to reach approximate or definite conclusions) and self-correction. Particular applications of AI include expert systems, speech recognition and machine vision.

AI can be categorized as either weak or strong. Weak AI, also known as narrow AI, is an AI system that is
designed and trained for a particular task. Virtual personal assistants, such as Apple's Siri, are a form of weak AI. Strong AI, also known as artificial general intelligence, is an AI system with generalized human cognitive abilities. When presented with an unfamiliar task, a strong AI system is able to find a solution without human intervention.

IX. CONCLUSION

A comprehensive review of recent literature reported on reactive power management in power grids with high penetration of REGs was presented in this paper. According to the review, many grid codes specify steady-state reactive power requirements for REGs, however only few grid-codes specify dynamic reactive power requirements. Nonetheless, with the increasing renewable power penetration levels, it is becoming a necessity for all grid operators to specify dynamic reactive power requirements for REGs in their grid codes to maintain a stable and a reliable power grid.

Various reactive power support devices are also used in power grids, and PEC interfaced devices (e.g. STATCOMs) offer much better dynamic reactive power compensation capability in comparison to conventional devices, such as capacitor banks. However the controlling of these devices are now a days in hand of AI based techniques which can be modified for further enhancement.

REFERENCES


