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Modelling & Simulation of Fuzzy Based Grid-Connected Wind-Photovoltaic Cogeneration Using Back-to-Back Voltage Source Converters

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ABSTRACT—This paper introduces a new topology, yet simple and efficient, for a grid-connected wind-photovoltaic (PV) cogeneration system. A permanent magnet synchronous generator-based fullscale wind turbine is interfaced to the utility-grid via back-to-back (BtB) voltage-source converters (VSCs). A PV solar generator is directly connected to the dc-link capacitor of the BtB VSCs. No dc/dc conversion stages are required, and hence the system efficiency is maximized. The proposed topology features an independent maximum power point tracking for both the wind and the PV generators to maximize the extraction of the renewable energy. The regulation of the VSCs is achieved via the vector control scheme in the rotating reference frame. The detailed small signal models for the system components are developed to investigate the overall stability. The influence of the utility-grid faults on the performance of the proposed system is also evaluated. Nonlinear time-domain simulation results under different operating conditions are presented to validate the effectiveness of the proposed topology.

Index Terms--AC-DC power converters, DC-AC power converters, maximum power point trackers, permanent magnet machines, solar power generation, wind power generation.

I.INTRODUCTION

The cost of the wind and solar energy generation has been rapidly falling since the last decade. Driven by their economic and technical incentives, the global installed capacity of photovoltaic (PV) and wind generators has approached 303 Gigawatt (GW) and 487 GW in 2016, as compared to 6 GW and 74 GW in 2006, respectively [1]. Due to the intermittent and unregulated nature of the wind and solar energy, power-electronic converters are utilized as an interfacing stage to the load-side or the utility-grid, and hence distributed generation units are created [2]-[3]. In literature, most of the distributed generation systems are solely dedicated for one form of renewable resources, e.g., a solar energy as in [4]-[5] or a wind energy as in [6]-[8]. In order to maximize the benefits of the available renewable resources, the combination of the wind and solar energy in the same vicinity has been considered [9]-[22]. The cogeneration of the wind and solar energy has the following characteristics; 1) the availability of the wind and solar energy is generally complementary, and hence combining both forms of energy increases the overall operational efficiency [23]. 2) the combination of the wind and solar co-generators optimizes the utilization of lands resources, and hence improves the capital investments [24]. 3) as compared to the static PV generators, the wind-solar cogeneration systems are more dynamically capable to support the utility-grid due to the available moment of inertia in the mechanical system of the wind generators [8]. 4) having two sources of energy increases the generation reliability [9]- [10]. The grid-connected wind-PV cogeneration systems are not widely addressed [9]-[10]. On the contrary, several wind-PV cogeneration systems are proposed for the standalone off-grid applications. A standalone wind-PV cogeneration system is proposed. On the small-scale level, a single-phase cogeneration system has been proposed in [18] whereas a laboratory-scale system is introduced.

Generally, the system structure in [16]-[20] comprises a common dc-bus that interfaces several parallel connected converters-interfaced renewable energy resources, which might reduce the overall system efficiency and increase the cost [12]. More importantly, the cascaded connection of power converters requires rigorous controllers coordination to avoid the induced interactions dynamics, which might yield instabilities. A back-toback (BtB) voltage-source converter (VSC) connected to a doubly-fed induction generator is used to interface a dc-dc converter-interfaced PV generator and an energy storage unit in [21]. In [22], a PV generator charging a battery bank and interfaced to a wind driven induction generator via a VSC is proposed. The wind-PV cogeneration systems in [21]-[22] highlights the efficient integration of the renewable energy resources with the minimal utilization of power-electronic conversion stages. However, these systems are proposed for specific off-grid applications. In [12]-[14], the utility-grid integration of the renewable energy resources has been improved

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by using multiple-input converters. A buck/buck-boost fused dc-dc converter is proposed in [12].

A dc-dc converter with a current-source interface, and a coupled transformer is proposed in [13] and [14], respectively. However, the proposed systems in [12]-[14] are based on the dc power distribution which might not be the ideal distribution medium in the ac-dominated power systems. Up to the authors' best knowledge, the combination of the grid-connected wind-PV systems has been solely addressed in [15]. The system in [15] comprises a BtB VSCs to interface the PV and wind generators to the utility-grid. On the machine-sideVSC, the dc-link voltage is regulated to the maximum powerpoint tracking (MPPT) value of the PV panels by an outer loop proportional-and-integral (PI) dc voltage controller. The reference values of the machine-side currents are calculated using the synchronous detection method, and a hysteresis current controller is utilized for the regulation. On the grid-side-VSC, a hysteresis grid-current controller is used to inject the total currents into the utility-grid. In spite of the potential benefits of the proposed system in [15], the following challenges are noted; 1) the MPPT of either the PV and wind power involves the operation of both VSCs, which in some cases might decreases the system reliability and increases the losses. For instance, if the wind velocity is lower than the cut-off speed of the wind turbine, i.e., no wind power, the machine-side VSC may be unable to track the solar PV MPPT dc-link voltage [15]. 2) the currents of the machine and grid-side converters are regulated using hysteresis controllers resulting in a variable switching frequency and higher harmonic contents. Motivated by the promising benefits of the wind-PV generation systems, this paper introduces a new topology, yet simple and efficient to interface both the wind and PV generators into the utility-grid. The contributions of this paper are as following; 1) The realization of the grid-connected wind-PV cogeneration system using BtB VSCs with no extra dc/dc conversion stages. 2) Independent MPPT operation where the MPPT of the wind and PV generators is solely achieved by the voltage-source rectifier (VSR), and the voltage-source inverter (VSI), respectively. 3) The development of the complete small-signal state-space model of the wind-PV cogeneration system to characterize the overall system stability. 4) The performance of proposed system has been investigated under different operating conditions, including the utilitygrid faults, using time-domain simulations.

II.LITERETURE SURVEY

The use of distributed energy resources is increasingly being pursued as a supplement and an alternative to large conventional central power stations. The specification of a power-electronic interface is subject to requirements related not only to the renewable energy source itself but also to its effects on the power-system operation, especially where the intermittent energy source constitutes a significant part of the total system capacity. In this paper, new trends in power electronics for the integration of wind and photovoltaic (PV) power generators are presented. A review of the appropriate storage-system technology used for the integration of intermittent renewable energy sources is also introduced. Discussions about common and future trends in renewable energy systems based on reliability and maturity of each technology are presented

This paper proposes a control strategy for a single-stage, three-phase, photovoltaic (PV) system that is connected to a distribution network. The control is based on an inner current-control loop and an outer DC-link voltage regulator. The current-control mechanism decouples the PV system dynamics from those of the network and the loads. The DC-link voltage-control scheme enables control and maximization of the real power output. Proper feedforward actions are proposed for the current-control loop to make its dynamics independent of those of the rest of the system. Further, a feedforward compensation mechanism is proposed for the DC-link voltage-control loop, to make the PV system dynamics immune to the PV array nonlinear characteristic. This, in turn, permits the design and optimization of the PV system controllers for a wide range of operating conditions. A modal/sensitivity analysis is also conducted on a linearized model of the overall system, to characterize dynamic properties of the system, to evaluate robustness of the controllers, and to identify the nature of interactions between the PV system and the network/loads. The results of the modal analysis confirm that under the proposed control strategy, dynamics of the PV system are decoupled from those of the distribution network and, therefore, the PV system does not destabilize the distribution network. It is also shown that the PV system dynamics are not influenced by those of the network (i.e., the PV system maintains its stability and dynamic properties despite major variations in the line length, line X / R ratio, load type, and load distance from the PV system)

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II.WIND POWER

Wind is abundant almost in any part of the world. Its existence in nature caused by uneven heating on the surface of the earth as well as the earth's rotation means that the wind resources will always be available. The conventional ways of generating electricity using non renewable resources such as coal, natural gas, oil and so on, have great impacts on the environment as it contributes vast quantities of carbon dioxide to the earth's atmosphere which in turn will cause the temperature of the earth's surface to increase, known as the green house effect. Hence, with the advances in science and technology, ways of generating electricity using renewable energy resources such as the wind are developed. Nowadays, the cost of wind power that is connected to the grid is as cheap as the cost of generating electricity using coal and oil. Thus, the increasing popularity of green electricity means the demand of electricity produced by using non renewable energy is also increased accordingly.

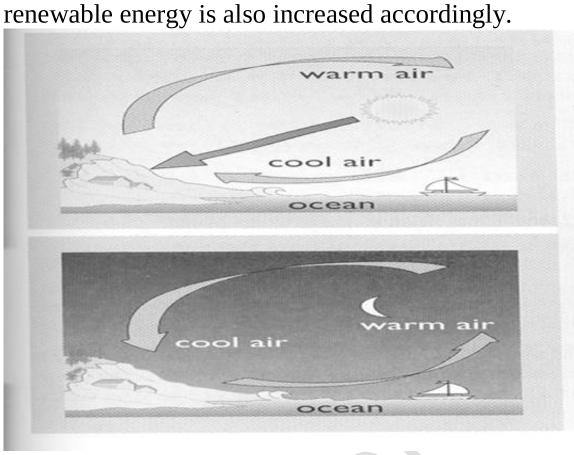

Fig: Formation of wind due to differential heating of land and sea

Power from the Wind:

Kinetic energy from the wind is used to turn the generator inside the wind turbine to produced electricity. There are several factors that contribute to the efficiency of the wind turbine in extracting the power from the wind. Firstly, the wind speed is one of the important factors in determining how much power can be extracted from the wind. This is because the power produced from the wind turbine is a function of the cubed of the wind speed. Thus, the wind speed if doubled, the power produced will be increased by eight times the original power. Then, location of the wind farm plays an important role in order for the wind turbine to extract the most available power form the wind.

The next important factor of the wind turbine is the rotor blade. The rotor blades length of the wind turbine is one of the important aspects of the wind turbine since the power produced from the wind is also proportional to the swept area of the rotor blades i.e. the square of the diameter of the swept area.

Hence, by doubling the diameter of the swept area, the power produced will be four fold increased. It is required for the rotor blades to be strong and light and durable . As the blade length increases, these qualities of the rotor blades become more elusive. But with the recent advances in fiberglass and carbon-fiber technology, the production of lightweight and strong rotor blades between 20 to 30 meters long is possible. Wind turbines with the size of these rotor blades are capable to produce up to 1 megawatt of power.

IV.PROPOSED SYSTEM AND CONTROL DESIGN

MODELING AND CONTROL OF THE PROPOSED WINDPHOTOVOLTAIC COGENERATION SYSTEM

As shown in Fig. 1, the proposed system consists of a VSR to interface the wind generator, and a VSI to connect the cogeneration system into the utility-grid. The PV generator is directly connected to the dc-link capacitor of the BtB VSCs via a dc cable [27]. The VSR and VSI are two-level converters consisting of six cells; each comprises an insulated-gate-bipolartransistor (IGBT) in parallel with a diode. In the following subsections, the complete modeling and control of the proposed system is provided.

A. Wind Generator

A full-scale wind turbine (FSWT) utilizing a permanent magnet synchronous generator (PMSG) is selected for its low maintenance and low operational cost [2]. The wind turbine model is represented as following

$$P_m = \frac{1}{2} C_p(\beta, \lambda) \rho \pi R^2 v_{wind}^3,$$
$$\lambda = \frac{R\omega_r}{v_{wind}}$$

where Pm" is the mechanical power captured by the wind turbine blades; Cp' is the rotor coefficient which is a non-linear function of the blade pitch angle (϶) and the tip-speed ratio (λ); ρ is the air density; is the radius of the wind turbine blade; Vwind 1234 is the wind speed; and Wr? is the mechanical speed of the rotor. In this paper, ϶ is set to zero in the normal operating conditions to maximize the wind power generation [13]. The PMSG is modeled as following

$$\bar{v}_s = R_s \bar{\imath}_s + L_s \frac{d\bar{\imath}_s}{dt} + j\mathrm{P}\omega_r(\psi + L_s \bar{\imath}_s)$$
$$J\frac{d}{dt}\omega_r + \beta\omega_r = \frac{3}{2}\mathrm{P}\psi I_{sq} - T_m$$

In (2), Vs A and Is A are the stator voltage and current in the complex vectors representation, respectively, where a complex vector N such that are the direct and quadrature components of in the rotating reference frame; A are the stator-winding resistance and inductance, respectively; is the imaginary unit number; is the flux linkage of the rotor magnets; Ƥ is the number of poles pairs; is the mechanical torque; whereas are the motor inertia, and viscous friction, respectively

B. **Machine-Side Voltage Source Rectifier (VSR)**

Fig. 2 shows the relationship between the mechanical rotor speed and the generated wind-turbine power at different wind speeds. At any wind speed, there is an optimal value of the mechanical rotor speed that corresponds to the generation of the maximum wind power. The extraction of the maximum wind power is achieved by the VSR in Fig. 1. The MPPT algorithm for the wind generator (MPPT1) uses the wind speed to generate the optimal value of the rotor speedfollowing the mechanical characteristics in Fig. 2 [17], [19]. As shown in (4), a PI speed controller is implemented to regulate the rotor speed to the optimal value and dictates the -component of stator current reference, whereas the -component of stator current reference is set to zero to operate at the maximum produced torque.

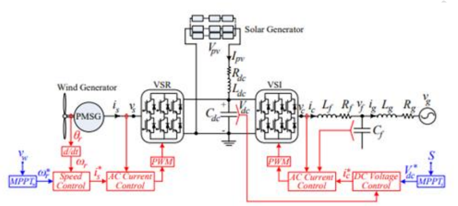

Fig. 1. The proposed wind-PV cogeneration system.

VI.SIMULATION RESULTS

A time-domain simulation model for the hybrid system in Fig. 1 is developed under the Matlab/Simulink® environment to evaluate the validity and the performance of the system. The wind and PV generators are rated at 2.0 and 0.9 MVA, respectively. The complete model entities are built using the SimPowerSystem® toolbox. The VSCs are simulated using average-model-based blocks. The simulation type is discrete with a sample time of 50 μs. In the following subsections, the proposed wind-PV cogenerator is subjected to theoretical challenging operating conditions which might not occur in the realty, e.g., large step variations in the wind speed and the solar irradiance levels, and three-phase-to-ground (3PG) faults conditions. These worst-case scenarios are applied to challenge the system stability and show the effectiveness of the designed controllers.

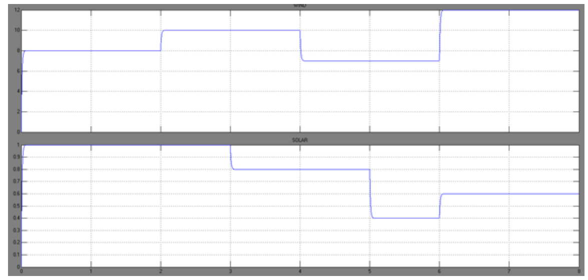

Fig: Wind speed and solar irradiance levels.

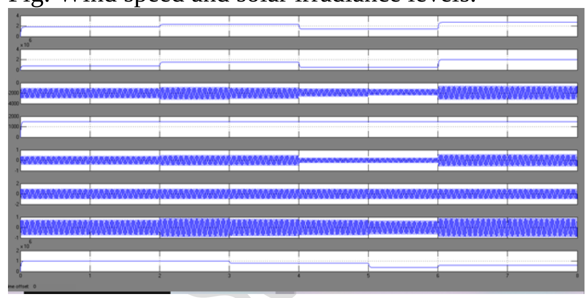

Fig . Performance of the wind-PV cogeneration scenario

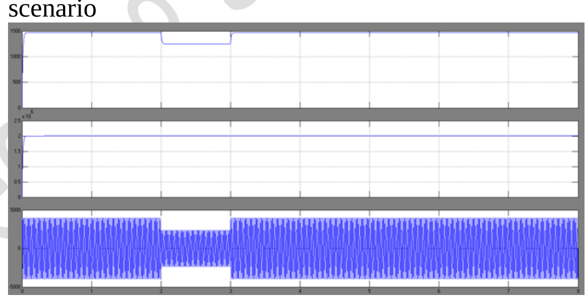

Fig . System performance at the wind-only generation scenario.

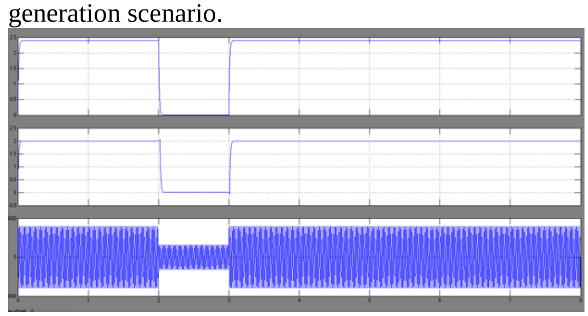

Fig .8. System performance at the PV-only generation scenario

VII.CONCLUSION

This THESIS has presented the wind-PV cogeneration systems using vector-controlled grid-connected BtB VSCs. The VSR at the wind generator-side is responsible for extracting the maximum wind power following the wind speed variations. On the utility-grid side, the roles of the VSI are to extract the maximum PV power from the PV generator, achieve the balance between the input-output powers across the dc-link capacitor, and to maintain a unity PCC voltage under different modes of operation. A small-signal stability analysis has been conducted for the entire system. The proposed system has the following advantages; 1) the increased reliability and efficiency due to the combined wind and PV generators. 2) the independent MPPT extraction as the VSR and VSI are solely responsible for extracting the wind and PV powers, respectively. 3) the regulation of the dc-link voltage under all operating conditions is maintained by the VSI and hence a better damped performance is yielded. 4) simple system structure and controllers design. 5) fault-ride through can be achieved using existing protection schemes. A well-damped performance has been presented using time-domain simulations results under the Matlab/Simulink® environment.

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