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Control Strategy For Wind Energy And Hybrid Generating Systems Based On The Concept Of Power Electronics

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Abstract-

The global electrical energy consumption is still rising and there is a steady demand to increase the power capacity. Deregulation of energy has lowered the investment in larger power plants, which means the need for new electrical power sources may be increased in the near future. In general, this paper discusses role of modern power electronics in small size wind energy and hybrid generating systems. A new and simple control method for maximum power tracking by employing a step-up dc-dc boost converter in a variable speed wind turbine system, using permanent magnet machine as its generator, is introduced. Output voltage of the generator is connected to a fixed dc-link voltage through a three-phase diode rectifier and the dc-dc boost converter. A maximum power-tracking algorithm calculates the reference speed, corresponds to maximum output power of the turbine, as the control signal for the dc-dc converter.

This paper also proposes a hybrid energy system consisting of a wind turbine, a photovoltaic source, and a fuel cell unit designed to supply continuous power to the load. A simple and economic control with dc-dc converter is used for maximum power extraction from the wind turbine and photovoltaic array. Due to the intermittent nature of both the wind and photovoltaic energy sources, a fuel cell unit is added to the system for the purpose of ensuring continuous power flow.

Keywords-Wind Power Systems, Photovoltaic power systems, Hybrid power system, Grid Integration, Power Converter, Control.

I.Introduction

With the rising cost and limited availability of fossil fuels, much attention has been focused on the use of renewable energy sources for electrical power generation. Renewable Energy Sources are those energy sources which are not destroyed when their energy is harnessed. Human use of renewable energy requires technologies that harness natural phenomena, such as sunlight, wind, waves, water flow, and biological processes such as anaerobic digestion, biological hydrogen production and geothermal heat. Among these, tapping wind energy with wind turbines appears to be the most promising source of renewable energy. Wind energy conversion systems are used to capture the energy available in the wind to convert into electrical energy. The power electronics is changing the basic characteristic of the wind turbine from being an energy source to be an active power source.

The standalone solar photovoltaic and wind systems have been promoted around the globe on a comparatively larger scale. These independent systems cannot provide continuous source of energy, as they are seasonal. For example, standalone solar photovoltaic energy system cannot provide reliable power during non-sunny days. The standalone wind system cannot satisfy constant load demands due to significant fluctuations in the magnitude of wind speeds from hour to hour throughout the year. Therefore, energy storage systems will be required for each of these systems in order to satisfy the power demands. Usually storage system is expensive and the size has to be reduced to a minimum possible for the renewable energy system to be cost effective. The power generated from both wind and solar components is stored in a battery bank for use whenever required. A hybrid renewable energy system utilizes two or more energy production methods, usually solar and wind power. The other advantage of solar / wind hybrid system is that when solar and wind power production is used together, the reliability of the system is enhanced. Additionally, the size of battery storage can be reduced slightly as there is less reliance on one method of power production. Often, when there is no sun, there is plenty of wind.

II. MODERN POWER ELECTRONICS

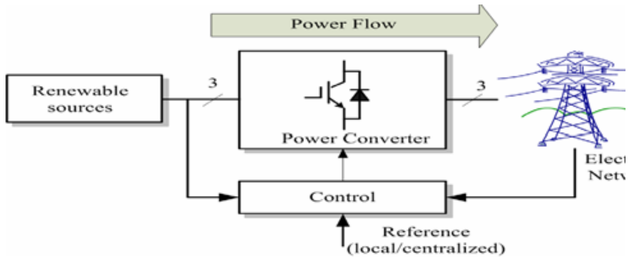

Figure 1. Power electronic system with the grid, renewable source, power converter and control.

The power converter is the interface between the generator and the grid. Typically, the power flow is unidirectional from the generator to the electrical network. Three important issues are of concern using such a system namely the reliability, the efficiency and last but not least the cost. Currently, the cost of power semiconductor devices is decreasing 1÷5 % every year for the same output performance and the price pr. kW for a power electronic system is also decreasing. The breakdown voltage and/or current carrying capability of the components are also continuously increasing. Important research is going on to change the material from silicon to silicon carbide, which may dramatically increase the power density of power converters as well as their voltage capability.

III. WIND ENERGY CONVERSION

Wind turbines capture power from the wind by means of aerodynamically designed blades and convert it to rotating mechanical power. The number of blades is three in a modern wind turbine. For multi-MW wind turbines the rotational speed is typically 10-15 rpm. The most weight efficient way to convert the low-speed, high-torque power to electrical power is to use a gear-box and a standard generator including a power electronic interface as illustrated in Figure 2.

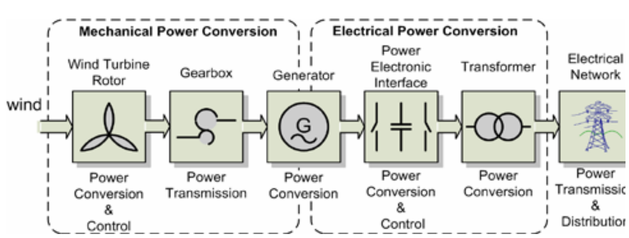

Figure 2. Power conversion stages in a modern wind turbine (based on [14]).

A typical power electronic system, consisting of a power converter, a renewable energy source and a control unit, is shown in Figure 1.

The gear-box is optional as multi-pole generator systems are also possible solutions. Between the grid and the generator a power converter can be inserted. The electrical output can either be AC or DC.

IV. PHOTOVOLTAIC ENERGY CONVERSION SYSTEMS

Photovoltaic energy systems consist of arrays of solar cells which create electricity from irradiated light. The yield of the photovoltaic systems (PV) is primarily dependent on the intensity and duration of illumination. PV offers clean, emission-less, noise-free energy conversion, without involving any active mechanical system. Since it is all electric it has a high life time (> 20 years) [20]. Fig. 3 shows a PV system.

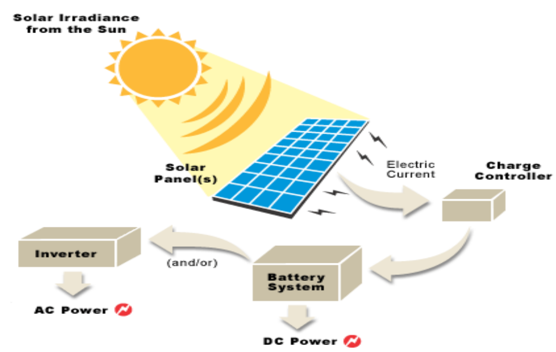

Figure. 3 Photovoltaic system

A lot of work is being done to enhance the efficiency of the solar cell which is the building block of PV. In this regard the focus is mainly on electro-physics and materials domain. Some of the existing PVs and their efficiencies are [2]:

1. Crystalline and multi-crystalline solar cells with efficiencies of ~11 %.
2. Thin film amorphous Silicon with an efficiency of ~10%.
3. Thin-film Copper Indium Diselenide with an efficiency of ~12% .
4. Thin film cadmium telluride with an efficiency of ~9%.

PV panels are formed by connecting a certain number of solar cells in series. Since the cells are connected in series to build up the terminal voltage, the current

flowing is decided by the weakest solar cell [2], [20]. Parallel connection of the cells would solve the low current issue but the ensuing voltage is very low (< 5 V). These panels are further connected in series to enhance the power handling ability. The entire PV I. To interconnect the individual solar panels – two solar panels cannot be identical hence a dc-dc converter interfacing the two will help maintain the required current and voltage, and with regulation improve the overall efficiency. Several non-isolated dc-dc converters have been employed for this purpose. Buck, buck-boost, boost, and Cuk topologies with suitable modifications can be employed for this purpose [2].
II. To interface the dc output of the PV system to the grid or the load - This includes the topics of dc-dc-ac and dc-ac-ac conversion.

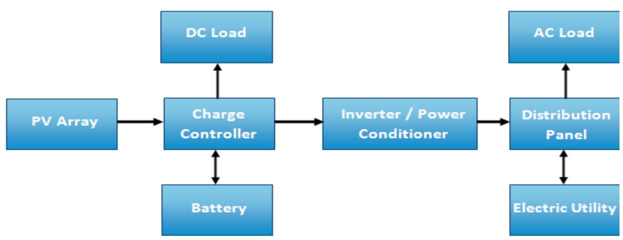

Figure 4 Grid connected PV system

V. Hybrid System Configurations:

A block diagram of the proposed integrated wind PV generating system is shown in Figure 5 . This configuration can be used for the study of stand-alone systems as well as network-connected systems. In this case, if the demand is greater than the sum of generation, then power must be supplied by the utility. Furthermore, if the total generated power is greater than the demand, then the excess generation is dumped to an external voltage-controlled resistive load. The purpose of incorporating a dumped load into the system is to preserve the stability of the system frequency and voltage. If the excess energy cannot be dissipated usefully, then it must be disposed as heat by a controlled resistor. The scope of the project is constrained to certain assumptions. The Peak Power Trackers will keep the wind and PV generators operating at their maximum power operating points. The system is assumed to be connected to the utility throughout and isolated PV panels and/or wind turbines are not taken into consideration. No battery storage or back-up generators are used in the system. The inverter used for DC/AC conversion as shown in Figure 5, is assumed to be an ideal one; that is, its efficiency is assumed as cent percent.

system can be seen as a network of small dc energy sources with PE power conditioning interfaces employed to improve the efficiency and reliability of the system. The role of PE is mainly two fold:

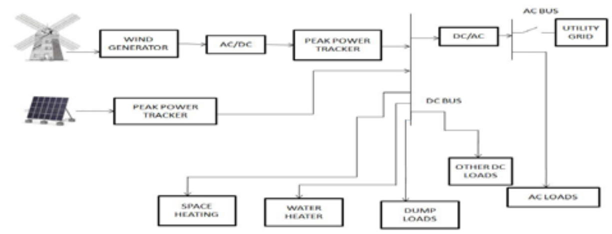

Figure 5: Overall scheme of the proposed system

VI. POWER CONVERTER TOPOLOGIES FOR WIND TURBINES

Basically two power converter topologies with full controllability of the generated power are currently used in the commercial wind turbine systems. These power converters are related to the partial-rating power converter wind turbine and the full-rating one. However, other topologies have been proposed in the last years.

A. Bi-directional back-to-back two-level power converter

The back-to-back Pulse Width Modulation-Voltage Source Converter (PWM-VSC) is a bi-directional power converter consisting of two conventional PWM-VSCs. This topology is shown in Figure 6.

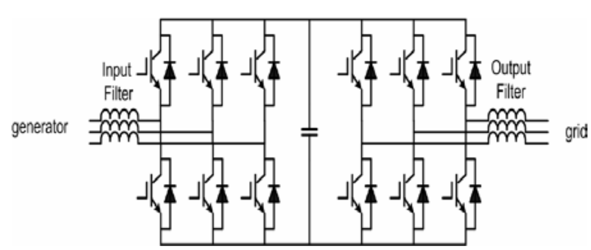

Figure 6. Structure of the back-to-back voltage source converter.

The PWM-VSC is the most frequently used three-phase frequency converter. As a consequence of this, the knowledge available in the field is extensive andvery well established. Furthermore, many manufacturers produce components especially designed for use in this type of converter (e.g., a transistor-pack comprising six bridge coupled transistors and anti-paralleled diodes). Therefore, the component costs can be low compared to converters requiring components designed for a niche production. A technical advantage of the PWM-VSC is the capacitor decoupling between the grid inverter and the generator inverter. Besides affording some protection, this decoupling offers separate control of the two inverters, allowing compensation of asymmetry both on the generator side and on the grid side, independently. The inclusion of a boost inductance in the DC-link circuit increases the component count, but a positive effect is that the boost inductance reduces the demands on the performance of the grid side harmonic filter, and offers some protection of the converter against abnormal conditions on the grid. However, some disadvantages of the back-to-back PWMVSC are reported in literature e.g. [1] and [3]. In several papers concerning adjustable speed drives, the presence of the DC-link capacitor is mentioned as a drawback, since: it is bulky and heavy; - it increases the costs and maybe of most importance; - it reduces the overall lifetime of the system. Another important drawback of the back-to-back PWMVSC is the switching losses. Every commutation in both the grid inverter and the generator inverter between the upper and lower DC-link branch is associated with a hard switching and a natural commutation. Since the back-to-back PWM-VSC consists of two inverters, the switching losses might be even more pronounced. The high switching speed to the grid may also require extra EMI-filters.

B. Unidirectional power converter

A wound rotor synchronous generator requires only a simple diode bridge rectifier for the generator side converter as shown in Figure 7.

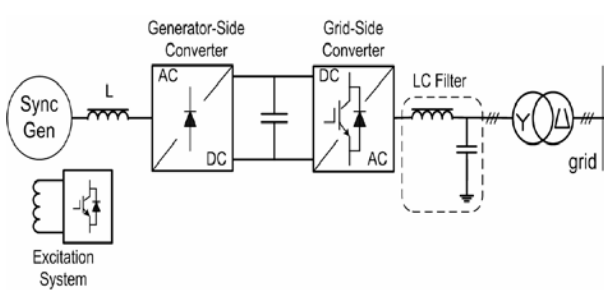

Figure 7. Variable speed wind turbine with synchronous generator and full rating power converter.

The diode rectifier is the most common used topology in power electronic applications. For a three-phase system it consists of six diodes. The diode rectifier can only be used in one quadrant, it is simple and it is not possible to control it. It could be used in some applications with a DC-link. The variable speed operation of the wind turbine is achieved by using an extra power converter which feed the excitation winding. The grid side converter will offer a decoupled control of the active and reactive power delivered to the grid and also all the grid support features. These wind turbines can have a gearbox or they can be direct-driven [2]. In order to achieve variable speed operation the wind turbines equipped with a permanent magnet synchronous generator (PMSG) will require a boost DC-DC converter inserted in the DC-link as shown in Figure 8.

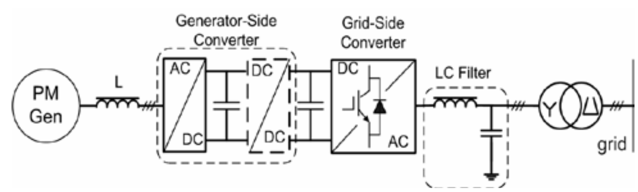

Figure 8. Full-rating power converter wind turbine with permanent magnet generator.

C. Multilevel power converter

Currently, there is an increasing interest in multilevel power converters especially for medium to high-power, high-voltage wind turbine applications [6] and [7]. Since the development of the neutral-point clamped three level converter [10], several alternative multilevel converter topologies have been reported in the literature. The general idea behind the multilevel converter technology is to create a sinusoidal voltage from several levels of voltages, typically obtained from capacitor voltage sources. The different proposed multilevel converter topologies can be classified in the following five categories [1], [6] and [11]: multilevel configurations with diode clamps, multilevel configurations with bi-directional switch interconnection, multilevel configurations with flying capacitors, multilevel configurations with multiple three-phase inverters and multilevel configurations with cascaded single phase H-bridge inverters. These topologies are shown in Figure 9 (based on [1], [6] and [11]).

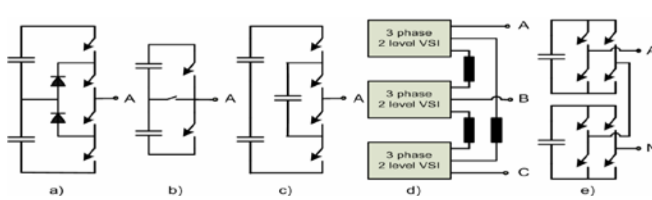

Figure 9. Multilevel topologies: a) one leg of a three-level diode clamped converter; b) one leg of a three-level converter with bidirectional switch interconnection; c) one leg of a three-level flying capacitor converter; d) three level converter using three two-level converters and e) one leg of a three-level H-bridge cascaded converter.

Initially, the main purpose of the multilevel converter was to achieve a higher voltage capability of the converters. As the ratings of the components increases and the switching- and conducting properties improve, the secondary effects of applying multilevel converters become more and more advantageous. The reduced content of harmonics in the input and output voltage as well as a reduced EMI is reported [1]. The switching losses of the multilevel converter are another feature, which is often accentuated in literature. In [12], it is stated, that for the same harmonic performance the switching frequency can be reduced to 25% of the switching frequency of a two-level converter. Even though the conduction losses are higher for the multilevel converter, the overall efficiency for the diode clamped multilevel converter is higher than the efficiency for a comparable two-level converter [1]. However, this depends on the ratio between the switching losses and the conduction losses. However, some disadvantages exist and are reported in literature e.g. [1], [6] and [7]. The most commonly reported disadvantage of the three level converters with split DC-link is the voltage imbalance between the upper and the lower DC-link capacitor. Nevertheless, for a three-level converter this problem is not very serious, and the problem in the three-level converter is mainly caused by differences in the real capacitance of each capacitor, inaccuracies in the deadtime implementation or an unbalanced load [14]. By a proper modulation control of the switches, the imbalance problem can be solved [15]. In [14] the voltage balancing problem is solved by hardware, while [16] and [17] proposed solutions based on modulation control. The three-level diode clamped multilevel converter (Figure 9a) and the three-level flying capacitor multilevel converter (Figure 9c) exhibits an unequal current stress on the semiconductors. It appears that the upper and lower switches in an inverter branch might be de-rated compared to the switches in the middle. For an appropriate design of the converter, different devices are required [13]. The unequal current stress and the unequal voltage stress might constitute a design problem for the multilevel converter with bidirectional switch interconnection presented in Figure 9b [1]. It is evident for all presented topologies in Figure 9 that the number of semiconductors in the conducting path is higher than for e.g. a two-level converter. Thus, the conduction losses of the converter might increase. On the other hand, each of the semiconductors need only to block half the total DC-link voltage and for lower voltage ratings, the on-state losses per switch decreases, which to a certain extent might justify the higher number of semiconductors in the conducting path [1].

D. Modular power converters

At low wind speeds and hence low level of the produced power, the full-rating power converter concept exhibits low utilization of the power switches and thus increased power losses. Therefore, a concept in which several power converters are running in parallel is used by some manufacturers as shown in Figure10.

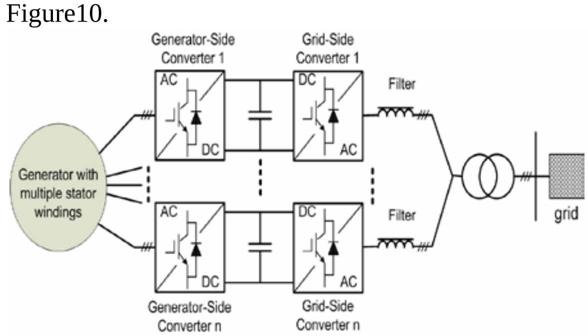

Figure 10. Full-rating power converter based wind turbine with n-paralleled power converters.

The power converter in this case can be one of the structures presented above. This configuration can also be used for standard generators. Modern wind turbines have a fast response in respect with the grid operator demands. However the produced real power depends on the available wind speed.

VII. POWER ELECTRINICS INTERFACE OF THE HYBRID SYSTEM

In many small-scale systems, the dc system is set at a constant dc voltage and is usually comprised of a battery bank which energy storage, a controller to keep the batteries from overcharging; and a load. The load may be dc or may include an inverter to an ac system. Connecting a wind generator to a constant dc voltage has significant problems due to the mismatching the poor impedance matching between the generator and the constant dc voltage (battery), which will limit power transfer to the dc system. In response to these problems, researchers have investigated incorporating a dc–dc converter in the dc link. The power conditioning system which governs entire power control of the hybrid system. Figure11 presents the proposed power electronic based interface, which is composed of a wind-side dc/ac converter, a PVside dc/dc converter, a common dc

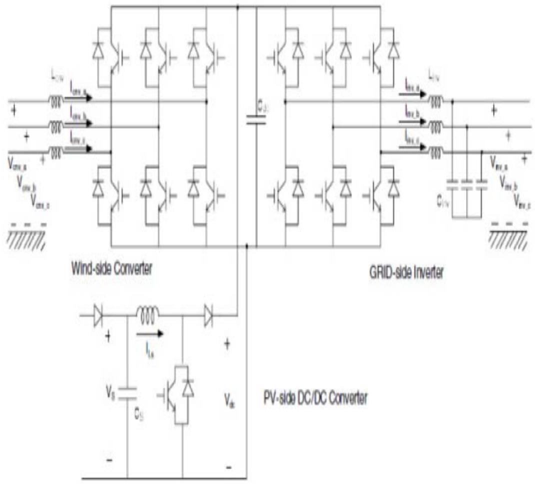

Figure 11. Power electronic interface of the hybrid system

Adjusting the voltage on the dc rectifier will change the generator terminal voltage and thereby provide control over the current flowing out of the generator. Since the current is proportional to torque, the dc–dc converter will provide control over the speed of the turbine. Control of the dc–dc converter can be achieved by means of a predetermined relationship between rotor speed and rectifier dc voltage to achieve maximum power point tracking or by means of a predetermined relationship between generator electrical frequency and dc-link voltage. Using these methods the PV/WT hybrid generation system can supply almost good quality power. However, these methods have disadvantages that they require batteries, which are costly and the installation of dump load is not an efficient method to dissipate fluctuating power. Moreover, they cannot guarantee certainty of load demands at all times especially at bad environmental conditions, where there is no power from the PV and WG systems.

VIII. PROPOSED HYBRID ENERGY SYSTEM

The configuration of household hybrid wind and PV system is shown in Figure12. This configuration is fit for stand-alone hybrid power system used in remote area. Wind and solar energy are converted into electricity and then sent to loads or stored in battery bank. The topology of hybrid energy system consisting of variable speed WT coupled to a permanent magnet generator (PMG) and PV array. The two energy sources are connected in parallel to a common dc bus line through their individual dc-dc converters. The load may be dc connected to the dc capacitor and a grid-side inverter.[5][8]

bus line or may include a PWM voltage source inverter to convert the dc power into ac at 50 or 60 Hz. Each source has its individual control. The output of the hybrid generating system goes to the dc bus line to feed the isolating dc load or to the inverter, which converts the dc into ac. A battery charger is used to keep the battery fully charged at a constant dc bus line voltage.

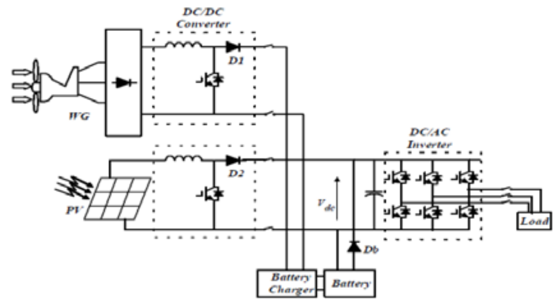

Figure12. Equivalent circuit of Hybrid module

IX. CONCLUSIONS

The proposed model takes sunlight irradiance and cell temperature as input parameters and outputs the I-V and P-V characteristics under various conditions. This paper describes renewable energy hybrid Wind-PV with battery energy storage system. In Hybrid Wind-PV System, PV system acts as a main source. The power fluctuation of the hybrid system is less dependent on the environmental conditions as compared to the power generated of individual PV and WG systems. This power fluctuation has been suppressed using a battery in this project and it will be the subject of future work.

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