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An Efficient Energy Storage System Fed by Permanent Magnet Synchronous Generator Based Wind Energy Conversion System

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ABSTRACT : Standalone operation of a wind turbine generating system under fluctuating wind and variable load conditions is a difficult task. Moreover, high reactive power demand makes it more challenging due to the limitation of reactive capability of the wind generating system. A Remote Area Power Supply (RAPS) system consisting of a Permanent Magnet Synchronous Generator (PMSG), hybrid energy storage, a dump load and a mains load is considered in this paper. The hybrid energy storage consists of battery storage and a super capacitor where both are connected to the DC bus of the RAPS system. An energy management algorithm (EMA) is proposed for the hybrid energy storage with a view to improve the performance of the battery storage. A synchronous condenser is employed to provide reactive power and inertial support to the RAPS system. A coordinated control approach is developed to manage the active and reactive power flow among the RAPS components. In this regard, individual controllers for each RAPS component have been developed for effective management of the RAPS components.

Keywords – RAPS(Remote Area Power Supply), EMA(Energy Management System), PMSG(Permanent Magnet Synchronous Generator)

1.INTRODUCTION

The use of renewable energy increased greatly just after the first big oil crisis in the late seventies. At that time, economic issues were the most important factors, hence interest in such processes decreased when oil prices fell. The current resurgence of interest in the use of renewable energy is driven by the need to reduce the high environmental impact of fossil-based energy systems. Harvesting energy on a large scale is undoubtedly one of the main challenges of our time. Future energy sustainability depends heavily on how the renewable energy problem is addressed in the next few decades. Although in most power-generating systems, the main source of energy (the fuel) can be manipulated, this is not true for solar and wind energies. The main problems with these energy sources are cost and availability: wind and solar power are not always available where and when needed. Unlike conventional sources of electric power, these renewable sources are not “dispatch able”—the power output cannot be controlled. Daily and seasonal effects and limited predictability result in intermittent generation. Smart grids promise to facilitate the integration of renewable energy and will provide other benefits as well. Industry must overcome a number of technical issues to deliver renewable energy in significant quantities. Control is one of the key enabling technologies for the deployment of renewable energy systems. Solar and wind power require effective use of advanced control techniques. In addition, smart grids cannot be achieved without extensive use of control technologies at all levels.

This research paper will concentrate on two forms of renewable energy respectively wind and solar, on the role of smart grids in addressing the problems associated with the efficient and reliable delivery and use of electricity and with the integration of renewable sources. Solar and wind power plants exhibit changing dynamics, nonlinearities, and uncertainties—challenges that require advanced control strategies to solve effectively. The use of more efficient control strategies would not only increase the performance of these systems, but would increase the number of operational hours of solar and wind plants and thus reduce the cost per kilowatt-hour (KWh) produced. The electrical energy can be generated by wind energy by utilizing the kinetic energy of wind. The wind energy which is an indirect source of energy can be used to run a wind mill which in turn drives a generator to produce electricity. Understanding the your location is critical to understanding the potential for using wind energy. With many thousands of wind turbines in operation, the total worldwide installed capacity is currently about 160 GW. According to the World Wind Energy Association, the net growth rate is expected to be more than 21% per year. The top five countries, the United States, Germany, Spain, China, and India, currently share about 73% of the world capacity.

1.1 PERMANENT-MAGNET SYNCHRONOUS GENERATORS

Generally wind turbines are based on permanent-magnet synchronous generators (PMSG), and are connected using the topology. A fully rated power electronics converter that can handle the full power output of the generator is needed to interface the generator with the power system. The converter enables the decoupling of the rotational speed of the machine from the constant electrical frequency of the grid. For variable-speed operation, the stator-side converter generates ac voltages and currents of the appropriate frequency to match the rotor's speed. (Remember, in synchronous machines, the rotor must be synchronized with the magnetic field of the stator.) It can also regulate the magnitude and phase of the stator current, in order to control the electromagnetic torque of the generator, and therefore to make the rotor speed approach the value required to obtain optimal tip-speed ratio., i.e., employing two back-to-back IGBT-based converters with a dc link, although other topologies can be used as well. In another quite common topology, an uncontrolled diode rectifier is connected at the stator side instead of a fully controllable converter. This helps reduce the complexity and cost of the power electronics, but does not provide as much flexibility to control the stator currents. In these notes, we will analyze the former topology, thus implicitly assuming that we can precisely adjust the stator current magnitude and phase angle.

1.2 ENERGY STORAGE

Power systems are fundamentally reliant on control, communications, computation for ensuring stable, reliable, efficient operations. Generators rely on governors and automatic voltage regulators (AVRs) to counter the effects of disturbances that continually buffet power systems, and many would quickly lose synchronism without the damping provided by power system stabilizers (PSSs). Flexible AC transmission system (FACTS) devices, such as static var compensators (SVCs) and high-voltage DC (HVDC) schemes, rely on feedback control to enhance system stability.

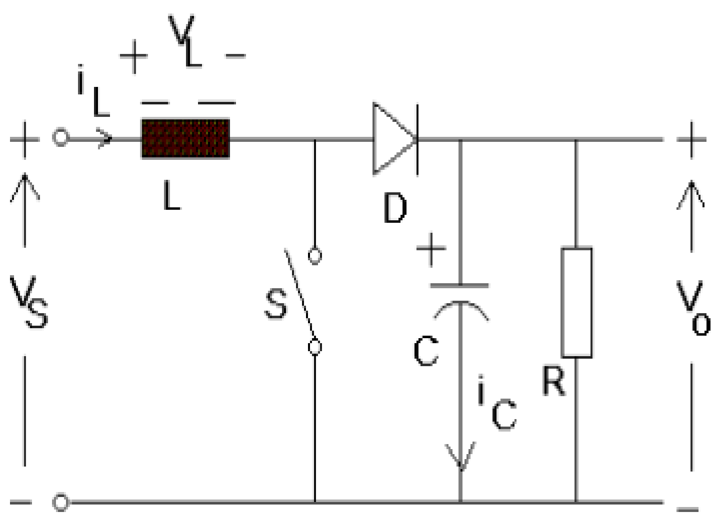
At a higher level, energy management systems (EMSs) use supervisory control and data acquisition (SCADA) to collect data from expansive power systems and sophisticated analysis tools to establish secure, economic operating conditions. Automatic generation control (AGC) is a distributed closed-loop control scheme of continental proportions that optimally reschedules generator power set points to maintain frequency and tie-line flows at their specified values. Multilevel energy storage consisting of a flow battery storage and a super capacitor is explained the battery storage and super capacitor with a view to achieve to help maintain the power balance of the RAPS system, to operate wind turbine generator at variable-speed based on the maximum power point tracking algorithm, to improve the performance of the battery storage system by avoiding its operation with high frequency ripple currents and high rate of DODs. This will relieve the battery stress and increase the battery life. This paper presents a novel control strategy for a high penetrated wind based hybrid Remote Area Power Supply (RAPS) system. The proposed RAPS system consists of a Permanent Magnet Synchronous Generator (PMSG) based variable speed wind turbine and a battery energy storage system with a dump load for DC bus voltage control and a diesel generator as a back-up supply. An integrated control approach based on active and reactive power balance of the proposed RAPS system has been proposed and developed with a view to regulate the voltage and frequency within an acceptable bandwidth. The proposed integrated control algorithm is implemented by developing controller for the individual system components in the RAPS system including wind energy conversion system, diesel generator, battery storage and dump load while coordinating their responses to achieve optimal operation. The optimized operation for the proposed RAPS system is realized by operating the wind turbine generator on its maximum power extraction mode while restricting the operation of diesel generating system at low-load conditions. The entire RAPS system has been designed using Sim Power System toolbox in MATLAB. As wind energy reaches higher penetration levels, there is a greater need to manage intermittency associated with the individual wind turbine generators. This paper considers the integration of a short-term energy storage device in Permanent Magnet Synchronous Generator design in order to smooth the fast wind-induced power variations.

1.3 ENERGY MANAGEMENT

To manage the energy exchanges between the sources and the load at dc bus, three operating modes (or states) can be identified are Charge mode, in which the main source supplies energy to the storage devices and to the load. Discharge mode, in which main source and storage devices supply energy to the load. Energy storage technology is a main device in harvesting the kinetic energy that is wasted whenever vehicles or large machines must be slowed or stopped, called “regenerative braking energy”. Although batteries have been successfully used in light-duty vehicles, hybrid platforms for trucks, buses, tramways and trains will require storage and delivery of much higher powers than can be accommodated readily by batteries. Unlike batteries, new technology storage device of electrochemical capacitors (ECs) can operate at high charge and discharge rates over an almost unlimited number of cycles and enable energy recovery in heavier duty systems.

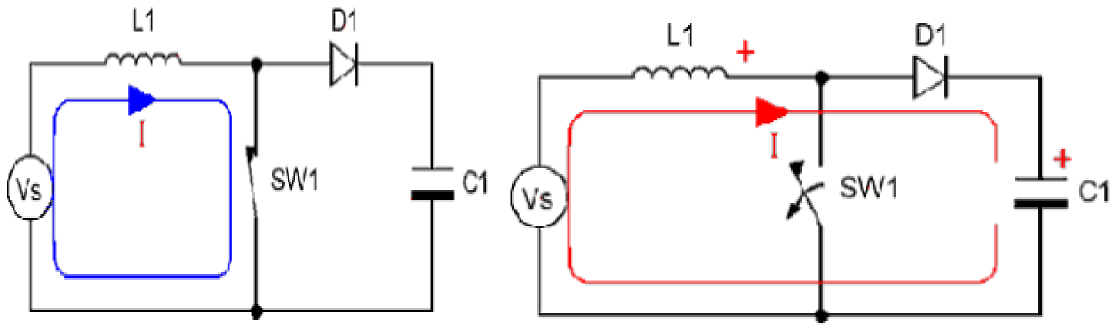
1.3.1 BOOST CONVERTER

A boost converter (step-up converter) is a DC-DC converter with an output voltage greater than its input voltage. It is a class of switched mode power supply (SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element, a capacitor, inductor, or the two in combination. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple. Power for the boost converter can come from any suitable DC sources, such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a with a DC-DC converter output voltage greater than the source voltage. A boost converter is sometimes called a step-up converter since it "steps up" the source voltage. Since power must be conserved the output current is lower than the source current. The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. In a boost converter, the output voltage is always higher than the input voltage. A schematic of a boost power stage is shown in below Figure.



a) When the switch is closed, current flows through the inductor in clockwise direction and the inductor stores the energy. Polarity of the left side of the inductor is positive.

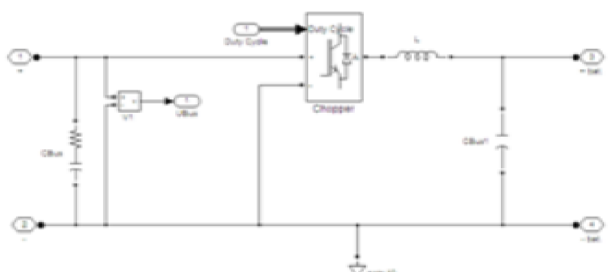
b) When the switch is opened, current will be reduced as the impedance is higher. Therefore, change or reduction in current will be opposed by the inductor. Thus the polarity will be reversed (means left side of inductor will be negative now). As a result two sources will be in series causing a higher voltage to charge the capacitor through the diode D.



Sim Power Systems is a modern design tool that allows scientists and engineers to rapidly and easily build models that simulate power systems. Not only you can draw the circuit topology, but your analysis of the circuit can include its interactions with mechanical, thermal, control, and other disciplines. This is possible because all the electrical parts of the simulation interact with the extensive Simulink modeling library. Since Simulink uses MATLAB as its computational engine, designers can also use MATLAB tool boxes and Simulink block sets. Sim Power Systems and Sim Mechanics share a special Physical Modeling block and connection line interface.

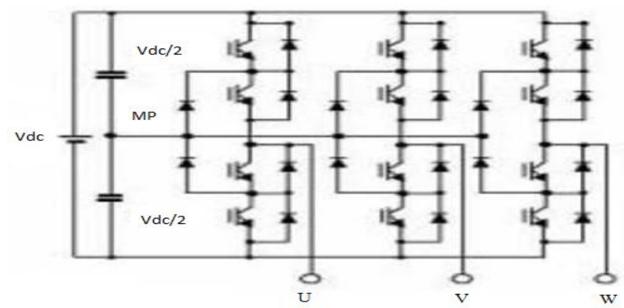
Simulink model of Boost Converter

The simulation block diagram and result for the boost converter is shown in the below figure.



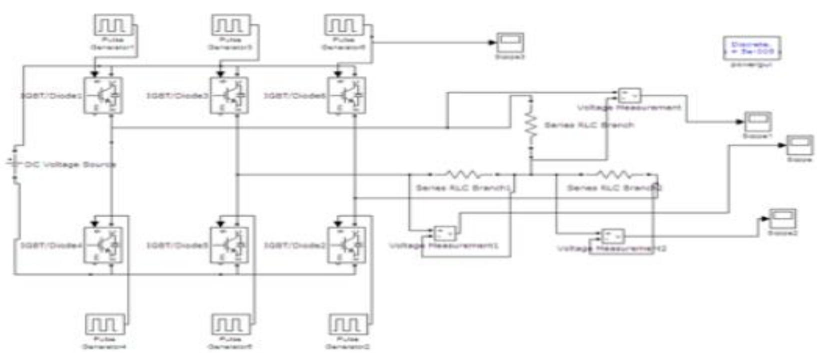
1.3.2 VOLTAGE SOURCE INVERTER

The single-phase five-level inverter topology is shown in Fig..The inverter adopts a full-bridge configuration with an auxiliary circuit. PV arrays are connected to the inverter via a dc–dc boost converter. Because the proposed inverter is used in a grid-connected PV system, utility grid is used instead of load.

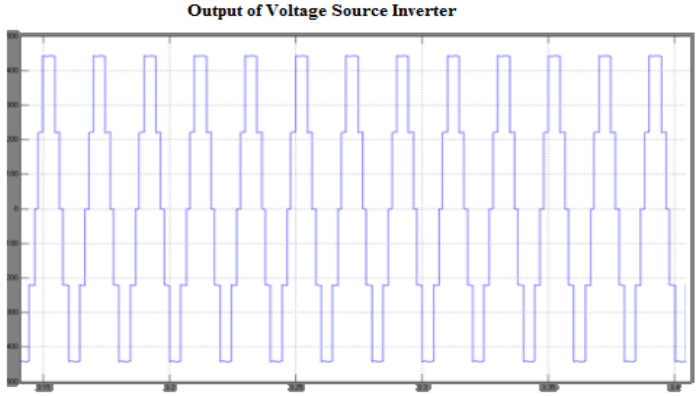


Simulink model of Voltage Source Inverter

The dc–dc boost converter is used to step up inverter output voltage Vinv to be more than√2ofgridvoltageVg to ensure power flow from the PV arrays into the grid.A filtering inductance LF is used to filter the current injected into the grid.



Output of Voltage Source Inverter



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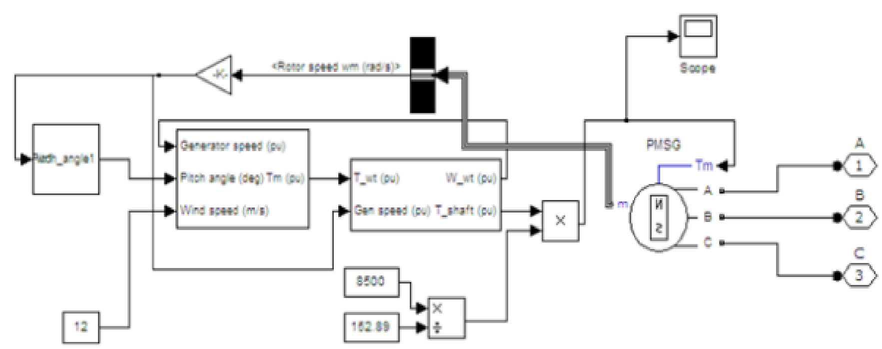
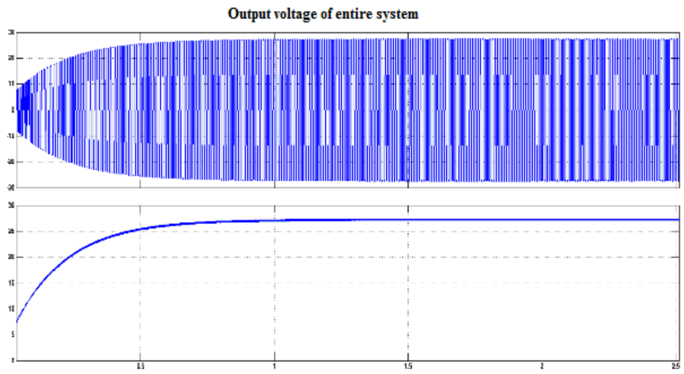
The injected current must be sinusoidal with low harmonic distortion. In order to generate sinusoidal current ,sinusoidal PWM is used because it is one of the most effective methods. Sinusoidal PWM Is obtained by comparing a high-frequency carrier with a low-frequency sinusoid ,which is the modulating or reference signal .The carrier as a constant period ;therefore, the switches have constant switching frequency .The switching constant is determined from the crossing of the carrier and the modulating signal. From a +/- 1800 volts DC source, a 400-kW, three-phase 3-level inverter delivers variable power to a distribution power system. The inverter output is connected to the 25-kV, 40 MVA, 50-Hz system through a 2200 V / 25 kV transformer. The inverter topology is based on the model described in. Each 3-level leg of the inverter comprises three commercial half-bridge IGBT modules. The IGBT pulsing of module 3 is not required since only the anti-parallel diodes are operating as neutral clamping diodes. The control system contains two PI controllers (one PQ regulator and one current regulator) to generate the required inverter pulses to achieve the reference output power.

1.4 SIMULINK MODEL OF ENTIRE WIND ENERGY SYSTEM

Generally Synchronous or Asynchronous generator is used in wind power plant means it leads to very large designing procedure. Since it is large design we give a new design feature with ease and understandable one.



. In this paper PMSG(Permanent Magnet Synchronous Generator) is used as generator. In a permanent magnet synchronous generator, the magnetic field of the rotor is produced by permanent magnets. Permanent magnet generators do not require a DC supply for the excitation circuit, nor do they have slip rings and contact brushes. The output also get with high efficient and be continuous.A permanent magnet synchronous generator is a generator where the excitation field is provided by a permanent magnet instead of a coil. The model 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 must be combined with those of the generator coupled to the turbine. Wind energy is plentiful and readily available, and capturing its power does not deplete our natural resources.



The Great Plains and offshore areas have tremendous untapped wind energy potential.

1.5 CONCLUSION

This paper has investigated the standalone operation of a PMSG with a hybrid energy storage system consisting of a battery storage and a super capacitor, a synchronous condenser and a dump load. The entire RAPS system is simulated under over-generation and under-generation conditions covering the extreme operating conditions such as load step changes and wind gusts. The suitability of the adopted control strategy for each system component is assessed in terms of their contributions towards regulating the load side voltage and frequency. Investigations have been carried out in relation to the voltage and frequency regulation at load side, DC bus stability, maximum power extraction capability of wind turbine generator and the performance of the hybrid energy storage system. From the simulated behavior, it is seen that the proposed approach is capable of regulating both voltage and frequency within tight limits for all conditions including the worst-case scenarios, such as wind gusts and load variations. Also, the performance of the battery storage is improved with the implementation of the proposed energy management algorithm, as super capacitor absorbs the ripple or high frequency power component of demand generation mismatch while leaving the steady component for the battery storage. Moreover, the super capacitor helps in avoiding battery operation in high rate of depth of discharge regions. The proposed control algorithm is able to manage power balance in the RAPS system while extracting the maximum power output from the wind throughout its entire operation. With the integration of the synchronous condenser, it has been proven that the RAPS system is able to maintain the load voltage within acceptable limits for all conditions including the situation when reactive power demand becomes very high.

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