

Energy Management of Hybrid Energy Storage for Wind Power Generation Systems

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ABSTRACT

A Remote Area Power Supply (RAPS) system composed of a Permanent Magnet Synchronous Generator (PMSG), a hybrid energy storage unit, a dump load, and a mains load is examined in this paper. The hybrid energy storage includes a battery storage unit and a super capacitor, where both are linked to the DC bus of the RAPS system. An energy management algorithm (EMA) is introduced for the hybrid energy storage in order to enhance the performance of the battery storage system. A synchronous condenser is utilized to supply reactive power and inertia support to the RAPS system. A coordinated control strategy is designed to regulate the active and reactive power flow among the RAPS components. In this context, separate controllers for each RAPS component have been designed for efficient control of the system components. The suggested method is capable of achieving: a) stable voltage and frequency regulation (within their permissible bandwidth limits), b) efficient control of the hybrid storage system, c) reactive power capability and inertia support through the synchronous condenser, and d) maximum power extraction from wind energy. By using svpwm method the ripple content in the output wave forms reduced. The results are implemented using the MATLAB/Simulink environment.

Index Terms— Battery storage, hybrid energy storage system, permanent magnet synchronous generator, remote area power supply, super capacitor and synchronous condenser, space vector modulation (SVM).

I.INTRODUCTION

Variable nature of wind and fluctuating load profiles make the operation of wind based power systems challenging, particularly when they operate in stand-alone mode. The random variation of wind speed leads to fluctuating torque of the wind turbine generator resulting in voltage and frequency excursions in the Remote Area Power Supply

(RAPS) system. Integration of an Energy Storage System (ESS) into a wind based power system provides an opportunity for better voltage and frequency response, especially during wind and load demand variations. The application of energy storage to a standalone power system can be used to fulfill one or more of the following requirements: (1) to improve the efficiency of the entire RAPS system, (2) to reduce the primary fuel (e.g., diesel) usage by energy conversion, and (3) to provide better security of energy supply. The justification behind the integration of an energy storage into a wind energy application is based on the factors which include total wind turbine inertia, low voltage ride through capability, power quality issues, etc. For a wind turbine based RAPS system, an ideal ESS should be able to provide both high energy and power capacity to handle situations such as wind gust or sudden load variations which may exist for a few seconds or even longer. However, among all the energy storage options available, a single type of energy storage is not seen to satisfy both power and energy requirements of the RAPS system thus requiring the combination of two or more energy storage systems to perform in a hybrid manner. The selection of an energy storage option requires good understanding of its operational characteristics. In general, battery and super capacitor are seen to provide high energy and power requirements respectively. Therefore, the integration of a super capacitor ensures a healthy operation of the battery

storage by preventing it to operate in high Depth of Discharge (DOD) regions and to operate at low frequency power regions. Permanent Magnet Synchronous Generator (PMSG) offers many advantages but not limited to self-excitation capability which allows operation at a high power factor and improved efficiency, gear-less transmission, high reliability, good control performance, Maximum Power Point Tracking (MPPT) capability, low noise emissions, etc.

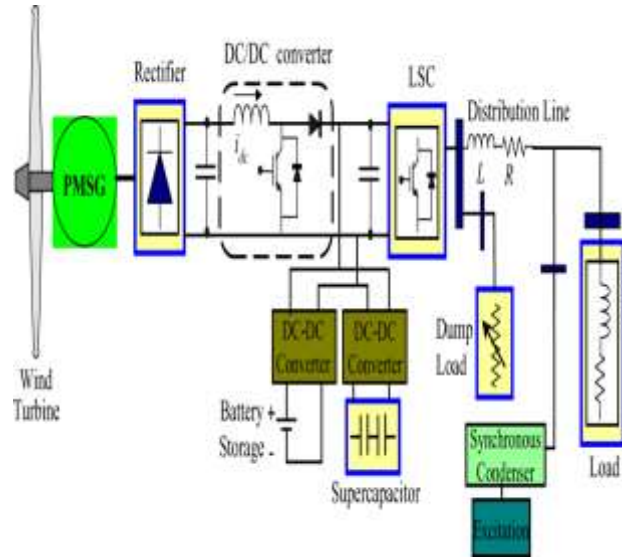


Fig1.shows PMSG based RAPS with hybrid energy storage system

F.Liu, J.Liu, and L.Zhou [1]proposed energy storage system in wind power system is required to deal with the difference of power between generator side and load side. However, single storage element cannot fulfill this goal ideally. Then, Hybrid energy storage system (HESS) is proposed that which combines two (or more) different kinds of storage elements has more superior performance than single storage element. In this paper, a topology of hybrid energy storage system which consists of a battery and a super capacitor is used. Besides, a corresponding control strategy is proposed, which use moving average filter (MAF) to substitute traditional low pass filter to distinguish the DC and AC component of the imbalance power and deliver the DC part to the battery and absorb the AC part to the super capacitor. It makes full use of the energy storage elements and the battery life is extended.

C. Abbey and G.Joos,[2] the need to limit power fluctuations resulting from wind turbine generators (WTG) is becoming more important as wind energy reaches higher levels of penetration. This paper considers the integration of a short-term energy storage device in a doubly-fed induction generator (DFIG) design in order to smooth the fast,

wind induced power variations. This storage feature can also enhance the low voltage ride through (LVRT) capability. The topology is evaluated in terms of its ability to improve both the steady state and transient performance. The system is modeled in EMTP and a number of cases and configurations are illustrated. Results show that when storage is sized based upon the LVRT requirement, it can provide improved performance both under steady state and during transients when compared with conventional technologies.

W Li, G Joós, J Belanger[3]proposed wind power generation studies of slow phenomena using a detailed model can be difficult to perform with a conventional offline simulation program. Due to the computational power and high-speed input and output, a real-time simulator is capable of conducting repetitive simulations of wind profiles in a short time with detailed models of critical components and allows testing of prototype controllers through hardware-in-the-loop (HIL).This paper discusses methods to overcome the challenges of real-time simulation of wind systems, characterized by their complexity and high-frequency switching. A hybrid flow- battery super capacitor energy storage system (ESS), coupled in a wind turbine generator to smooth wind power, is studied by real-time HIL simulation. The prototype controller is

embedded in one real-time simulator, while the rest of the system is implemented in another independent simulator. The simulation results of the detailed wind system model show that the hybrid ESS has a lower battery cost, higher battery longevity, and improved overall efficiency over its reference ESS.

M.E.Haque, M.Negnevitsky, and K.M.Muttaqi [4]proposed a novel control strategy for the operation of a direct drive permanent magnet synchronous generator (PMSG) based stand-alone variable speed wind turbine. The control strategy for the generator side converter with maximum power extraction is discussed. The stand-alone control is featured with output voltage and frequency controller capable of handling variable load. The potential excess of power is dissipated in the damp resistor with the chopper control and the dc link voltage is maintained. Dynamic representation of dc bus and small signal analysis are presented.

Simulation results show that the controllers can extract maximum power and regulate the voltage and frequency under varying wind and load conditions. The controller shows very good dynamic and steady state performance.

II. CONTROL ASSOCIATED WITH PMSG

As mentioned earlier, in the RAPS system shown in Fig. 1, the PMSG performs as the main source of energy and is interfaced with an uncontrolled rectifier-inverter arrangement before connecting to the mains load. In this regard, control is developed for the Line Side Converter (LSC) and DC/DC converter which is presented in the proceeding sub-sections.

A. Line Side Converter Control

The LSC is modeled as a voltage controlled voltage source inverter. The control objective of the LSC is to regulate the magnitude and frequency of the load side voltage. In this regard, vector control has been employed to develop the control associated with the LSC. The voltage balance across the filter of the LSC shown in Fig2.

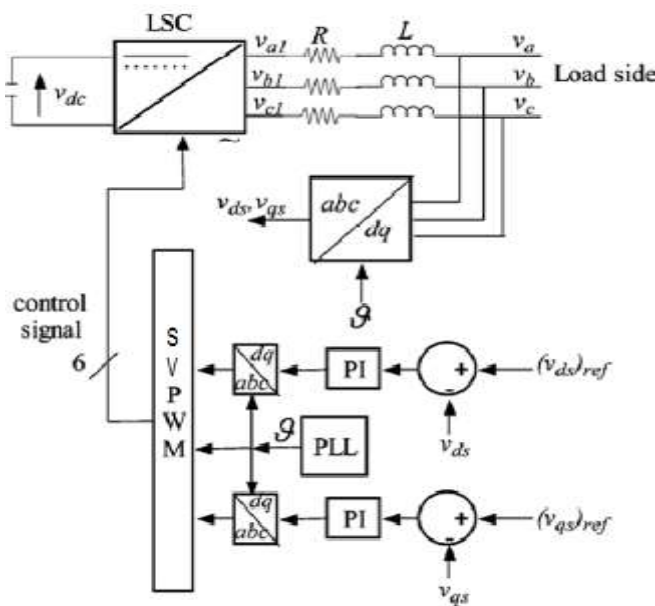


Fig.2. Vector control scheme for the LSC

B. Control Strategy for DC/DC Converter

The DC link voltage of the RAPS system is regulated using a DC/DC converter (i.e., boost converter). The rectified voltage output, V_{dc} presents at the full converter diode bridge is a function (i.e., linearly proportional) of the generator speed, and can be explained[1]. The proposed control scheme for the DC/DC converter is shown in Fig.3. The outer control loop measures the DC link voltage, which is compared with the reference DC link voltage, and the error is compensated using a PI controller to generate the reference current through the inductor of the boost converter, as in (10). This current is then compared with

the actual current, and the corresponding error is compensated through the second PI controller to generate the switching signal for the DC-DC converter. Further, the highest boosting factor, of the boost converter is recorded at the lowest generator speed.

III. ENERGY MANAGEMENT ALGORITHM (EMA) FOR HYBRID ENERGY STORAGE

In this paper an energy management algorithm is developed and implemented between the battery storage and super capacitor with a view to achieve the following objectives:

- 1) To help maintain the power balance of the RAPS system,
- 2) To operate wind turbine generator at variable-speed based on the maximum power point tracking algorithm, and
- 3) 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. Among several options of connection topologies, bi-directional buck-boost converters (or choppers), C1 and C2, have been used to interface both the super capacitor and battery storage respectively. The energy management algorithm applied for both storage options have been developed to satisfy the above-stated objectives. The energy management algorithm for the battery storage and super capacitor is depicted. The input signal to the energy management algorithm is selected as the demand-generation mismatch, with a view to achieve the first objective listed above. To realize the second objective, the demand-generation mismatch is estimated using the optimal wind power, which can be derived

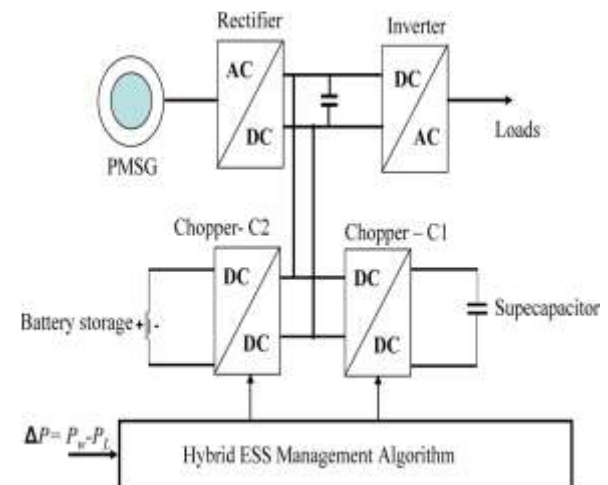


Fig.3. Proposed topology for hybrid energy storage system in a PMSG based RAPS system.

IV. SPACE VECTOR PWM

Space vector pulse width modulation technique is an advanced, computation-intensive PWM method and is possibly the best among all the PWM techniques for variable frequency drive applications [16]. Because of its superior characteristics and easy implementation with digital signal processors, it has been finding wide spread application in recent years. The space vector modulation is a highly efficient way to generate the six PWM pulses necessary at the power stage for two-level inverter [13], [14]. The circuit model of a typical three-phase voltage source PWM inverter is shown in figure4. S1 to S6 are the six power switches that shape the output, which are controlled by the switching variables a, a', b, b', c and c' . When an upper transistor is switched on, i.e., when a, b or c is 1, the corresponding lower transistor is switched off, i.e, the corresponding a', b' or c' is 0. Therefore, the on and off states of the upper transistors S1, S3 and S5 can be used to determine the output voltage.

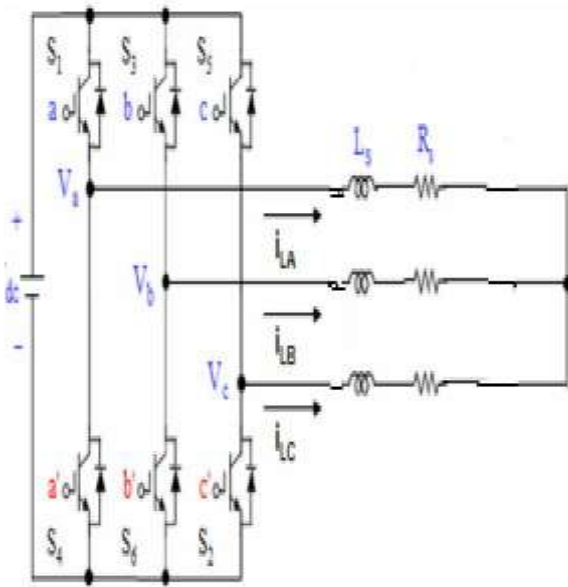


Fig 4: Three-Phase Voltage Source PWM Inverter

The objective of space vector PWM technique is to approximate the reference voltage vector V_{ref} using the eight switching patterns. One simple method of approximation is to generate the average output of the inverter in a small period, T to be the same as that of V_{ref} in the same period.

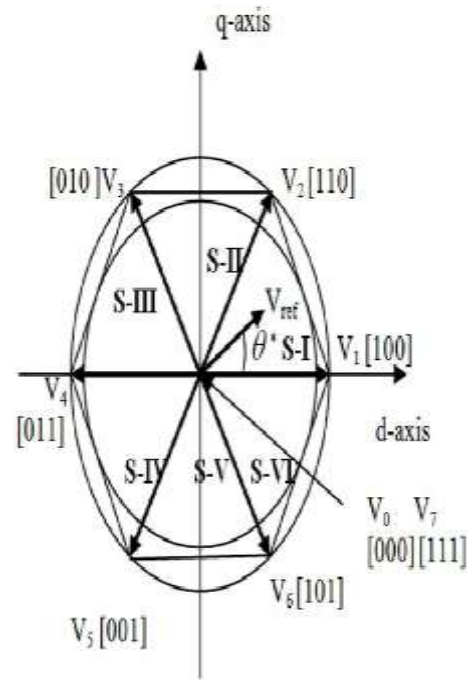


Fig5: Vector Representations of the Switching Gates.

V.SIMULATION RESULTS AND DISCUSSIONS

The proposed strategy was implemented with the detailed model of the MATLAB/Simulink/Simpower and also with the highly accurate models of the system components. The simulation time step used was 5 micro-seconds to capture the true behavior of the system components. To prove the robustness of the proposed method, wind gusts and load step changes in wind profile and load profile respectively are used to synthesize the worst system conditions in a RAPS system. Such worst-case scenarios are used to show how well the proposed control strategy behaves in relation to the voltage and frequency regulation. The performance of the proposed RAPS system shown in the below simulation results.

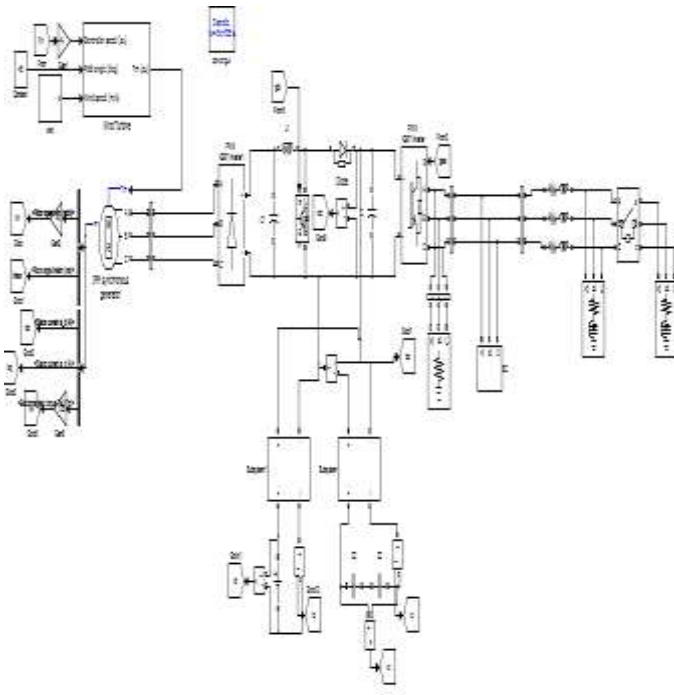


Fig 6 MATLAB/Simulink Model for Simulation of PMSG based hybrid remote area power supply system with a hybrid energy storage

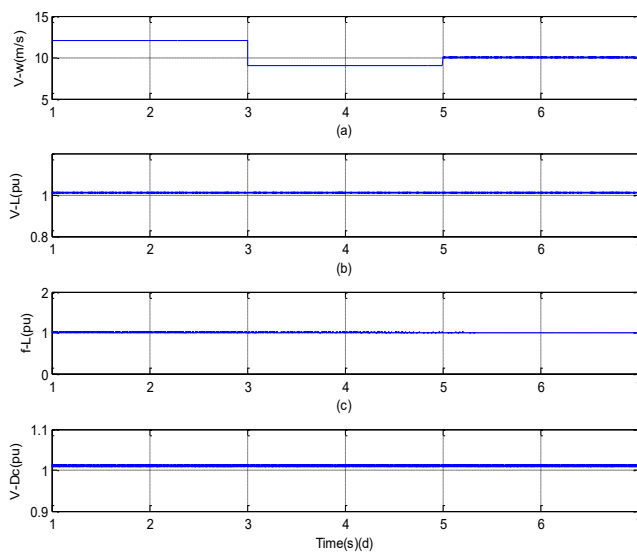


Fig.7 Response of the RAPS system at variable wind and load conditions a)wind speed, b)voltage at load

side, c)frequency at load side d)DC-link voltage.

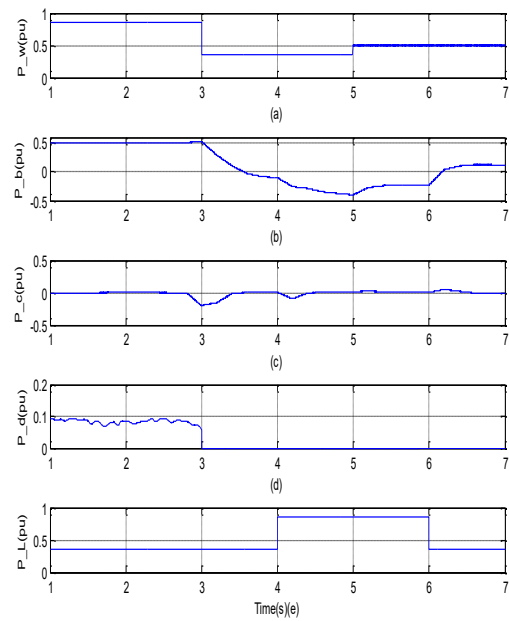


Fig.8. Power sharing of the RAPS system at variable wind and load conditions
(a) wind power (b) Battery power (c) super capacitor power (d) Dump load power (e) load demand

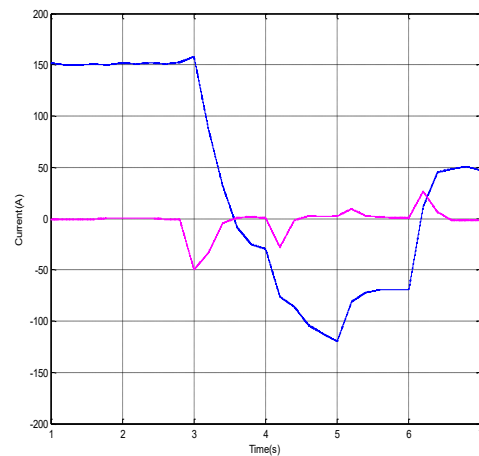


Fig.9. Currents of battery storage and supercapacitor.

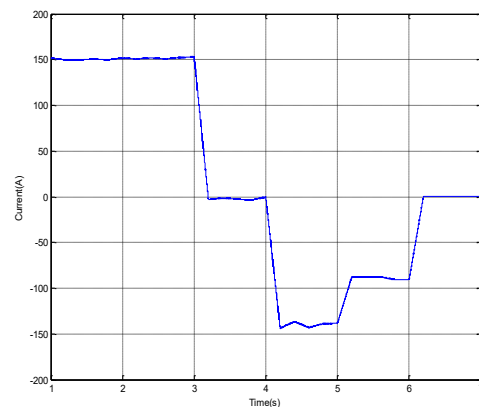


Fig.10. Battery storage current without super capacitor.

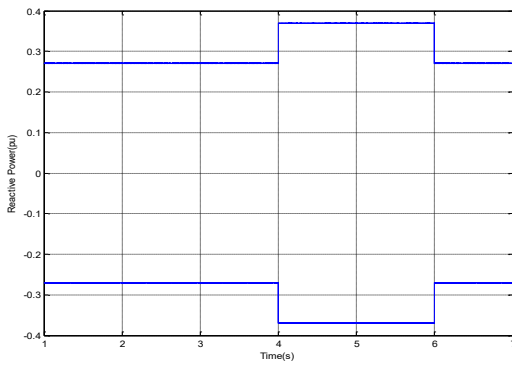


Fig11. Reactive power supply through inverter without integrating the synchronous condenser.

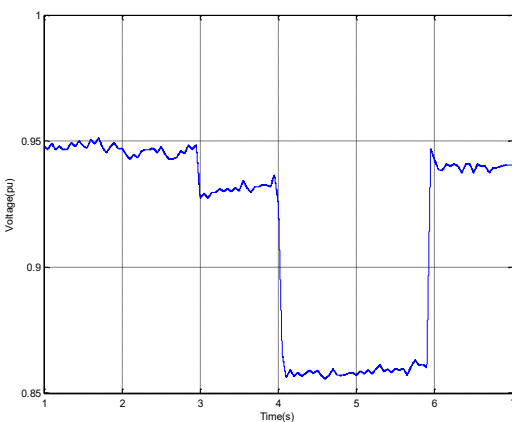


Fig. 12. Voltage at load side without employing the synchronous condenser.

VI. 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. By using svpwm method the ripple content in the output wave forms reduced.

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