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A Control Strategy for a Variable-Speed Wind Turbine with a Permanent-Magnet Synchronous Generator

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***Abstract* - This paper presents a novel control strategy for the operation of a direct-drive permanent-magnet synchronous generator- based stand-alone variable-speed wind turbine. The control strategy for the generator-side converter with maximum power extraction is presented. The stand-alone control is featured with output voltage and frequency controller that is capable of handling variable load. The potential excess of power is dissipated in the dump-load 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.**

***Keywords* - Maximum power extraction, permanent-magnet Synchronous generator (PMSG), switch-mode rectifier, variable-speed wind turbine, voltage and frequency control..**

I. INTRODUCTION

Wind energy is clean silent and emission-free source of energy. Using small wind energy conversion system increases rapidly nowadays all over the world due to its availability, small size, high performances, low cost installation, and it has low weight compared to induction generators. PMSG is used more frequently in small wind turbine application due to its robustness, reliability and high efficiency when connected to variable speed wind turbine [1]. Most papers [2], [3], [4] are considering using PMSG and normally include controlled three phase ac to dc conversion and to extract maximum power from the fluctuating wind, variable-speed operation of the wind-turbine generator is necessary besides achieving unity power factor at the generator side. The dc/ac inverter is used to regulate the load voltage and frequency and for stand-alone systems. Additionally, a battery power flow controller is used to balance the load power as the wind power changes [3], [4]. A control strategy for the generator-side converter with output maximization of a PMSG-based small-scale wind turbine is developed. The generator-side switch-mode rectifier is controlled to achieve maximum power from the wind. The method requires only one active switching device [insulated-gate bipolar transistor (IGBT)], which is used to control the generator torque to extract maximum power. According to grid connected systems, the MPPT control is achieved using the dc/ac inverter and the controller achieve unity power factor at the grid side. The load-side pulse-width modulation (PWM) inverter is using a relatively complex vector-control scheme to control the amplitude and frequency of the inverter output voltage. The stand-alone control is featured with output voltage and frequency controller capable of handling variable load. A dump-load-resistor controller is used to dissipate excess power during fault or over generation. The excess power is dissipated in the dump-load resistor with the chopper control, and the dc-link voltage is maintained. The Section II introduces the System overview. The Section III describes the Control of Switch-mode rectifier with maximum power extraction. The Section IV discusses on the Control of Load-Side inverter. The Section V,VI,VIII and VIII discusses on test system and waveforms/results and conclusion respectively.

II. SYSTEM OVERVIEW

The Fig. 1 shows the control structure of a PMSG-based standalone variable-speed wind turbine which include a wind turbine, PMSG, single-switch three-phase switch-mode rectifier, and a vector-controlled PWM voltage-source inverter. The output of a variable-speed PMSG is not suitable for use as it varies in amplitude and frequency due to fluctuating wind. A constant dc voltage is required for direct use, storage, or conversion to ac via an inverter. In this paper, a single-switch three-phase switch-mode rectifier is used to convert the ac output voltage of the generator to a constant dc voltage before conversion to ac voltage via an inverter. The single-switch three-phase switch-mode rectifier consists of a three-phase diode bridge rectifier and a dc to dc converter. The output of the switch-mode rectifier can be controlled by controlling the duty cycle of an active switch (such as IGBT) at any wind speed to extract maximum power from the wind turbine and to supply the loads. A vector-controlled IGBT inverter is used to regulate the output voltage and frequency during load or wind variations. Voltage drop due to sudden fall in wind speed can be compensated by the energy-storage system. During wind gust, the dump-load controller will be activated to regulate the dc-link voltage to maintain the output load voltage at the desired value.

III. CONTROL OF SWITCH-MODE RECTIFIER WITH MAXIMUM POWER EXTRACTION

This section describes the main techniques that have been reported to the control of wind turbine toward the maximization the output power. To allow the turbine to transfer a maximum fraction of available wind power for fluctuating wind velocities incident upon the turbine blades, it is desirable to maintain the tip-speed ratio at point of maximum power coefficient $cp(\lambda)$. Based in this principle several control techniques have been developed to optimize output power for a given wind velocity. Other techniques employed a Maximum Power Point Tracking (MPPT) algorithm with search for the turbine rotating speed, which result in the maximum power, is based on a measurement of the power generated Therefore, since the measurement of the power generated is simpler and more accurate than the measurement of the wind velocity, the MPPT is preferred..

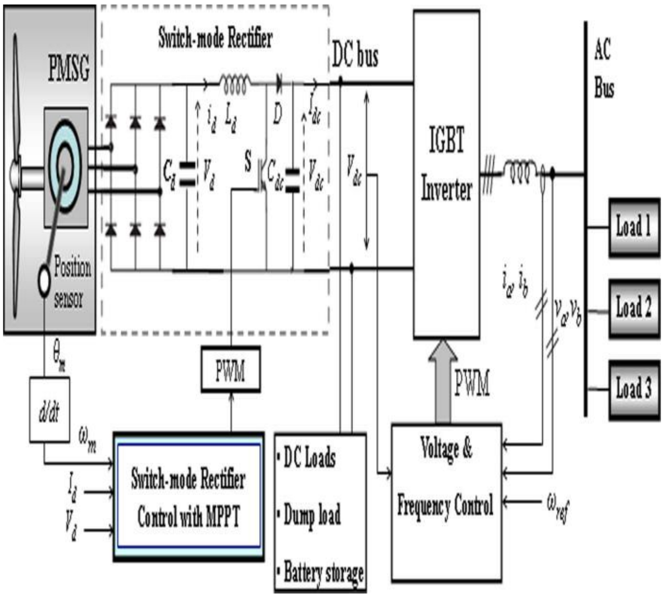


Fig 1 .Control structure of a PMSG Based Stand-alone Variable-Speed Wind turbine

The structure of the proposed control strategy of the switch-mode rectifier is shown in Fig. 2. The control objective is to control the duty cycle of the switch ***S*** in Fig. 2 to extract maximum power from the variable-speed wind turbine and transfer the power to the load. The control algorithm includes the following steps.

1) Measure generator speed ωg.
2) Determine the reference torque (Fig. 4) using the following equation:

$$T_g^* = K_{opt}(\omega_g)^2 \quad (1)$$

3) This torque reference is then used to calculate the dc current reference by measuring the rectifier output voltage V_d as given

$$I_d^* = (T_g^* \times \omega_g) / V_d \quad (2)$$

4) The error between the reference dc current and measured dc current is used to vary the duty cycle of the switch to regulate the output of the switch-mode rectifier and the generator torque through a Proportional–Integral (PI) controller.

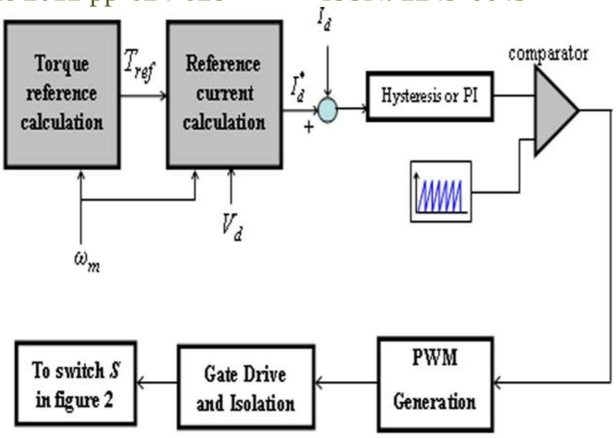


Fig. 2 Control strategy of the switch-mode rectifier.

The generator torque is controlled in the optimum torque curve according to the generator speed. The acceleration or deceleration of the generator is determined by the difference of the turbine torque *Tm* and generator torque *Tg*. If the generator speed is less than the optimal speed, the turbine torque is larger than the generator torque, and the generator will be accelerated. The generator will be decelerated if the generator speed is higher than the optimal speed. Therefore, the turbine and generator torques settle down to the optimum torque point $T_{m\_}$ opt at any wind speed, and the wind turbine is operated at the maximum power point.

IV. CONTROL OF LOAD-SIDE INVERTER

The control strategy of Vector-Control Scheme is used to perform the control of the grid side converter. They control of the DC-link voltage, active and reactive power delivered to the grid, grid synchronization and to ensure high quality of the injected power [2].The objective of the supply-side converter is to regulate the voltage and frequency. The control schemes is in the inner loops where they use different reference frames to perform the current control. In the first case, the currents are controlled in the synchronous rotating reference frame using PI controllers. The dc voltage PI controller maintains the dc voltage to the reference value. The PI controllers are used to regulate the output voltage and currents in the inner control loops and the dc voltage controller in the outer loop. This is the classical control structure, it is also known as dq-control. It transforms the grid voltages and currents from the abc to the dq reference frame. In this way the variables are transformed to DC values which can be controlled more easily. This structure uses PI controllers since they have good performance for controlling DC variable.

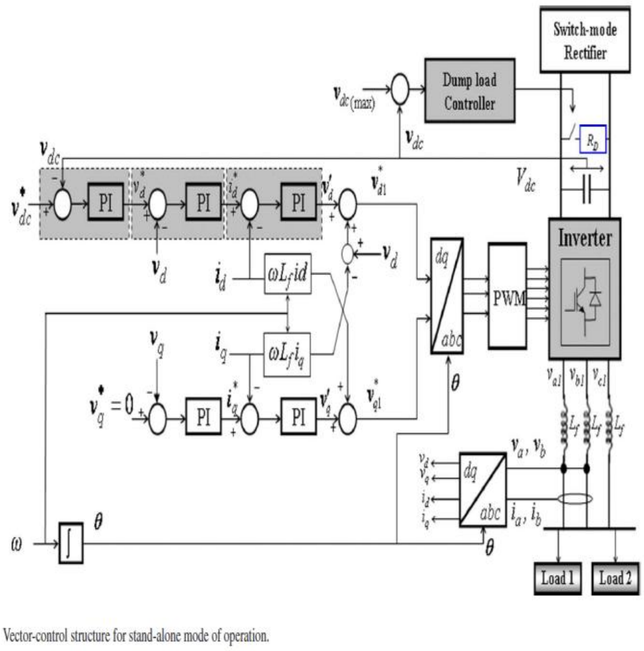


Fig 3.Vector control structure

V. SIMULATION MODEL OF PROPOSED SYSTEM

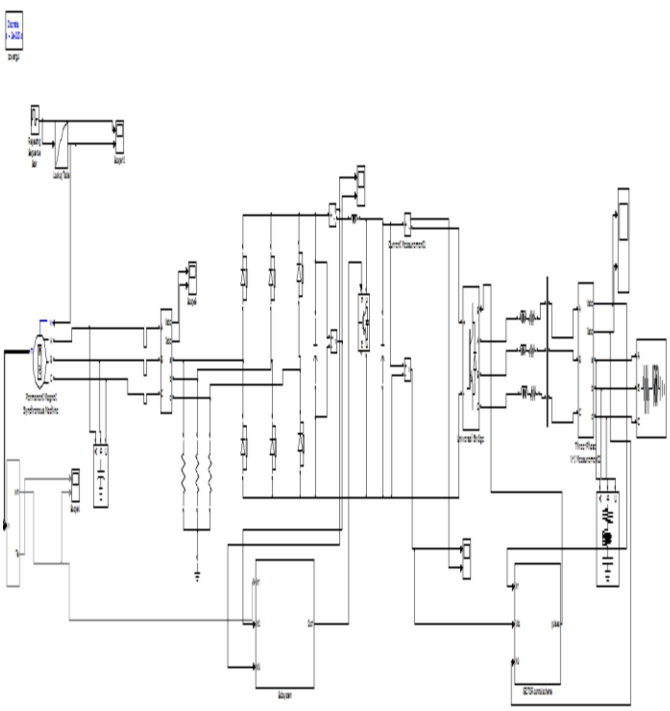


FIG.4 Simulation model Control structure of a PMSG-based stand-alone variable-speed wind turbine.

VI. CONTROL STRATEGY OF THE SWICH-MODE RECTIFIER WITH MPPT

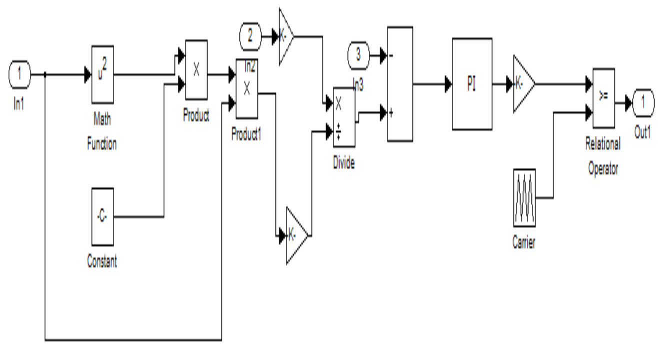


Figure 5 Control Strategy of the Switch-mode rectifier.

VII. VECTOR CONTROL SCHEME FOR GRID SIDE CONVERTER

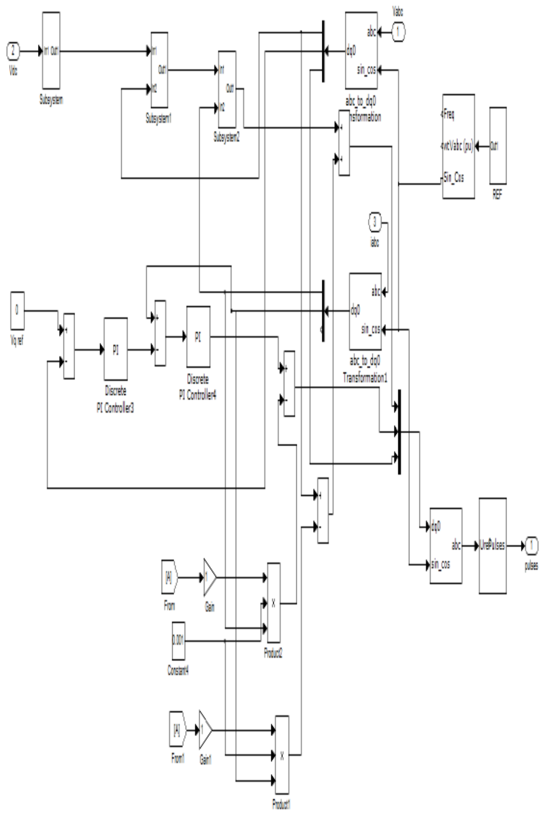
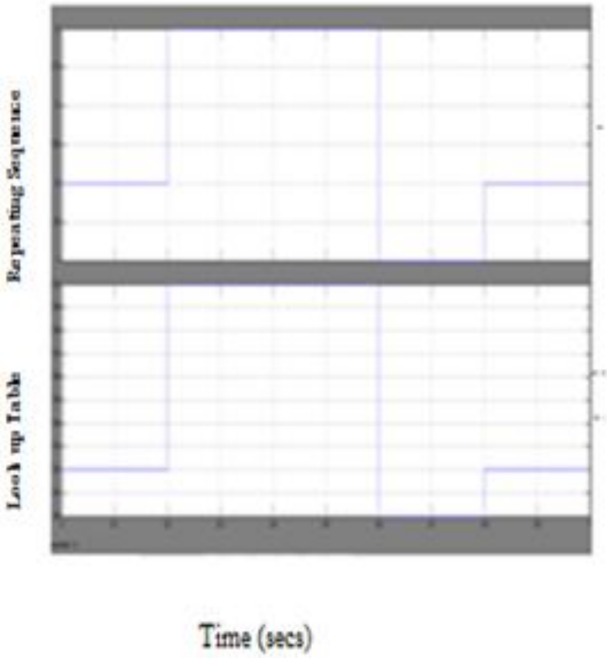


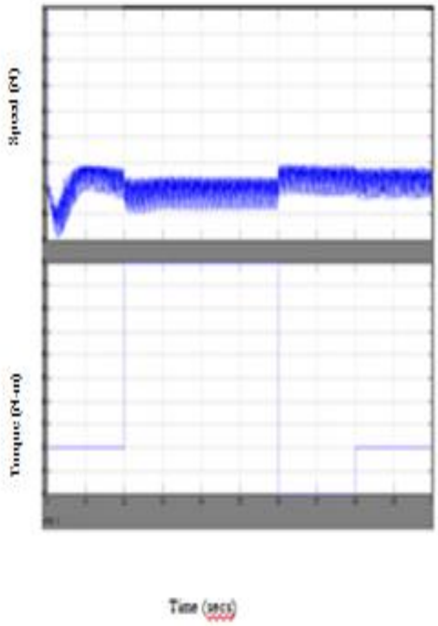
Fig 6. Vector control scheme

VIII. RESULTS FOR PROPOSED SYSTEM

The model of the PMSG-based variable-speed wind-turbine system of Fig. 4 is built using Matlab/ Simpower dynamic system simulation software.



(a)



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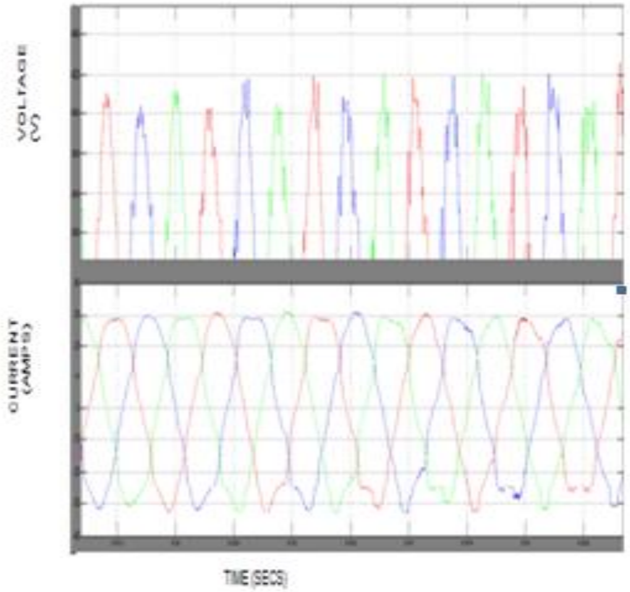

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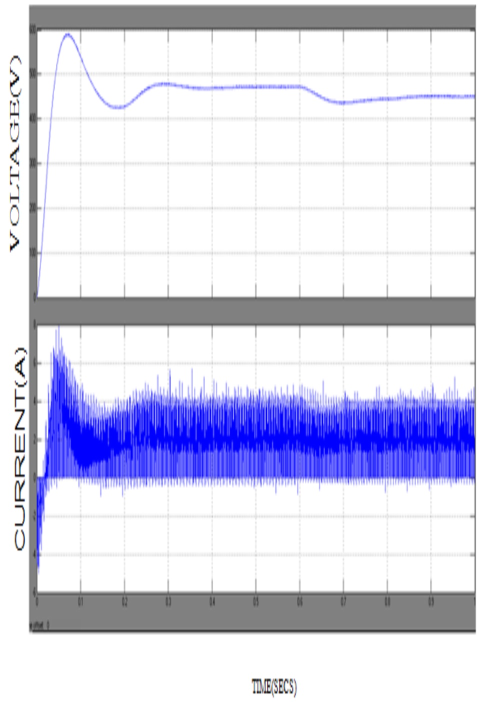

(d)

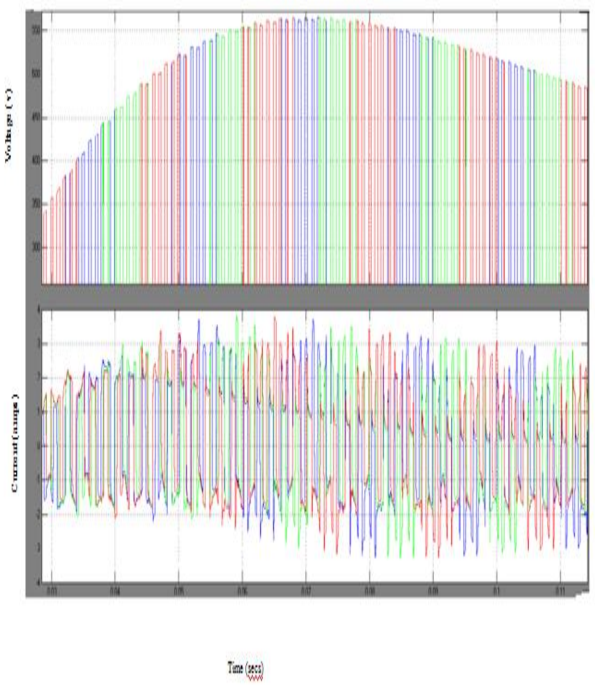
(e)

Fig. 8. (a) Wind Speed (b) Torque and Speed (c) Three phase V-I Measurement (d) Inverter –side control (e) Grid-side control.

IX. CONCLUSION

A control strategy for a direct-drive stand-alone variable speed wind turbine with a PMSG has been presented in this project. A simple control strategy for the generator-side converter to extract maximum power is discussed and implemented using Simpower dynamic-system simulation software. The controller is capable of maximizing output of the variable-speed wind turbine under fluctuating wind. The generating system with the proposed control strategy is suitable for a small-scale stand-alone variable-speed wind-turbine installation for remote-area power supply. The simulation results demonstrate that the controller works very well and shows very good dynamic and steady-state performance.

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