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Steady State Performance of Grid Connected PMSG Wind-Turbine Using New ZDC Control Under Asymmetrical Voltage Sags

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Abstract: Permanent Magnet Synchronous Generator (PMSG) based Wind Energy Conversion System (WECS) is highly preferred these days with back-to-back converter topologies. The operation and control of a grid-connected wind turbine with a PMSG have been investigated under asymmetrical grid side voltage sags. To deal with such conditions, a fast-acting control scheme is needed. It is shown in this project new Zero-Direct Axis (ZDC) control can meet the challenge. In the proposed control scheme, first the active/reactive powers and DC link voltage are decoupled, so that the asymmetrical grid side voltage sag problems can be able to dealt with proposed control scheme independently. To minimize voltage stress inflicted by the grid side asymmetrical voltage sag on the power electronic converters, a feed-forward negative sequence voltage is used in the vector current control strategy. In both the converter (GSC converter and MSC converter) strings the generator-side converters are controlled by using separate ZDC control with Optimal Torque Control (OTC) technique for Maximum Power Point Tracking (MPPT) and both the grid-side converters are controlled with the help of separate grid-side control. The effectiveness of the proposed control scheme has been validated by extensive MATLAB simulations platform.

Key Words— ***PMSG, ZDC, WECS***

I. INTRODUCTION

Over the last years, with technological advancement, wind power has grown rapidly and becomes the most competitive form of renewable energy [1-2]. The basic configuration of grid-connected MW-WECS is composed of several components that convert wind kinetic-energy into electric energy in a controlled, reliable and efficient manner [3]. The major components of a WECS can be broadly classified as mechanical and electrical. The mechanical components include tower, nacelle, rotor blades, rotor hub, gearbox, pitch drives, yaw drives, wind speed sensors, drive-train and mechanical brakes [3-5]. The electrical components of a wind turbine system include a turbine rotor, generator, a power electronic system, generator-side harmonic filter, grid-side harmonic filter, step-up transformer and three phase grids (collection-point) shown in Fig.1.4. In that Wind turbines capture the power from wind by means of turbine blades and convert it to mechanical power [5]. Hau [8] presents various Wind turbine (WT) concepts have been developed into wind power technologies and led to significant growth of wind power capacity during the last two decades. Variable speed operation and direct drive WTs have been the modern aspects of the wind energy conversion system (WECS) technology. Bin Wu [19] presents Variable-speed has many advantages over fixed-speed operations such as increased energy capture, operation at maximum power point over a wide range of wind speeds, high power quality, reduced mechanical stresses, aerodynamic noise improved system reliability, providing 10–15% higher output power and less mechanical stresses compared to the operation of a fixed speed systems [15]. Wind Turbines can be classified into direct drive (DD) and geared drive (GD) according to the type of drive train. The GD type uses a gear box and squirrel cage induction generator (SCIG). The GD configuration can be classified into stall, active stall and pitch control systems in constant speed applications. The variable speed applications used doubly fed induction generator (DFIG) especially in high power Wind turbine (WT)s.

II. CONTROL TECHNIQUE

The PMSG generator used in variable speed WECS decides the proposed control scheme to be implemented. The most popular PMSG generator control techniques used Unity Maximum Torque per Ampere (MTPA) control, Power Factor (UPF) control and Zero Direct-axis Current (ZDC) control. In this paper, new ZDC control scheme for variable speed wind energy conversion system (WECS) with single PMSG generator using back-to-back converter tropology has been proposed. In this control, the stator current phasors in stationary reference frame are resolved into synchronous reference frame namely *direct*-axis and *quadrature*-axis. Here, *direct*-axis stator current is set to zero for implementation of new proposed ZDC control. The stator current equal to *quadrature*-axis stator current as I_{ds} is controlled to be zero as given in (1),

$$I_{stator} = \sqrt{I_{ds}^2 + I_{qs}^2} = I_{qs} \quad for \;\; I_{ds} = 0 \tag{1}$$

The electromagnetic torque (EMT) of the PMSG generator can be given as,

$$\tau_e = \frac{3}{2} P\lambda_r I_{qs} - (L_{ds} - L_{qs}) I_{ds} I_{qs} \tag{2}$$

Hence, for proposed ZDC control,

$$\tau_e = \frac{3}{2} P\lambda_r I_{qs} = \frac{3}{2} P\lambda_r I_{stator} \tag{3}$$

where *P* is number of pole pairs, *r* is magnetic flux linkage to the generator rotor, L_{ds} is stator inductance of direct-axis and L_{ds} is stator inductance of q-axis. In equation (4.3), it can be observed that generator torque is proportional to stator current I_{stator} and accordingly for new proposed ZDC control scheme vector diagram is shown in Fig.1(c). Here, the stator resistance is neglected and *r* is linear with direct-axis. The vector rotates with synchronous speed which is equal to the speed of rotor represented *r*. The three-phase stator current *I*stator is perpendicular to *r*. The stator voltage is given as,

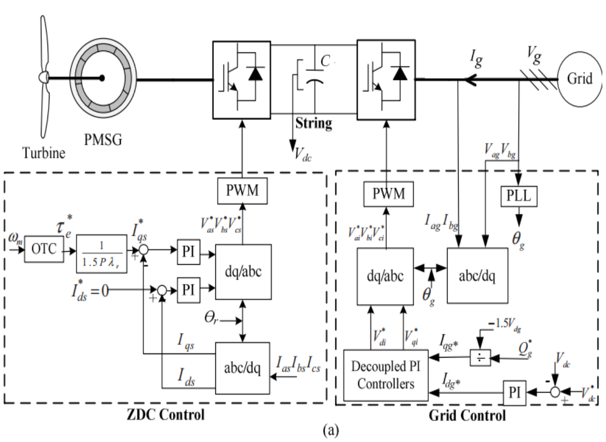
$$V_{stator} = \sqrt{(v_{ds}^2) + (v_{qs}^2)} = \sqrt{(\omega_r L_{qs} I_{qs})^2 + (\omega_r \lambda_r)^2} \tag{4}$$

where *vds* is stator voltage of d-axis and v_{qs} is stator voltage of quadrature-axis. The power factor angle of stator flux Φ_{stator} angle is given as,

$$\phi_{stator} = \theta_v - \theta_i \tag{5}$$

$$\theta_v = \tan^{-1} \frac{v_{qs}}{v_{ds}} \tag{6}$$

where, θ_v and θ_i indicates the angles of three phase stator voltage and stator current, respectively



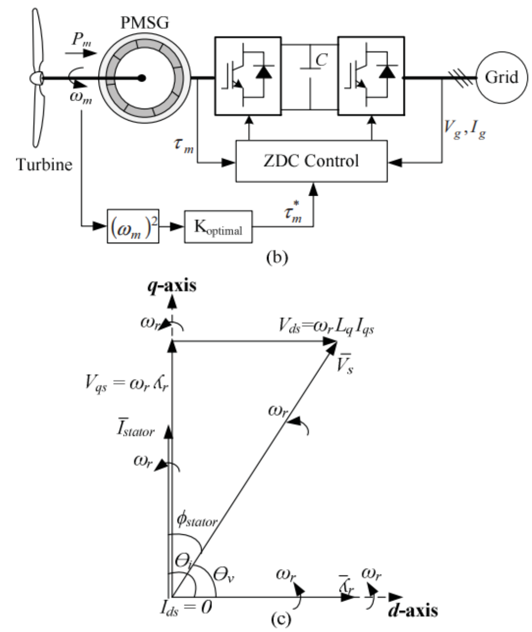


Fig.1. (a) new proposed ZDC control for grid connected PMSG generator-based wind energy conversion system (WECS) (b) (OTC) (c) Vector diagram for proposed new ZDC control

As I_{ds}=0,

$$\phi_{stator} = \theta_v - \theta_i = \tan^{-1}\left(\frac{v_{qs}}{v_{ds}}\right) - \frac{\pi}{2} \tag{7}$$

Further, to extract the maximum power under variable wind speed, optimal torque control (OTC) maximum power point technique MPPT technique is used for wind energy conversion system (WECS) which results in torque reference *e** of the generator. In Optimal torque control, the maximum power can be obtained using below equations (8) - (9)

$$\tau_m \alpha \omega_m^2 \tag{8}$$

In (8), *m* is PMSG generator torque. The coefficient of optimal torque $K_{optimal}$ is derived as

$$\tau_e^* = K_{optional} \omega_m^2$$

Thus (4.9) gives *e** reference which is further used to implement new proposed ZDC control. The reference of stator current of q_{axis} is i_{qs}^* is generated using τ_e^* as shown in Fig. 2(a). The *d*-axis and *q*-axis voltage references i.e. V_{ds}^* and V_{qs}^* undergoes *dq-abc* transformation which are then transformed to $V_{as}^*, V_{bs}^*, V_{cs}^*$. These reference voltage used to generate switching signals for the power converter using Sinusoidal Pulse Width Modulation technique and also to

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control the real power of the PMSG generator. The grid voltage angle g is obtained by phase-lock loop and the DC-link voltage V_{dc} is regulated by GSC. The *direct*-axis and *quadrature*-axis reference voltages (V_{dg}, V_{qg}) and currents (I_{dg}, I_{qg}) are generated by *abc-dq* transformation. Similarly, the switching pattern is generated for grid-side inverter control (GSC). Small voltage difference among the parallel converters can cause zero-sequence circulating currents. This current can be represented as,

$$i_{10} = \frac{i_{1a} + i_{1b} + i_{1c}}{3} \quad (9)$$

$$i_{20} = \frac{i_{2a} + i_{2b} + i_{2c}}{3} \quad (10)$$

Various methods are used for elimination of this zero-sequence circulating current such as lead-lag compensation, active damping, passive damping, band-stop filter, optimal control using PQR transformation or separate DC-links. Out of these methods use of separate DC-link capacitors of same value is implemented with proper isolation among the power converters

III. Proposed System

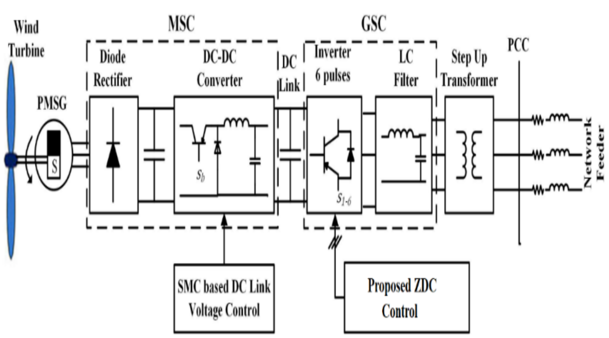


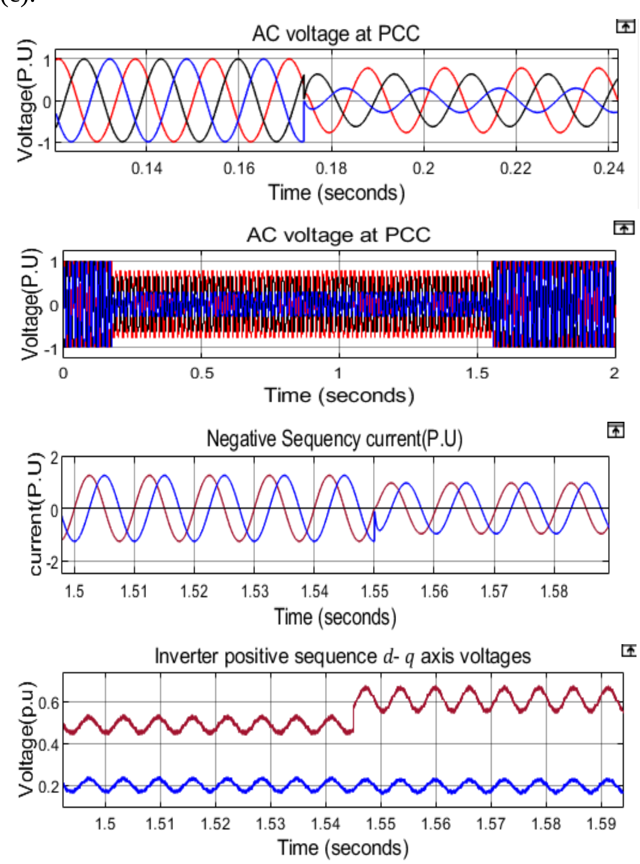
Fig.2. Schematic diagram of PMSG based variable speed wind turbine connected to a power grid network

A wind turbine-driven PMSG investigated is shown in Fig.2. Power electronic converter is used to maintain system operation under the power grid connected mode. The first stage consists of a diode rectifier plus a DC-DC converter (referred as MSC), and the second stage consists of an H-bridge of six pulse inverter (referred as GSC). The MSC is used to regulate the DLV in a voltage control mode with the inner current loop, whereas the GSC performs the power flow control based on a MPPT scheme. The LC filter is used in line with the inverter to provide a smooth and pure sinusoidal waveform, while the step-up transformer is used to bring the inverter output voltage up to the grid level at the PCC.

IV. Results And Discussion

A power grid disturbance causing an asymmetrical voltage sag is considered to validate the effectiveness of the developed proposed control strategy. Transient disturbances, such as changes in wind speed and grid frequency, have also been considered. Properly designed *PI* controllers are used as a benchmark. They are designed using frequency response techniques to provide at least 60° phase margin. Proposed system analyzed under asymmetrical grid voltage sag (87%, 37% and 50 % drop) with proposed control.

It is assumed that an asymmetrical power grid three phase voltage sag has occurred due to a sudden change in unbalanced three phase loads. The asymmetrical three phase loads considered are for 80 cycles starting at 0.175 s as shown in Fig. 3 (a). As a result, the negative sequence current appears as shown in Fig. 3 (b). Consequently, the inverter d - q axis positive sequence voltages and currents start to oscillate at twice of the system frequency as indicated in Fig. 3 (c) and (d). The voltage and current continue to oscillate for a few more cycles even after the clearance of the asymmetrical condition when the *PI* controller is used. In fact, the current hits the upper saturation limit for the pre-disturbed power reference and reduced voltages as shown in Fig. 3 (d). The DLV also oscillates at 20% in amplitude as shown in Fig. 3 (e).



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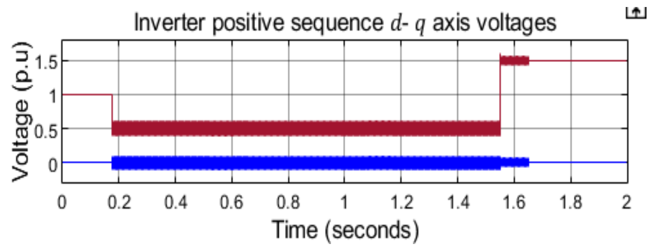

Fig.3. Wind system during an asymmetrical voltage sag with proposed control scheme (a) AC voltage at PCC (zoom),(d) AC voltage at PCC (c) Inverter negative sequence *d*- *q* axis currents (d) Inverter positive sequence *d*- *q* axis voltages (zoomed at upper display), (e) Inverter positive sequence *d*- *q* axis currents.

V. CONCLUSION

In actual operation, there are many cases of unbalanced voltage caused by the asymmetric fault. In [1]-[2], the technology of suppressing overcurrent of the grid side converter (GSC) and suppressing overvoltage of the DC bus capacitor is studied. This paper highlights the necessity of supporting the point of common coupling (PCC) voltage by the fully rated converter of permanent magnet synchronous generator (PMSG) type wind turbines under unbalanced voltage sags. According to the positive and negative sequence reactive currents injected into the grid by the grid side converter (GSC) are related to the voltage of each phase at PCC during asymmetric grid faults, a voltage support control strategy is proposed. The proposed method can achieve the purpose of supporting the PCC voltage of the grid and enhance the asymmetric ride-through capability of the wind turbine. And it can retain the sequence component characteristics of the current in the event of asymmetrical faults in the grid. The effect of different control options has been demonstrated using simulation on a test network and conclusion deduced.

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