Modeling and Analysis of Wind-Driven PMSG for Healthy and Unhealthy Conditions

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Abstract This paper shows the analysis and modeling of wind-driven permanent magnet synchronous generator. The maximum power is extracted from wind turbine by controlling pitch angle and tip to speed ratio. The modeling of permanent magnet synchronous machine is assessed. Thereafter, healthy and unhealthy analysis of PMSG is assessed. The unhealthy condition is being specified in terms of different faults like LLL, LG. Subsequently, power quality issues like THD and MSE are being analyzed for both the conditions.

Keywords THD · Wind · PMSG · Healthy · MSE

1 Introduction

Over the years, the wind generator sector has become increasingly popular. Conventional power generators did not reach the megawatts system. As a result, the majority of the early models used permanent magnet synchronous generators (PMSGs) or a common asynchronous generator. A gearbox is usually connecting an asynchronous generator to a turbine. If the generator has a large number of poles, a permanent compatible generator (PMSG) can be connected to a turbine with a gearbox or directly outside the gearbox [1, 2]. Because of the increase in power per megawatt system, which is now up to 10 MW, PMSG changes necessitate an increase in converter size and weight. Permanent magnetic generators with synchronous generators having the advantages of being more durable, smaller in size, requiring no additional power supply to stimulate the magnetic field, and requiring less adjustment than conventional generators. Furthermore, when compared to the constant-speed technique, variable-speed wind power has advantages such as magnitude, the ability to track

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spots, and reduced acoustic noise at low wind speeds [3, 4]. The modeling and control approaches used in two permanent magnet synchronous generator farms for wind applications are described in this paper. A completely integrated rear-turning converter, consisting of two three-phase capacitors, a central DC bus, and an inverter, is used to link generators to the power grid [5, 6]. The entire system is phase connected to the electrical grid. Maximum power point tracking (MPPT) for PMSG speed control, active power control, and DC bus power management are among the proposed control solutions. Some simulation results are shown and examined using the MATLAB/Simulink programming to demonstrate the effectiveness of control schemes [7, 8].

2 Modeling of Wind Turbine

An aerodynamic model of the wind turbines is a basic part of the dynamic models of the electricity producing wind turbines. Theoretical power generated by the turbine is given by,

$$\boldsymbol{P_m} = \frac{1}{2}\boldsymbol{\rho A V}^3\boldsymbol{C_p}(\boldsymbol{\lambda}, \boldsymbol{\beta}) \tag{1}$$

where

P_{m} mechanical power developed in turbine.
ρ air density 1.223 kg/m^3.
A area swept by rotor blades.
C_{p} coefficient of power.
λ ratio between blade tip speed and wind speed at hub height.
β pitch angle,
C_{p} (λ, β) can be determined as

$$\boldsymbol{C_p} = \frac{1}{2}\left[\frac{116}{\boldsymbol{\lambda}} - 0.4\boldsymbol{\beta} - 5\right]\boldsymbol{e}^{\left(\frac{-21}{\lambda_i}\right)} \tag{2}$$

where λi is defined as,

$$\frac{1}{\boldsymbol{\lambda_i}} = \frac{1}{\boldsymbol{\lambda}} + 0.08\boldsymbol{\beta} - \frac{0.035}{\left(1 + \boldsymbol{\beta}^3\right)} \tag{3}$$

3 Modeling of PMSG

In this research paper, permanent magnet synchronous generator (PMSG) is used as the wind turbine generator due to its property of self-excitation (by permanent magnet) which eliminates the excitation loss, i.e., excitation losses are not increases as number of poles doubled. Two-phase synchronous reference rotating frame (*d*-*q* frame) is used to derive the dynamic model of the *d*-axis with PMSG in which the *q*-axis is 90° ahead with respect to the direction of rotation [9, 10]. The electrical model of permanent magnet synchronous generator in synchronous reference rotating frame is represented by the differential equations,

$$\frac{\mathrm{d}}{\mathrm{d}t}(i_d) = \frac{-R_a}{L_d} i_d + \omega_e \frac{L_q}{L_d} i_q + \frac{1}{L_d} U_d \tag{4}$$

$$\frac{\mathrm{d}}{\mathrm{d}t}\left(i_q\right) = \frac{-R_a}{L_q} i_q - \omega_e \left(\frac{L_d}{L_q} i_d + \frac{1}{L_d} \lambda_o\right) + \frac{1}{L_q} U_q$$
$$\omega_e = P\omega_g, e_q = \omega_e \lambda_o, T_e = 1.5P\left[\left(L_d - L_q\right) i_d i_q + i_q \lambda_o\right] \tag{5}$$

where R_a is resistance of stator winding, ωe and ωg are electrical and mechanical rotating speed, λ∘ is flux produced by the permanent magnets, *P* is number of pole pairs, U_d and U_q are *d* and *q*-axis voltages, L_d and L_q are *d* and *q*-axis inductances, Te is electromagnetic torque, and e_q is *q*-axis counter electrical potential [11–15].

4 Performance Assessment with Balanced and Unbalanced Condition

The various performance characteristics like voltage and current at stator terminal and grid have been plotted for healthy and unbalanced condition are shown from Figs. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12. It is observed that THD or harmonics are found to be less with unbalanced condition in comparison to healthy condition. Such comparative analysis is also shown in Table 1.

Similar kinds of results are also obtained for MSE which is shown in Table 2.

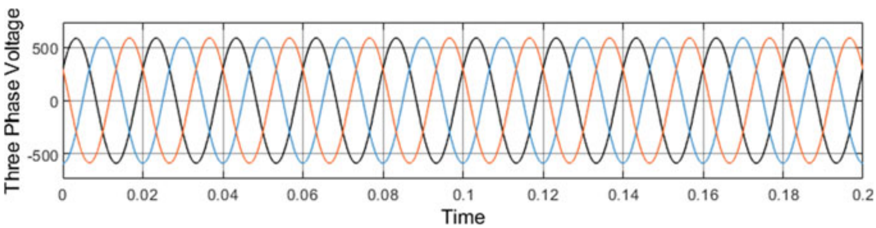

Fig. 1 Balance three-phase voltage at stator terminal

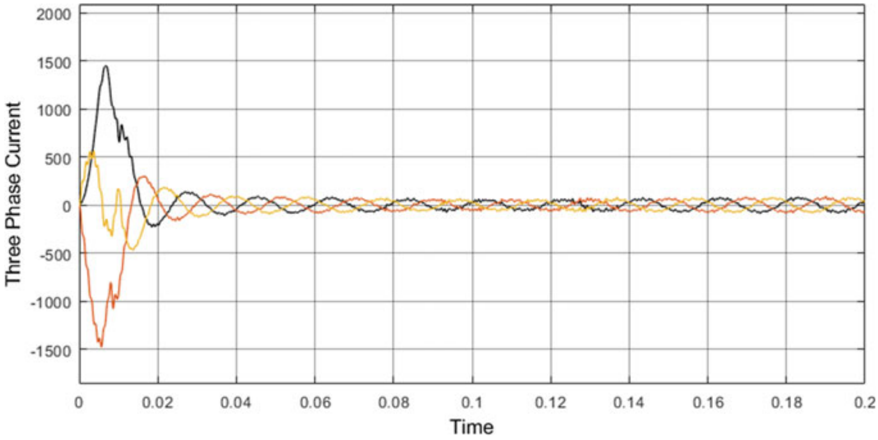

Fig. 2 Balance three-phase current at stator terminal

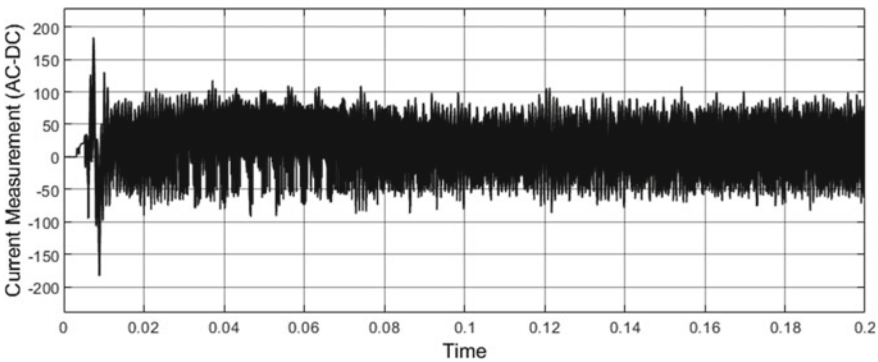

Fig. 3 Current measurement at stator terminal

5 Conclusions

The analysis and modeling of a wind-driven permanent magnet synchronous generator are presented in this study. Controlling the pitch angle and tip to speed ratio of a wind turbine allows it to produce the most power. A permanent magnet synchronous machine's modeling is evaluated. After that, PMSG is analyzed to see if it is healthy or not. Variable loading conditions are used to define the unhealthy situation. Following that, power quality issues such as THD and MSE are investigated for both circumstances. It is observed that MSE and THD are found to be less with healthy condition in comparison with unhealthy condition.

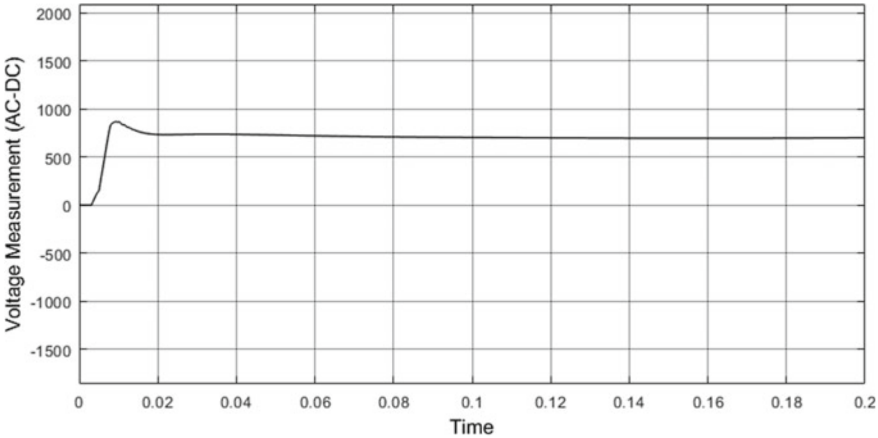

Fig. 4 Voltage measurement at DC link

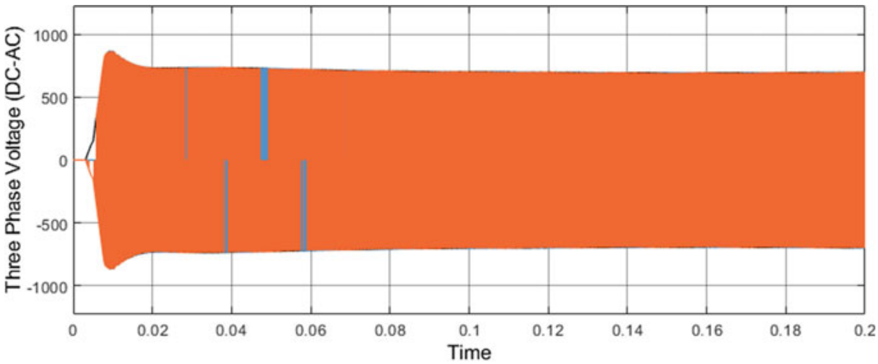

Fig. 5 Three-phase voltage at grid

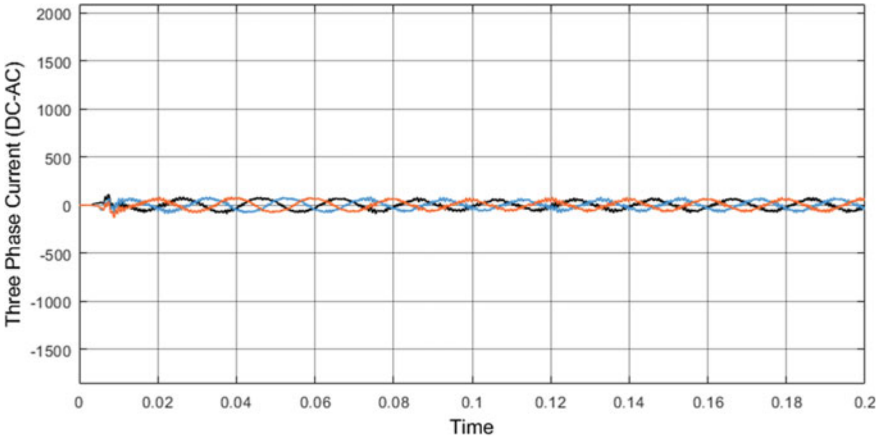

Fig. 6 Three-phase current at grid

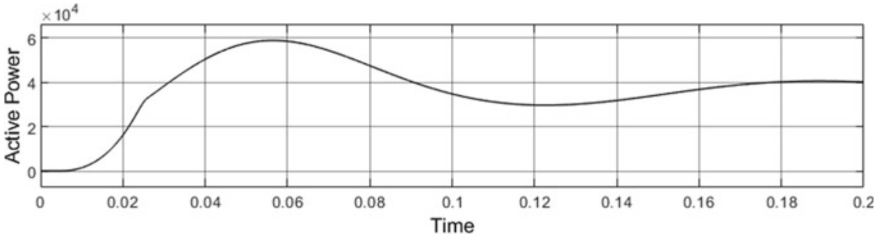

Fig. 7 Active power at stator terminal

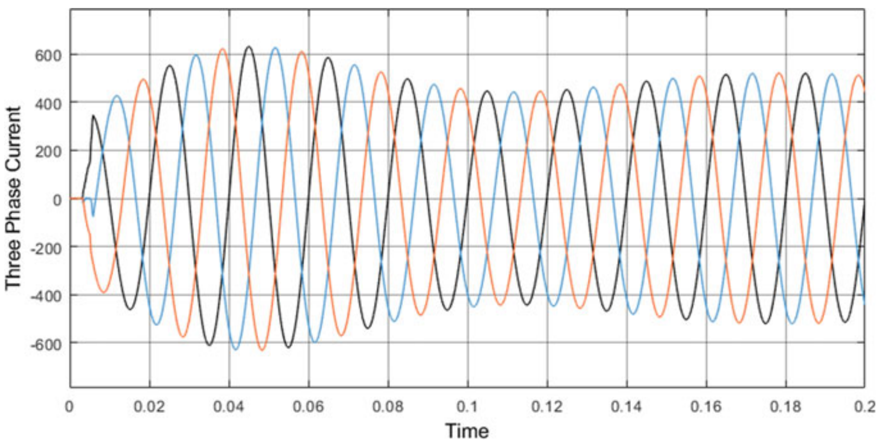

Fig. 8 Unbalanced three-phase current (LLL Fault) at stator terminal

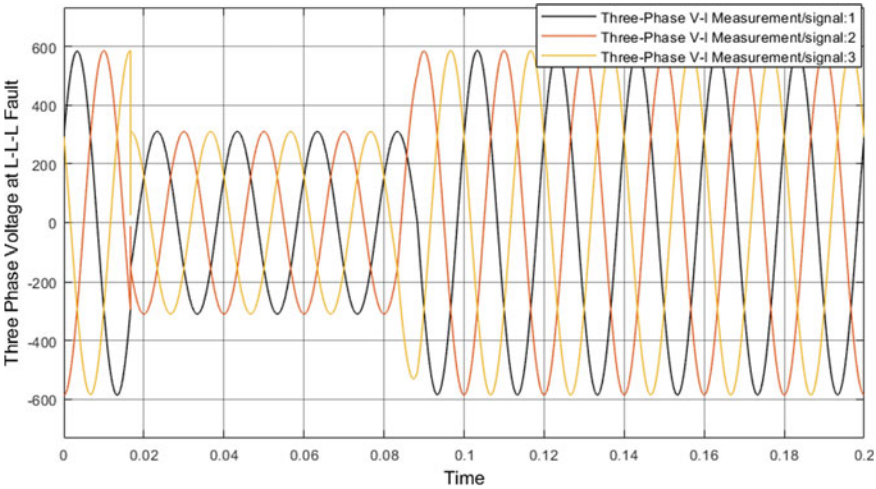

Fig. 9 Unbalanced three-phase voltage (LLL Fault) at stator terminal

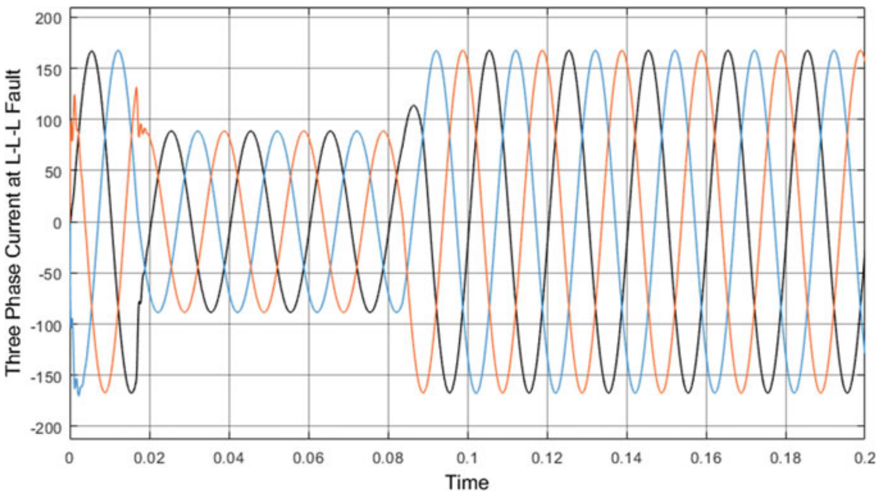

Fig. 10 Unbalanced three-phase current (LLL Fault) at grid

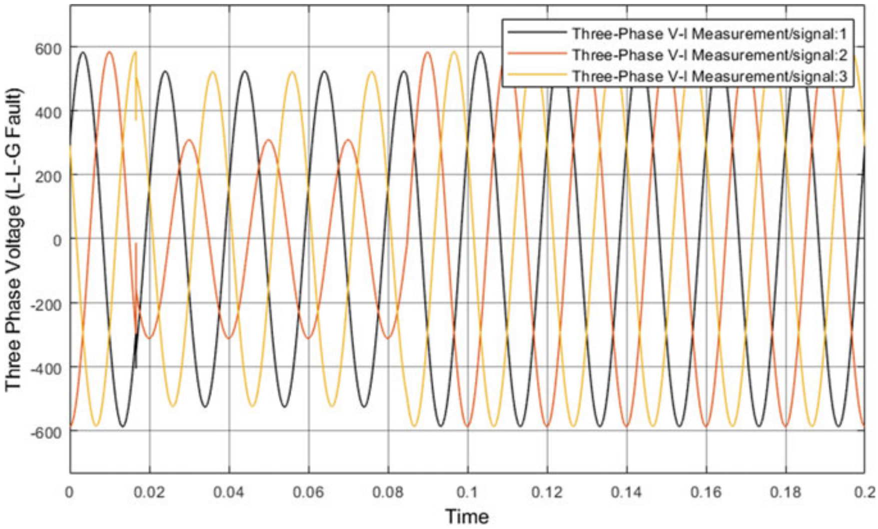

Fig. 11 Unbalanced three-phase voltage (LG Fault) at stator terminal

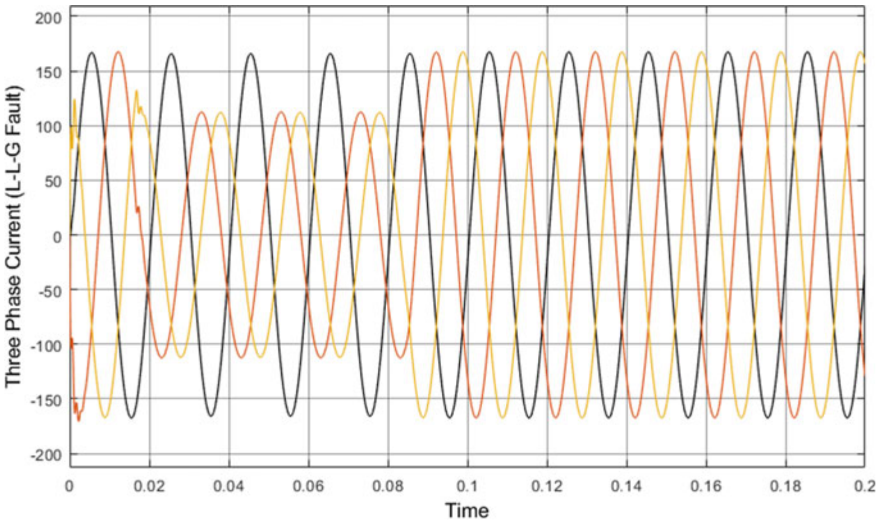

Fig. 12 Unbalanced three-phase current (LG Fault) at stator terminal

Table 1 THD (%) comparison with balanced and unbalanced condition

THD (%)	Healthy condition	Unhealthy condition
Voltage at stator terminal (LLL)	4	8.9
Current at stator terminal (LLL)	5.5	9.1
Voltage at grid (LG)	4.3	9.6
Current at grid (LG)	5.1	9.5
Current at stator terminal (LLG)	4.9	10.2

Table 2 MSE comparison with balanced and unbalanced condition

MSE	Healthy condition	Unhealthy condition
Voltage at stator terminal (LLL)	6	9.8
Current at stator terminal (LLL)	7.2	10.6
Voltage at grid (LG)	5.6	9.8
Current at grid (LG)	4.8	10.8
Current at stator terminal (LLG)	6.1	11.6

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