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FAULT ANALYSIS OF WIND TURBINE GENERATOR SYSTEM CONSIDERING SIX-MASS DRIVE TRAIN MODEL

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ABSTRACT

This paper analyzes different types of symmetrical and unsymmetrical fault of grid connected wind turbine generator system (WTGS), where the six-mass drive train model is considered. The unsuccessful re-closing due to permanent fault is also considered. Moreover, the blade-shaft stresses of the six-mass drive train model of WTGS are also analysed for both successful and unsuccessful re-closing.

1. INTRODUCTION

Recently huge numbers of wind farms are going to be connected with the existing network due to its clean and economical energy generation. Normally, the wind generator is disconnected from the grid after the network disturbance occurs in power system. But it is going to be a practice to reduce the wind generator disconnection or shut down phenomenon when voltage of the generator is greatly dropped. As for example, in Germany the wind generator shut down phenomenon is reduced by adopting the low voltage ride through (LVRT) requirement from German grid operator named E.ON Netz. The E.ON Netz standard requires that the machine remains connected for voltages at the terminals as low as 15% of nominal per unit for approximately 0.6 s [1]. American Wind Energy Association (AWEA) also recommended the adoption of an LVRT requirement developed by E.ON Netz. Therefore, it is essential to investigate different types of fault and blade-shaft loading of WTGS due to network disturbances as the wind generator terminal voltage drops hugely during the fault condition.

In [2-3], the transient stability of the wind generator at faulted conditions are reported, where the wind turbine and the wind generator are modeled as one-mass lumped model, having a combined inertia constant. Stability analysis based on one-mass shaft model may give significant error as presented in [4-7]. In [4], we presented that the turbine and the generator inertias and spring constant of the shaft between the two-mass model have significant effect on the transient stability of the wind generator. In [8], we analyzed the transient stability using three-mass and two-mass shaft models. In this paper, we considered the six-mass drive train model for the different types of symmetrical and unsymmetrical fault analysis for both successful and unsuccessful re-closing. Though the shaft stresses of the six-mass drive train are presented in [9], but the blade stresses are not presented there. The unsuccessful re-closing is also not considered there. In this paper, the turbine blades and the low and high speed shaft stresses are presented in detailed when network disturbances occur in the power system.

2. WIND TURBINE MODELING

The mathematical relation for the mechanical power extraction from the wind can be expressed as follows:

$$P_W = 0.5\rho\pi R^2 V_W{}^3 C_P(\lambda, \beta) \tag{1}$$

The wind turbine characteristic is taken from [10].

In this paper, the six-mass drive train model shown in Fig. 1 is considered for the precise analysis of WTGS. The six-mass model system has six inertias. These are three blade inertias (J_{B1}, J_{B2}, and J_{B3}), hub inertia (J_H), gearbox inertia (J_{GB}), and generator inertia (J_G). θ_{B1}, θ_{B2}, θ_{B3}, θ_H, θ_{GB}, and θ_G represent the angular positions of the blades, hub, gearbox, and generator. ω_{B1}, ω_{B2}, ω_{B3}, ω_H, ω_{GB}, and ω_G correspond to the angular velocities of the blades, hub, gearbox, and generator. The elasticity between adjacent masses is expressed by the spring constants of K_{HB1}, K_{HB2}, K_{HB3}, K_{HGB}, and

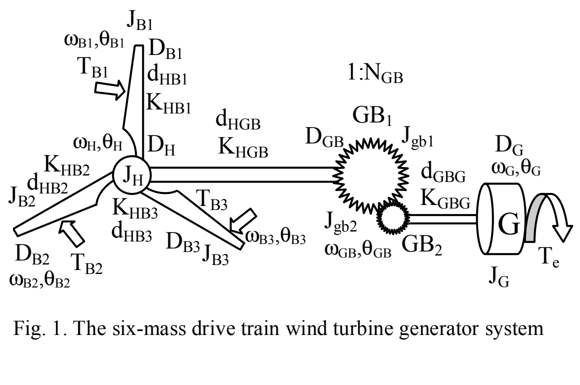


Fig. 1. The six-mass drive train wind turbine generator system

K_{GBG}. The mutual-dampings between adjacent masses are d_{HB1}, d_{HB2}, d_{HB3}, d_{HGB}, and d_{GBG}. There exist some torque losses through external damping elements of individual masses, which are represented by D_{B1}, D_{B2}, D_{B3}, D_H, D_{GB}, and D_G. The sum of the blade torques develops the turbine torque, T_{wt}. It is assumed that the aerodynamic torques acting on hub and gearbox are zero.

3. MODEL SYSTEM

Fig. 2 shows the model system used for simulation of the transient stability of power system. One wind farm (Induction generator, IG) is connected with the network via a transformer and transmission line. A capacitor bank has been used for reactive power compensation at steady state [10]. The AVR and GOV models for synchronous generator (SG) and the parameters of both SG and IG are chosen from [10]. The six-mass drive train parameters are available in [11]. For transient stability analysis the symmetrical three-line-to-ground fault, 3LG, is considered at fault point F in Fig. 2. Some unsymmetrical faults such as double-line-to-ground fault, 2LG (at phase a and b), line-to-line fault, 2LS (between phase a and b), and single-line to ground fault, 1LG (at phase a) are also considered at fault point F in Fig. 2. The fault time sequences are shown in Table I, where FOT, CBOT, and CBCT represent the fault-occurring-time, circuit-breaker-opening-time, and circuit-breaker-closing-time respectively. Case2 of Table I is the time sequence of unsuccessful re-closing due to the permanent fault (PF). Time step has been chosen 0.00005 sec. The simulations have been done by using PSCAD/EMTDC [12].

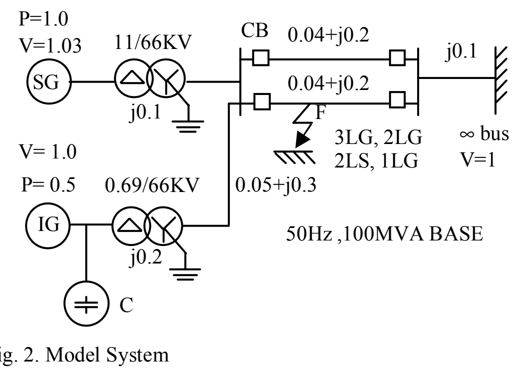


Fig. 2. Model System

TABLE I. TIME SEQUENCE OF FAULT CONDITIONS

Case No.	FOT	CBOT	CBCT	CBOT(PF)
1	0.1	0.2	1.0	-
2	0.1	0.2	1.0	1.1

4. SIMULATION RESULTS

The initial values used in this study is calculated according to [10].

4.1. Fault Analysis

In this section, different types of symmetrical and unsymmetrical faults are analyzed at different wind generator power level, for both successful and unsuccessful re-closing by using six-mass drive train model of WTGS. Table II represents the simulation results when fault time sequence is used from case1 of Table I. Table III represents the simulation results due to unsuccessful re-closing. Simulation results show that 2LG and 3LG faults are more severe compared to 1LG and 2LS faults for successful re-closing. It is noticeable that when the IG is unstable, the synchronous generator remains stable. For unsuccessful re-closing, even at 2LS fault the IG becomes unstable when the IG generates 46 MW. For the 3LG fault both of the IG and the SG become unstable when the IG generates above 26 MW. In Table II and Table III, O and × represent the stable and unstable states, respectively.

TABLE II. TRANSIENT STABILITY RESULTS FOR SIX-MASS DRIVE TRAIN (FAULT TIME SEQUENCE: CASE1 OF TABLE I)

IG POWER (MW)	1LG		2LS		2LG		3LG	
	IG	SG	IG	SG	IG	SG	IG	SG
50	O	O	O	O	×	O	×	O
44	O	O	O	O	×	O	×	O
43	O	O	O	O	O	O	×	O
40	O	O	O	O	O	O	×	O
39	O	O	O	O	O	O	O	O

TABLE III. TRANSIENT STABILITY RESULTS FOR SIX-MASS DRIVE TRAIN (FAULT TIME SEQUENCE: CASE2 OF TABLE I)

IG POWER (MW)	1LG		2LS		2LG		3LG	
	IG	SG	IG	SG	IG	SG	IG	SG
50	O	O	×	O	×	O	×	×
46	O	O	×	O	×	O	×	×
45	O	O	O	O	×	O	×	×
37	O	O	O	O	×	O	×	×
36	O	O	O	O	O	O	×	×
27	O	O	O	O	O	O	×	×
26	O	O	O	O	O	O	O	O

4.2. Blade-Shaft Stress

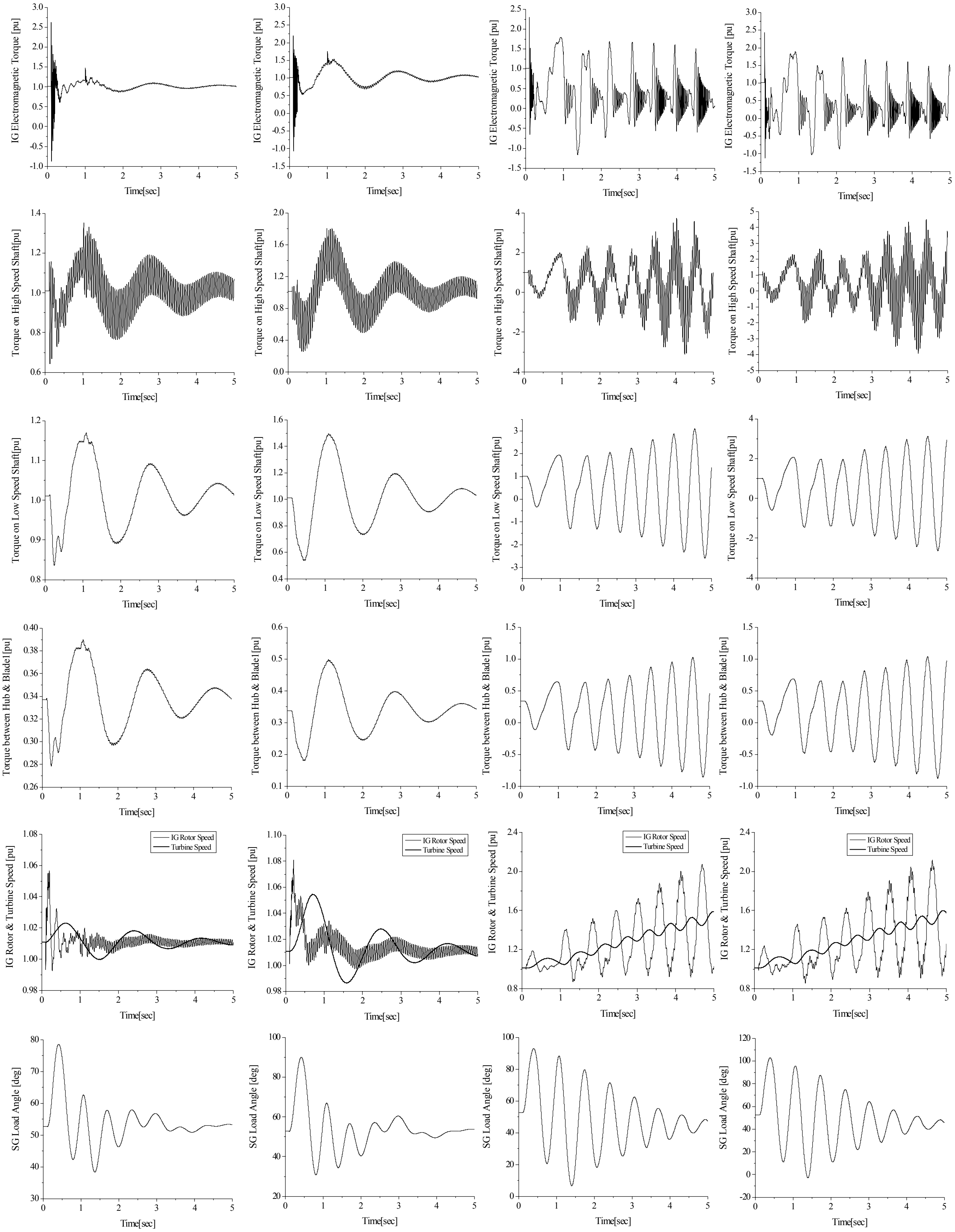
To investigate the maximum stress on shaft and blade the induction generator power is kept constant at rated level, i.e. 50MW. All types of dampings are neglected to investigate the worse scenario. Both the symmetrical and unsymmetrical faults are considered in the simulation.

4.2.1 Fault with Successful Re-closing

The fault time sequence is used from case-1 of Table I. The electromagnetic torque of IG, high-speed and low-speed shaft torques and the torque acting between hub and blades, IG rotor and turbine hub speeds and the load angle of SG after different types of symmetrical and unsymmetrical fault conditions are shown in Fig. 3. It is seen that 2LG and 3LG fault significantly increase the blade-shaft torsional loading of WTGS.

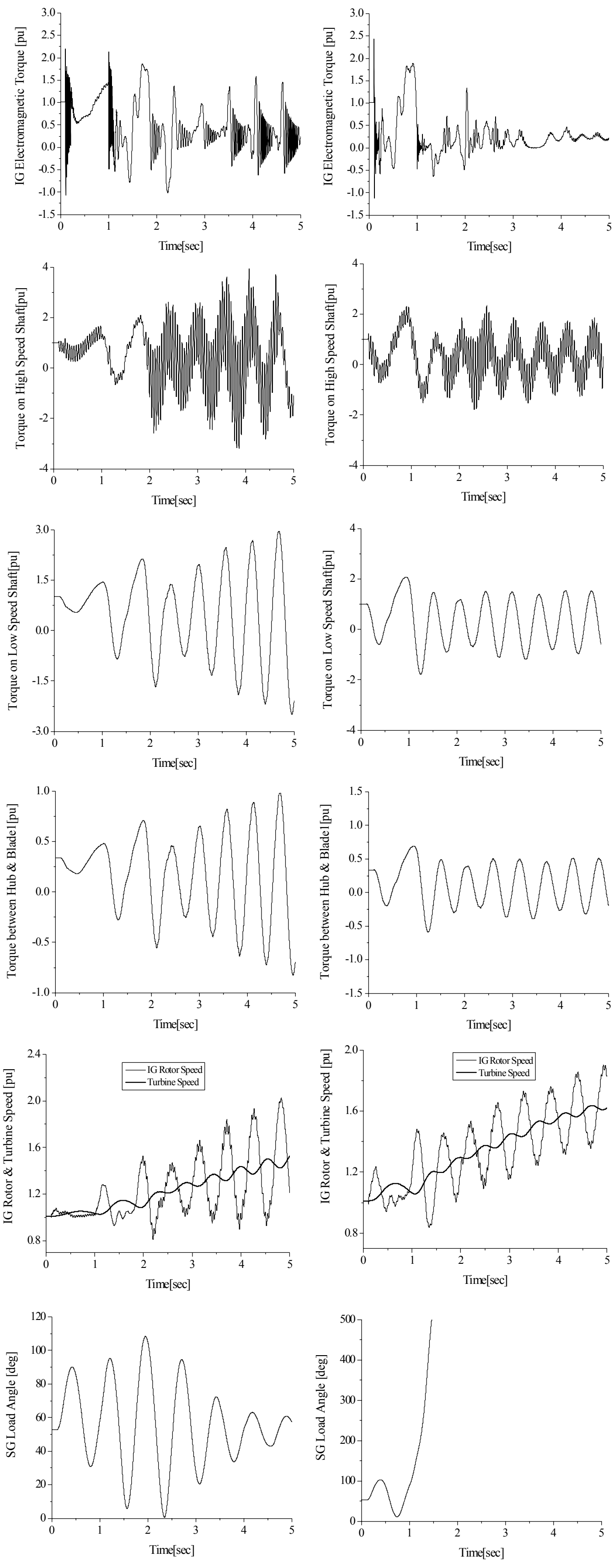
4.2.2 Fault with Unsuccessful Re-closing

This fault time sequences is used from case-2 of Table I. The blade-shaft stresses and the load angle of SG are shown in Fig. 4 for both symmetrical (3LG) and unsymmetrical (1LG) faults. It can be expected that



(a) 1LG (b) 2LS (c) 2LG (d) 3LG

Fig. 3. Blade and shaft stress of WTGS and load angle of synchronous generator (Table I, Case1).



(a) 2LS (b) 3LG

Fig. 4. Blade and shaft stress of WTGS and load angle of synchronous generator for unsuccessful re-closing (Table I, Case2).

the unsuccessful re-closing due to permanent faults will increase severe shaft-blade loading of WTGS compared to successful re-closing. Even for 2LS fault the IG becomes unstable as shown in Fig. 4(a). It is noticeable that for the balanced 3LG fault, the synchronous generator goes out of step. Therefore, the grid voltage becomes very low. As the IG electromagnetic torque is proportional to the square of its terminal voltage, the IG electromagnetic torque cannot be re-established. Therefore a decreased shaft torsional interaction can be expected for the 3LG fault as shown in Fig. 4(b).

5. CONCLUSION

In this paper, the detailed fault analyses of grid connected WTGS have been done for both successful and unsuccessful re-closing, where the six-mass drive train model is considered. Moreover, the blade and shaft stresses due to network disturbances are also analyzed for different types of fault condition. In future the damping of shaft torsional oscillation of WTGS will also be analyzed.

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