

A METHOD TO CALCULATE INITIAL CONDITIONS OF WIND GENERATOR IN TRANSIENT STABILITY SIMULATION

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ABSTRACT

In order to investigate the impacts of the integration of wind farms into utilities networks, various wind turbine models have been developed. Transient stability analysis for severe network disturbances can also be done by using those models. But before the analysis of transient stability one of the important things is to determine the initial condition of both wind turbine and the entire power system model. In this paper the non-linear wind turbine characteristics has been analysed and a method for determining the initial condition of wind turbine has been proposed. Moreover, transient stability analysis has been demonstrated by using the initial settings of wind turbine.

1. INTRODUCTION

Generating of electricity using wind power recently has received much interest and considerable attention all over the world. It has been predicted that the annual growth of wind power might be 20 to 30% from 1998 to 2040 [1]. From this prediction, it can be easily comprehended that a huge number of wind farms are going to be connected with the existing network in the near future. Therefore, it is essential to investigate the characteristics of wind turbine, as it is the energy extractor of the wind farm. When a wind turbine modelling is performed for computer simulation or stability analysis, it is also very important to determine the initial condition of the wind turbine. Attention must be paid to set the initial condition of wind turbine due to the non-linear characteristic of power coefficient, C_p . In ref [2] the wind turbine characteristic is linear and initial value calculation method was not discussed also. In this paper, initially the wind turbine modelling has been analysed where the non-linear wind turbine characteristic has been chosen from ref [4] and then a method has been revealed to determine the initial conditions of wind turbine which was not mentioned

in ref [4]. Beside these, some simulation has been performed by using the data attained from the initial condition settings, for both stable and unstable cases of induction generator.

2. MODEL SYSTEM

Fig.1 shows the model system used for simulation of the transient stability. Here, one synchronous generator (SG) is connected to infinite bus through a transformer and a double circuit transmission line. In the figure, the double circuit transmission line parameters are numerically shown in the form of $R+jX$, where R and X represent the resistance and reactance, respectively. 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. The value of capacitor C is chosen so that the power factor of the wind power station becomes unity [2]. Generator parameters are shown in Table 1.

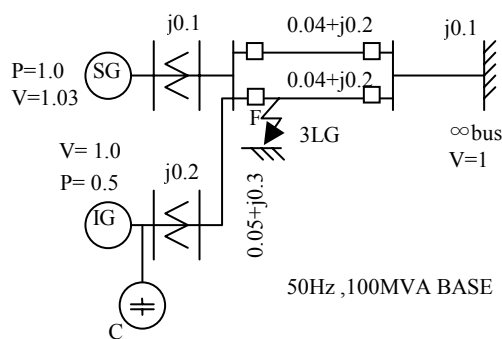


Fig.1 Model System

3. WIND TURBINE MODELLING

3.1 Blade and Shaft Dynamics

Modelling of wind turbine rotor is a complicated one. According to the blade element theory [3], modelling of blade and shaft needs complicated and lengthy computations. Moreover, it also needs details and accurate informations about rotor geometry. For that reason, considering only the electrical behaviour of

Table 1: Generator Parameters

	SG	IG	
MVA	100	MVA	50
r_a (pu)	0.003	r_1 (pu)	0.01
x_a (pu)	0.13	x_1 (pu)	0.1
X_d (pu)	1.2	X_{mu} (pu)	3.5
X_q (pu)	0.7	r_{21} (pu)	0.035
X'_d (pu)	0.3	x_{21} (pu)	0.030
X'_q (pu)	0.22	r_{22} (pu)	0.014
X''_d (pu)	0.22	x_{22} (pu)	0.098
X''_q (pu)	0.25	H(sec)	1.5
T'_{do} (sec)	5.0		
T''_{do} (sec)	0.04		
T''_{qo} (sec)	0.05		
H (sec)	2.5		

the system, a simplified method of modelling of the wind turbine blade and shaft is normally used. The mathematical relation for the mechanical power extraction from the wind can be expressed as follows:

$$P_w = 0.5 * \rho * \pi * R^2 * V_w^3 * C_p(\lambda, \beta) \dots \dots \dots (1)$$

Where, P_w is the extracted power from the wind, ρ is the air density [kg/m³], R is the blade radius [m], V_w is the wind speed [m/s] and C_p is the power coefficient which is a function of both tip speed ratio, λ , and blade pitch angle, β [deg]. The numerical approximation which have been developed to calculate C_p [3,4], are shown as follows:

$$\lambda = \frac{\omega * R}{V_w} \dots \dots \dots (2A)$$

$$\lambda_i = \frac{1}{\frac{1}{\lambda - 0.02\beta} - \frac{0.003}{\beta^3 + 1}} \dots \dots \dots (2B)$$

$$C_p(\lambda, \beta) = 0.73 * \left[\frac{151}{\lambda_i} - 0.58\beta - 0.002\beta^{2.14} - 13.2 \right] e^{-\frac{18.4}{\lambda_i}} \dots (3)$$

The C_p - λ curves are shown in Fig.2 for different values of β in deg, and the turbine related data are shown in Appendix. From each curve in Fig.2, we can get an idea about the operating region of wind turbine for the particular β .

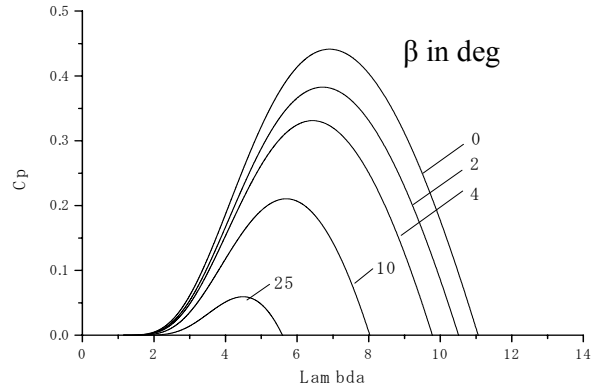


Fig. 2 C_p -Lambda curves

3.2 Blade Pitch Angle Per Unitisation

Now β has been normalized to β' so that β' is zero when the wind speed is operating at steady state condition, which is shown in Table 2 and is one when the developed torque of wind turbine is zero at the same speed. So, finally the torque equation becomes

$$\tau = 0.5 * \rho * \pi * R^3 * V_w^2 * C_p(\lambda, \beta') / \lambda \dots \dots \dots (4)$$

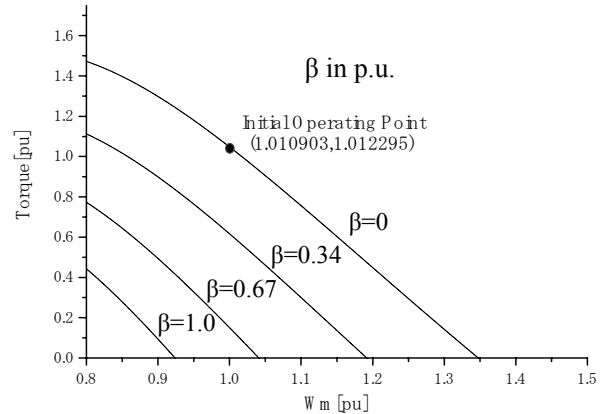


Fig. 3 $\tau - \omega_m$ characteristic

Fig.3 shows the torque characteristics obtained from Eq. (4), from which we can easily understand how much we need to vary the pitch angle for getting a particular wind turbine torque.

3.3 Induction Generator Equivalent Circuit

Most of the wind farms use induction generator as wind generators. In this paper, equivalent circuit of double cage induction generator has been analysed to determine the initial condition of wind turbine. The equivalent circuit is shown in Fig.4 where s denotes a rotational slip. From Fig.4 the loop equations can be derived as follows:

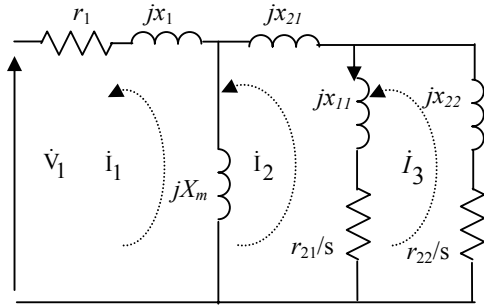


Fig. 4 Equivalent circuit of induction

$$\dot{V}_1 = -(r_1 + jx_1 + jx_m)\dot{I}_1 + jx_m\dot{I}_2 \dots\dots\dots(5)$$

$$0 = jx_m\dot{I}_1 - \left(\frac{r_{21}}{s} + jx_{11} + jx_{12} + jx_m\right)\dot{I}_2 + \left(\frac{r_{21}}{s} + jx_{11}\right)\dot{I}_3 \dots\dots\dots(6)$$

$$0 = \left(\frac{r_{21}}{s} + jx_{11}\right)\dot{I}_2 - \left(\frac{r_{21}}{s} + \frac{r_{22}}{s} + jx_{11} + jx_{22}\right)\dot{I}_3 \dots\dots\dots(7)$$

From equations (5), (6) and (7) we can get the desired currents $\dot{I}_1, \dot{I}_2, \dot{I}_3$.

3.4 Initial condition determination

From the equivalent circuit we can calculate the input power of induction generator, P_{IG_IN} , which is actually the output power of wind turbine. We can also calculate the desired output power of the induction generator, P_{IG_OUT} , from the equations below:

$$\left. \begin{aligned} P_{IG_IN} &= I_{22}^2 * \frac{(1-s)}{s} * r_{22} + I_{21}^2 * \frac{(1-s)}{s} * r_{21} \\ P_{IG_OUT} &= \text{Re}[\dot{V}_1 * \dot{I}_1^*] \end{aligned} \right\} \dots\dots\dots(8)$$

Table 2: Initial Conditions

	Case-I		Case-II	
	SG	IG	SG	IG
P(pu)	1.0	0.5	1.0	0.48
V(pu)	1.03	1.0	1.03	1.00914
Q(pu)	0.33	0.00 (0.26)*	0.316	0.0107 (0.258)*
E_{fd} (pu)	1.803	-	1.786	-
T_m (pu)	1.003	-	1.003	-
δ (deg)	50.71	-	50.69	-
slip	0.0	-1.0903%	0.0	-1.0237%
V_w (m/s)	-	12.00939	-	11.90293
β' (p.u)	-	0	-	0

(*) reactive power demand of induction generator

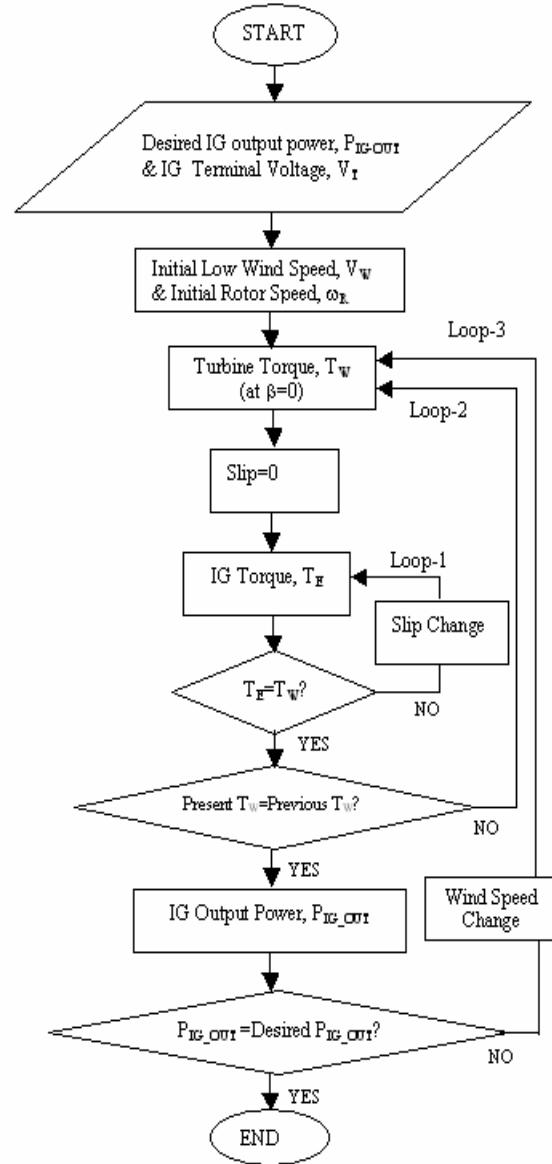


Fig. 5 Flowchart for initial condition settings

To calculate induction generator's input power, i.e. wind turbine output power, we need to search the particular slip, s , and for wind turbine's desired mechanical power generation we need to search particular wind speed, V_w . The flowchart for the whole procedure is shown in Fig.5.

4. SIMULATION RESULTS

In the simulation study, 3LG fault is considered to be occurred at point F (shown in Fig.1). The fault occurs at 0.1 sec, the circuit breakers (CB) on the faulted lines are opened at 0.2 sec and at 1.0 sec the circuit breakers are re-closed. Time step and simulation time are considered 0.00005

sec and 10.0 sec, respectively. Various parameters of the both generators, those are used for the simulation are shown in Table 1. The simulation has been done by using PSACD/EMTDC [5].

For simulation study two cases have been considered. For Case-I, induction generator is generating rated power and after the 3LG fault, it is going to unstable. For Case-II induction generator's output power is considered below rated power and after the fault, it is stable. The power flow results and initial conditions of wind turbine for both cases are shown in Table 2.

Response of the terminal voltage, real power and rotor speed of induction generator are shown in Fig.6, Fig.7 and Fig.8 respectively for both study cases I and II. After the occurrence of the fault the induction generator draws more reactive power for case-I than case-II. So, the capacitor bank can't compensate the reactive power demand. For that reason the terminal voltage drops suddenly for case-I and also the real power drops as can be observed from Fig.6 and Fig.7 respectively. As a result, the rotor speed of induction generator starts to increase and it goes out of step for case-I as shown in Fig.8.

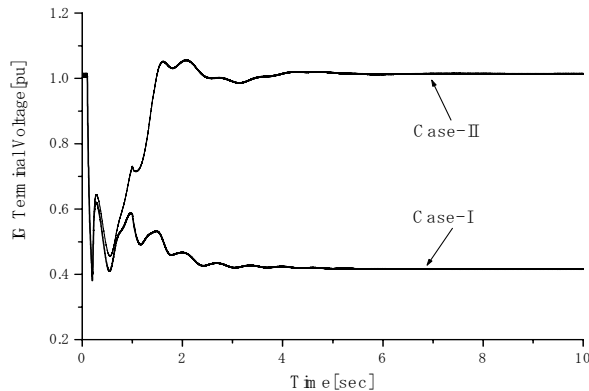


Fig. 6 Terminal voltage of induction generator.

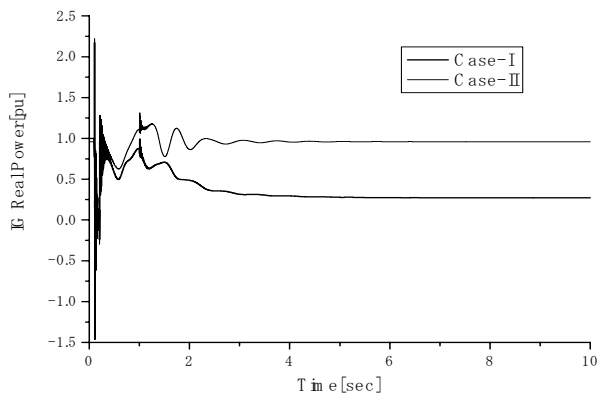


Fig. 7 Real power of induction generator.

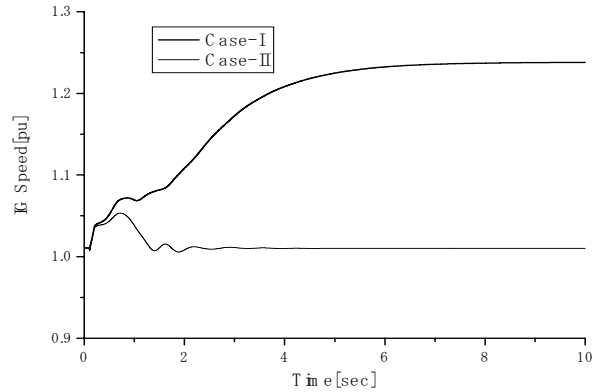


Fig. 8 Rotor speed of induction generator.

On the other hand, for case-II the induction generator's terminal voltage can return back to its pre-fault value after the fault clearance. Therefore it doesn't go out of step.

5. CONCLUSION

In this paper, a method of initial condition settings of wind turbine has been presented. Moreover, some simulation results have been shown by using the initial values those have been attained from this study. Finally it can be concluded that the proposed method to calculate initial conditions of wind generator can be used effectively in transient stability simulation of power system including wind power stations.

6. APPENDIX

Turbine data:

Type-3Balde H. Axis
 Radius-22 m; Gear ratio-1:35
 Rotor speed-42 rpm; Air density-1.225 kg/m³
 Cut in wind speed-7 m/s
 Cut out wind speed-25 m/s

REFERENCES

- [1] The European Wind Energy Association (EWEA). "EWEA Publications, 1998" [Online]. <http://www.ewea.org/Force10.htm>
- [2] Junji Tamura et al., "Transient Stability Simulation of Power System Including Wind Generator by PSCAD/EMTDC", IEEE Porto Power Tech Proceedings, Vol.4, EMT-108, 2001.
- [3] S.Heier, Grid Integration of Wind Energy Conversion System, Chicester, UK: John Wiley & Sons Ltd., 1998
- [4] J.G.Slootweg, S.W.H. de Haan, "General Model for representing Variable Speed Wind Turbines in Power System Dynamics Simulation", IEEE Transactions on Power Systems, Vol.18, pp.144-151, Issue 1, 2003.
- [5] PSCAD/EMTDC manual, Manitoba HVDC Research Center, 1994.