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Modeling and fault analysis of wind turbine with a Permanent Magnet Synchronous Generator using PSCAD

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Abstract- **The aim of this work is to analyze a typical configuration of a Wind Turbine Generator System (WTGS) equipped with a Distribution Grid. Now a days, doubly fed induction generators are being widely used on WTGS, although synchronous generators are being extensively utilized too. There are different types of synchronous generators, but the multi-pole Permanent Magnet Synchronous Generator (PMSG) is chosen in order to obtain its model. It offers better performance due to higher efficiency and less maintenance since it does not have rotor current and can be used without a gearbox, which also implies a reduction of the weight of the nacelle and a reduction of costs. Apart from the generator, the analyzed WTGS consists of another three parts: wind speed, wind turbine and drive train. These elements have been modeled and the equations that explain their behaviour have been introduced. What is more, the whole WTGS has been implemented in PSCAD.**

Index Terms—**PSCAD/EMTDC, PMSG, Distribution Grid Fault analysis**

I. INTRODUCTION

The utilization of wind energy has a very long tradition. Some historians suggest that wind turbines (windmills) were known over 3000 years ago [1]. Until the early twentieth century wind power was used to provide mechanical power to pump water or to grind grain.

The first wind turbines appeared at the beginning of the last century and technology was improved step by step from the early 1970s. By the end of the 1990s, wind energy has reemerged as one of the most important sustainable energy resources, partly because of the increasing price of the oil, security concerns of nuclear power and its environmental issues. Moreover, as wind energy is abundant and it has an inexhaustible potential, it is one of the best technologies today to provide a sustainable electrical energy supply to the world development.

Actually, during the last decade of the twentieth century, World wide wind capacity doubled approximately every three years. Currently, five countries (Germany, USA, Denmark, India and Spain) concentrate more than 83% of world wide Wind energy capacity in their countries [2]. Studies have shown that by the end of2003, the total installed capacity of the wind turbines reached 39.234 GW and will exceed 110 GW by the year of 2012[3].

The need for increased power production from the wind and economic reasons, when the rated power of today's wind turbines is still relatively small (2MW units are now typical), makes it necessary to group wind turbines into so-called wind farms.

Wind farms are built on land, but in recent years there has been (and will probably be in the future) a strong trend towards locating them offshore. The lack of suitable wind turbine sites on land (it is particularly the case of densely populated countries) and the highest wind speeds located near the sea (and consequently higher energy can be extracted from the wind) are the two main reasons for locating wind farms offshore. Horns Rev in Denmark [4] is an example of a current Off shore wind farm, which is capable of producing 160 MW.

Both induction and synchronous generators can be used for wind turbine systems [5]. Mainly, three types of induction generators are used in wind power conversion systems: cage rotor, wound rotor with slip control and doubly fed induction rotors. The last one is the most utilized in wind speed generation because it provides a wide range of speed variation. However, the variable-speed directly-driven multi-pole permanent magnet synchronous generator (PMSG) wind architecture is chosen for this purpose and it is going to be modeled: it offers better performance due to higher efficiency and less maintenance because it does not have rotor current. What is more, PMSG can be used without a gearbox, which implies a reduction of the weight of the nacelle and reduction of costs.

This paper makes the choice to define a wind turbine connected to a permanent Magnet Synchronous Generator with 100 pole pairs. The connection to the grid is then performed through a full AC/DC/AC converter and a step up transformer. The main advantage of this strategy is to allow to remove the gear box in the wind turbine.

II. SYSTEM DESCRIPTION

The system analyzed is a variable speed wind turbine based on a multi-pole PMSG. Due to the low generator speed, the rotor shaft is coupled directly to the generator, which means that no gearbox is needed. The generator is connected to the grid via an AC/DC/AC converter, which consists of an uncontrolled diode rectifier, an internal DC-Link modeled as a capacitor and a PWM voltage-source inverter.

A transformer is located between the inverter and the Point Of Common Connection(PCC) in order to raise the voltage by avoiding losses in the transport of the current. The layout of the electrical part is depicted in Fig. I.

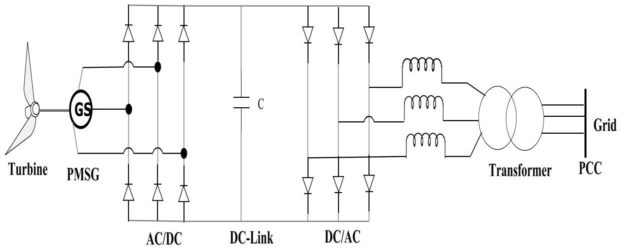


Fig.I. Electrical Scheme of a wind turbine equipped with direct-driven

III. SUBSYTEM MODELS

A. Wind Turbine Model

The kinetic energy of the air through the rotor blades is:

$$Ec = ½ mWs^2 \qquad (1)$$

The theoretical power we can obtain from a wind turbine is:

$$P_{th} = ½ \rho S\, Ws^3 \qquad (2)$$

with ρ= air density (1.22 kg/m^3)
S = rotor surface (m^2)
Ws= Wind speed (m/s)

In practice, the power is smaller because the wind speed behind the hub is not Zero . This efficiency is characterized by the Betz coefficient (given by Bernouilli's equations), also called the Power Coefficient Cp:

$$Cp= P_{real}/P_{th} \qquad (3)$$

$$Cp = ½ (1-a^2) (1+a)$$

a = Wind speed behind the rotor / wind speed in front of the rotor

The amount of aerodynamic torque (τ_w) in (N-m) is given by the ratio between the power extracted from the wind (P_{th}) , in W, and the turbine rotor speed (ω_w), in rad/s, as follows

$$\tau_w = \frac{P_{th}}{\omega_m} \qquad (4)$$

It should be noted that the mechanical torque transmitted to the generator (τ_{wg}) is the same as the aerodynamic torque,since there is no gearbox. It implies that the gear box ratio is n_g= 1.Therefore $\tau_w = \tau_{wg}$. The power coefficient Cp reaches a maximum value equal to Cp= 0.593, which means that the power extracted from the wind is always less than 59.3% (Betz's limit), because various aerodynamic losses depend on the rotor construction (number and shape of blades, weight, stiffness, etc.). This is the well known low efficiency to produce electricity from the wind. The turbine subsystem model is depicted in Fig.II.

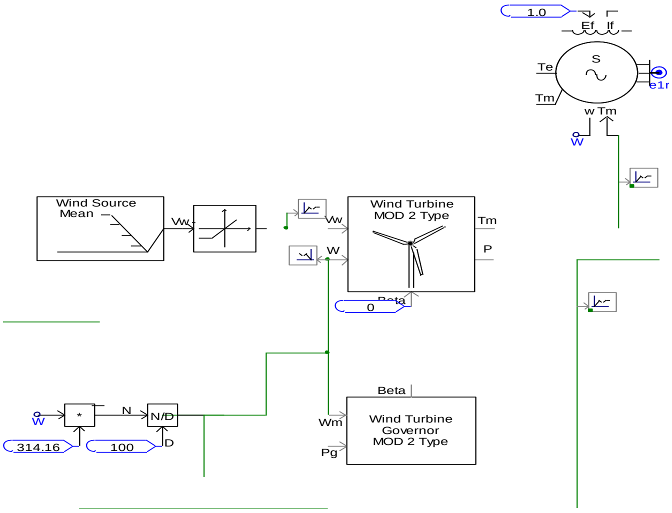


Fig.II. Wind turbine Subsystem build in PSCAD

B. Distribution Grid

A distribution grid is a radial grid managed as an open loop. The power always flows in the same direction. The grid study is modeled as Fig.III.

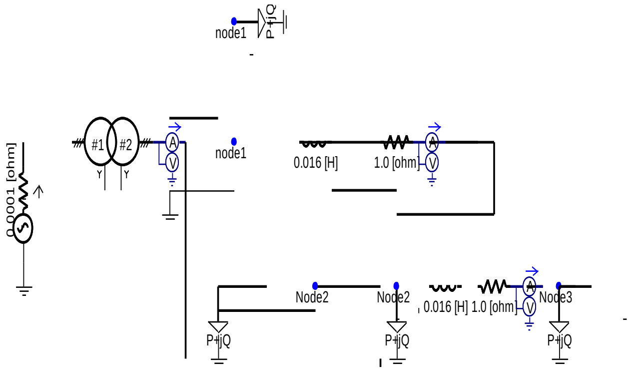


Fig.III. Distribution Grid

C. AC/DC/AC: Power and Frequency Conversion

The speed of the wind source being variable, a converter stage AC-DC-AC must be implemented in order to connect the output of the synchronous generator (variable frequency and voltage) to the grid, where a constant frequency and a constant voltage is needed. In the following parts, the power conversion stage will be described and parameterized.

It is composed of a :

- A diode rectifier
- A dc bus with a storage capacitance voltage
- A six pulse bridge thyristor inverter

The output voltage of a generator is proportional to its speed. The speed of the generator not being controlled, the DC bus must be protected from over-voltage. With a secure margin of 10%.

To secure the bus, it is possible to block the rectifier in case of over-voltage. This is done with the Single Input Level Comparator. The Dc bus model used in system depicted in Fig.IV

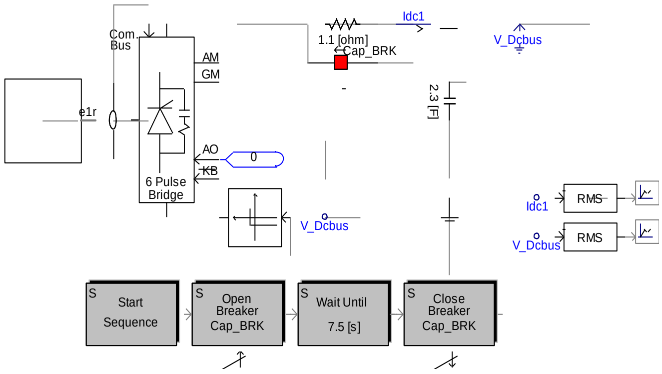


Fig.IV. Dc Bus

IV. SIMULATION RESULTS

A. Turbine –Generator

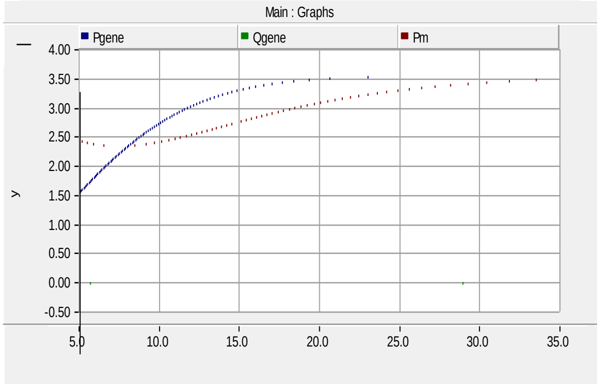
The PMSG has been considered as a system which makes possible to produce electricity from the mechanical energy obtained from the wind. The dynamic model of the PMSG is derived from the two phase synchronous reference frame, which the q-axis is 90°ahead of the d-axis with respect to the direction of rotation.

Table.I. shows the parameter of turbine- generator that has been considered

Table.I.Computation Parameter

Parameter	Symbol	Values & Unit
No.of pole pair	P	100
Rated speed	ω_m	3.1416 rad/sec
Rated power	S_n	3 MVA
Rated Voltage	E	0.69Kv
d-axis reactance	X_d	0.4p.u
Rated current	I_n	1450A

Fig.V. shows simulation result of turbine-generator model



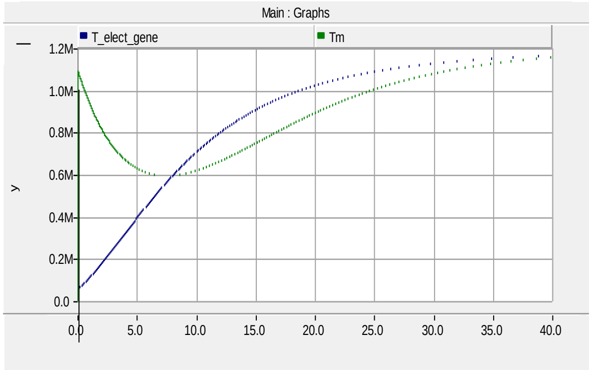
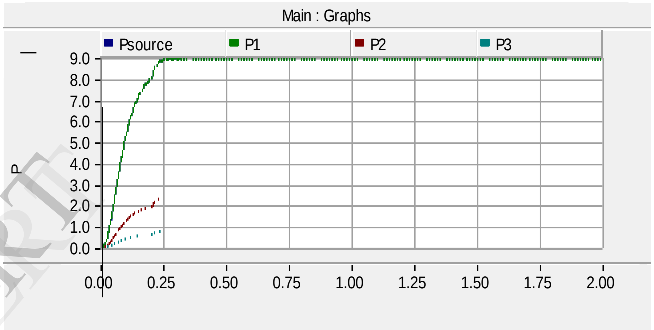


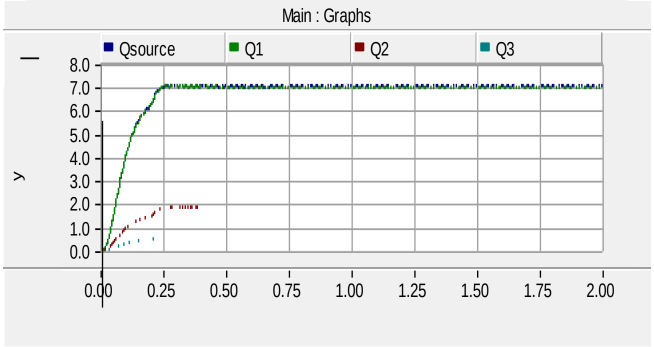
Fig.V simulation of WTGS in PSCAD

B. Distribution grid

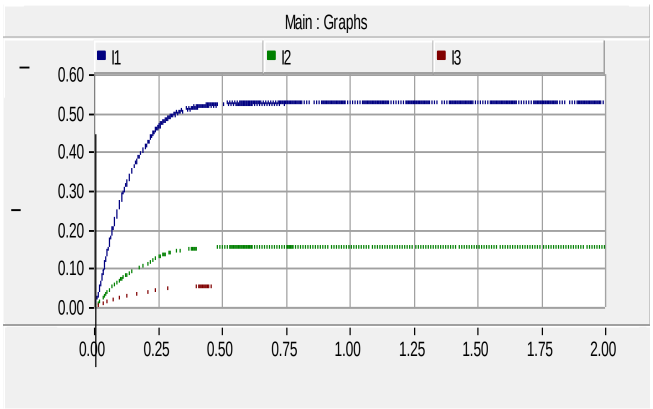
A distribution grid is a radial grid connected with the turbine-generator system through AC-DC-AC converter. The power always flows in the same direction.Fig.VI. shows simulation result of Distribution Grid



(a) Active Power of Grid at Various Node



(b)Reactive Power of Grid at Various Node



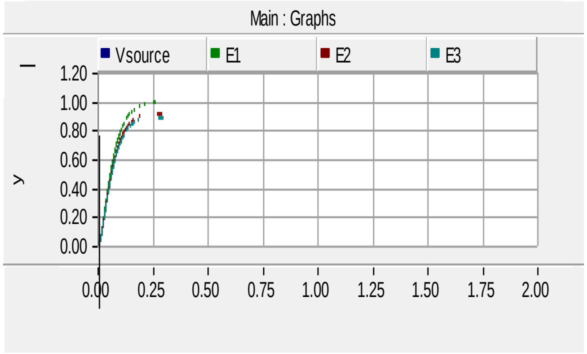


Fig.VI. Simulation of Distribution Grid in PSCAD

At t=2s,We have the following values:

	Node1	Node2	Node3
P(MW)	8.9	2.41	0.78
Q(MVAR)	7.0	1.80	0.55
V(pu)	1.0	0.91	0.90
I(KA)	0.52	0.15	0.05

C. *Fault Analysis*

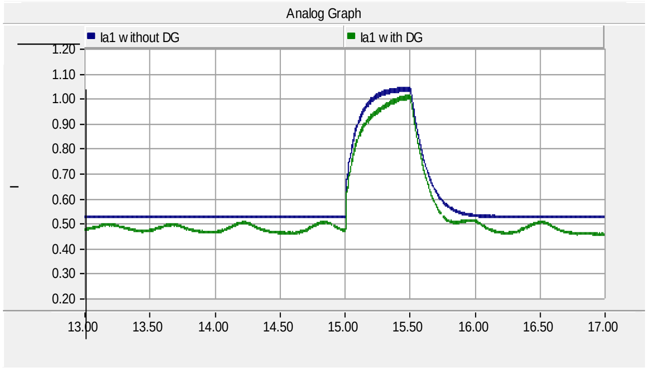
The connection of a distributed generator to a radial distribution system leads to situations not normally supported by the network in case of faults. The distribution network is a radial network and the protections are based on the current measurement.

This simulation consists of connecting the distributed generator at one node and the fault component at another node. Then, the current and the active power are measured in order to determine the protection level necessary and compared to the values measured without the wind turbine generator.

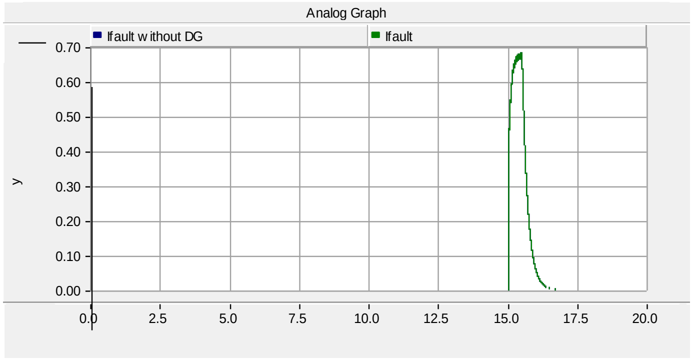
This simulation comprises of two cases. In the First case, fault is connected at Node 3 and distributed generator is connected at Node 1.the simulation is formed in both mode.i. e with and without DG and the results are compared.

CASE 1 Fault at Node 3

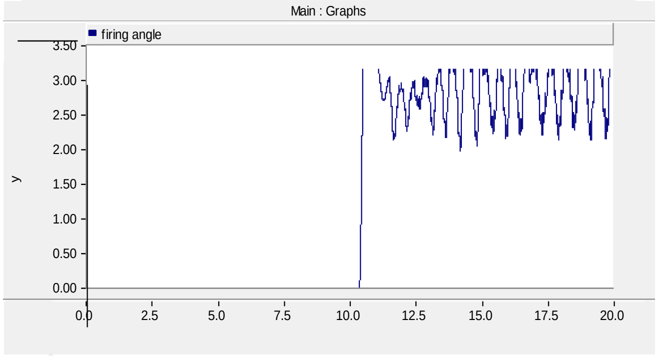
First perform a simulation with distribution grid alone and add the grid to the distribution generator .Fig.VII. shows simulation result and comparison between the two mode.



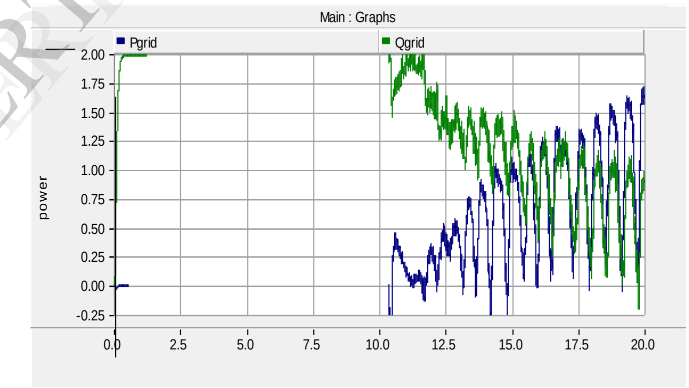
(a) Simulation result current at Node 1



(b)Fault current at Node 3



(c) Thyristor firing angle



(d) Real and Reactive power of grid

Fig.VIII. Simulation Results of Fault occurred at Node 3

Table.III. shows the comparison of fault analysis of two mode.

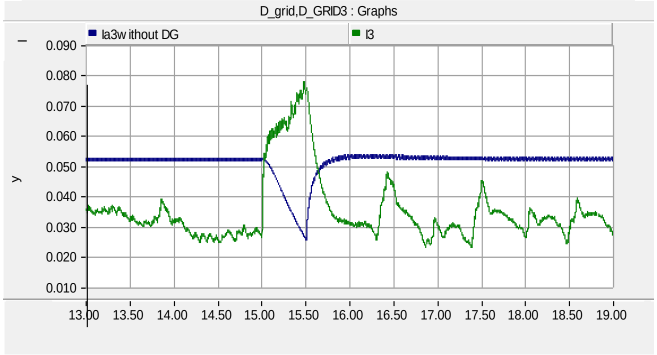
Table.III. Result of fault analysis

Default node 3	Peak without using DG	Peak values with DG node1
I1(KA)	1.04	1.00
Ifault(KA)	0.68	0.68

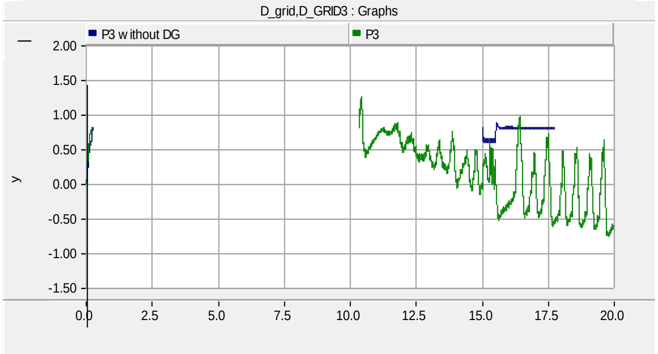
The peak values at Node 1 is lower with DG than without DG.

CASE 2 Fault at Node 2

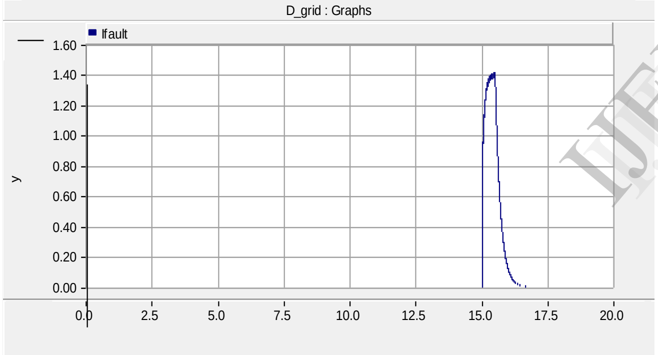
In this case the fault is connected at Node 2 and distribution grid is connected at Node 3. Fig.IX. show the results of fault accured at Node 2



(a) Current at Node 3 for Fault occurred at Node 2



(b) Variation of Power at Node 3



(c) fault current at Node 2

Fig.IX. Simulation of case 2 in PSCAD

Simulation result of case 2 is shown in Table.IV.

Table.IV.Results of Fault Analysis

Default Node2-DG node3	Peak values without DG	Peak Values with DG at node3
I3(KA)	0.02	-0.08
Ifault(KA)	1.43	1.43

During a fault, the current at I3 flows in the other direction with DG (the active power is negative). If there is a power protection at this point, this protection will see a negative active power and thus, it will never act! The distributed generator fault current will never be stopped.

The peak value at I3 is greater with DG. This could cause a serious problem if the new and larger I3 exceeds the circuit breaker maximum interrupting rating. In this case the circuit breaker must be changed.

V. CONCLUSION

The modeling of a wind turbine with a Permanent magnet synchronous generator has been treated. The model has been implemented in PSCAD in order to validate it.

The permanent magnet synchronous generator has been connected with distribution grid through ac-dc-ac converter. More ever fault analysis has done on distribution grid with and without DG.

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