Evaluation of 1-phase, 3-phase and Lightning Faults on Wind Farms using EMTP-RV

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ABSTRACT:
Since the development of wind power plants installation is growing, problems which are related to network connecting, stability and voltage effects become more important. On the other hand, wind farms are often open to lightning because of their long height and specific appearance. In this paper, modeling and simulation of 1-phase, 3-phase and lightning faults in a wind farm consisting of 40 wind turbines and faults impact on wind farm and the network is investigated in EMTP-RV environment. In this field, it's necessary to develop a precise modeling out of wind power plant in order to evaluate the effects of these power plants on dynamical behavior of the power system. These models can be used in designing new protection systems, new protection algorithms, and new strategies for power plants exploitation improvement. Each wind unit in the farm is connected to the whole units that are connected to the network using a doubly fed induction generator (DFIG).

KEYWORDS: Wind Farm, Transient State, 3-phase Fault, Lightning, EMTP-RV

1. INTRODUCTION

Wind farms have some advantages compared to other types of power plants: Not using water for cooling, not emitting carbon, being located near the production and local loads, not using transmission lines capacity. Since the development of wind power plants is daily increasing the problems related to network connecting, stability and voltage effects are becoming more important [1]. Hence, several transmission system operators have defined certain characteristics and circumstances in which a wind power plant can be connected to the network [2]-[4] Topology of wind farm networks has major difference with other transmission and distribution systems. In order to reduce array losses the turbines are usually separated by at least 5 blade diameters which needs expensive cable systems and a number of devices like circuit breakers and step-up transformers [5]. Combination of these devices in large offshore wind farms has been identified as a potential source of transient over voltages [6]. In addition, fault existence in any of the wind farm transformers cause to high costs of fixing. Regarding transient stability, some Eltra constraints are needed which occur between wind power plant and power network and they are investigated in the network by simulation when faults occur [7]. One of the most efficient ways to increase the turbine output power is increasing the height in order to exploit more wind. Nowadays, wind turbines are on average 50 meters, height and some turbines with nearly 100 meters height. The more the height of a tower, the more the chance of being struck by the lighting which can cause the following damages:

- Increasing potential of wind farms.
- Voltage drop along the cable.
- Heating of blades and ball-bearings which can cause them to melt.

In this field, it seems necessary to develop a precise model of wind power plants to evaluate effects of these power plants on system dynamical behavior [8]. Such models can support designing new protection systems, new protection algorithms and new strategies for power plant exploitation improvement. Transient states in large wind farms are studied in PSCAD/EMTDC environment [9], dynamical model of wind farms and power system is studied in DigSilent including both normal operation and transient state [10]. Also, investigating the effects of various aspects of wind farms such as generator's technology, distributed generation and so forth are investigated in DigSilent environment [11]. In [12] the effects of lightning on wind farms were studied using a current source to simulate the lightning.

In this paper, the 1-phase, 3-phase and lightning fault's impact are investigated on a wind farm consist of 40 wind turbine using its modeling and simulation in EMTP-RV environment. The impacts of faults are analyzed on wind farm- faulted bus and the bus of network connected to wind farm.

2. BASIC CONCEPTS

2.1. DFIG concept

DFIG is an abbreviation for Double Fed Induction Generator, a generating principle widely used in wind turbines. It is based on an induction generator with a multiphase wound rotor and a multiphase slip ring assembly with brushes for access to the rotor windings. The rotor winding is connected to the main grid by self commutated AC/DC converters allowing to controll the slip ring voltage of the induction machine in magnitude and phase angle. Doubly-fed induction generator system is illustrated in Fig. 1.

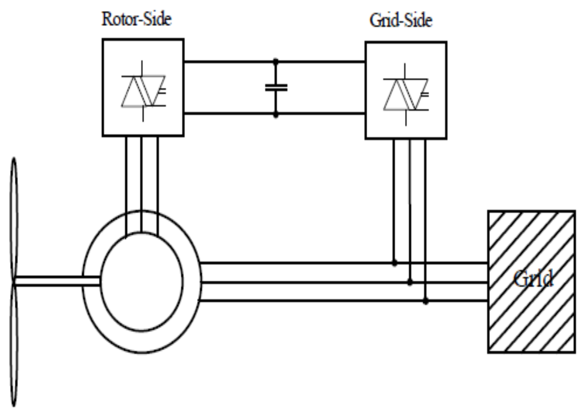

Fig. 1. Doubly-fed induction generator system

In contrast to a conventional, singly-fed induction generator, the electrical power of a doubly-fed induction machine is independent from the speed [13]. It is possible to understand a variable speed wind generator allows toadjust the mechanical speed to the wind speed and hence operating the turbine at the aerodynamically optimal point for a certain wind speed range.

2.2. Wind model

The power extraction of wind turbine is being known to be a function of three main parameters: the wind power available, the power curve of the machine and the ability of the machine to respond to wind fluctuations [14].

The wind turbine aerodynamic is modeled with an algebraic equation as given by:

$$P_R = \frac{1}{2}\rho\pi R^2 C_p(\lambda,\beta)V_w^{\ 3} \quad (1)$$

Where,

P_R :	Rotor power
V_w :	Wind speed
$C_p(\lambda,\beta)$:	Characteristic power coefficient
λ :	Tip speed ratio
β :	Pitch angle
ρ :	Air density
R :	Blade radius

The tip speed ratio λ is defined by (2):

$$\lambda = \frac{\omega_R R}{V_w} \quad (2)$$

Where ω_R refers to the angular speed of rotor blades.

2.3.Induction generator

The induction generator is represented using the wind torque model, applied to the shaft of the induction machine model as shown in Fig. 2. The model also incorporates a pitch control block, which changes the angle of the blades of the machine at high wind speeds in order to modify the torque characteristic and thus limit the output power to the rating of the machine [15].

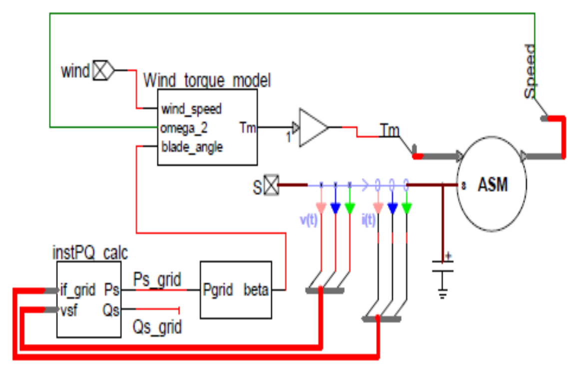

Fig. 2. Direct connected induction generator model in EMTP-RV

2.4. EMTP-RV solver

The transient analysis software program used in this paper allows for the representation of very large systems and produces very accurate results, enabling simulation of numerous cycles to even multiple seconds, with relatively short execution times [16].

The ability of the software to model large systems with multiple machines, power electronics, and control makes it ideal for modeling wind energy systems and studying the interconnection characteristics.

3. SYSTEM SIMULATION ANDFAULTS STUDY

3.1. The network under Study

Fig. 3 shows the studied network which comprises 40 wind units which each one of them are connected to the wind farm system and network by a DFIG. Each Turbine is connected to the correspondent bus by a YΔ transformer and a capacitor. The units start working in each radial row each with 0.2 seconds of delay. Therefore, the first turbine is placed in the network from the beginning of simulation and the last unit in each radial row is placed in the circuit at t=1.4s.

Capacity of each power plant unit is 10 MVA, series capacity is 400 MVA (active power of each unit is $\sqrt{3/2}\,S_r = \sqrt{3/2} \times 10 = 8.66\ MW$ and reactive power is $0.5S_r = 5MVAR$. Inertia constant of each generator is 0.3s and that of each turbine is considered 3s.

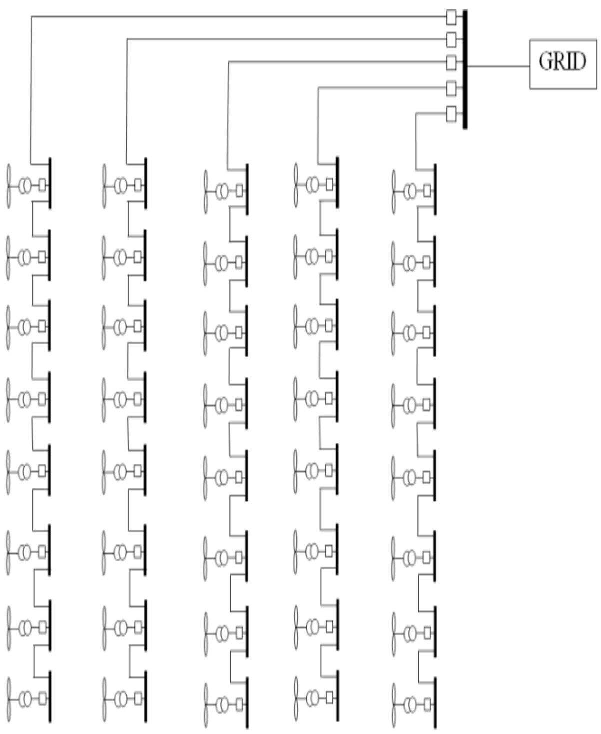

Fig. 3. The network under study

Nominal voltage of each generator is 0.69 kV and number of poles is 4. Three loads are connected to the network. Load 1: ($P = 77MW, Q = 40MVAR$), Load 2: ($P = 120MW, Q = 60MVAR$) and Load 3: ($P = 150MW, Q = 100MVAR$). Each wind units is modeled as in Fig.4 which includes equations relating to turbine and DFIG. The required parameters for simulation are given in Table 1.

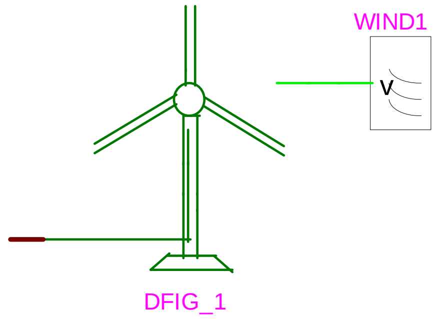

Fig. 4. Schematic illustration of a wind power plant

Table 1. Required Parameters for Simulation

Parameter	Value
Vbase	0.69 kV rms
H_Gen	0.3 Generator Inertia in s
H_Tur	3.0 Turbine Inertia in s
Sbase	45 MVAr
Droop	5 %
Fs	60 Hz
Qrating	0.5*SbaseMVAr
P	4 poles
Rs	0.00662 pu
Lls	0.0850 pu
Llr	0.101 pu
Lm	3.1 pu
Rr	0.01 pu

WIND block consists of data relating to the wind speed in 3 time periods namely 0-200, 200-400, 400-600 s. internal schema of this block is shown in Fig. 5.

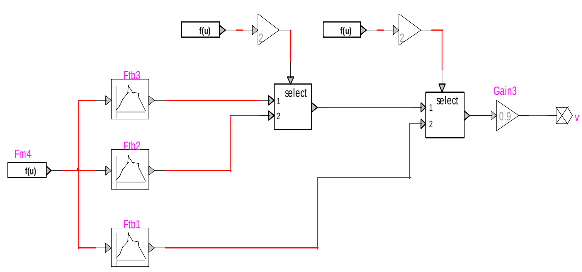

Fig. 5. Internal schema of WIND block

4. 3-PHASE FAULT STUDY

In this section, we study 3-phase faults stimulation on a wind farm with 40 wind turbine. The turbines in 5 rows are connected to a bus as radial so that the bus connects to a 150 KV low voltage network through a transformer. This network is illustrated in Fig. 6.

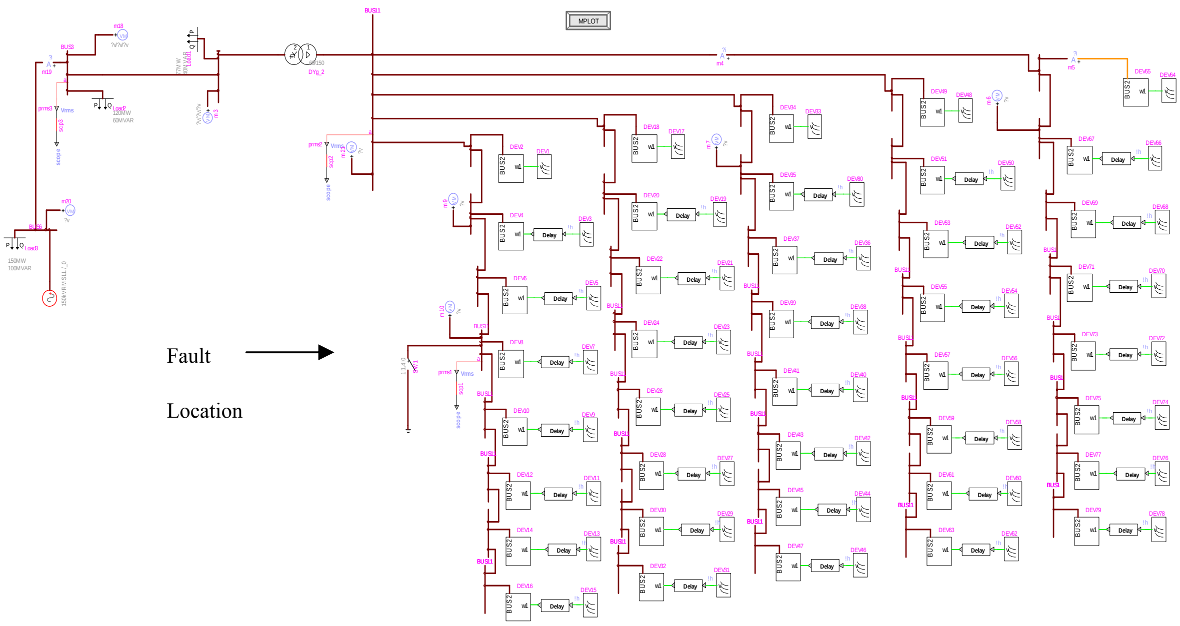

Fig. 6. Fault location in a wind farm simulated in EMTP-RV

A 3-phase fault in t=6s occurs on wind power plant unit which is shown in Fig. 5 and itremains in the network until t=7s. The curvesare related to thevoltage, amount of effective voltage in different buses, speed and torques of DFIG generators are shown in Fig. 7-10.

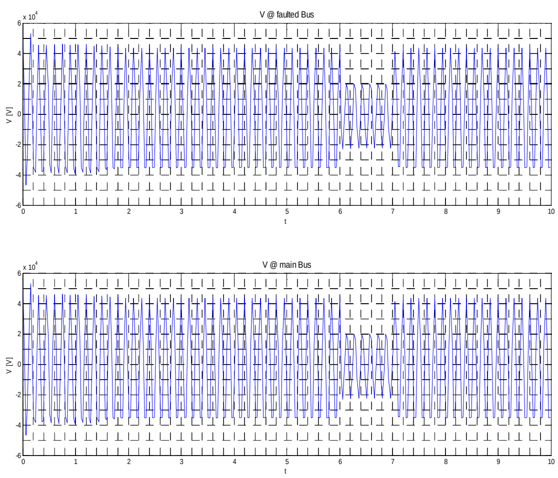

Fig.7. Faulted bus voltage curve and the main bus of the wind farm

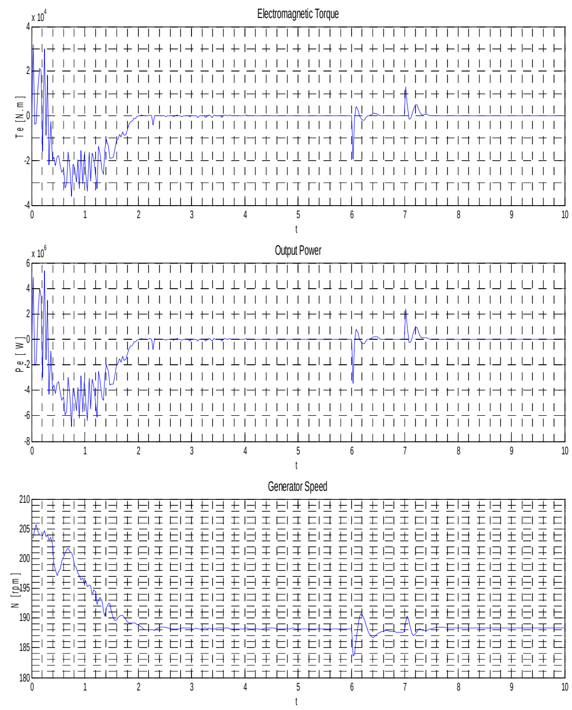

Fig. 8. Torque, output power and speed of generator

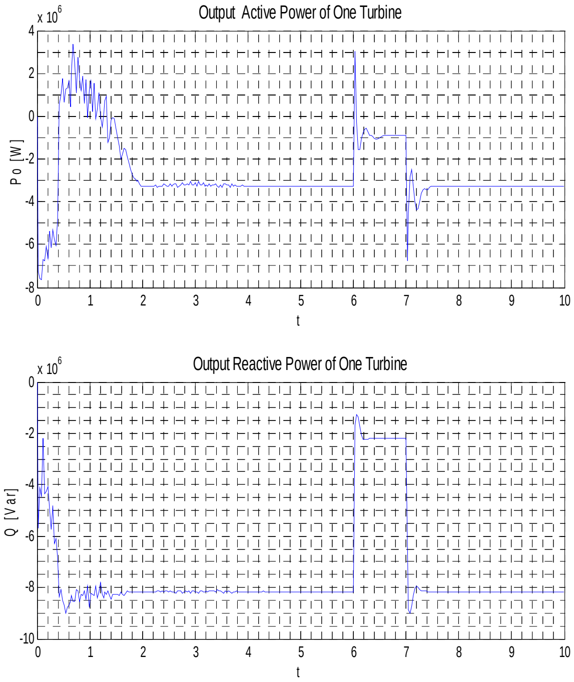

Fig. 9. Active power curve and turbine reactive of a wind unit

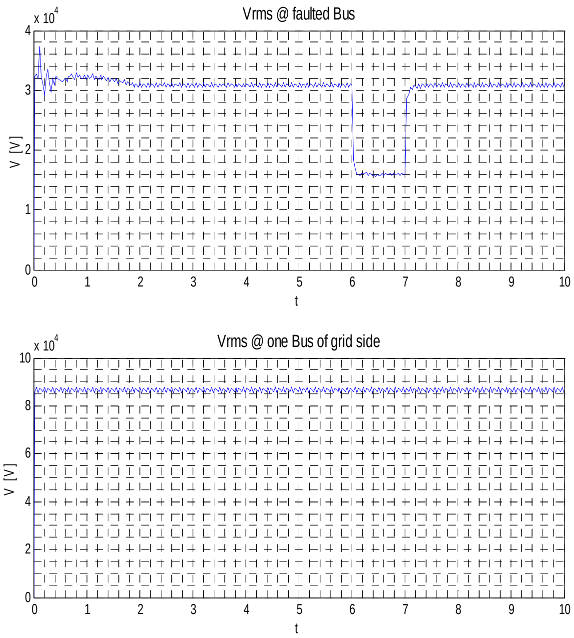

Fig. 10. Effective voltage curve of the faulted bus and a bus from the network

According to Fig. 7, Faulted bus voltage and the main bus of the wind farm drops to 0.5 pu in spite of danger which is very dangerous and can cause voltage and the network to collapse. Fig. 8 shows the fluctuation in the generator torque, output power and speed due to fault. As the generator torque drops, the speed of generator accelerates since the torque given to the turbine by the wind is nearly constant and vice versa. Fig. 9 shows active and reactive power of wind turbine unit is decreased in fault time. Also in Fig. 10 the effective voltage value of faulted bus dropped to 0.5 pu when fault occurred but effective voltage of bus from the network (high voltage) remained constant. In order to compensate speed fluctuations and prevent network collapse due to severe voltage drops, using FACTS devices such as STATCOM and SVC seems necessary.

5. 1-PHASE FAULT STUDY

In this section, a 1-phase fault occurs in the same place as the previous 3-phase fault from t=6s to t=7s for 1 second. Curves of voltage, effective voltage in different busses, along with speed and torques of DFIG generators are next.

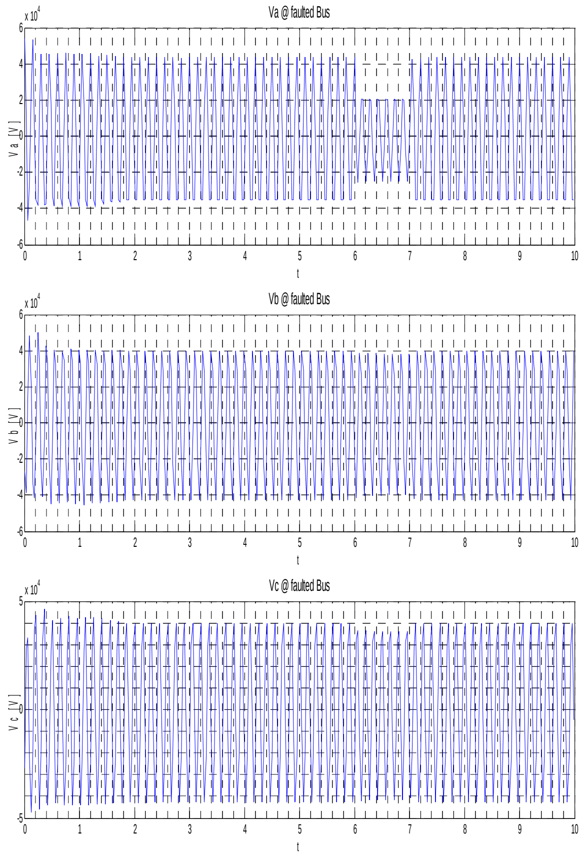

Fig. 11. 3-phase faulted bus voltage curve

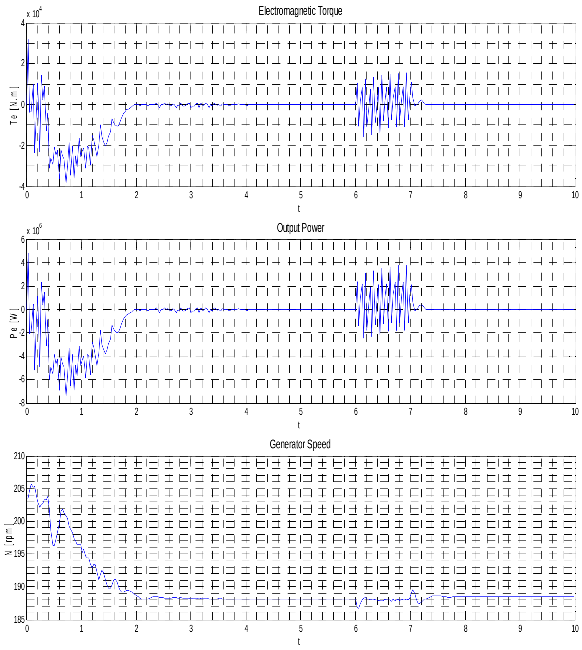

Fig. 12. Ttorque curve, speed and output power of the generator

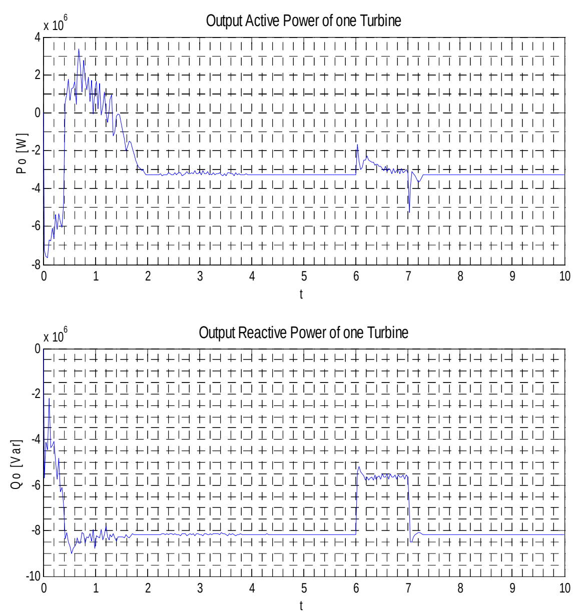

Fig. 13. Active and reactive power curve of a turbine in a wind farm

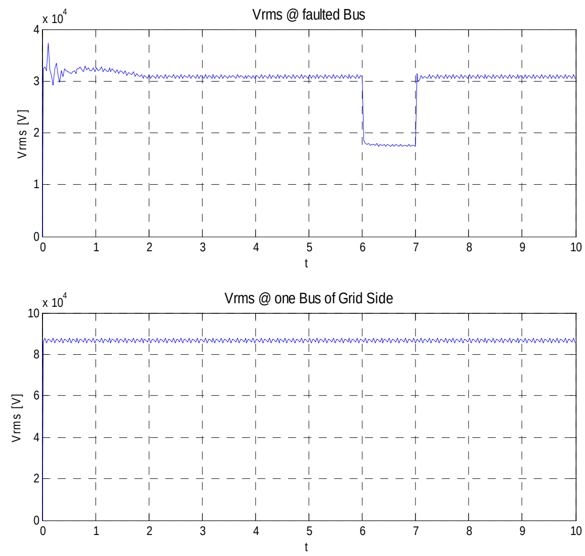

Fig. 14. Effective voltage curve of faulted bus and that of a bus from network

Fig. 11 shows the faulted bus voltage declined to 0.5 pu in phase a and in other phases itis invariable. Also according to Fig. 12, electromagnetic torque and generator's speed and power during faulting cause intensive fluctuations. In Fig. 13, active and reactive powers of wind turbine unit are decreased in fault time as they are shown in the picture. Since not enough reactive power is injected (because there are no FACTS devices) during the fault, speed shows a slight increase after fault elimination. Also faulted bus effective voltage value decreases to $(1/\sqrt{3})*0.57\ pu$ in the moment of fault and the bus voltage from network is invariable as it's shown in Fig. 14.

6. LIGHTENING STRIKES STUDY

This section is dealt with lightening strikes to a wind farm. To simulate lightening, a current source is employed which generates a maximum current of 200 KA and a pre-wave time of 3 ms. Lightening block and its internal schema are depicted in Fig. 15.

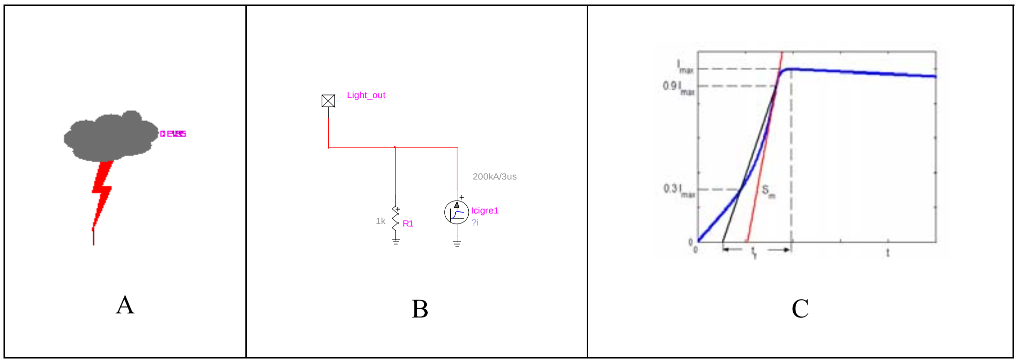

Fig. 15. A) Lightning block B) internal schema C) current wave diagram for modeling the lightning($I_{max} = 200KA$, $t_f = 3ms$)

The curves of current, effective voltage in different buses, speed and torques of DFIG generators are shown in Fig. 16-19.

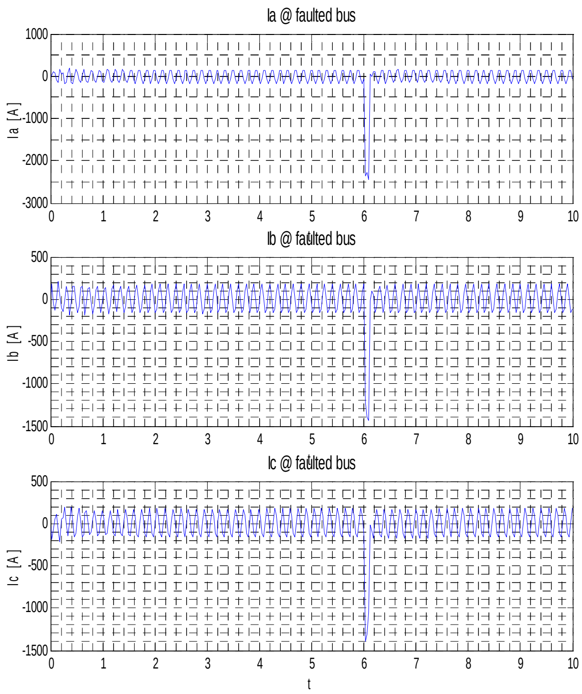

Fig. 16. 3-phase current curve of faulted bus

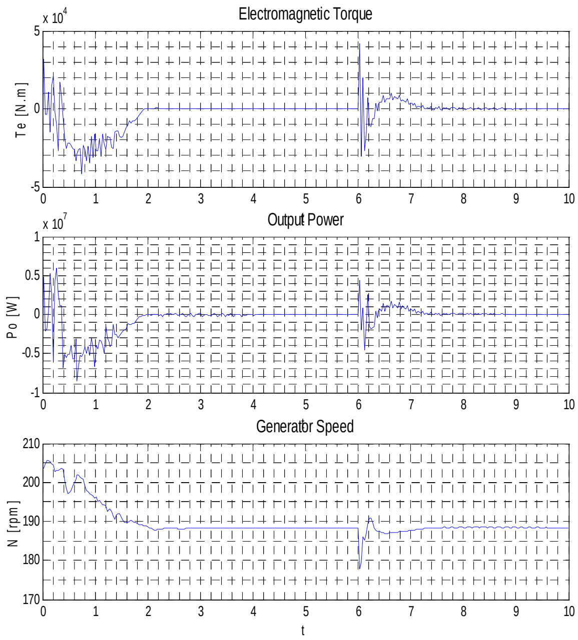

Fig. 17. Torque curve, output power and speed of the generator

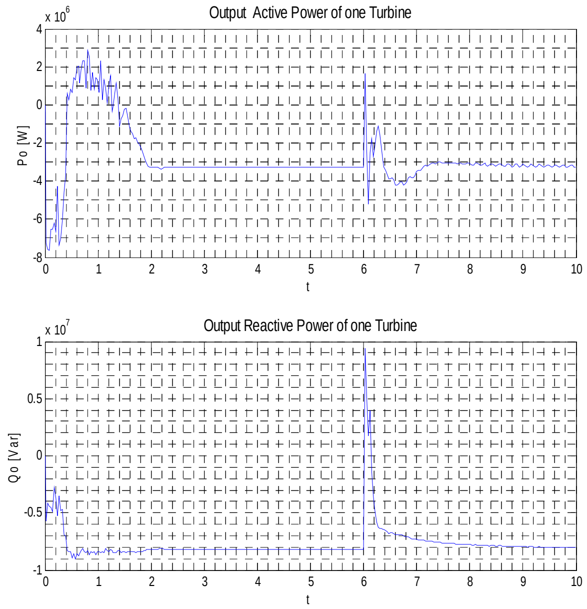

Fig. 18. Active and reactive power curves of a turbine in a wind farm.

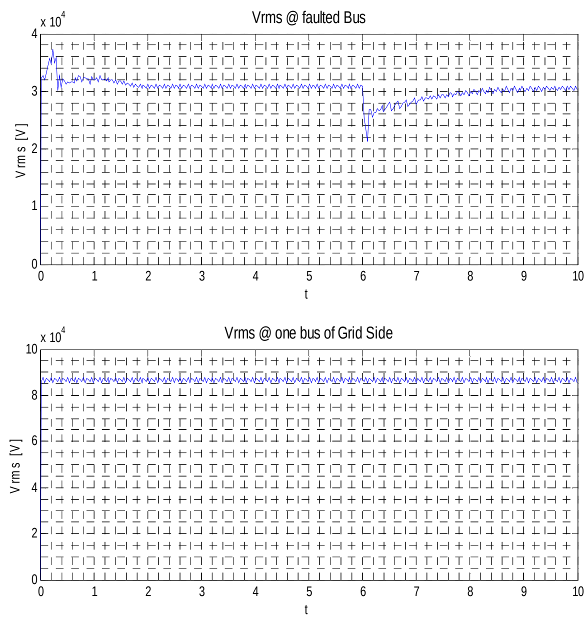

Fig. 19. Effective voltage of faulted bus, and that of the main bus of wind farm and a bus from network

Fig. 16 shows curves of 3-phase faulted bus current which has a sever peak when lightning strikes and this intense currents can damage protection devices and transformers. Intensive fluctuations in electromagnetic torque and generator output power, along with great speed changes can be clearly observed in Fig. 17. Also according to Fig. 18, active and reactive power of wind turbine unit is decreased in fault time. Fig. 19 shows a decrease in effective voltage value of faulted bus and the effective voltage of bus from network is invariable.

7. CONCLUSION

In this paper we investigated 1-phase, 3-phase and lightning faults impact on a wind farm consisting of 40 wind turbines in EMTP-RV environment. Results of the experiments were presented and it was observed that in each of 3 cases, faulted bus voltage and the main bus of the wind farm was declined to 0.5 Pu, which was very dangerous and can cause voltage and the network to collapse but the bus voltage of network connected to wind farm was invariable during faulting. The generator torque, speed and output power fluctuation due to fault was concluded. Also the active and reactive power of faulted bus was decreased. According to obtained results, if there was no device to supply network with more reactive power during the fault, we will inevitably face severe voltage loss in various points of the network which can possibly cause it to collapse. In the next study, the effect of using FACTS devicesuch as SVC and STSTCOM for decreasing severe fluctuations of torque, speed and voltage drops will be proposed.

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