Improving the Fault Behavior of Wind Farms Facing Wind Speed Changes Using STATCOM

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Abstract— Generation of electricity using wind power has received considerable attention worldwide in recent years but the short circuit current contribution of wind turbines has not received much attention so far. This paper considers the short circuit behavior of induction generators in a wind farm considering wind speed changes and its influence on the wind farm and the power system and tries to find a way to decrease the effect of this phenomenon. Changes in wind speed have been considered in a positive and negative ramp manner. A Matlab-Simulik simulation is used for conducting this study.

***Keywords*—Wind farm; Wind Speed Changes; STATCOM.**

I. INTRODUCTION

Wind energy has been used for thousands of years by humans. Ancient Persians used wind energy to pump water before the birth of Christ [1]. The past decade has seen a growing interest in wind energy generation as environmental concerns are on the rise. At the end of 2008, the total installed capacity of wind power generation in the whole world is summed to 121,188 MW, from which USA had the biggest installed capacity, 25,170 MW, followed by Germany, Spain, China and India. It is predicted that the whole world wind power generation capacity arises to 180,000 MW at the end of 2010 [2]. Also, based on accelerated development and further improved policies, a global capacity of more than 1,500,000 MW seems possible by the year 2020 [2].

In spite of this growth, more technology advances are needed to make wind energy competitive with many other energy resources.

To successfully deploy wind energy, the resources and the transmission means to carry the electrical energy product to the load centers are needed. In an interconnected grid, the power system network and the wind power plants are interrelated. Knowing the characteristics of the wind power plant and the transmission and distribution systems is very important for identifying the problems and finding the resources to resolve the issues.

In Fig. 1, the single-line diagram represents a wind power plant. Each wind turbine has a pad-mounted transformer to step up the voltage generated by the wind turbine from the low voltage to the sub-transmission level.

One of the most important difficulties in treating wind power during the steady state operation of power systems is always wind fluctuations. Variation in wind speed, the primary driving power, makes the output power vary, and voltage quality deteriorates in the case of a weak connection.

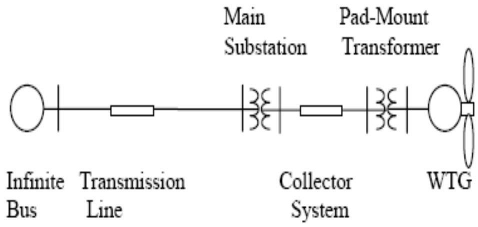

Figure 1. A typical network topology of a wind power plant

The short circuit current at the point of interconnection plays an important role in the behavior of the wind power plant. This paper presents the results of simulation of short circuit analysis considering wind speed changes in a wind farm connected to a power network. Also, in this paper a solution is proposed for this problem. The dynamic analysis in this paper is performed by using Matlab-Simulink simulation.

II. SHORT CIRCUIT CURRENT FED FROM INDUCTION GENERATOR

A three node model system depicted in Fig. 2 is the model of a wind farm connected to a power system. A wind farm consists of n individual induction generators the electrical constants of which are identical. Each unit is connected together at the lower voltage terminal of the step-up transformer.

The transformer is connected to the main system via tie line the impedance of which is (R_s+jX_s). The short circuit fault is assumed to take place at the high voltage terminal of the transformer because it is the severest fault for the wind farm occurring in transmission system and also because it suffices the objective of the present analysis, i.e. to study the group behavior.

In many cases, reactive compensation such as shunt capacitors are installed near the induction generators in order to supply the reactive power required. In this paper, too, these capacitors are considered in the simulation modeling.

The short circuit current of the model mentioned before can be calculated easily, but is not presented here for the sake of brevity.

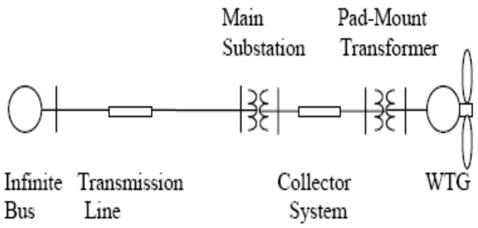

Figure 2. A typical network topology of a wind power plant

III. Modeling of Wind Speed Changes

It is necessary to model wind speed changes in order to study its influence on short circuit condition. By reviewing the literature for finding wind speed changes, one understands that it has a nearly sinusoidal pattern in long time [2-10]. In this paper, however, the effect of wind speed changes is studied in a somehow short period

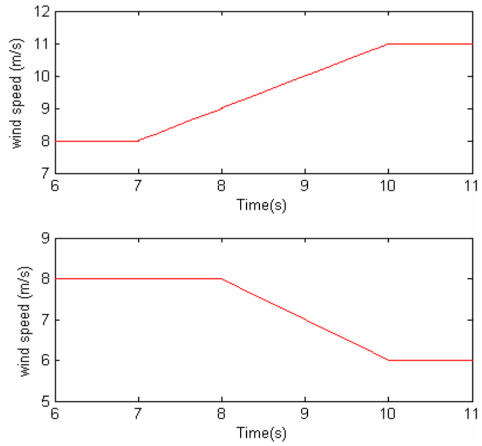

Figure 3. The model of wind speed changes

of time. If the measurement of the wind speed is precise, these changes are like positive and negative slopes. For this reason, the wind speed changes are modeled in a positive and negative ramp pattern. Fig. 3, shows these models. In the positive ramp, the wind speed varies from 8 to 11 m/s in 3 seconds and in the negative ramp, it changes from 8 to 6 m/s in 2 seconds. The short circuit fault is supposed to happen in 9th second for positive and negative slopes. The fault clears after 0.1 seconds.

IV. The Effects of Wind Speed Changes

A. The Case Study

In this paper, a wind farm, consisting of three wind turbines connected to a power system, is simulated in Matlab-Simlink. Fig. 4, shows this model.

The information regarding the case study is listed below:

- Base power is: 4MVA.
- Each wind turbines power is: 2×1.5MW.
- The nominal wind speed is 9 m/s.
- The nominal frequency of network is 60Hz.
- Each turbine has a 400KVar capacitor.
- Transformer of the wind turbines: 575V/25KV, 4MVA, R_0=66Ω, Y_n /Y_g.

-Turbine lines (3 lines): 1Km, R=0.1153Ω/Km, L=0.00105H/Km, C=11.39nF/Km.

- Power system transformer: 120KV/25KV, Y_g/D, 47MVA.

- Power system Lines (3lines): 25km, R=0.1153Ω/Km, L=0.00105H/Km, C=11.39nF/Km.

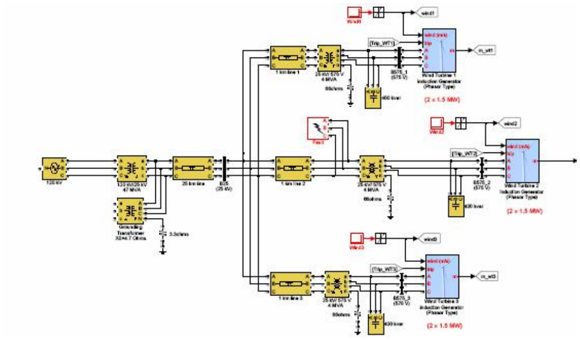

Figure 4. Matlab-Simulink model of the case study

In order to examine the effects of wind speed changes on the short circuit condition, the short circuit fault is simulated on the high voltage terminal of the wind turbine transformer. All kinds of short circuit faults can be simulated.

B. Simulation Results with Wind Speed Increasing

In this section, the results of the short circuit fault with wind speed increasing are shown.

In order to compare the fault influence on the system when the wind speed is increasing and when it is constant, the short circuit fault is simulated in these two conditions. In the constant speed condition, the wind speed is increased up to 10m/s and when the transient condition is cleared, the fault occurs. But in changing wind speed condition, it increases up to 11m/s and the short circuit fault happens when the speed is 10m/s (when the wind speed is increasing).

By studying the results of simulation of all kinds of faults (LG, LL, LLG, LLL and LLLG), it is seen that the worse case of faults is the LLLG fault. Figs. 5 and 6 show the results of the LLLG fault when the wind speed is constant and increasing respectively. Each figure shows four parameter of the model: turbines' speed changes, short circuit current, 25KV bus voltage and turbines' output power.

Since the result of the LLG fault is considerable, it is described in this paper too. Figs. 7 and 8 show the results of LLG fault when wind speed is constant and increasing respectively.

C. Simulation Results with Wind Speed Decreasing

In this section, the results of short circuit fault with wind speed decreasing are shown.

In order to compare the fault influence on the system when the wind speed is decreasing and when it is constant, the short circuit fault is simulated in these two conditions. In the constant speed condition, the wind speed is decreased down to 6m/s and when the transient condition is cleared, the fault occurs. But in changing wind speed condition, it decreases down to 6m/s and the short circuit fault happens when the speed is 7m/s (when the wind speed is decreasing).

By studying the results of simulation of all kinds of faults (LG, LL, LLG, LLL and LLLG), it is seen that the worse case of faults is LLLG fault. Figs. 9 and 10 show the results of LLLG fault when the wind speed is constant and decreasing respectively.

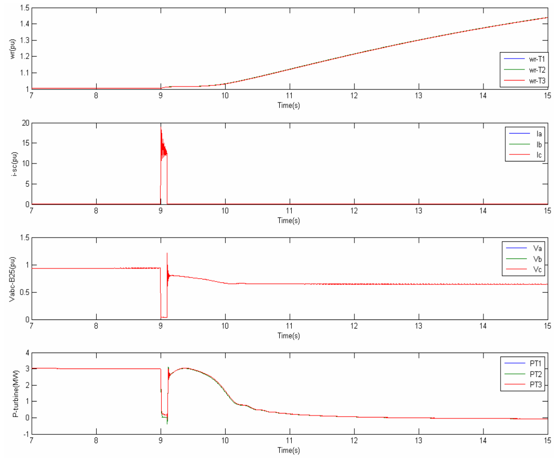

Figure 5. LLLG fault results (constant wind speed 10 m/s)

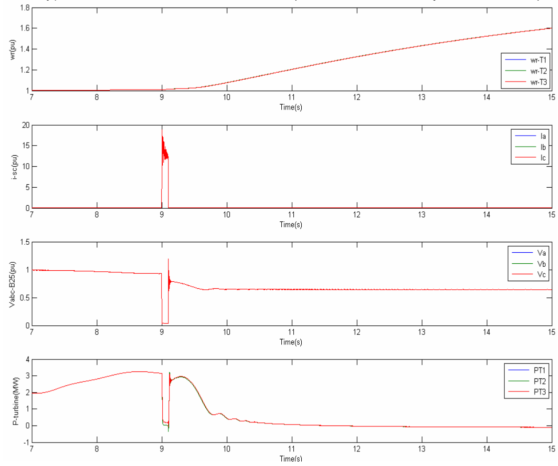

Figure 6. LLLG fault results (increasing wind speed)

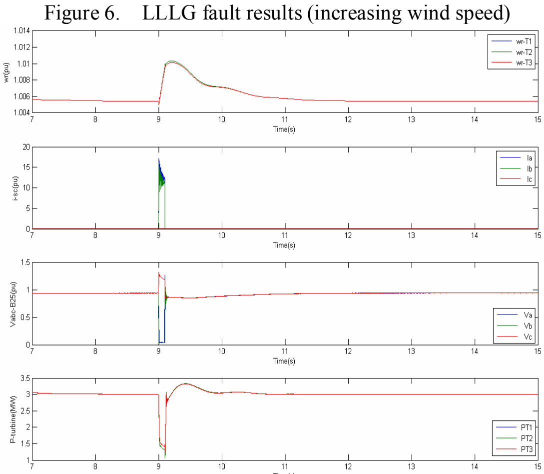

Figure 7. LLLG fault results (increasing wind speed)

D. Analyzing The Results

By comparing Figs. 5 and 6 it is seen that the wind farm loses its stability in both conditions and the turbines' rotor speed increases violently. The power system also works under nominal voltage and it is not tolerable by the system. But in the condition of increasing wind speed, the wind farm loses its stability quicker.

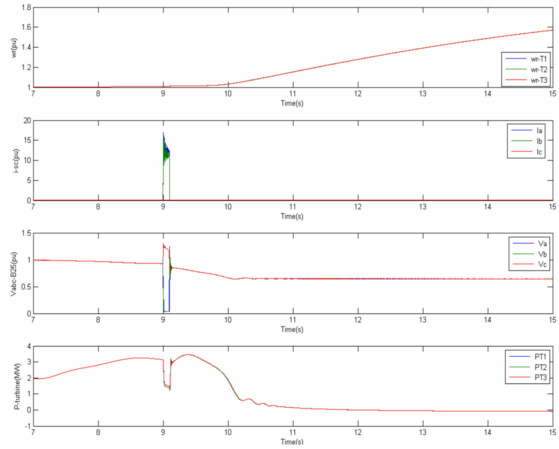

Figure 8. LLG fault results (increasing wind speed)

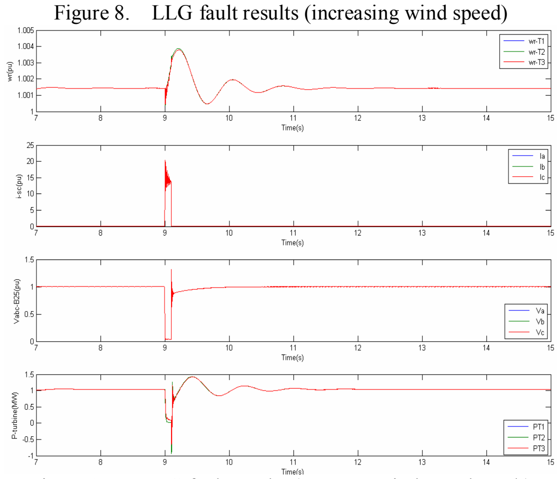

Figure 9. LLLG fault results (constant wind speed 7 m/s)

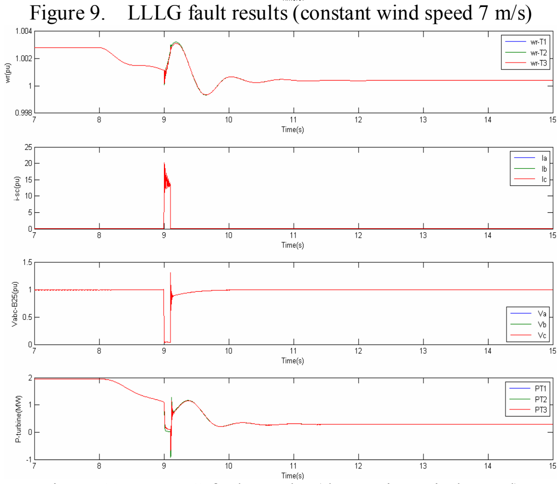

Figure 10. LLLG fault results (decreasing wind speed)

In Figs. 7 and 8 something noticeable happens. When the speed is constant, the LLG fault can be tolerated by the wind farm, but in the case of changing wind speed, the wind farm loses its stability and shuts down.

When the wind speed decreases, the output power of the wind farm decreases too, (because the output power is proportional to the third power of the wind speed [11]) and in this condition, changing in wind speed does not have a considerable influence on the short circuit simulation results. It can be seen in Figs. 9 and 10.

One can see that the wind speed changes can influence the stability of the wind farm and the power system connected to it. Thus, the change of wind speed must be considered by the wind farm designers and they should find a way to control this condition.

V. Introduction of the Solution Method

In this section, a solution to decrease the effect of wind speed changes on wind farm stability is proposed.

A. The Case Study

In order to study the proposed model, a STATCOM is modeled and is installed in the simulation model at the point where the wind farm is connected to the power system network. Fig. 11 shows this model.

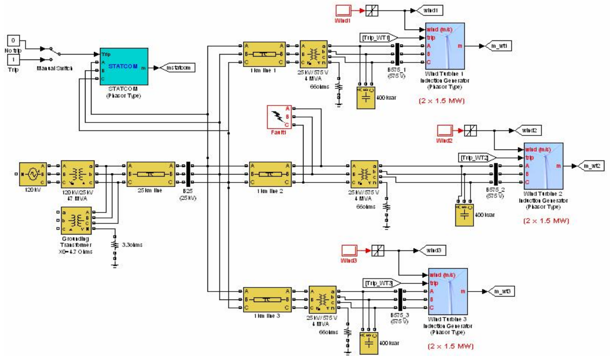

Figure 11. Matlab-Simulink model of the case study with STATCOM

The model is exactly the same as the before mentioned model and only a STATCOM is added to it.

The parameters of STATCOM are listed below:

- Nominal voltage: 25KV
- Nominal frequency: 60Hz
- Rated power: 3MVA
- DC link nominal voltage: 4KV
- Converter resistance: 0.0073 p.u.
- Converter inductance: 0.220 p.u.

In order to examine the effects of installing STATCOM on the short circuit condition, the short circuit fault is simulated on the high voltage terminal of the wind turbine transformer. All kinds of short circuit faults can be simulated. The test conditions are the same as the case without STATCOM.

B. Simulation Results with Wind Speed Increasing

In this section, the results of the short circuit fault with wind speed increasing when a STATCOM is installed are shown.

By studying the results of simulation of all kinds of faults (LG, LL, LLG, LLL and LLLG), it is seen that the worse case of faults is the LLLG fault. Figs. 12 and 13 show the results of the LLLG fault when the wind speed is constant and increasing respectively. Each figure shows four parameter of the model: turbines' speed changes, short circuit current, 25KV bus voltage and turbines' output power.

Since the result of the LLG fault is considerable, it is described in this paper too. Figs. 14 and 15 show the results of LLG fault when wind speed is constant and increasing respectively.

C. Simulation Results with Wind Speed Decreasing

In this section, the results of short circuit fault with wind speed decreasing when a STATCOM is installed are shown.

By studying the results of simulation of all kinds of faults (LG, LL, LLG, LLL and LLLG), it is seen that the worse case of faults is LLLG fault. Figs. 16 and 17 show the results of LLLG fault when the wind speed is constant and decreasing respectively.

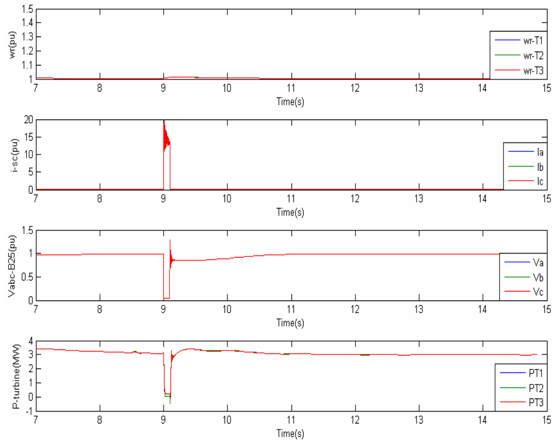

Fig. 12. LLLG fault results (constant wind speed 10 m/s)

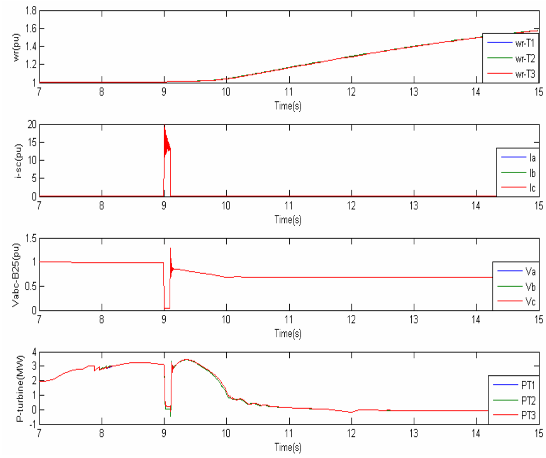

Fig. 13. LLLG fault results (increasing wind speed)

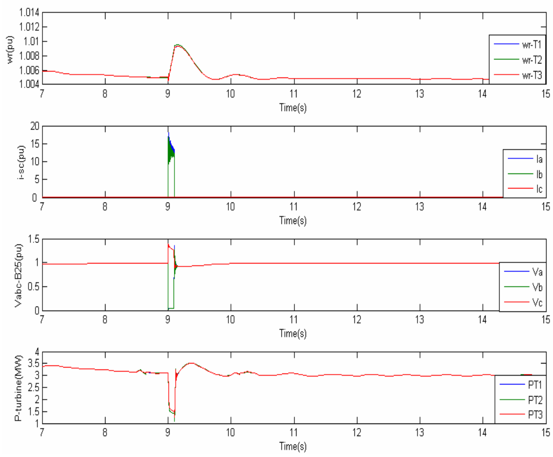

Fig. 14. LLG fault results (constant wind speed 10 m/s)

D. Analyzing The Results

By comparing Figs. 12 and 13 it is seen that the wind farm remains stable when the wind speed is constant. In the second case, wind farm is unstable and the turbines' rotor speed increases violently.

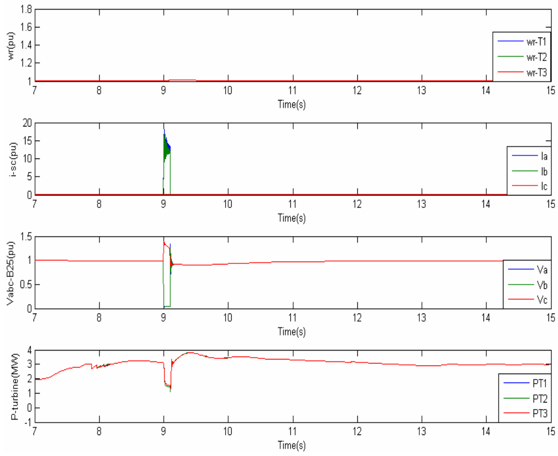

Fig. 15. LLG fault results (increasing wind speed)

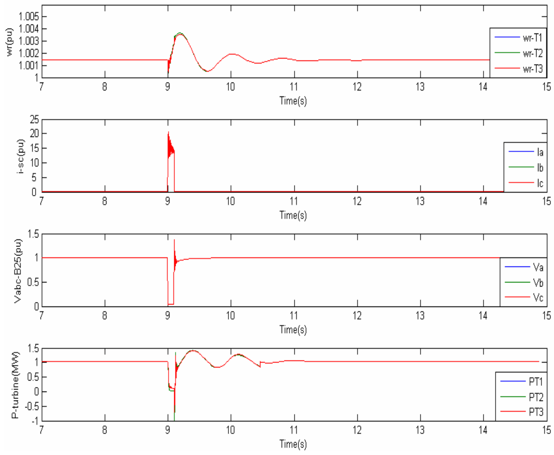

Fig. 16. LLLG fault results (constant wind speed 7 m/s)

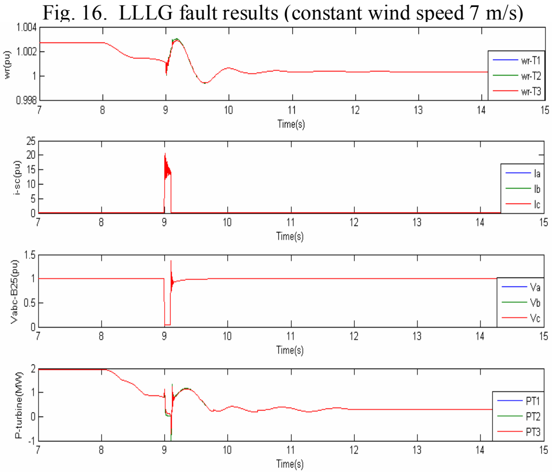

Fig. 17. LLLG fault results (decreasing wind speed)

Figs. 14 and 15 show the system and wind farm stability after the fault clearance time.

When the wind speed decreases, the output power of the wind farm decreases too, (because the output power is proportional to the third power of the wind speed [11]) and in this condition, the change in wind speed does not have a considerable influence on the short circuit simulation results. It can be seen in Figs. 16 and 17. The power system also works under nominal voltage and it is not tolerable by the system. But in the condition of increasing wind speed, the wind farm loses its stability quicker.

One can see that the wind speed changes in the model with a STATCOM have less influence in comparison with the model without a STATCOM.

VI. Comparing The Results with and without Installing STATCOM

By comparing the results of the two models mentioned before, the following results can be concluded:

- By comparing Figs. 5 and 12, it can be seen that in the model with STATCOM the system and the wind turbine remain in stable condition, whereas in the case without STATCOM, the wind turbine losses its stability and the effects on the power system is noticeable.

- In the two cases, when LLLG fault happens in increasing wind speed condition, the wind turbine losses its stability and installing STATCOM does not make any difference (Figs. 6 and 13).

- Comparing Figs. 7 and 14 shows a little better quality of stability for wind turbine and power system in Fig. 14.

- By comparing Figs. 8 and 15, it can be seen that in the model with STATCOM the system and the wind turbine remain in stable condition, whereas in the case without STATCOM, the wind turbine losses its stability and the effects on the power system is considerable.

- Figs. 9 and 16 do not have any noticeable differences. Also, comparing Figs. 10 and 17 don't show any considerable differences.

Reviewing of the above results show that installation of STATCOM is a good way to decrease the effect of wind speed changes influence on the power system and the wind farm.

VII. Conclusions

This paper considers the short circuit behavior of the induction generators in a wind farm considering wind speed changes and its influence on the wind farm and the power system and proposes the installation of STATCOM as a way to decrease the effect of this phenomenon. Changes in wind speed are considered in a positive and negative ramp pattern. A Matlab- Simulik simulation is used for depicting the results of this study. By reviewing the results, it is clear that the wind changes have an influence on the stability of the wind farm and also the power system connected to it. Also, comparing the results of the case study with and without STATCOM shows the positive influence of STATCOM in power system and the wind farm. It, however, seems necessary to investigate the economic considerations and the benefits and disadvantages of STATCOM. This is the subject of our future research.

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BIOGRAPHIES

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