Study and Simulation of Wind Farms Based on Squirrel Cage Induction Generator in Electrical Distribution System

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***Abstract*— Wind power sources are evolving and becoming more prevalent in energy systems, which has implications for a variety of operational metrics, including stability and frequency regulation. To guarantee the stability and reliability of the modern power system, it is crucial that grid-connected wind turbines operate consistently and reliably. It is still challenging to accurately and reliably characterize these generators and their components to analyze sequestered operational possibilities like short-circuit faults, soft-starting, and generator switching. To comprehensively understand the stability interactions within distribution grids or localized networks, an accurate simulation is essential. In this study, the effect of a static synchronous compensator (STATCOM) in a distribution system with an induction generator wind farm is analyzed and simulated. The studied system consists of a 9 MW wind farm linked to a 25 kV distribution system that delivers power to the grid through a 25 kV. The results show that the STATCOM can, in addition to providing active power in short-circuit fault conditions, adjust the voltage changes at the common connection point between the electricity distribution system and the wind in both normal and fault conditions. Based on the outcomes, the effectiveness of the proposed approach is highly dependent on the wind energy system's parameters. Due to the inherent parameter uncertainty, non-stationarity, and nonlinearity in the wind power system, the use of a parameter prediction approach based on artificial intelligence (AI) is recommended for future research.**

Keywords*— *Distribution system; Artificial Inteligent (AI), FACTS devices; STATCOM; Wind energy conversion system.

I. INTRODUCTION

Electric energy cannot be stored on a large scale with high efficiency, and therefore one of the main conditions of operation is to balance the demand and consumption of the network at any moment [1,2]. Energy is a fundamental requirement for the maintenance of economic growth, the enhancement of quality of life, the promotion of social welfare, and the strengthening of community safety [3]. One of the important issues is the extent of human need for energy sources, so that the effort to achieve permanent energy sources is one of the long-standing goals of man. The world's need for energy has increased significantly in recent years, and fossil power resources are not the answer to this requirement for elaboration and development in the future [4]. Energy sources are separated into two major classifications: non-renewable resource such as oil and coal, and renewable resource like solar, wind, and fuel cells.

Renewable energy (reversible energy) is a type of energy, the source of which, unlike non-renewable energy (fossil), can be renewed by nature in a short duration of time [5,6]. Since renewable power resources are available in all parts of the planet, and they do not have access restrictions like fossil fuels (oil, gas, coal), the role of new energies is well known, while fossil fuel sources are not only It is found in certain countries, but they also face an increase in price. In recent years, owing to the reduction of non-renewable power resources, renewable energies have gained a critical and significant role in the world, and many studies have been conducted to exploit these resources [7,8].

The rapid development of power electronics and the construction of high-power semiconductors have provided amazing possibilities for the development of new equipment in the field of power system compensators [9,10]. So far, many control tools have been designed and completed under the title of flexible alternating current transmission systems (FACTS) technology for transmission and distribution networks [11].

FACTS devices have a fundamental role in boosting the flexibility of energy transmission and the security of the dynamic stability of the power system through the activation of its elements and components [12]. FACTS controllers provide many facilities and capabilities for the power system [13,14]. Flexible AC Transmission Systems are classified into three groups: thyristor-controlled FACTS devices, post-voltage-source-converter FACTS devices, and hybrid devices [15].

Usually, the establishment of FACTS devices relies on the purpose of their application, which can be mentioned to increase the productivity of the system, minimize the production cost, and increase the voltage stability. Most recently built farms typically employ either permanent magnet synchronous generators (PMSG) or doubly fed induction generators (DFIG) linked to the grid via a back-to-back converter [16].

However, more than half of today's wind farms rely on squirrel-cage induction generators (SCIG) that are hardwired into the national power grid. To help these wind farms (SCIG-based wind power systems) meet the new stringent requirements, explanations established for static compensators (STATCOMs) are frequently utilized. The wind farm's reactive electrical power consumption is managed, and the voltage magnitude at the point of common coupling is regulated, both of which contribute to excellent stability (PCC). Nevertheless, STATCOM's power rating needs to be high because a SCIG's reactive power consumption can rise to as much as twice its rated power after a major fault event. But several issues arise when a SCIG-based wind power system is supplied with unbalanced voltages from the grid [15,16].

A SCIG's low negative-sequence impedance yields considerable negative-sequence currents to flow through the stator. These current drives the generator to overheat, lose efficiency, and wear out prematurely. Then the high stress in the mechanical system of the turbine is induced by the pulsation in the mechanical torque generated by the interplay of negative sequence voltages with positive sequence currents [17]. Damage to the wind farm's electrical or mechanical components may trigger SCIG protections and cause it to be shut down. Because they function like a current source, STATCOMs are unable to correct for imbalanced voltages that originate at the PCC. Wind power systems based on SCIGs are especially vulnerable to this voltage distortion and require special attention.

In this paper, the aim is to study and investigate the operation of wind farms according to the squirrel cage induction generator in the electricity distribution system. A power compensator unit is utilized to improve the wind power system stability and voltage regulation of this widespread energy system. The numerical results demonstrate the effective performance of the compensator on the voltage and output power of the system [18].

A. Static synchronous compensator

FACTS devices are split into two classes according to the mode of operation: devices based on reactive impedance and devices based on voltage source [19].

One of the FACTS devices, the static synchronous compensator (STATCOM), is built on the same voltage source converter architecture and is implemented in parallel in the power system to regulate the voltage across the transmission lines [20,21]. The static synchronous compensator can inject reactive and active electrical power into the energy system in a short period of time, and affect the system's dynamic and steady state performance, and improve the system's damping and voltage profile [22,23]. Compared to common compensators such as SVC, it has a faster response in controlling harmonics and stability and does not require large and expensive inductors [24].

B. Wind energy conversion systems

The increasing usage of renewable energies in electricity production is a response to the issues provoked by the pollution of fossil fuels and the depletion of energy sources [25,26]. Wind power is one of the most widespread renewable power sources due to its configuration being widely implemented as a decentralized or centralized solution, and it is almost available in most parts of the world [27,28]. The goal of a wind energy conversion system, a complex system made up of interconnected components, is to convert the kinetic energy of the wind into mechanical energy and then into electrical energy by generators [29,30]. Maximizing output power across a wide range of wind speeds is a key concern for systems that convert wind energy.

C. Paper organization and structure

This study is structured as follows: After stating the problem description in the introduction and briefly referring to the two main parts of the studied system, the system under study is illustrated in the second section. In the section III, to verify the effectiveness of the suggested procedure, the numerical results employing MATLAB/Simulink are demonstrated. Eventually, in the section IV, the conclusion is declared. In this part, the author's recommendation for future research direction is also expressed.

II. STUDIED WIND TURBINE SYSTEM

The wind farm being investigated consists of six 1.5 MW wind turbines (three pairs of 1.5 MW wind turbines), which are linked to and supplied by a 25 kV/25 km feeder and a 25 kV distribution power system, respectively. A 120 kV power grid receives the electricity that the described system exports. Variable-pitch wind turbines drive the rotor of wind turbines equipped with squirrel cage induction generators, which have stator windings that are phase-locked to the 60 Hz grid. The generator's output power is restricted to its rated value for winds greater than the rated speed by controlling the pitch angle.

The induction generator needs to operate at a speed slightly higher than synchronous speed (9 m/s) in order to generate electrical power. The speed varies from about 1 pu at no load to about 1.005 pu when fully loaded. Protection systems monitor the voltage, speed, and current of each individual wind turbine. Each wind turbine has a bank of capacitors wired to its low-voltage bus, which helps to offset the induction generators' need for reactive power.

This power is 400 KW for each pair of 1.5 MW turbines. The remaining reactive power needed to keep the 25 kV distribution bus voltage close to one unit constant is provided by a 3 MW static synchronous compensator with a 3% droop setting. 3 MVA is regarded as the minimum power. In addition, the wind's rated speed, which creates the rated mechanical power, is 9 m/s.

III. SIMULATION RESULTS

In this part, to demonstrate the effectiveness of the STSTCOM on the wind power system stability and its voltage and power regulation. Several simulations carried out on the test system mentioned in the previous part. Note that the numerical outcomes for a period of 20 second is reported in this part using the Simscape library in MATLAB software.

As depicted in the numerical results, the behavior of three turbines is illustrated with a solid line (black color) for the first turbine (1), a dashed line (green color) for the second turbine (2), and a dotted line (blue color) for the third turbine (3), respectively. At first scenario, the wind speed for all turbines is considered to be 8 m/s. As shown in Fig. 1, the speed of turbines one, two and three change to 11 m/s in 2, 4 and 6 second respectively for three seconds. During 15 second a temporary fault is applied to the wind turbine terminal 2 (low voltage 575 volts). Table 1 shows the parameters set for three pairs of turbines for simulation.

TABLE I. SET PARAMETERS OF TURBINES

Parameter	Value
The gain of the pitch angle controller integrator	25
Maximum pitch angle change rate	2 deg/s
Nominal mechanical output power of the wind turbine	$2\times1.5\times10^6$ W
Main rotation speed	1 pu/main generator speed
Proportional gain of pitch angle controller	5
Main wind speed	9 m/s

Fig. 2 shows the voltage of bus 25 with compensator. As can be seen, without the compensator, the voltage drop in the steady state has increased.

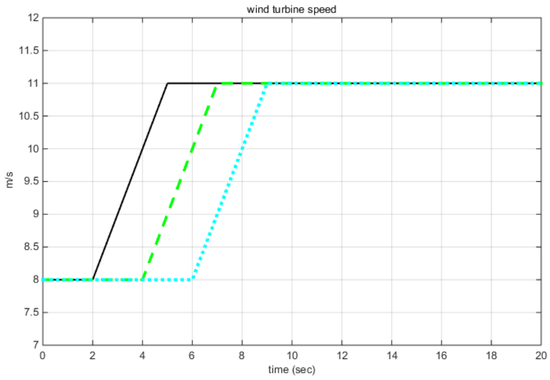

Fig. 1. Wind turbine speed

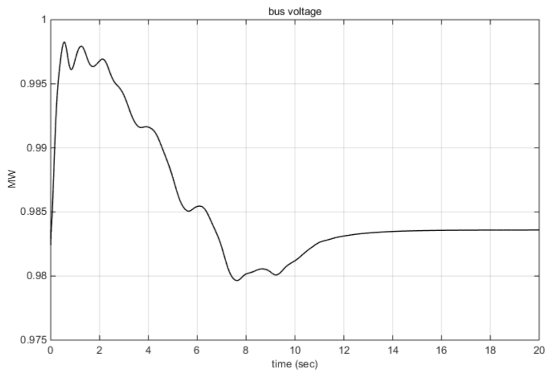

Fig. 2. Voltage bus (with compensator)

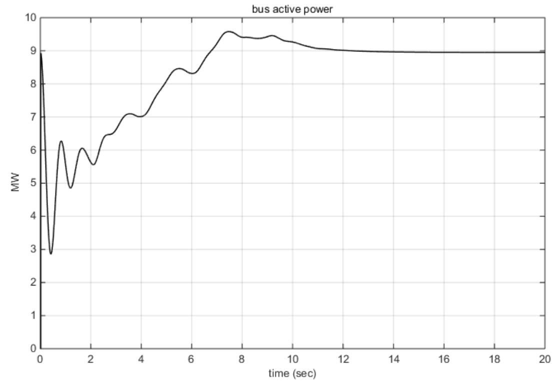

Fig. 3. Bus active power (with compensator)

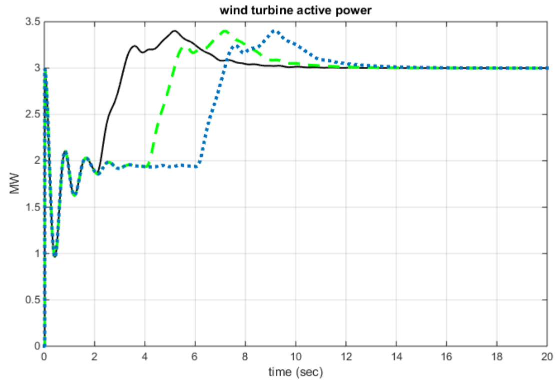

Fig. 4. Wind turbine active power (with compensator)

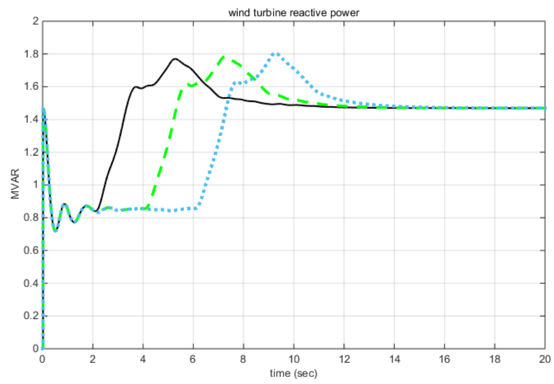

Fig. 5. Wind turbine reactive power (with compensator)

Fig. 3 shows active bass power in two modes. As you can see, in steady state, one of the turbines is out of the circuit and the throughput is 6 MW. Fig. 4 depicts the productive active power and Fig. 5 show the productive reactive power of wind turbines in two states. With the presence of the compensator, the turbines are in the circuit and each of them produces 1.5 MW. Fig. 6 show the pitch angle for two cases. Figs. 7 and 8 show the size of the compensator bass and the reactive power produced by the compensator. The compensator prevents voltage drop by generating reactive power and injecting it into the network.

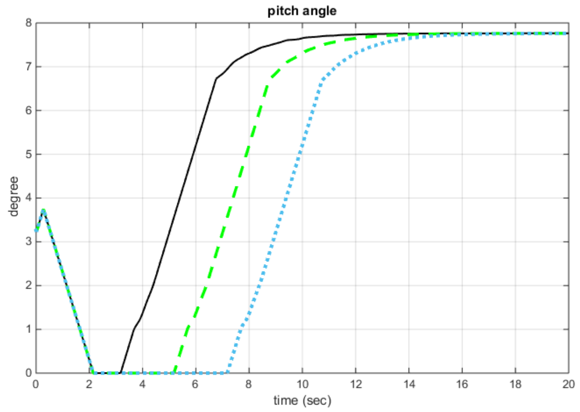

Fig. 6. Pitch angle (with compensator)

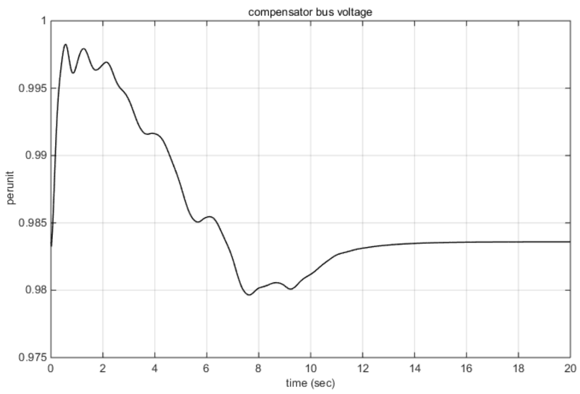

Fig. 7. Compensator bus voltage

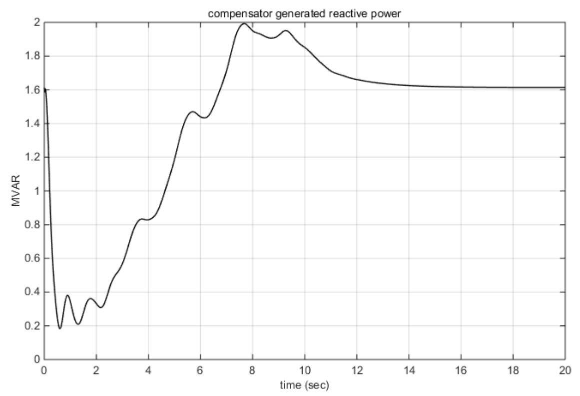

Fig. 8. Compensator generated reactive power

The numerical analysis demonstrated that the input parameters of the squirrel-cage induction generators used in wind power plants play a significant role in the reliability of the power grid and the voltage profile of these plants. More than half of today's operational wind farms use SCIGs that are directly connected to the national power grid, as we discussed upfront. In this paper, the input parameters of the wind power plan are assumed to be defined based on an exact prediction. However, due to its non-stationarity, nonlinearity, and chaos, predicting the input parameters of a SCIG-based wind power plant is a complicated task. Therefore, the authors suggest utilizing an efficient estimation approach based on artificial intelligence to accurately predict the input parameters of a wind power plant in the future works. Curtailment, operating constraints, faults and maintenance of wind turbines, and other situations that exert artificial control to reduce the wind farm's output power are also inevitable in the actual operation of the wind farm. It's like the wind farm's capacity is fluctuating in real-time, so we need a novel method to describe how these variables affect the wind farm's power output. That's why we need to tweak interval prediction or uncertainty analysis based on artificial intelligence to make our predictions more precise and less risky [31,32].

IV. CONCLUSION

Along with the demand for electrical energy and the progress of the industry, energy supply is very important from an economic point of view while respecting environmental issues. In this paper, the effect of a static synchronous compensator on the behavior of the distribution system is investigated. Numerical analysis is carried out, and three pairs of wind turbines with speed variations were considered. The simulation outcomes demonstrated the compensatory effect of power compensation devices on improving voltage regulation, stability, and reliability of wind turbines in the power system. Future research is suggested to utilize a parameter estimation procedure established on artificial intelligence because of the inherent parameter uncertainty in the input data of wind power systems.

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