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Using STATCOM to Improve the Wind Farm's Stability while Connected to the Grid.

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ABSTRACT—

Given the rapid growth of wind power as a renewable energy source, it becomes imperative to identify the challenges involved with ensuring a reliable power system when integrating it into the grid. This article presents a concise technique for enhancing the stability of a grid-connected wind farm through the implementation of reactive power regulation and voltage fluctuation minimization. This is achieved by employing a straightforward 6-pulse Static Synchronous Compensator (STATCOM). The STATCOM is regulated by the implementation of a voltage control loop, utilizing a proportional-integral (PI) controller. Additionally, Pulse Width Modulation (PWM) is employed, employing a carrier frequency that is nine times the fundamental frequency, along with a variable direct current (DC) voltage. This report furthermore includes a comparative analysis of the stabilization of a wind farm through the utilization of a Static Synchronous Compensator (STATCOM) vs only employing a capacitor bank in response to fluctuations in wind speed. The simulation findings indicate that the implementation of STATCOM has the potential to enhance the stability of the wind farm. The rationale for selecting this study is supported by the utilization of simulation in the PSCAD/EMTDC programmer.

Keywords— STATCOM; stability; wind turbine; pulse width modulation; Voltage control loop.

I. INTRODUCTION

The escalating crises around traditional energy sources, such as fossil fuels, gas, and coal, coupled with the pressing issue of global warming, has garnered significant attention towards wind energy. This renewable energy source has captured the interest of many individuals due to its potential to enhance energy security and provide environmental benefits. Wind energy has emerged as a promising and feasible method for providing environmentally friendly energy generation in the foreseeable future. Regarding the noteworthy aspects of demand, the year 2014 witnessed the installation of 51.2 GW of fresh wind capacity, so establishing a novel annual capacity milestone. Consequently, the cumulative installed capacity escalated to 372 GW at the conclusion of the aforementioned year [1]. Nevertheless, wind energy is subject to many limitations as a result of its reliance on harnessing power from the wind. One of the primary technical obstacles encountered in wind power plants is to the volatility of power production and terminal voltage in fixed speed wind generators. The power fluctuations are a result of the fluctuations in wind speed, which in turn affect the power output of the generator at different points in time. Hence, the investigation of methodologies aimed at enhancing voltage stability, frequency stability, and power quality [2] represents a significant area of scholarly inquiry within the domain of wind power. The induction generator (IG) is widely utilised in the field of wind turbine generators due to its cost-effectiveness and sturdy nature [3].The coupling between the reactive power consumed by induction generators and the active power they produce results in fluctuations in voltage and power due to variations in wind speed [3].Reactive power control in big wind farms is a significant technological challenge. While the primary purpose of placing a capacitor bank is to supply the required reactive power during steady state conditions, it is unable to effectively regulate the output voltage in the presence of fluctuating wind speeds. In order to address this issue, various devices utilising voltage or current source inverters have been employed. These devices include the static var compensator (SVC), static synchronous compensator (STATCOM), dynamic voltage restorer (DVR), solid state transfer switch (SSTS), and unified power flow controller (UPFC). Their purpose is to enable flexible power flow control, ensure secure loading, and mitigate power system oscillation [4]-[6]. The primary rationale for using STATCOM as a preferred option in wind farms is in its capacity to deliver expedited and seamless voltage regulation, along with its comparatively lower cost vis-à-vis other devices. The STATCOM is a voltage-source converter device that utilises either GTO or IGBT technology. Its primary function is to convert a direct current (dc) input voltage into an alternating current (ac) output voltage. This conversion process is employed to effectively address the active and reactive power requirements of the system [7]. The STATCOM system enhances voltage stability through the management of reactive power. Consequently, STATCOM systems have been implemented in several applications and are gaining widespread recognition. Numerous researchers are now engaged in efforts to improve the stability of grid-connected wind farms through the use of Static Synchronous Compensators (STATCOM). This work presents a novel control strategy for grid-connected wind energy generation, specifically focusing on a 6-pulse STATCOM. The suggested technique demonstrates improved reaction time and enhanced voltage support capabilities compared to earlier findings. The simulation results obtained with PSCAD/EMTDC [8] demonstrate the comparative performance of a wind farm when equipped just with a capacitor bank vs when equipped with a STATCOM. The structure of the paper is as follows. Section II provides an introduction to the analysis of the model system. Section III provides an introduction to the STATCOM. In Section IV, the STATCOM controller and the overall system architecture in PSCAD/EMTDC are shown. Sections V and VI provide an account of the simulation results and draw conclusions, respectively.

II. MODEL SYSTEM ANALYSIS

Wind turbines are complex systems comprising several components such as a rotor, generator, turbine blades, and a driving or coupling mechanism. The kinetic energy possessed by air molecules in motion is transformed into rotational energy by the action of the rotor of a wind turbine. This rotational energy is subsequently transferred into electrical energy by a wind electric generator.

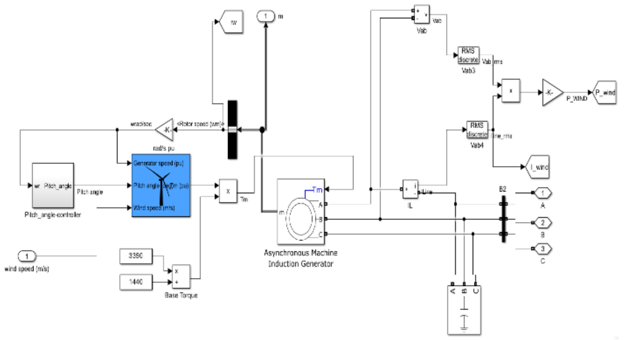

Fig. 1(a). Simulink model Wind turbine and induction generator

Pitch Controller

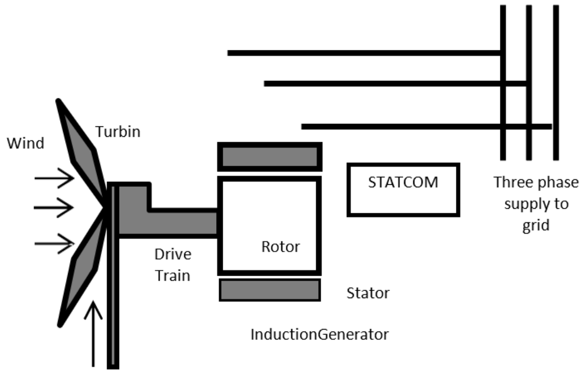

Fig. 1. Wind turbine and induction generator

Figure 1 illustrates the model system employed in this investigation. The STATCOM device is installed and linked to the terminal bus of the wind farm. The wind turbine modelling equation and pitch controller employed in this analysis are consistent with those utilised in a previous work [3].

III. STATIC SYNCHRONOUS COMPENSATOR(STATCOM)

The STATCOM system refers to a static synchronous generator that functions as a static compensator when linked in parallel. Its output current, whether inductive or capacitive, may be independently adjusted to regulate the voltage of the AC system [9]. The present device is a voltage converter that utilises either a Gate Turn-Off thyristor (GTO) or an Insulated Gate Bipolar Transistor (IGBT). Power electronic switches are employed for the purpose of generating an output voltage that closely resembles a sinusoidal waveform, utilising a direct current (DC) source. Figure 2 depicts the power circuit design of a Voltage Source Converter (VSC)-based Static Synchronous Compensator (STATCOM). In this configuration, six Gate Turn-Off Thyristors (GTOs) are employed, together with their anti-parallel diodes and a DC-link capacitor, to provide the three-phase voltage.

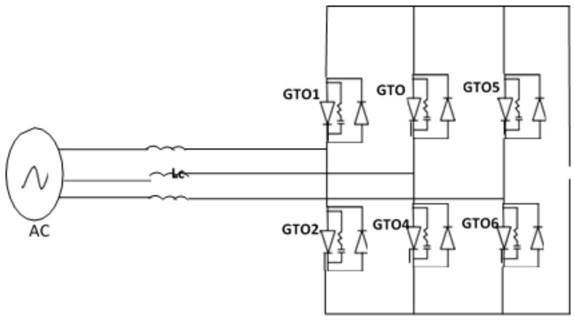

Fig. 2. Power circuit diagram of a STATCOM

According to the literature sources [10] and [11], it has been argued that the STATCOM exhibits superior performance compared to the SVC. Furthermore, it should be noted that the STATCOM device is somewhat more cost-effective when compared to the SMES device.

IV. CONTROL STRATEGIES OF STATCOM

The objective of our study is to demonstrate the efficacy of STATCOM in regulating reactive power compensation as a means of mitigating voltage fluctuations at the terminal. To accomplish this task, a 20MW induction generator, a basic 6-pulse STATCOM, and an appropriate load are interconnected with the grid. The STATCOM in question exhibits voltage control functionality through the use of a proportional-integral (PI) controller. Additionally, it employs pulse width modulation (PWM) with a carrier frequency that is nine times greater than the fundamental frequency. Furthermore, the STATCOM operates with a variable direct current (DC) voltage. A capacitor that is charged exhibits the behaviour of a direct current (DC) source. The present electrical supply powers an AC/DC power converter, which generates a series of outputs featuring adjustable three-phase voltages. In this study, a set of Gate Turn-Off Thyristors (GTOs) was employed as the chosen switching device. The GTOs in question are operated using the Voltage Source Converter Pulse Width Modulation (VSC-PWM) technology. The control of the STATCOM is implemented through the utilisation of the following methodologies.

A. Voltage control loop

The voltage control loop, seen in Figure 3, is employed to generate the angle order by using the voltage error. The error voltage is produced as a result of the disparity between the reference voltage and the voltage that has undergone filtration. The filtered voltage is obtained from the summation of reactive power and the measured voltage, which are subsequently subjected to the notch filter. All of the values are computed on a per unit basis. Subsequently, the erroneous voltage is sent by the LED-lag compensation and the proportional-integral (PI) controller. The angle order produced by the PI controller signifies the desired phase shift between the system voltage and the voltage provided by the STATCOM. This phase shift impacts both the direction and magnitude of real power flow.

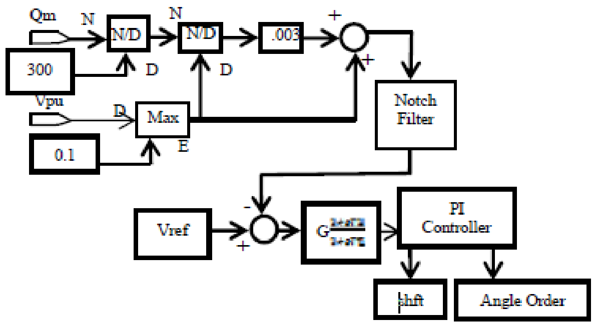

Figure 3 illustrates the voltage control loop, which involves the generation of an angle order derived from the voltage error.

B. Pulse width modulation (PWM)

Pulse Width Modulation (PWM) has two primary components. The first component involves the creation of triangle waveforms that are synchronized with the alternating current (AC) voltage of the system. Part 2 involves the development of reference waveforms that are synchronized with the alternating current (AC) voltage of the system and adjusted by a certain angle order.

Part 1: An angle denoted as theta is produced by a Phase Locked Loop (PLL) and afterwards multiplied by the carrier frequency. The outcome of the multiplication operation is linked to a component that has been defined y the user.

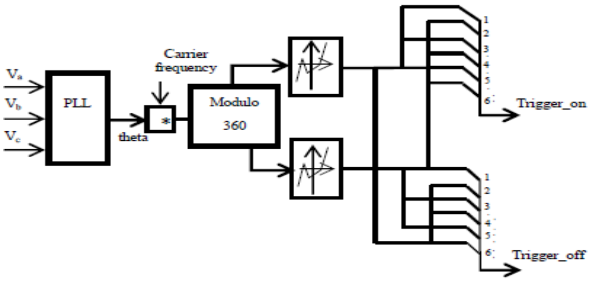

Fig. 4. PWM Control 1: Triangular Waveform Generation

The device is synchronized with the alternating current (AC) voltage of the system. The aforementioned component corresponds to a mathematical function known as MODULO, with a modulation factor of 360. The identification of the Trigger on and Trigger off pulses may be achieved by analyzing the non-linear transfer characteristics and utilizing the data merging components, as seen in Figure 4.

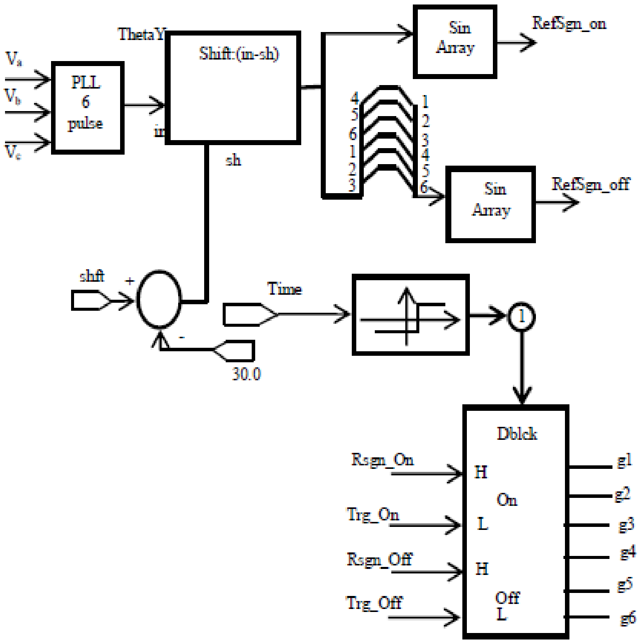

Fig. 5. PWM Control 2: The production of reference waveforms that are synchronized with the alternating current (AC) voltage of a system and adjusted according to the order of the phase angle.

In this context, an additional phase-locked loop (PLL) is employed to generate the angle theta. The output of the phase-locked loop (PLL) and the output of the voltage control loop, which is displaced by 30 degrees owing to the presence of a Y-delta transformer, are interconnected with a user-defined component. This component is designed to perform subtraction operations and operates inside six-dimensional arrays. Following the identification of the Refsgn_on signal, which is obtained by a user-defined component referred to as "sin array," this component serves to represent the SIN function and operates on arrays with six dimensions. Similarly, the Refsgn_off signal is obtained using another sin array. These two signals depicted in Figure 5 serve as reference signals. The interpolated firing pulses block receives four signals, namely Trg_on, Trg_off, Rsgn_on, and Rsgn_off. This particular component is designed to provide firing pulses and offers interpolated time lag for the purpose of achieving interpolated turn-on or turn-off of gate turn-off thyristors (GTOs). In conclusion, a total of six firing pulses, namely g1, g2, g3, g4, g5, and g6, have been identified.

V. SIMULATION AND RESULT:

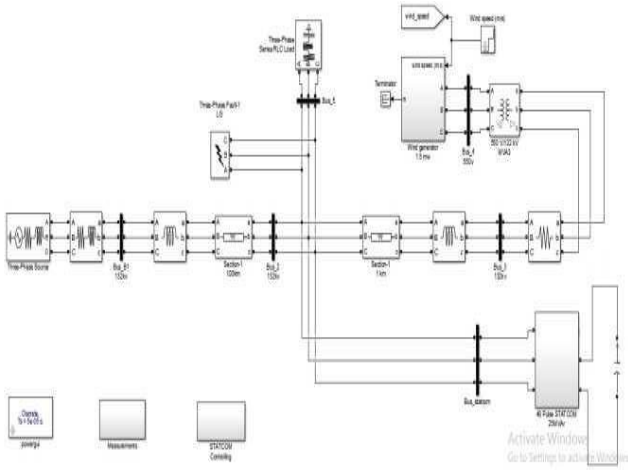

Fig. 6 Simulation of grid connected wind generator with STATCOM

The simulation model in Powerful is executed in discrete mode over a time period of 2 seconds. The topic of discussion is to the transmission of electrical power at a voltage level of 132 kilovolts (kV) utilizing a three-phase voltage source. The topic of discussion is to the 132kV transmission line, which is divided into two sections: one spanning 100km and the other spanning 1km. The analysis of these sections is conducted using the Nominal Pi model of transmission line. The use of simulation The squirrel cage induction generator has a rating of 550 volts and a power output of 1.5 megawatts. The generated power is stepped up from 550 volts to 132 kilovolts using a transformer, after which it is connected to the 132 kilovolt grid. The wind speed first starts at 5 m/s and subsequently increases to 9 m/s, with the final value reaching a maximum wind speed of 12 m/s. Between the time interval of 1.0 seconds to 1.02 seconds, induce a Line-to-Line-to-Line-to-Ground (LLLG) fault by connecting one phase-A, phase-B, phase-C, and ground. During a fault, the behaviour of a system becomes unstable. The block diagram illustrating the control of a Static Synchronous Compensator (STATCOM).

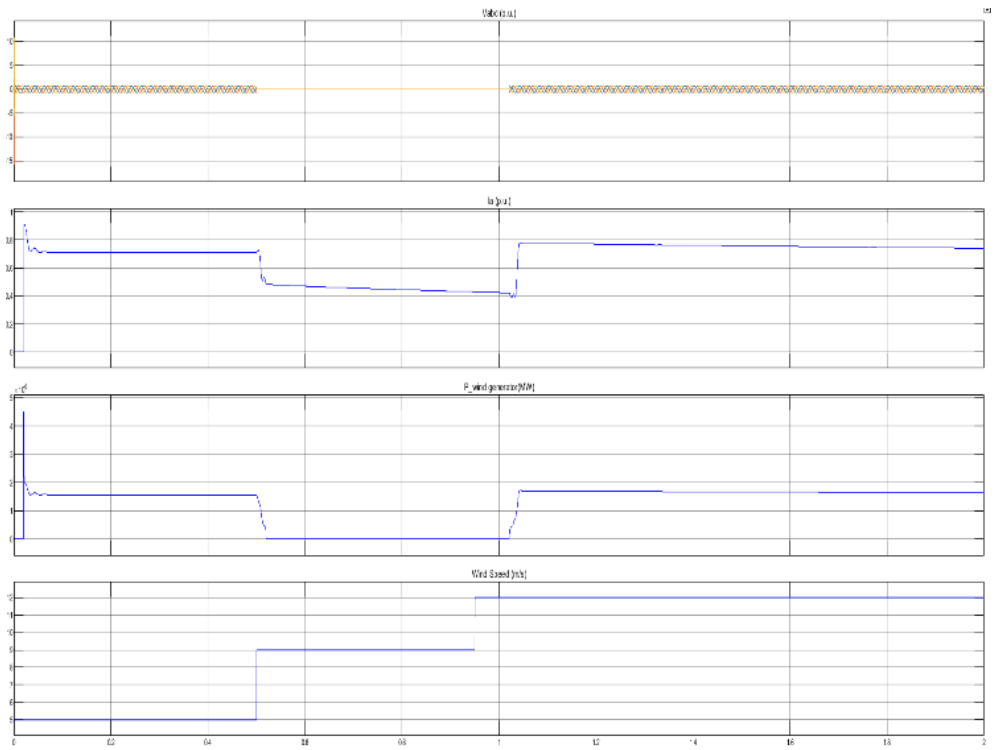

Fig7: The waveform of the wind generator bus with a reactive power of 25MVAr in the absence of a Static Synchronous Compensator (STATCOM) connection.

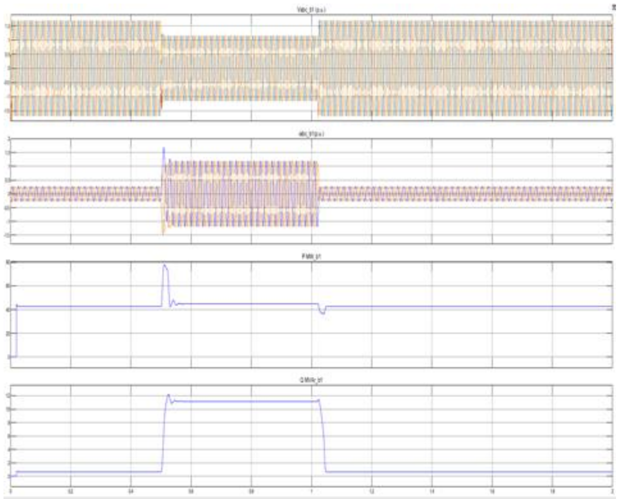

Fig 8: shows the waveform of the wind generator bus with a 25MVAr STATCOM connected.

VI. CONCLUSION

The comprehensive outcomes of the fault (LLLG) in the absence of STATCOM and the fault with STATCOM have been meticulously recorded and examined in the simulation, accompanied by appropriate reasoning. Considering this, the wind generator bus was analyzed in Figure 7, where measurements were conducted without the presence of a STATCOM. The waveform of the fault seen over the time interval from 1.0 second to 1.02 seconds. Following the occurrence of a fault clearing event, a subsequent period of voltage instability lasting around 1.1 seconds is seen, following which the voltage returns to a stable state. When the STATCOM is connected to the grid and obtains measurements from the wind generator (as shown in Figure 8), the system voltage experiences instability for about 1.028 seconds before returning to a stable state. The inclusion of a STATCOM in a power system has been shown to enhance transient voltage stability.

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