IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 16, Issue 3 Ser. II (May – June 2021), PP 01-8
www.iosrjournals.org

Power Quality Improvement Using Statcom In Grid Connected Wind Power

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Abstract
When the wind power is connected to an electric grid affects the power quality. The effects of the power quality measurements are-the active power, reactive power, variation of voltage, flicker, harmonics, and electrical behavior of switching operations. The installation of wind turbine with the grid causes power quality problems are determined by studying this paper. For this Static Compensator (Statcom) with a Battery energy storage system (BESS) at the point of common coupling to mitigate the power quality problems. The grid connected wind energy generation system for power quality improvement by using Statcom - control scheme is simulated using Matlab/Simulink in power system block set. This relives the main supply source from the reactive power demand of the load and the induction generator in this proposed scheme. The improvement in power quality on the grid has been presented here according to the guidelines specified in IEC-61400-21 standard (International Electro-technical Commission) provides some norms and measurements.
Keywords: *IEC-61400-21, power quality, wind power, Statcom*

Date of Submission: 25-05-2021 Date of Acceptance: 09-06-2021

I. Introduction

Wind energy is the most clean and natural source of energy. It is available in abundant on earth [1]. The wind is converted into the most suitable and useful form for production of energy. Wind power is energy that is created through the conversion of wind into forms that are more practically useful, such as electricity. Wind energy is currently supplying as much as 1% of the world's electricity use; however the power of wind energy could potentially supply as much as 20% of global electricity [2]. Wind energy is created through the use of Wind Turbines, or wind turbine towers. How much energy is produced from one wind turbine depends entirely on how large the turbine is. A large wind turbine will produce several hundred megawatts of electricity which is enough electricity to power several hundred homes. A smaller wind turbine is defined as one that provides 100 kW of electricity or less. These smaller turbines are used for homes or small businesses, or as a resource of backup for electricity. Today, wind turbines come in all forms and sizes, but they all function and are built in a very similar manner. Standard components of a wind turbine include [3-5]:

- Rotor – the blades with surfaces engineered with aerodynamics in mind. As the wind moves over these blades, the rotor will turn, and the generator in the turbine rotates and produces the electricity.
- Gearbox – the gearbox will match the speed of the rotor to the speed of the generator. The smallest wind turbines do not use a gearbox.
- Tail vane – this component will align the wind turbine with the wind direction.
- Tower – this component is used on horizontal turbines, and is where the turbine is mounted. Vertical turbines do exist, and these are generally built into the ground.
- Battery Station – the larger wind turbines are connected to a battery station which is the system that operates the turbine. Because a generator is used to run the turbine, battery power is necessary to run the generator. The batteries will be turned on and off with the turbine generator switch.

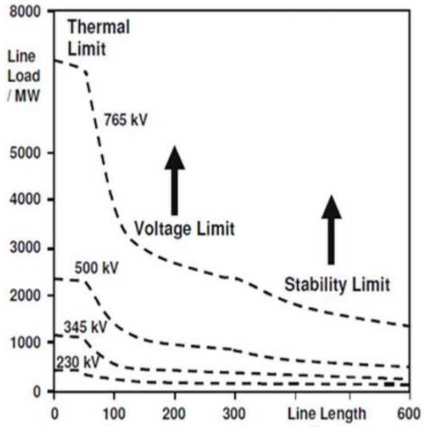

Fig 1: Operational limit of transmission line for different voltage levels [6]

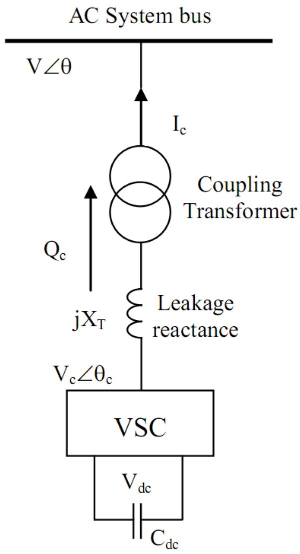

Fig 2: Basic model of Statcom [7, 10]

The Statcom is a shunt-connected device that is capable of generating and/ or absorbing reactive power. In these the output can be varied to control the specific parameters of an electric power system. Because of fast switching characteristics its response time is fast as compared to SVC [3]. Statcom acts as interlink between renewable resources and grid system and also for real power exchange between them. Statcom is an electronic device it has no inertia so it is more superior to the synchronous condenser. The Statcom has similar characteristics with the synchronous condenser. So it has better dynamics, a lower maintenance cost as well as investment cost.

Statcom consist of three parts a controller, a step up coupling transformer and a voltage source converter as shown in fig. 2. For high voltage system the leakage inductance from transformer can act as coupling reactors. Coupling inductor filters out the current harmonic components that are generated by the pulsating output voltage of power converter mainly.

Statcom acts as an inter-link between renewable energy resource and grid system. It also has the ability to exchange real power between the wind energy and load. When load requires reactive power Statcom takes active part in delivering the reactive power to the load. When load reactive power is more Statcom supplies the reactive power back to the grid. During light load there will be some losses in the system. The Statcom consists of a voltage source converter connected in shunt with the power system, and enables to control a leading or lagging reactive power by means of adjusting its AC voltage. The pulse width modulation (PWM) gate pulses for Statcom are generated by using hysteresis current control method. PWM when connected with converter will provide smooth current and low harmonics [2]. A Statcom based control technology for improving the power quality can manages the power level associates with the wind turbines. The Statcom control scheme for grid connected wind energy generation for power quality improvement has following objectives.

- Reactive power support only from Statcom to wind Generator and Load.
- Unity power factor at the source side.

II. Power quality Improvement issues

Variation in voltage: Voltage is directly proportional to real and reactive power variation. The variations of is classified as [8]:

- Long duration variation in voltage
- Voltage sag
- Voltage swells
- Short duration interruptions

Harmonics: harmonics occurs due to power electronics converters. The harmonics voltages and currents in the grid are acceptable to some limits. Those limits are discussed in as per the IEC-61400-36 guideline [4]. Rapid switching reduces the low order harmonics current but the high frequency current will be present in output.

Wind turbine location in power field: The installation of wind turbine highly affects the power quality. Its operation is influence by the structure of network installed.

Self-excitation of wind turbine generating station: Self excitation of wind turbine with an asynchronous generator takes place when the system is disconnected with the load. This problem arises when system is equipped with compensating capacitor. The capacitor provides reactive power compensation. Self-excitation has safety aspects and also balances real and reactive power [1].

III. Performance of statcom under load variations

The wind energy system is interlinked with grid having nonlinear load variation. It is also used to measure the performance of variation. When Statcom controller is ON, it starts to mitigate reactive demand in a load without changing any other load parameter. Thus Statcom can regulate the real power from the source.

- Voltage regulator: Statcom provides continuous voltage regulation to the grid system.
- Sag compensation: The source bus voltage drops from 1pu to 0.9 pu which represents there is heavy load or fault in the grid system. The Statcom respond to the voltage sag quickly and restore within 0.21s. The recovery speed is restricted by ramp of real power to avoid current distortion at transient [5]. The voltage ripple increases with the increase in reactive power and current magnitude.
- Power factor: It is defined as the ratio of real power flowing to the load to the apparent power in the circuit. The apparent power will be greater than the real power due to nonlinear load. Real power is capacity of performing work on that particular time and apparent power is the product of current and voltage to the circuit. It is dimensionless and lies between 0 to 1.
- Consequences of the issues: Voltage variations, harmonics, flicker causes the malfunctions of equipment's and these will leads to tripping of protection devices which can damaging the sensitive equipment's and finally it will degrades the power quality in the grid.

The Statcom has following objective for grid connected wind energy system for improving the power quality:

- Unity power factor
- Reactive power support fir grid and load
- Fast dynamic response using PI controller

One of the major issues that is concern in wind system is its dynamic stability on the power system [5]. Survey on enhancement of performance parameter of wind energy system using Flexible Alternating Current Transmission System (FACTS) devices:

- Sub synchronous resonance problem
- Voltage stability and Voltage security
- Transient stability
- Laudability and Reliability
- Control of wind
- Operation of wing

Some challenges faced by wind turbines when it is connected to weak grid are increased numbers and frequency of faults, grid abnormalities, voltage and frequency fluctuations that can trip relay. It can also suffer from generator heating.

IV. Grid coordination rule

The American Wind Energy Association (AWEA) led the effort in the United States for adoption of the grid code for the inter-connection of the wind plants to the utility system. The first grid code was focused on the distribution level, after the blackout in the United State in August 2003. The United State wind energy industry took a stand in developing its own grid code for contributing to a stable grid operation. The rules for realization of grid operation of wind generating system at the distribution net-work are defined as-per IEC-61400-21. The grid quality characteristics and limits are given for references that the customer and the utility grid may expect.

According to Energy-Economic Law, the operator of transmission grid is responsible for the organization and operation of interconnected system [6].

1) Voltage Rise: The voltage rise at the point of common coupling can be approximated as a function of maximum apparent power S_{max} of the turbine, the grid impedances R and X at the point of common coupling and the phase angle θ [7], given in (1).

$$\Delta u = \frac{S_{max} \cdot \left(R cos\theta - X \sin\theta \right)}{U^2} \qquad (1)$$

Where: Δu - voltage rise, S_{max} - apparent power, θ -phase difference, U - is the nominal voltage of grid. The limiting voltage rise value is < 2,5% [9].

2) Voltage Dips: The voltage dips is due to startup of wind turbine and it causes a sudden reduction of voltage. It is the relative % voltage change due to switching operation of wind turbine. The decrease of nominal voltage change is given in (2).

$$d = K_u \cdot \frac{S_n}{S_k} \qquad (2)$$

Where: d – is relative voltage change, S_n – rated apparent power, S_k – short circuit apparent power, K_u – sudden voltage reduction factor.

3) Flicker: The measurements are made for maximum number of specified switching operation of wind turbine with 10min period and 2hr period are specified, as given in (3).

$$P_{it} = C(\varphi_k) \frac{S_n}{S_k} \qquad (3)$$

Where: long term flicker, flicker coefficient calculated from Rayleigh distribution of the wind speed. The limiting value for flicker coefficient is about, for average time of 2hr [8].

4) Harmonics [9]: The harmonic distortion is assessed for variable speed turbine with a electronic power converter at the point of common connection. The total harmonic voltage distortion of voltage is given as in (4).

$$V_{THD} = \sqrt{\sum_{h=2}^{40} \frac{Vn^2}{V_1}}.100 \qquad (4)$$

Where: V_n is the n^{th} harmonic voltage and V_1 is the fundamental frequency 50Hz. The THD limit for distribution network is THD of current is given as in (5).

$$I_{THD} = \sqrt{\sum \frac{I_n}{I_1}}.100 \qquad (5)$$

Where I_n is the n^{th} harmonic current and $I_1$is the fundamental frequency (50) Hz. The THD of current and limit for distribution networks are ≤ 6.5% (110 kV; 35 kV; 22 kV; 10 kV; 6 kV and 0.4 kV) [9].

5) Grid Frequency: The grid frequency in Vietnam is specified in the range of 49.8 Hz – 50.2 Hz, for wind farm connection. The wind farm shall able to withstand change in frequency up to 0.5 Hz/s [9].

V. Topology for power quality Improvement

The Statcom based current control voltage source inverter injects the current into the system. To finish these objectives, the matrix voltages are sensed. They are synchronized in creating the current summon for the inverter. When the proposed framework associated framework is executed for force quality change at purpose of normal coupling. The framework comprises of wind vitality era framework and battery vitality stockpiling framework with Statcom.

Wind Energy Generating System: In this setup, wind generation is taking into account with constant speed topologies with pitch control turbine [8]. Therefore, the induction generator is utilized as a part of the proposed plan as a result of its effortlessness, it does not oblige a different field circuit, it can acknowledge consistent and variable loads, and has common protection against short out. The accessible force of wind vitality framework is displayed as under in (6).

$$P_{wind} = 0,5.\rho.A V_{wind}^3 \qquad (6)$$

Where ρ (kg/m) is the air thickness and a (m^2) is the range cleared out by turbine blade sharp edge, Wind is the wind speed in m/s. It is unrealistic to concentrate all of wind, hence it separates a small amount of force in wind, called power coefficient C_P of the wind turbine, and is given in (7).

$$P_{mech} = C_p.P_{wind} \qquad (7)$$

Where C_P is the force coefficient, relies on upon sort and working state of wind turbine. This coefficient can be express as an element of tip rate proportion and pitch point. The mechanical force deliver by wind turbine is given in (8).

$$P_{mech} = 0,5.\rho\pi R^2.V_{wind}^3.C_p \qquad (8)$$

Where R is the sweep of the turbine blade sharp edge (m).

VI. Result and discussion

The Statcom based current control voltage source inverter injects the current into the grid in such a way that the source current is harmonic free and their phase-angle with respect to source voltage has a desired value. The injected current will cancel out the reactive part and harmonic part of the load and induction generator current, thus it improves the power factor and the power quality. To accomplish these goals, the grid voltages are sensed and are synchronized ingenerating the current command for the inverter. The proposed grid connected system is implemented for power quality improvement at point of common coupling (PCC) – fig. 3.

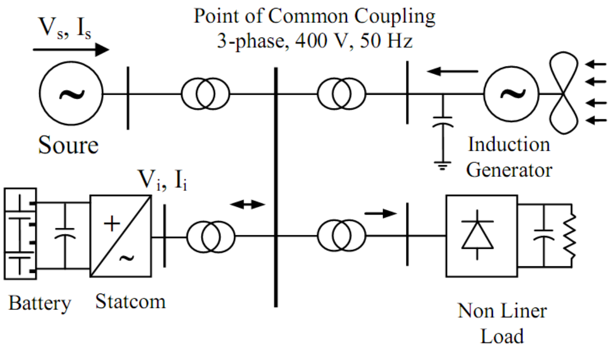

Fig 3: Grid connected system for power quality improvement

1) Bess-Statcom

The battery energy system is used for storing energy for voltage regulation. BESS maintains dc voltage constant which is best for Statcom as it inject or absorb reactive power for stability. It operating time is fast. When ever there is fluctuation in the system BESS level the power fluctuation by discharging and charging. BESS is connected in parallel with Statcom. Three phase voltage source inverter with capacitance DC link are connected at a point of common coupling in Statcom. It injects current compensation of variable frequency and magnitude.

2) System operation

The shunt connected Statcom along with BESS is connected with nonlinear load. The compensator output varies with controller strategy to maintain grid norms. The current controller defines the operation of Statcom. Statcom using bipolar transistor gives reactive power support to generator and also to nonlinear load – fig.4.

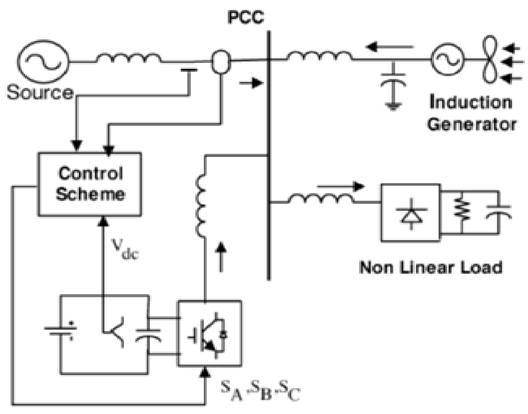

Fig 4: Scheme in grid system

3) Control Scheme

The controlled scheme injects current using bang-bang controller in which hysteresis current control technique is used where the control system gives correct switching for Statcom. It keeps signal between the boundaries of hysteresis area [10] – fig.5.

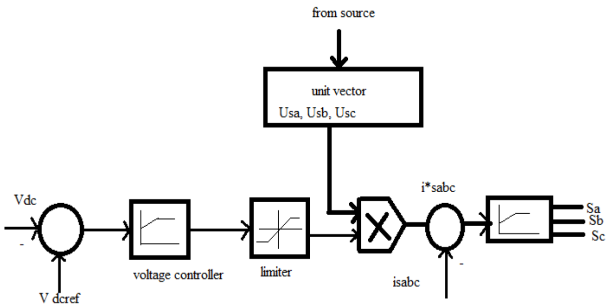

Fig 5: Control scheme system

4) Grid Synchronization

The RMS voltage source is calculated in the three phase balance system at sampling frequency from V_{sa} V_{sb}, V_{sc} are phase voltages. Sampled peak voltages shown in (9).

$$V_{sm} = \sqrt{\left[\frac{2}{3}\left(V_{sa}^2 + V_{sb}^2 + V_{sc}^2\right)\right]} \quad (9)$$

In-phase unit vectors are obtained from RMS values and AC source and phase voltage of unit vector as shown in (10).

$$u_{sa} = \frac{V_{sa}}{V_{sm}}; \quad u_{sb} = \frac{V_{sb}}{V_{sm}}; \quad u_{sc} = \frac{V_{sc}}{V_{sm}} \quad (10)$$

In-phase reference currents are obtained using in-phase unit voltage as, in (11).

$$i_{sa}^* = I.u_{sa}; \quad i_{sb}^* = I.u_{sb}; \quad i_{sc}^* = I.u_{sc} \quad (11)$$

Where I is filtered out. This shows that source current is sinusoidal. The important function in grid is unit vector for Statcom synchronization. This method is simple as compared to others.

5) Bang – Bang current controller

This controller uses current control scheme where the reference current is generated and actual current is detected by current sensor. They are subtracted for obtaining error. Therefore, switching signals for Insulated-gate bipolar transistor (IGBT) of Statcom is obtained [10].

VII. Simulation

The control scheme is simulated using Matlab/Simulink. The performance of system under dynamic condition is also given.

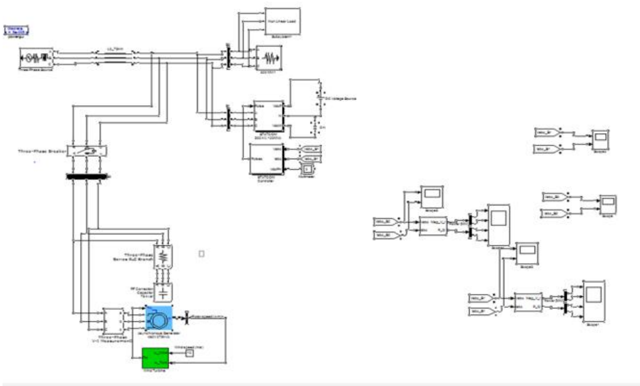

Fig 6: Matlab simulation of Wind energy system integrated with grid using Statcom

- Voltage Source Current Control - Inverter Operation. The distortion caused by nonlinear load and wind generator is cancel out when three phase current is injected. The three phase inverter is connected through transformer to the grid. The band switching improves the current quality. The choice of current band depends on interfacing transformer impedance and on operating voltage. Inverter provides the compensated current and reactive power to nonlinear load. Batteries provide real power which is also supported by controller – fig 6.
- Statcom – Performance under load Variations

The grid is integrated with wind energy system having nonlinear and linear load. The system performance is measured by switching Statcom in the system. Statcom responds according to the change in load. When Statcom is ON it starts to mitigate for harmonic current and reactive power demand. With the step change in load Statcom compensate. The result of source current and load is shown in figures: 7, 8, 9, 10.

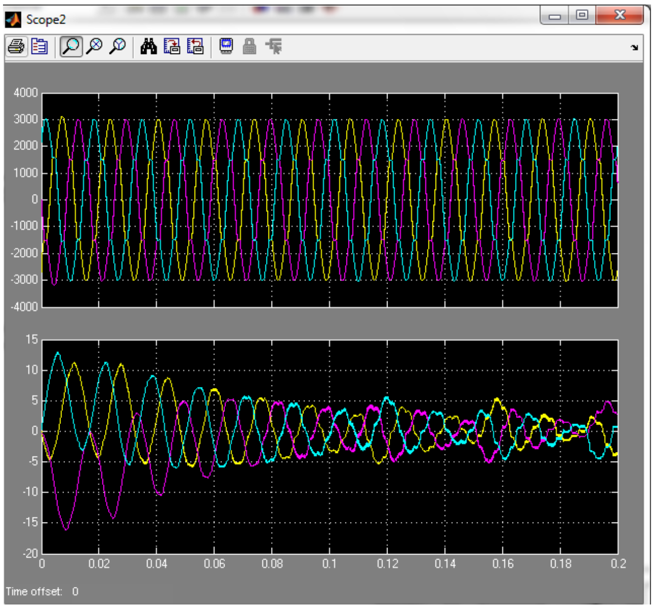

Fig 7: Source voltage and current

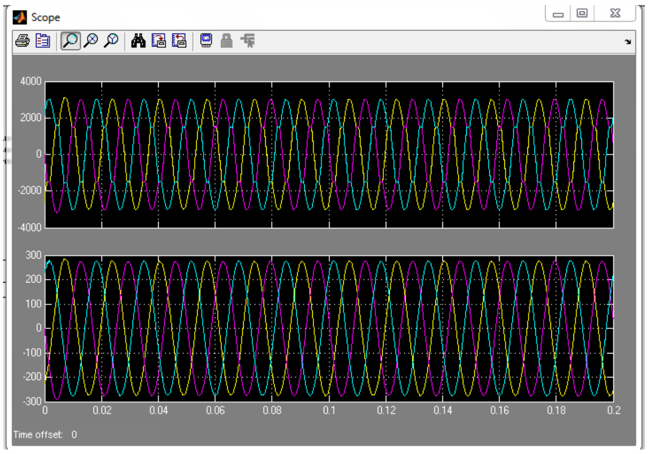

Fig 8: Statcom voltage and current

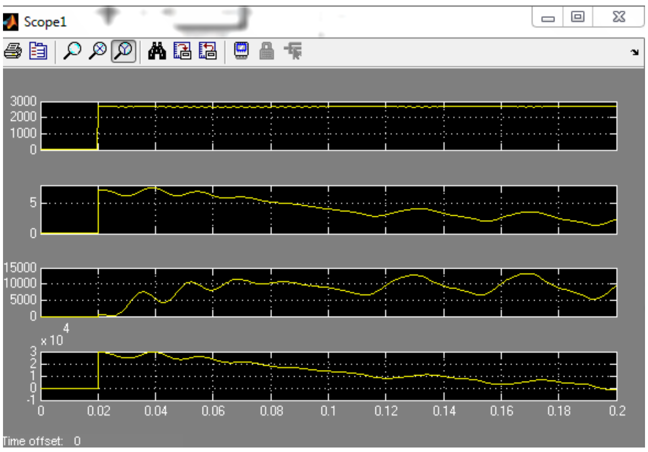

Fig 9: Voltage, current, active and reactive power magnitude without Statcom

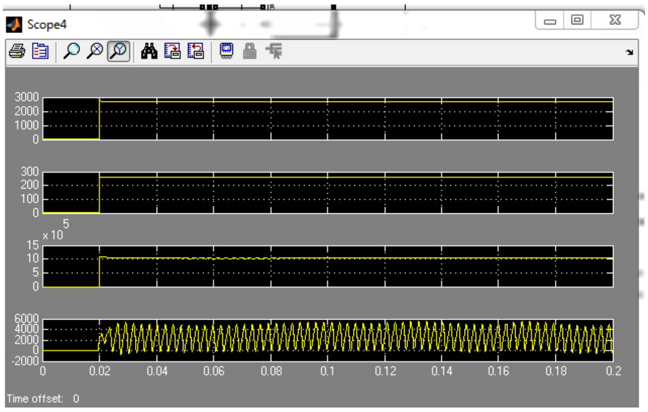

Fig 10: Voltage, current, active and reactive power magnitude with Statcom

VIII. Conclusion

In this research the renewable energy that is wind energy is used for power production. By using Statcom the power quality of in grid connected system is improved having nonlinear load. The power quality issues are described briefly which is to be improved. The scheme fulfills the norms as per the IEC standard 61400-21. When the wind farm is connected to weak power grid, during normal condition it is necessary to provide efficient power control and enhance supports when fault occurs. When voltage instability problems occur in power system the reactive power is not achieved during fault and heavy load conditions.

Compensation of reactive power is most important for the power quality improvement and for this Statcom is used. Statcom is reliable and provide better voltage characteristics during fault. It also improves the dynamic performance of the grid and also responds to changes of load in the system. Statcom maintain the source voltage and current in phase. It also supplies reactive power with the help of battery energy system which shows outstanding performance along with improved power factor.

Here Statcom is connected with the grid connected wind energy system. The Statcom controlled scheme is used for improving the power factor, voltage and current. Here the input value is set for wind i.e. 10 as there will be any change in the wind speed the feedback is given to the Statcom which will compensate the desired voltage or current required by the system which improves the power factor the system without any losses. Therefore, the overall efficiency of the system will increase.

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Cuong Nguyen Cong. "Power Quality Improvement Using Statcom In Grid Connected Wind Power." *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)*, 16(3), (2021): pp. 01-08.