Mitigation of Voltage Dip and Swell Faults in Wind Energy Conversion Systems

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Abstract - *Wind Energy Conversion Systems (WECS) are gaining popularity due to its low-maintenance functioning. WECS must stay up for at least a brief amount of time to provide dependability and stability even in the case of a network outage, according to network standards. In the literature, many strategies for implementing low-voltage riding (LVRT) have been presented. This paper examines different LVRT implementation strategies for synchronous computer-based, networked WECS across a fully assessed cascade system. converts. The inverter is operated from the machine side by employing a field-oriented control approach to drive the generator at the appropriate speed in order to harvest the greatest power from the wind turbine. To accomplish distinct management of active and reactive power, the mains transformer employs a voltage-oriented control algorithm. The LVRT capabilities of the system .*

Key Words: **wind turbines1, Voltage swells2, Voltage dips3.**

1. INTRODUCTION

As the world continues to rapidly develop and demand more energy, the negative environmental impacts of traditional fossil fuels as well as their limited reserves have become increasingly evident. To combat this, renewable energy sources like wind energy have gained significant global attention.Wind energy is pollution-free and widely distributed, making it an important renewable energy source in the transition to a low-carbon future. In 2020, 93 GW of new wind power installations were built, bringing the total installed capacity to 743 GW worldwide. China currently has the largest proportion of global wind energy capacity at 38.5%, followed by the United States at 16.1% [1]. in light of the need to combat climate change and reduce carbon dioxide emissions, renewable energy is becoming increasingly attractive. Wind energy, in particular, has many environmental ,economic, and social advantages. Policymakers, researchers, and stakeholders should take note of its potential contribution to the transition to a low-carbon future Looking forward [2], wind power is projected to continue growing rapidly, and could even become the primary source of global energy by 2050. Achieving this goal will require significant restructuring of regional and global energy systems, as well as strategic initiatives to overcome remaining obstacles. Ultimately, generating affordable and sustainable electricity will be critical to the success of this transformation [3].

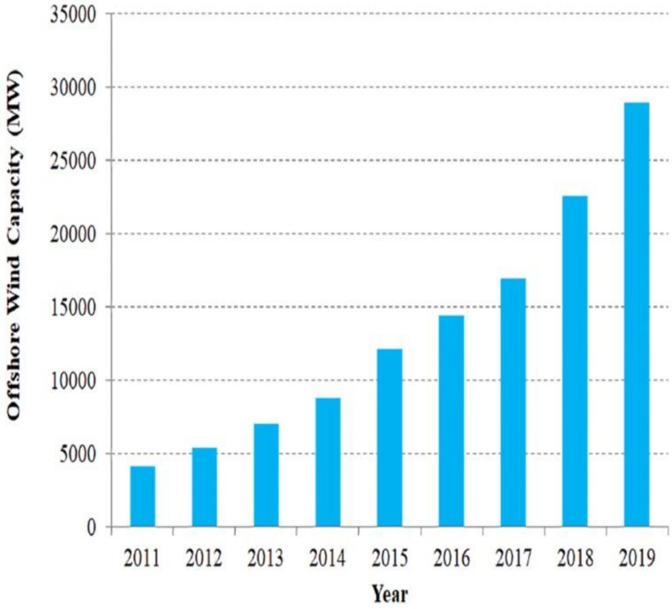

Chart -1: Global cumulative wind power capacity from 2011 to 2019

1.1 WPP at Constant Speed

The generator in a constant speed WPP is electrically locked to the grid to which its stator is linked. Regardless matter how quickly the wind blows, the generator will always run at the same pace. The constant speed of the rotor is determined by the grid frequency, the number of pole pairs in the generator, and the gear ratio .In this configuration, the rotor does not revolve faster than the synchronous speed. Constant speed wind turbines (CSWT) are normally stall controlled and employ induction generators to generate power. The three-phase rotor windings of the generator are directly linked to the grid, while the stator windings give excitation to the generator. The synchronous speed

1.2 WPP Variable Speed

Variable speed WPP allows the generator to be run at changing speeds in accordance with the wind. A power electronic converter (PEC) is used in this system to convert the generator's alternating current output to direct current and vice versa eventually making it grid-friendly AC. Stall, pitch, and active-stall regulation are all options for variable-speed wind turbines (VSWT). In stall-regulated WPP, the wind turbine (WT) blades are securely fastened to the hub at a certain angle, but in pitch-regulated WPP, the blade's angle of attack is changed to minimise torque. This is accomplished by shifting the direction, or pitch, of the blade, changing its aerodynamic efficiency. In active WPP, however, the rotation of

2. Wind Energy System:

The use of Wind Energy Conversion Systems (WECS) has become increasingly important as a clean and sustainable source of electricity, free from the issues associated with fossil fuels[5]. The primary component of WECS is the wind turbine (WT), which converts the kinetic energy from the wind to mechanical energy that can power electrical generators. WTs can be configured as either horizontal (HAWT) or vertical (VAWT) axis system[6].

2.1. Horizontal Axis Wind Turbine

HAWT, which has its electrical generator located at the top of the tower, produces maximum energy thanks to its tall tower base. The turbine blades' variable blade pitch allows for maximum energy production. Although HAWT's efficiency is relatively high, tower construction costs are higher, and the tower's height can interfere with radar installations. Additional control mechanisms are required to control the direction of the turbine blades.[7].

2.2. Vertical Axis Wind Turbine

VAWTs rotate around a vertically arranged shaft, offering the advantage of not requiring an additional controller as the wind is always perpendicular to the blades. Their maintenance process is easier than HAWTs and they produce less noise due to their lower speed. VAWTs can be placed in various locations such as highways and roofs. However, they are less efficient than HAWTs due to their shorter towers, resulting in slower rotation and lower power output.[8].

3. WECS Topologies and Generator

Different Wind Energy Conversion Systems (WECS) are established for various power rates, ranging from a few hundred kilowatts to several megawatts. This leads to various WECS designs based on different criteria, such as fixed or variable speed wind turbines, small or large wind turbines, and grid-connected wind turbines. While synchronous generators have been traditionally used for power generation, induction generators (IGs) are increasingly being used due to their cost-effectiveness, brushless and rugged construction, and self-protection against short-circuited faults. Additionally, IGs have adequate dynamic response and can produce electric power at different speeds, enabling their use in isolated areas where network expansion is not feasible. When used in conjunction with synchronous generators, IGs meet the growing demand for local power[9],[10].

3.1. Induction Generator.

he use of induction machines has become more popular due to recent advances in power electronics. Induction generators (IGs)are commonly used in fixed speed wind turbines but require a capacitor bank to supply reactive power. For off-grid applications with constant loads, a single capacitor can be used for self-excitation. To control IGs in variable speed wind turbines, back-to-back PWM inverters are used. The inverter on the IG side controls machine torque and the inverter on the grid side controls reactive power at the coupling point. Thyristor controlled reactor static volt-ampere reactive compensators can also be used to control voltage in variable speed wind turbines.[11].

3.2. Slip Ring Induction Generator.

DFIG, which is an advanced version of SRIG, relies on direct coupling of stator with the system via a slip ring and converter feeding. Recent focus has been on sub- and super-synchronous cascade drives using cycloconverters on the rotor side. Full AC-DC-AC is the current alternative which offers around ±33% working speed range. The rated power of the converter should be around 30% of the rated generator for ±30% speed variation from synchronous speed[12]. DFIG is a potential rival of wind energy generator system and eliminates the need for reactive power compensation by using the grid side converter and DC capacitor as a static compensator.[12].

3.3. Synchronous Generator.

The power generation industry uses large SGs for their variable reactive power production, which helps to control voltage. The SG of a wind turbine is connected to the grid through back-to-back PWM voltage source inverters. The grid side inverter manages the transfer of real and reactive power to the grid, while the generator side converter regulates the electromagnetic torque. Using multiple SGs with a large diameter synchronous generator ring eliminates the need for a gearbox, which reduces weight and avoids proximity issues with the rotor winding.[13].

4-Types of power quality problems

4.1.Under voltage

Under voltage could occur due to high voltage drop, low distribution voltage and/or heavy loads. The premature. failure and overheating of motors are the symptoms of under voltage. The value of under voltage is less than or .equal to 90% of nominal value with a duration of more than one minute.

4.2.Overvoltage

Overvoltage can be caused from high distribution voltage or light loads. Symptoms include premature failure of electronic and printed circuit boards. The value of overvoltage is equal to or above 110% of the nominal value and has duration of more than one minute.

4.3.Voltage sag

Voltage sag results from weather and utility equipment problems. Problem of voltage sag for industry is the malfunction of devices which may result in huge financial losses. Voltage sag is a very deep voltage drop with a short duration from 0.5 cycles to 60 seconds.

4.4.Voltage swell

Voltage swell is caused by energizing a capacitor bank or a sudden shut down of a very large load. Voltage swell is a very high voltage rise with a very short duration from 0.5 cycles to 60 seconds.

4.5. Harmonics

Harmonics are caused by arcs, saturated transformers ,rectifiers, motor drives and electronic loads. Symptoms include over heating or malfunction of devices.According to IEEE standard IEEE 519-2014 [14], theTHD limits is 5% for 1 kV through 69 kV systems.

4.6.Voltage flicker

Flicker is defined as "An impression of unsteadiness of visual sensation induced by a light stimulus, whose luminance or spectral distribution fluctuates with time" Voltage flicker is caused by electric arc furnaces,ovens, any large-draw varying load and wind turbine generators. Generally, it cases annoying changes in lighting level. rectifiers, motor drives and electronic loads. Symptoms include over heating or malfunction of devices. According to IEEE standard IEEE 519-2014 [14] The THD limits is 5% for 1 kV through 69 kV systems.

The effect of wind energy on the quality of electrical power:

Increasing the integration of wind energy into the grid can impact the power system's quality due to the variations in wind power generation, which poses challenges for power system planners and operators. These challenges include the security, stability, and quality of wind power.[2] To address these issues, various strategies have been proposed to improve grid integrity, allowing for flexible power system operation and smooth wind power integration [3].the THD limits is 5% for 1 kV through 69 kV systems.

5-Fluctuations in voltage in wind power plants connected to the grid

Voltage variations in grid-connected wind power plants (WPPs) can occur in the form of voltage sag, voltage swell, transient, flicker, or harmonic distortion. Voltage sag refers to a sudden reduction in grid potential, while voltage swell refers to a rapid increase in the nominal value of AC voltage. These variations can last for microseconds to a few minutes.

In a grid-connected WPP, the voltage variations are influenced by the impedance of the transmission line, cable, and transformer in the feeding grid. Kirchhoff's Voltage Law can be applied to analyze the voltage at different points in the system. When the WT generates power to meet the load demand, no current is drawn from the grid, resulting in equal voltages at the grid side and the WPP connection point. However, if the WT generates more or less power than demanded, the grid side voltage will be less or greater than the voltage at the connection point, respectively.

5.1.voltage sag

Also known as a voltage dip, refers to a sudden decrease in the electrical potential of the grid, usually between 10% and 90% of its normal value, followed by a quick return to normal. This typically lasts for a duration of 10 milliseconds to 60 seconds. Voltage sags can occur when large wind turbines are started up simultaneously, causing a high current draw for a brief period. Similarly, voltage dips can occur during the startup of large motors or due to grid short circuit, which is noticeable when lights flicker on and off momentarily. The decrease in nominal voltage, known as voltage dip, at the point of interconnection (POI) of the wind turbine can be calculated using the voltage change factor, Ku, the rated power of the wind turbine, Sn, and the short circuit apparent power of the grid, Sk. The acceptable limit for voltage dip is usually ≤ 3%.Voltage dips can result in the disconnection of sensitive loads and equipment failure. To mitigate the impact of voltage dips, proper arrangements must be made for the startup of wind turbines. Alternatively, the current and acceleration of the turbines can be reduced by adjusting the aerodynamic blade pitch.

5.2. Voltage swell

Voltage swell is a sudden increase in the AC voltage that lasts for less than one minute. It typically lasts between 30 to 60 seconds and has a threshold limit of 1.1 to 1.8 p.u. The minimum duration for a voltage swell is 10ms. Voltage swell can occur in grid connected wind power plants due to inrush currents or when large capacity wind turbines are shut down. Other causes include grid lightning strikes, earth faults on another phase, and incorrect substation settings. The voltage swell at the wind point of interconnection (POI) is determined by the turbine's maximum apparent power, grid resistance and reactance, and nominal phase to neutral voltage. The limiting value for voltage rise is less than 2%. Voltage swell can cause equipment disconnection, insulation aging, and harm to inadequately designed equipment. Measures to prevent voltage swell include using a soft starter to reduce inrush current during start-up and using transformers with tap changers. Large loads can also be connected at the point of common coupling to mitigate voltage swell.

6-LVRT METHODS

Whenever a line-side voltage sag occurs, the DC bus voltage rises begins to rise due to the power imbalance that exists between the mgenerated and transmitted power. To give him relief four techniques are proposed here. This LVRT techniques are applicable to all WECS with full power converters such as PMSG Wind or SyRM energy systems. Power supply from MSC to DC Association can be restricted using one of four techniques: MSC modulation index

-Modulation Index Control of the MSC.

- Unloading via machine-side control.

-crowbar protection.

6.1. MSC modulation index control.

This triple method uses the multiplier MSC modulation signals Va, Vb and Vc before generating sinusoidal PWM signals until the intermediate circuit voltage reaches its maximum value again. But when the DC bus voltage exceeds the limit, the multiplier drops to lower values and goes to zero quickly, reducing the transformer output to zero. The transformer closes and prevents the generator terminals from flowing into the DC bus, effectively limiting the DC bus voltage. The main drawback of this scheme is the high transient current in the generator during the generating stations across the circuit

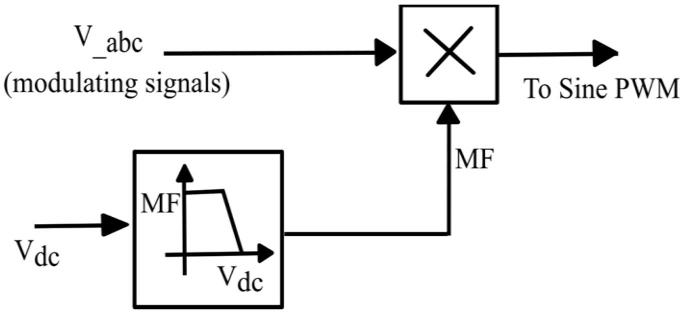

Fig -1: Modulation Index Control of the MSC.

6.2. Unloading via machine-side control

The variable "MF" (which depends on the direct current) is multiplied by the generator's algorithm speed. "MF" decreases rapidly to zero when the voltage in the direct current circuit exceeds the maximum limit. The PI control loop determines the machine's torque. Therefore, if the value of "MF" drops to zero, the torque signal is adjusted to zero, reducing the motor's torque to zero and thus generating zero performance value for the machine. This way, the generator current remains locked in the circuit with fewer disturbances associated with low voltage conditions and balancing the control model. When the electrical torque decreases to zero, the increase in generator speed becomes more evident.

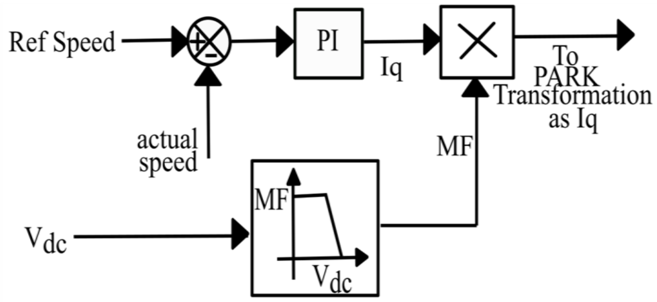

Fig –2:. Unloading via machine-side control

6.3.crowbar protection.

The generator speed increase is higher.

This is the traditional method used in most wind power conversion systems (WECS). It involves the use of a chopper circuit and a resistor connected to a DC coupler capacitor. Under normal circumstances, the chopper circuit does not receive a gate pulse. However, if the network encounters a low voltage, the DC bus voltage rises above a certain threshold and activates the controller PI and this generates a non-zero signal, allowing gate pulses to be generated for the chopper circuit. This method ensures that the DC bus voltage remains within safe limits by dissipating excess power in the lever bar resistance. One disadvantage of this method is that it requires a resistance of the same rating as the generator, wasting all the power generated.

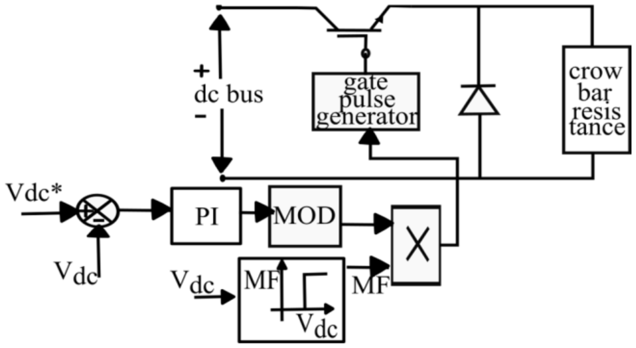

Fig –3: Crowbar protection scheme

CONCLUSION

The paper explores the effect of voltage drop and voltage amplification on the power quality of the connected network.

Results reveal that voltage drops can lead to sensitive load shedding, failure of system functions, system crashes, data loss, and complete system shutdown. By contrast, voltage swells can lead to equipment disconnects, disrupted downtime, damage to equipment, or reduced lifespan. Due to the unique behavior of wind power plants (WPPs) compared to conventional sources, careful planning is necessary to ensure WPPs are integrated into the grid. Networked WPPs , are expected to meet certain network code requirements, such as fault riding (FRT) or low voltage riding across power (LVRT), power quality control, frequency control, voltage control, active and reactive control of power at the point of interconnection with the network . WPPs with LVRT capability can withstand electrical disturbances on transmission lines and remain connected to the grid network despite such disturbances.

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