POWER QUALITY IMPROVEMENT IN A GRID CONNECTED WIND ENERGY CONVERSION SYSTEM USING DYNAMIC VOLTAGE RESTORER

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***Abstract*—The mitigation of power quality disturbances in grid connected wind energy conversion system using dynamic voltage restorer will be discussed in this paper. Wind power injection into an electrical grid will be also affects the power quality. In wind turbines particularly of induction type can draw great amount of reactive power from the grid. The DVR is installed between the source voltage and critical or sensitive load. The configuration of DVR can be proposed by using PI controller. To minimize the reactive power exchange between grid and wind generators and mitigate the power quality disturbance the reactive power can be injected to the grid by using DVR. The simulation model of the system will be developed and result will be obtained by MATLAB/SIMULINK software.**

***Keywords*—Dynamic Voltage Restorer (DVR), voltage sags, voltage swells, custom power, power quality.**

I. INTRODUCTION

Wide application of power electronic based equipment has resulted in a serious impact on the nature of electric power supply. Smooth uninterrupted sinusoidal voltage at desired magnitude and frequency should always be provided to the consumers. On the other hand consumers should draw sinusoidal current. Efforts are being made by many researchers for the effective improvement of power quality. DVR is considered as the solution to the problems arising due to power quality. It is adequate enough to take care of supply voltage disturbances like voltage sag/swells, voltage flickers, load reactive power as well as voltage and current harmonics. The need to integrate the renewable energy like wind energy into power system is to make it promising to minimize the environmental impact on conventional plant [1]. The integration of wind energy into the power system presents has a technical challenges and that requires consideration of voltage regulation, stability, power quality issues. Power quality is considered as an important customer-focused measure and is greatly affected by the distribution and transmission network operation. The issue of power quality is of great importance to the wind turbine [2]. There has been a widespread growth and rapid development in the exploitation of wind energy in recent days. Every units are assumed to be of large capacity up to 2 MW, supplying into distribution network, particularly with nearby associated customers. [3]. All over the world more than 28 000 wind generating turbine are successfully operating today. In the fixed-speed or constant speed wind turbine operation, all the fluctuations in the wind speed are seen to be transmitted as fluctuations in the mechanical torque, electrical power on the grid and leads to large voltage fluctuations. During normal operation condition, wind turbine yields a continuous variable output power. These power variations are primarily caused by the consequence of turbulence, wind shear, tower-shadow and of control system in the power system. Thus, the network must be able to for such fluctuations. The power quality issues can be viewed such as voltage sag, swells, flickers, harmonics etc with respect to the wind generation, transmission and distribution networks,. However the wind generator produces disturbances into the distribution network. The simplest method of operating a wind generating system is to use the induction generator connected directly to the grid. The induction generator has advantages of cost effectiveness and robustness. However induction generators need reactive power for magnetization purpose. When the active power generated by an induction generator is varied due to wind, then the absorbed reactive power and terminal voltage of an induction generator can be significantly affected. A appropriate control method in wind energy generation system is required under normal operating condition to permit the proper control over the active power generation. In the event of increasing grid disturbance, a battery energy storage system (BESS) for wind energy generating system is generally essential to compensate the fluctuation generated by wind turbine.

A control technology based on DVR has been proposed for improving the power quality which can technically manages the power level associating with the commercial wind turbines.

The proposed DVR control scheme for grid connected wind energy generation for power quality improvement has following objectives.

• Unity power factor to be maintained at the source side.

• Reactive power support only from DVR to wind Generator and Load.

• Simple bang-bang controller for DVR to achieve fast dynamic response.

II. POWER QUALITY

The phrase electric power quality generally refers to maintaining a near sinusoidal power distribution bus voltage at rated magnitude and frequency. Also the energy supplied to a customer must be uninterrupted from the reliability point of view.

Power Quality Terms and Definitions:

- Transients.
- Short duration voltage variations.
- Long duration voltage variations.
- Voltage imbalance.
- Waveform distortions.
- Voltage fluctuations.
- Power frequency variations.

III. GRID COORDINATION RULE

The American Wind Energy Association (AWEA) has taken effort in the united state for implementation of the grid code to the utility system for the interconnection of the wind plants. After the blackout in the United State in August 2003 the first grid code was focused on the distribution level,. The United State wind energy industry took a stand in developing their own grid code for contributing to a stable grid operation[4]. The rules for realization of grid operation of wind generating system for the distribution networks are defined as-per IEC-61400-21. According to Energy-Economic Law, the operator of transmission grid is in charge for the organization and proper operation of interconnected system [5].

A. VOLTAGE RISE (U)

The voltage rise at the point of common coupling (PCC) can be approximated as a function of maximum apparent power of the turbine, the grid impedances R and X at the PCC and the phase angle Φ [6] given in (1)

$$\Delta u = S_{\max}(R\cos\Phi - X\sin\Phi)/U^2$$

Where Δu— Voltage rise, $S_{\max}$— Maximum Apparent power, Φ— Phase difference, U— Nominal voltage of grid. The Limiting voltage rise value is normally $< 2\%$.

B. VOLTAGE DIPS (D)

The voltage dips is mainly due to start up of wind turbine and it causes a rapid reduction of voltage. It is the relative % voltage change due to the wind turbines switching operation. The decrease of nominal voltage change is given in (2).

$$d = K_u \frac{S_n}{S_K}$$

Where d - Relative voltage change, S_n Rated apparent power, S_K Short circuit apparent power, and K_u sudden voltage reduction factor. The acceptable voltage dips limiting value is $\leq 3\%$.

C. FLICKER

The measurements has been made for maximum number of specified switching operation of wind turbine with 10-min period and 2-h period are specified, as given in (3) The Limiting Value for flicker coefficient is about ≤ 0.4, for average time of 2 h [7].

$$p_{it} = C(\Psi_K)\frac{S_n}{S_K}$$

Where p_{it} _ Long term flicker. $C(\Psi_K)$—Flicker coefficient calculated from Rayleigh distribution of the wind speed.

D. HARMONICS

The harmonic distortion is evaluated for variable speed turbine with an electronic power converter at the point of common coupling [8]. The total harmonic distortion of voltage is given as in (4):

$$V_{THD} = \sqrt{\sum_{h=2}^{40}\frac{V_n^2}{V_1}100}$$

Where V_n is nth harmonic voltage and V_1 is the fundamental frequency (50) Hz. The THD limit for 132 KV is $\% < 3$.

THD of current I_{THD} is given as in (5)

$$I_{THD} = \sqrt{\sum\frac{I_n}{I_1}100}$$

Where I_n is nth harmonic current and I_1- the fundamental frequency (50) Hz. The THD of current and limit for 132 KV is $< 2.5\%$.

E. GRID FREQUENCY

The grid frequency in India is specified in the range of 47.5–51.5 Hz, for wind farm connection. The wind farm shall able to withstand change in frequency up to 0.5 Hz/s [8].

IV. DYNAMIC VOLTAGE RESTORER

At first the DVR was installed in North America in 1996 - a 12.47 kV system located in Anderson, South Carolina. Dynamic voltage restorer is a static VAR machine that has applications in a variety of transmission and distribution systems. DVR is a series compensation device, which protects sensitive electric load from power quality problems through power electronic controllers. The DVR have been applied to protect critical loads in utilities, semiconductor and food processing. Now the dynamic voltage restorer is one of the most effective Power quality devices in solving voltage sag problems.

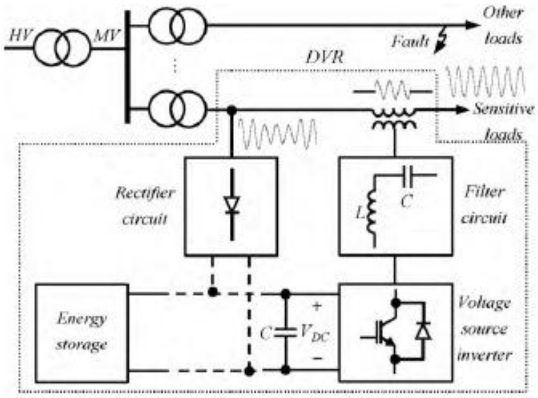

Figure 1 Dynamic voltage restorer (DVR)

The working principle of the DVR is to inject a voltage of required magnitude and frequency. Then it can restore the load side voltage with desired amplitude and waveform even when the disturbance will occur on the line. In general, DVR employs an insulated-gate bipolar transistor (**IGBT**) power electronic switches in a pulse width modulated (PWM) inverter. Dynamic Voltage Restorer has a capable of generating or absorbing controllable real and reactive power at the load side independently. Dynamic voltage restorer is said to be a series connected device which maintains a constant RMS voltage across a sensitive load [9]. The structure of DVR is shown in figure 1. The DVR consists of:

A. VOLTAGE SOURCE CONVERTER (VSC)

Voltage source converter converts the dc voltage from the energy storage device to a controllable three phase ac voltage. The inverter switches are normally operates using a sinusoidal Pulse Width Modulation scheme.

B. INJECTION TRANSFORMER

Injection transformers used in the DVR. It plays an important role in ensuring the maximum reliability and effectiveness of the restoration method. It is connected in series with the distribution feeder.

C. PASSIVE FILTERS

Passive Filters are always fixed at the high voltage side of the Dynamic Voltage Restorer to filter the harmonics. The filters at the inverter side which introduces phase angle shift and it can disrupt the control algorithm.

D. ENERGY STORAGE DEVICE/ CONTROL SYSTEM

Some basic examples of energy storage devices are batteries, dc capacitors, inductors and flywheels diodes. The capacity of energy storage device creates big impact on the compensation capability of the system. Compensation of real power is important when large voltage sag occurs.

V. PROPORTIONAL-INTEGRAL (PI) CONTROLLER

To mitigate the voltage sags in the test system of each compensation technique and to compensate the voltage sags in practical application. For this compensation discrete PWM-based control scheme is used, with reference to DVR.

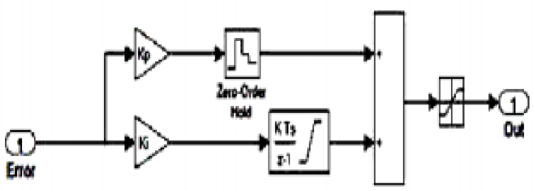

Figure 2 Discrete PI Controller

The major role of this control method is to maintain constant voltage magnitude at the sensitive load point, under the system disturbance. The discrete PI controller will be shown in figure 2.

This will derives the system to be controlled with a weighted sum of the error and integral of that value. The proportional response can be adjusted by multiplying the error by proportional gain (k_p). The contribution from integral term is proportional to both error duration and the error magnitude at first the proportional plus integral controller is called as PI controller. It has two gain constants which includes the proportional gain k_p and integral gain k_i. The proportional term gives the output value which is proportional to the error value of the current. The integral term contributes to both the magnitude and duration of error. The response based on the error could be adjusted by multiplying the error with gain values. From the Fig it is seen that the signals from the phase locked loop is fetched with the abc to dq0 transformation via a selector switch to the controller. After relevant completion of the process the signals are then transformed from dq0 to abc which is the acceptable voltage format.

When the voltage sag or swell has occurred, it is sensed and proper gain setting is made in the controller and based on this control the PWM generator generates the required pulses to the inverter. From the inverter is received the AC power to the injection transformer which is fed to the system in par with the bus voltage.

The major job of controller in the DVR is to identify the voltage sag occurrences, calculate the compensating voltage, to produce trigger pulses of PWM inverter and stop the trigger pulses when the occurrence has been passed. Using Root Mean Square (RMS) vale calculation of the voltage to analyses the sags does not give fast result. In this study, Park's transformation or dq0 transformation is used in voltage calculation [10].

VI. SIMULATION AND RESULT DISCUSSION

To understand the performance of DVR along with control, a simple distribution network is implemented. There are different types of faults in the system [12]. They are,

- Line to ground fault
- Double line to ground fault
- Three phase fault

A. LINE TO GROUND FAULT

The simulation result of the DVR with PI controller for voltage sag conditions with fault occurring at only one phase in sensitive loads is given in figure 3. In the Figure 3 the first waveform represents the source voltage of the system. The second one denotes the voltage present across the sensitive loads. The third waveform figures out the injected voltage which is nothing but the compensation voltage.

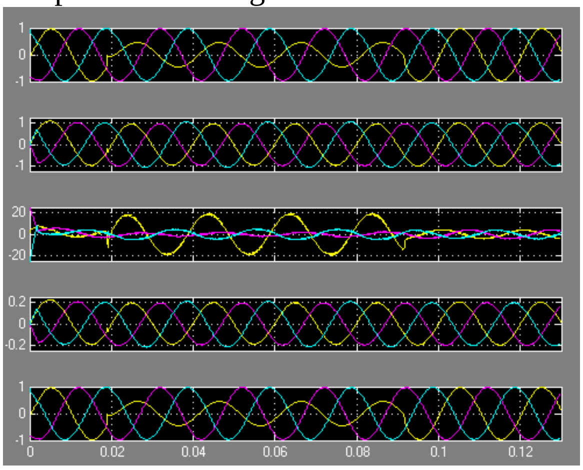

Figure 3 Output voltage of DVR with Single phase fault

The next waveform represents the current at the sensitive load. The last waveform is the voltage at the non-sensitive load.

B. DOUBLE LINE TO GROUND FAULT

The simulation result of the DVR with PI controller for voltage sag conditions with fault occurring at two phase in sensitive loads is given in figure 4.

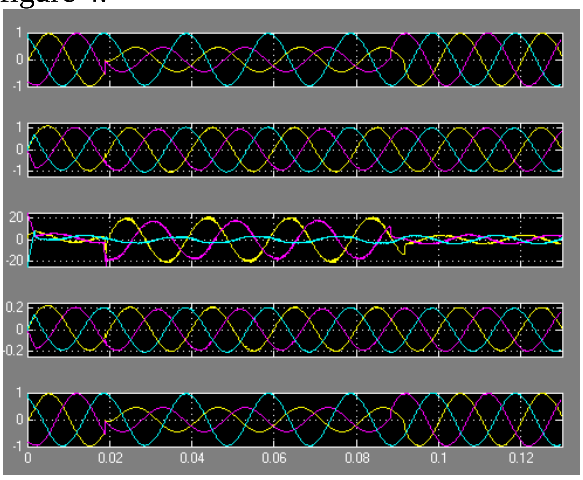

Figure 4 Output voltage of DVR with Two phase fault

In the Figure 4 the first waveform represents the source voltage of the system. The second one denotes the voltage present across the sensitive loads. The third waveform figures out the injected voltage which is nothing but the compensation voltage. The next waveform represents the current at the sensitive load. The last waveform is the voltage at the non-sensitive load.

C. THREE PHASE FAULT

The simulation result of the DVR with PI controller for voltage sag conditions with fault occurring at three phase in sensitive loads is given in figure 5.

In the Figure 5 the first waveform represents the source voltage of the system. The second one denotes the voltage present across the sensitive loads the third waveform figures out the injected voltage which is nothing but the compensation voltage. The next waveform represents the current at the sensitive load.

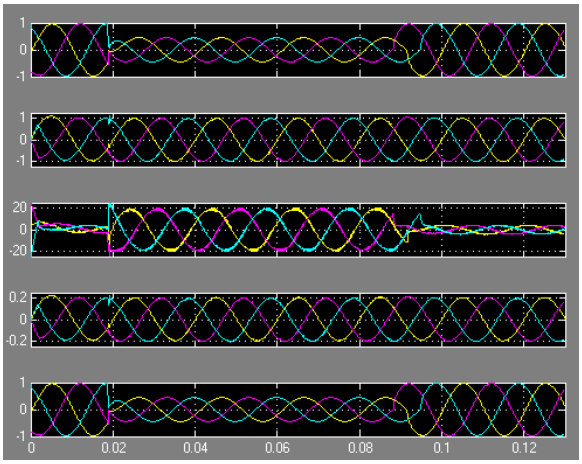

Figure 5 Output voltage of DVR with Three phase fault

The above all faults will be cleared by using MATLAB/SIMULINK software. PI controller is used for the control operation. The DVR system connected to the distribution system using boosting transformer.

VII. CONCLUSION

In this paper, the modeling and simulation of dynamic voltage restorer (DVR) using PI has been implemented using Matlab /Simulink. The simulation result shows that the dynamic voltage restorer compensates the sag quickly in 0.002 sec and provides excellent voltage regulation. Dynamic voltage restorer handles different fault condition like single phase fault, two phase fault and three phase fault without any difficulties and injects the suitable voltage to maintain the balanced supply voltage during any above faulty situation in order to maintain the balanced load voltage at the nominal value.

The DVR has shown the ability to perform compensation for grid side voltage sags which can be proved through simulation. The effectiveness in voltage sags compensation is improved by the DVR with greater efficiency which makes it an attractive custom power device.

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