ANALYSIS OF FAULT RIDE THROUGH CAPABILITY IN DFIG BASED WIND TURBINES USING DYNAMIC VOLTAGE RESTORER WITH PWM TECHNIQUE

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ABSTRACT

Power quality be a serious concern of modern industries within the present era. Voltage sags/swells are considered because the most vital power quality snags because of increasing complexity within power grid. To beat these problems, Custom Powers Devices (CPD) is connected closer to load end. One among those devices is Dynamic Voltages Restorers (DVR) which may a series connected most effective and effective modern CPD utilized in power distributions network. The most utility of DVRs is to monitors the load's voltage continuously and if some sag or swells occurs, it can speedily mitigate by inoculating the balance voltage (or excess) to load voltage. The first benefit of the DVRs is to keeps the system continuously on-line with maximum quality constant voltage to sustain the continuity of production. The anticipated topology and the present topology are replicated under voltage sag/swell by means of MATLAB / Simulink and the simulation consequences are equated to show that the projected system efficiently pay off the voltage sag/swell.

1. INTRODUCTION

The main objective of Power distribution systems is to provide uninterrupted flow of energy with constant magnitude level sinusoidal voltage and frequency to their customers. The modern manufacturing and process equipment which operates at high efficiency require high quality power for the successful operation of their machines. The failure of required quality power can cause complete shutdown of the industries which will make a major financial loss to the industry concerned.. In practice, power systems, especially the distribution system has numerous nonlinear loads which produce power quality problems such as voltage sag and swell, flicker, harmonics, distortion, impulse transient and interruptions [1]. Among these, two power quality problems such as voltage sag and swell have been identified a major concern to the customers .The voltage sag and swell have major impact on the performance of the microprocessor based loads as well as the sensitive loads[2]. Though there are many different methods to mitigate voltage sag and swell, but the use of a custom Power device is considered to be the most efficient method. The term custom power pertains to the use of power electronics controllers in a distribution system specially to deal with various power quality problems. Dynamic Voltage Restorer (DVR) is one of the most efficient and effective modern custom power device used in power distribution networks. DVR is series connected solid state device that injects voltage into the system in order to regulate the load side voltage [3]. It is normally installed in the distribution system between the supply and the critical load feeder at the Point Of Common Coupling (PCC). Other than voltage sag and swell compensation, DVR can also have other features like: line voltage harmonics compensation, reduction of transients in voltage and fault current limitations.

1.1 WIND POWER

Environmental degradation is an alarming situation in the present day world. Sustainable development and environmental protection are the two great challenges. In context, besides hydro power, the electrical power sector plays much attention to seek and utilize alternative renewable resources like wind energy, solar energy, tidal energy, and geo thermal energy. The automobiles and thermal power plant consume a large quantity of the nonrenewable fossil fuel energy (oil and coal) resources. It has been withered that a proliferation of atmospheric air pollution causing health hazards. The CO 2 concentration in the atmospheric is increasing day-by-day and it has been experienced the symptoms of global warming. The world average per capita carbon emission is 4.47 and in respect of India is 1.56. As a measure of environmental protection, most energy-producing countries prefer power generation based on environmental-friendly, clean, renewable energy sources. Power generation from wind energy is one of the innocuous options in electrical power sector. Among the world countries, India occupies fifth position in harnessing the wind energy; the first four positions are held by China, USA, Germany, and Brazil.

In REN21 Renewables (2018) global status report (Renewable Energy Policy Network for the 21 century, 2018), it is pointed out that the wind energy market has increasing over the last few decades. The year 2016-2017 was a stellar year of the wind trade. It was one of best years in alternative energy harnessing. An alternative energy generation is increasing nearly 6 to 11 % of the total installed capacity in India. The production of wind energy in India has reached nearly 32,848 MW of power; nearly 61% of wind energy can be accounted for renewable energy in India. Figure 1 shows the total installed capability of wind energy form the year 2001, and it observed that the wind energy has predominant growth in recent years. This plot affirms that India has a good potential of growing in green energy. In India, in the fourth coming years, it is planned to install many wind energy power plants.

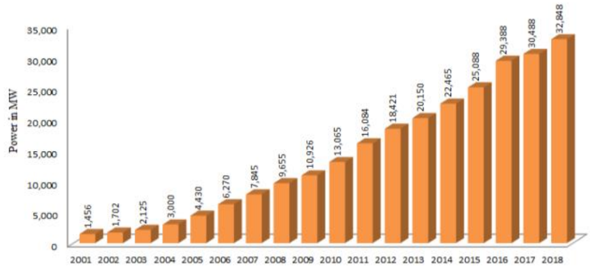

Figure 1: Total Wind Energy Installed Capacity Power in India

2. SIMULATION

AC to AC power translation requires mutable output voltage and mutable frequency. The Pulse Width Modulation (PWM) topology is most used in indirect AC-AC converters with a DC link and direct AC-AC converters. An indirect AC-AC converter can be used to give output voltage with an adjustable or different frequency. Conversely, for uses where only voltage regulation is obligatory, the direct PWM AC-AC converters can be a more sensible choice to realize smaller size and lower cost. it's qualities like providing an honest power factor, great efficiency, little harmonic current, single- stage conversion, an informal topology, humble control, insignificant size and small cost.

AC–AC converters correspondingly accomplish conditioning, filtering and isolating of the entering power in accumulation to voltage. Self-commutated switches with PWM control methodology can expressively expand the performance of AC–AC converters.

3. BLOCK DIAGRAM OF MODEL

In this segment we resolve and discuss about the components that are essential for the execution of System. The subsequent steps will be used to instrument the system and DVR in injection n mode.

Step 1: To seek out whether there's any sag/swell contained by the source voltage. It's completed by relating the terminal source voltages with reference to load voltages. The alteration between the source voltages and reference load voltages is that the essential amount of voltage that has got to be injected by the system.

Step 2: In this step we will produce switching commands to the VSI in directive to track the reference voltages (as already engendered in step 1) by means of an appropriate switching pattern such as PWM.

Step 3: The filtrations of harmonics existing in the system is at most required in view of quality assurance. In this section we will filter out the harmonics that are existing in the output of the Voltage Source Inverter (VSI).

Step 4: To inoculate the filtered output through the three isolation transformers extant stuck between the source and the load. Ensuing above cited steps, the DVR should work only if systems have any change between the fatal source voltage and load voltage.

To implement above steps, the following building blocks are required to realize the DVR.

i. Detection and control block
ii. Voltage source inverter.
iii. Filter components.
iv. Isolation transformers

Fig. 2 shows the block diagram of DVR. It can be seen that the DVR is connected in series between the source and the load.

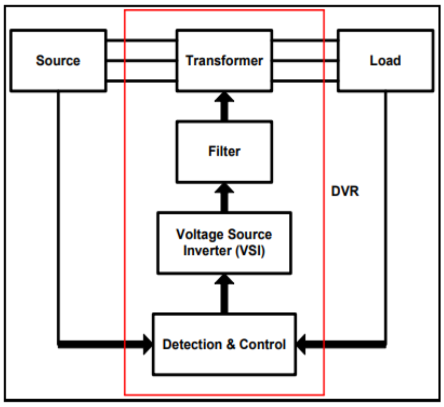

Fig.2: Block diagram of DVR

3.1 DETECTION AND CONTROL BLOCK

The first component of the DVR is the detection and control block. All it needs to do is to monitor the terminal source voltage and the reference load voltages in the dq reference frame.

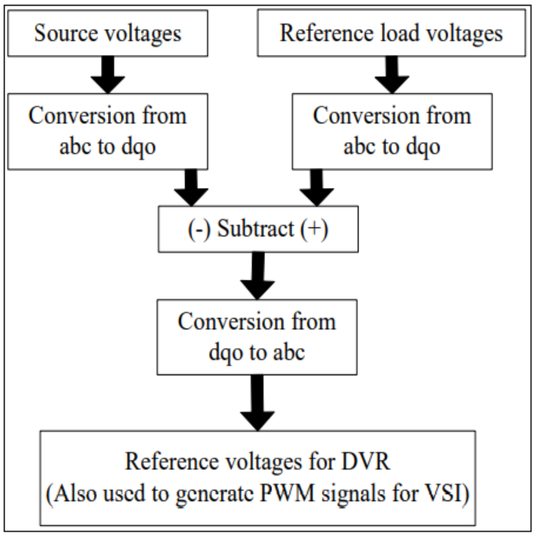

Fig.3: Flow chart showing the implementation of detection and control block

Whenever, there is any sag/swell in the source voltage there will be deviation in the dq components of the source voltage from those of the reference load voltages. Based on the difference between the dq components of the source and reference load voltages, the detection block will generate a reference voltage 'V_{DVR}' that needs to be injected by the DVR. The same reference voltage is used to generate the PWM signals for the VSI block. The shape of the reference voltage, 'V_{DVR}', depends on two factors i.e. whether the sag/swell voltages are balanced or not and contain harmonics or not. The flow chart of implementing the detection and control block is as shown in Fig. 4.

3.2 VOLTAGE SOURCE INVERTER

The voltage source inverter should be controlled in such a way as to generate the voltages which are same as the reference voltages generated by the detection and control block. Here in this work, sinusoidal pulse width modulation (SPWM) is used as the switching strategy for the inverter. Actually any PWM technique can be used as the switching strategy for the VSI. However, due to the merits, SPWM has been chosen to control the VSI. The following reasons will justify the selection of SPWM as the control strategy for the VSI.

The output of the inverter should be same as the reference voltages generated by the detection and control block. From the theory of SPWM, we know that the fundamental of the output of the inverter will be same as the modulating waveform used to compare the triangular carrier. Combining (i) and (ii) it can be concluded that if the reference voltages generated by the detection and control block are given as the modulating waveforms for the inverter then the fundamental component of the output of the inverter will be same as the reference voltages generated by the detection and control block. This inherent advantage of SPWM (which makes our design much simpler) justifies the selection of SPWM as the switching strategy for the inverter. Along with this, SPWM also have following advantages.

Inverter implemented using SPWM will have a constant switching frequency.

By choosing the modulation frequency (which is nothing but the ratio of carrier frequency to the modulating waveform frequency) very high, the switching harmonics can be pushed to high frequency side which in turn will make the filter requirement less.

The modulation index is equal to

$$M_a = \frac{Amplitude\ of\ the\ modulating\ waveform}{Amplitude\ of\ the\ Carrier\ waveform} \quad \text{…..4.1}$$

The modulating waveforms are nothing but the reference voltages generated by the detection and control block. Therefore the amplitude of modulating waveform is nothing but the magnitude of sag whereas the amplitude of carrier waveform is set as 1 pu. Therefore

M_a = Magnitude of Sag

The modulation frequency is defined as

$$M_f = \frac{Frequency\ of\ the\ carier\ waveform}{Frequency\ of\ the\ modulating\ waveform} \quad \text{…..4.2}$$

The next step is to find out the value of DC source voltage of the inverter. In the linear region of modulation ($0<M_a<1$) the amplitude of the fundamental component of the inverter output is equal to the product of the modulation index and the DC source voltage. Therefore

$$V_{inv\ out,\ 1} = M_a \times V_{dc} \quad \text{…..4.3}$$

Where $V_{inv\ out,\ 1}$ is the amplitude of the fundamental component of the inverter output V_{dc} and is the voltage of the DC source. The constraint for successful compensation is that the amplitude of the fundamental component of the inverter output should be equal to the magnitude of sag. Therefore, $V_{inv\ out,\ 1} = M_a \times V_{dc}$ should be equal to the magnitude of sag. Substituting the value of in (4), we get the value of DC source voltage as

$$\text{Magnitude of sag} = (\text{Magnitude of sag} \times V_{dc}) \quad \text{…..4.4}$$

It implies that V_{dc} = 1pu

Now having figured out all the values that are required for the inverter the next step is to filter out the harmonics that are present in the inverter output.

3.3 FILTER COMPONENTS

The non-linear characteristics of semiconductor devices present in the inverter result in distorted waveforms associated with harmonics at the inverter output. To overcome this problem and provide high quality energy supply, filter unit is used. Since SPWM technique with high modulation frequency is used to implement the inverter, all the harmonics are pushed to the high frequency side which in turn are easier to filter out. All the harmonics are centered on the multiples of carrier frequency. So, higher the carrier frequency easier will be the filtering. But as mentioned earlier, always there will be a tradeoff between switching losses and filtering. The values of the filter components used in the simulation are the following R=2Ω; C= 50μF; L=5mH

3.3.1 ISOLATION TRANSFORMER

The filtered inverter output is injected to the line with the help of an isolation transformer. The isolation transformer has the following advantages

- ✓ They isolate the inverter from the line and thus prevent the DC source of the inverter being shorted through the switches.
- ✓ The ratings of the inverter can be reduced by using a step up transformer

4. SIMULATION MODEL

This is a representation of the simulation block. In this we are concentrating on the wind turbine. As we know that wind turbine and DFIG which is there as a generator is responsible for the voltage sag and swell we are implementing DVR to neutralize this sag and swell. Below are the parameters of DFIG we are implementing in our model.

4.2.1. SIMULATION PARAMETERS FOR DFIG

The following parameters are used to simulate DFIG which are showing below in table 4.1

Table 4.1 simulation parameters for Doubly Fed Induction Generator (DFIG)

S. No.	PARAMETER NAME	RATING
1.	Rated Power	*2.00 MVA*
2.	Rated Voltage	*690 V*
3.	Rated Current	*2.00 KA*
4.	Rated Frequency	*50 Hz*
5.	Pole Numbers	*4no*
6.	Stator Resistance	*0.34 p.u.*
7.	Rotor Resistance	*0.009p.u.*
8.	Stator Leakage Inductance	*0.105 p.u.*
9.	Rotor Leakage Inductance	*0.111 p.u.*
10.	Magnetic Inductance	*3.34 p.u.*
11.	Magnetic Resistance	*47.61 p.u.*
12.	Angular Moment Of Inertia	*3.825 p.u.*
13	Mechanical Damping	*0.01 p.u.*

The first table consist of Rated Power, Rated Voltage, Rated Current, Rated Frequency, Pole Numbers, Stator Resistance, Rotor Resistance, Stator Leakage Inductance, Rotor Leakage Inductance, Magnetic Inductance, Magnetic Resistance, Angular Moment Of Inertia, Mechanical Damping ratings specified for the DFIG . These are standard ratings and we are also using them in our simulation model.

4.2.2 COMPLETE SIMULATION MODEL

Figure below shows the MATLAB/SIMULINK diagram of DVR compensated network using a SVPWM based scheme that are used in the system.
In order to show the performance of the VSI based DVR in voltage sags and swells mitigation, a simple distribution is simulated using MATLAB / SIMULINK as shown in Figure 4.3. In this system three phase source is connected to the three phase load through series impedance and the DVR. The VSI is connected to the system using injection transformer and ripple filter is connected across the terminals of secondary of the transformer. Voltage sags and swells are simulated by subsystem 1 and subsystem 2 shown in Figure. A DVR is connected to the system through a series transformer with a capability to insert a maximum voltage of 50 % of phase to ground system voltage. The simulation parameters are shown in table 4.1

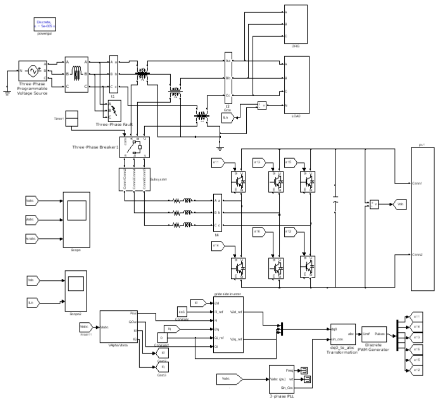

Fig 4: Simulation MATLAB complete circuit model

VSI converter this shows that in open loop system, DC link voltage fluctuation is very large. To achieve minimum fluctuation, we have to increase the DC link capacitor size, which will be difficult to implement in practical case. So we adopt an advance control scheme for GSC such as vector control scheme.

4.2.3 CONTROL METHOD OF DVR

First step is to generate the sine wave. Second step is to generate the carrier wave signal. The carrier wave is a triangular wave. The triangular wave frequency is 1800Hz. Because 1800 is multiple of three, so that the third order harmonics are eliminated. Modulating signal (sine wave) is compared with the carrier signal (triangular wave), if the modulating signal is greater than or equal to carrier signal, sinusoidal pulse width modulation pulses are generated .The PWM pulse is directly fed to the positive group of switches whereas complement PWM signal is fed to the negative group of switches.

DVR can be controlled by controlling its inverter. The control unit gives information on required voltage to be inserted and its duration during sag. Inverter is the core component of DVR. The control strategy of inverter will directly affect the performance of the DVR. Since numerical variables are changed over into phonetic variables, scientific demonstrating of the framework is not required.

4.2.3 MODEL OF DVR

MATLAB Simulink programming is utilized for reenactment and results. Simulink is a product bundle for displaying, reproducing and dissecting dynamic frameworks. It bolsters straight and non-direct frameworks displayed in consistent time, tested time or a half and half of the two Simulink incorporates a complete square library of sinks, sources, direct and non-direct segments and connectors. It has a broad control library that permits simple usage of any control calculation, including direct control, fluffy rationale, neural systems and others.

The DVR utilizes self-commutating IGBT strong state power electronic changes to moderate voltage hangs in the framework. The voltage controlled three single-stage full scaffold PWM inverters are utilized to create remunerating voltage. The exchanging recurrence of the inverters is 3 kHz. Three of single-phase inverters are connected to the common DC voltage source. The DC voltage source is an external source supplying DC voltage to the inverter for AC voltage generation. The three 600/10000 V (rms) single-phase injection transformers boost the output waveform of the inverter unit and supplies voltage to load side, where the voltage is further stepped down to 0.4 kv for sensitive load (load to be protected).

The circuit breakers are placed in the circuit with the injection transformers allowing the protection of the DVR.

4.2.4 DVR CONFIGURATION

The DVR uses self-commutating IGBT solid-state power electronic switches to mitigate voltage sags in the system. The voltage controlled three single-phase full bridge PWM inverters are used to produce compensating voltage. The switching frequency of the inverters is 3 kHz. Three of single-phase inverters are connected to the common DC voltage source. The DC voltage source is an external source supplying DC voltage to the inverter for AC voltage generation. The three 600/10000 V (rms) single-phase injection transformers boost the output waveform of the inverter unit and supplies voltage to load side , where the voltage is further stepped down to 0.4 kv for sensitive load (load to be protected).The circuit breakers are placed in the circuit with the injection transformers allowing the protection of the DVR

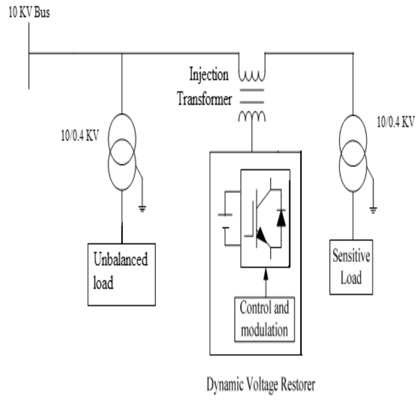

Fig 5: Single line diagram of system

Simulink Model of DVR connected to a distribution network (voltage sag produced through load) the power circuit of DVR systems can be represented as a three- phase equivalent circuit as shown in Fig 5.

4.2.4 CALCULATION OF DC LINK VOLTAGE

RMS value of grid line voltage

$$V_g = 690 \text{ V} \quad \ldots 4.4$$

Grid phase voltage RMS value is

$$V_{rms} = 690/\sqrt{3} = 398.37 \quad \ldots 4.5$$

Peak value of grid phase voltage

$$V_{gm} = \sqrt{3} * 398.37 = 563.392 \quad \ldots 4.6$$

For SVPWM technique,

$$V_{dc} = \sqrt{3} * V_{gm} \quad \ldots 4.7$$

Hence DC link voltage

$$V_{dc} = \sqrt{3} * V_{gm} = 975.8 \quad \ldots 4.8$$

So reference value of V_{dc} i.e. Vdc* must be greater than calculated Vdc so 1000 V can be selected as a reference value.

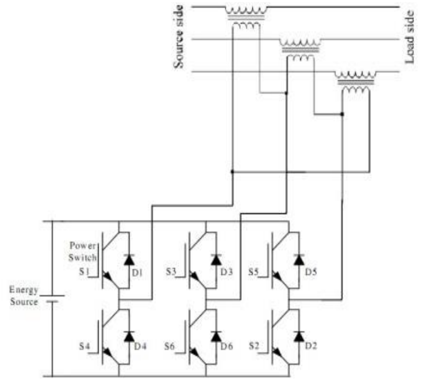

Fig 5: Equivalent three phase circuit diagram for DVR

5. SIMULATIONS AND RESULTS

This section discusses the simulation results of series compensation of voltage sags during balanced and unbalanced fault conditions using DVR with DFIG. The test system is simulated for DFIG of 1.5 MW wind turbine connected to electrical grid. The simulation parameters of the DFIG and DVR are given in Table.4.1. The FRT performance is evaluated for balanced and unbalanced fault conditions. The performance of DVR for improving FRT capability is analyzed in response to the grid fault during balanced and unbalanced fault conditions at PCC.

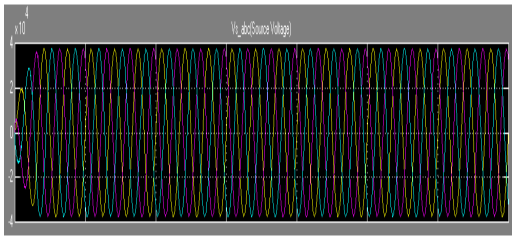

Fig 6: Source Voltage

The system runs at 50 Hz frequency and total simulation time is chosen to be 0.35 seconds in each case. The scope connected to the V-I measurements at supply side as shown in fig 6.

Load side gives the simulations of supply voltage having sag and the voltage across load. We have taken DFIG and three phase programmable sources. The disadvantage of DFIG as a source is that it creates voltage misbalance in the system due to which sag is produced. In Fig 7 it is observed that initially there is no voltage injection and power flow from DVR to the system. As no voltage sag is sensed. As soon as the load becomes unbalanced the voltage sag occurs

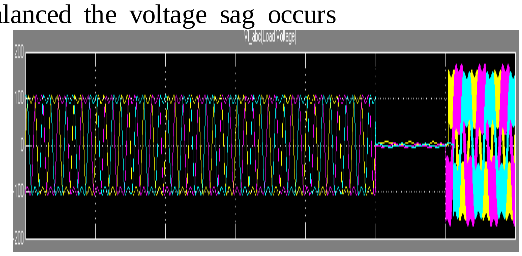

Fig 7: Voltage Sag due to DFIG/disturbances

A sag of 0.35 pu which lasts for 6 cycles between 0.7 s to 0.8 s. Fig.4.7 shows the DC-link voltage, rotor speed, stator current and stator voltage respectively after series compensation during balanced fault condition.
After the occurrence of Voltage Sag DVR comes into action and injects voltage which somewhat lessen the sag. Thus the system becomes more stable.as shown in fig 4.8 and 4.9 the sensing of DFIG disturbances by the DVR results in a rectified output voltage profile in which the voltage sag is compensated. The proposed methodology proves very unique that rectified the critical load changes disturbance problem.

The primary task of DVR is providing the high quality voltage to the critical loads. DVR enable the proposed system for providing a good power and voltage quality to the critical load. The controller output signals stabilize when all the phase voltages of the load attain the desired value. DVR gives high performance in injecting the more in-phase voltage with proper polarity and phase angle.

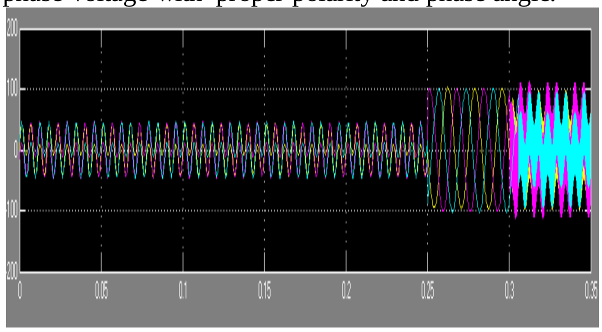

Fig 8: Injected Voltage due to DVR

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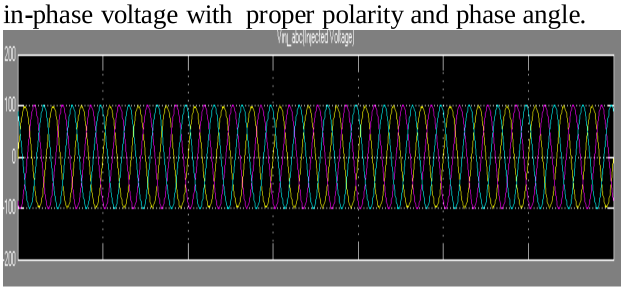

Fig 9: Final rectified voltage by DVR

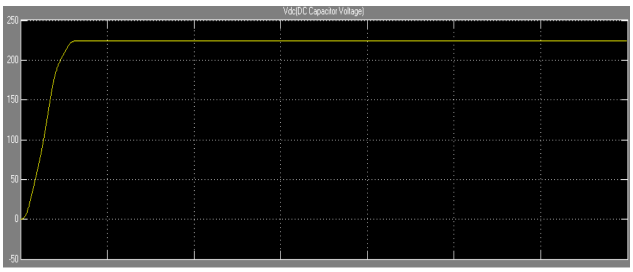

Fig 10: Capacitor voltage output

Harmonics have great negative impacts to the system and most grid disturbances are accompanied with harmonics. Fig. 13 shows the harmonic spectrum of DVR using conventional Feed Forward control and the harmonic spectrum of DVR with CFFFB control is shown in Fig. 14. The CFFFB control based DVR shows lower harmonic distortion within the IEEE 519 standards [35]. The comparison shown in Table 2 shows a significant improvement in the performance of DVR using the PI feedback based CFFFB control. DVR complies to operate within the acceptable limits of THD%. The THD% of DVR without any control is 15.65%, whereas using Feed Forward control it is 5.24% and it is improved by using CFFFB control to 4.47%. The comparison of the harmonic mitigation using the conventional Feed Forward control and the Combined Feed Forward and Feed Back control (CFFFB) is shown in Table 2.

The results and discussion conclude that the improvements in terminal voltage, stator current, rotor current, DC-link voltage are analyzed. Smooth active power evacuation of 1.5 MW power of DFIG is analyzed. Reactive power support during balanced, unbalanced and short-circuit fault conditions are observed. Improvement in harmonic mitigation using the CFFFB control and the operation of DVR for effective FRT capability operation of DFIG based wind turbines during fault is analyzed. The improvement in harmonic mitigation is observed in the harmonic spectrum analysis shown in Fig.13 and Fig.14. The comparison of the performance of the conventional Feed Forward control and the Combined Feed Forward and Feed Back control (CFFFB) is shown in Table 3.

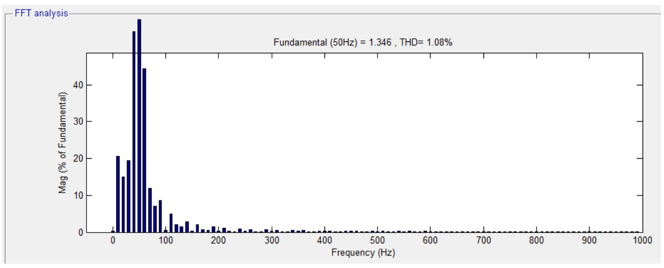

Figure 4.10: THD of The system

The simulation results clearly show an effective mitigation of balanced and unbalanced fault condition by utilizing the combined Feed-Forward and Feed-Back control. Since active power injection, rotor speed control, DC link control, stator voltage and current compensation are effectively done, the grid code adherence is effectively done through this method.

6. CONCLUSION

In this work, cost effective & reliable custom power concept, dynamic voltage restorer is used to mitigate the voltage sags in the distribution system, thereby improving the performance of the system. The various control strategies are employed & tested for 11kV distribution system. The PI controller based DVR, fuzzy controller based DVR and PI-fuzzy controller based DVRs are connected step by step in the compensated feeder to compare their performances. The effectiveness of different control techniques based DVRs for static linear & static non-linear loads have been investigated. As seen from the load voltage waveform & frequency spectrum of uncompensated system, the THD level is reduced effectively from 25% to a much less value of 16.68%. Load voltage waveforms & frequency spectrum of hybrid control scheme for static non-linear load depicts that the harmonics are effectively reduced to a less value as compared to 23.70% with PI controller & 17.49% with Fuzzy controller. Simulation results indicate that the non-linear control techniques provide better compensation to the system as compared to the linear PI technique based DVR connected to the feeder during static non-linear loads.

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