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Performance and Analysis of Dynamic Voltage Restorer against Voltage Sag and Swell

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Abstract:-- **In recent years, power quality has become more important part of today's Electrical power system. A survey defines that roughly 92% of power quality problems are occurred in distribution system are voltage sag, voltage swell and harmonics. Most of the times Voltage sag and voltage swells present in the Distribution system and are due to faults at a remote bus also Non-linear loads generate harmonic currents which are responsible for poor power quality. The Power Quality Analysis aspires to bring out electricity consumers for improved power quality with application of power electronics devices.**

Keywords:— **Voltage Sag, Voltage Swell, Dynamic Voltage Restorer, Power Quality.**

I. INTRODUCTION

The electric power system is considered to be composed of three functional parts generation, transmission and distribution. For reliable and stable power system, the generation unit must produce adequate power to meet customer's demand, transmission system has to transport bulk amount of power over long distances without overloading effects on the system and distribution system must deliver electric power to each customer's equipment. Distribution system located at the end of power system and is connected directly to the customers, so the power quality mainly depends on distribution system. The reason behind that the electrical distribution network failures account for 90% of the average customer interruptions. The term custom power is relates to the use of power electronics controller in a distribution system, specially deals with various power quality problems. Custom power gives assurance to customers to get pre-specified and reliability of power supply. The pre-specified quality of power may contain a combination of specifications such as low flicker at the load voltage, low harmonic distortion, and low phase unbalance, no power interruptions in load voltage, magnitude and duration of over voltages and under voltages within predetermined limits, acceptance of fluctuations without significant effect on the terminal voltage.

At the transmission level, the improvement of power quality or reliability of the system is obtained by FACTS devices like Interline power flow controller (IPFC), Unified power flow controller (UPFC), Static synchronous compensator (STATCOM), Static synchronous series compensator (SSSC), etc. are introduced. These FACTS devices are designed in such way that they maintain constant power flow in transmission system. But now days for the improvement of power quality more attention is on the distribution system. So in the distribution system these devices are modified which are known as custom power devices. The main custom power devices which are used in distribution system for power quality improvement are unified power quality conditioner (UPQC), distribution static synchronous compensator (DSTATCOM),active filter (AF), Dynamic Voltage Restorer (DVR) etc.There are different types of custom power devices used in electrical network to improve power quality. The DVR is mostly considered as an effective custom power device for the mitigation of voltage sags, swells. In addition to voltage sags and swells compensation, DVR has other additional features like harmonics reduction and Power Factor correction. The DVR is clearly considered as one of the best economic solutions for its size and capabilities compared to the other devices.

II. DYNAMIC VOLTAGE RESTORER (DVR)

Dynamic Voltage Restorer is a Custom Power Device which is used to eliminate voltage disturbances at the supply side. DVR also known as Static Series Compensator which maintains the load voltage at a constant desired level of magnitude and phase by compensating the voltage sags/swells and voltage unbalances presented at the point of common coupling.

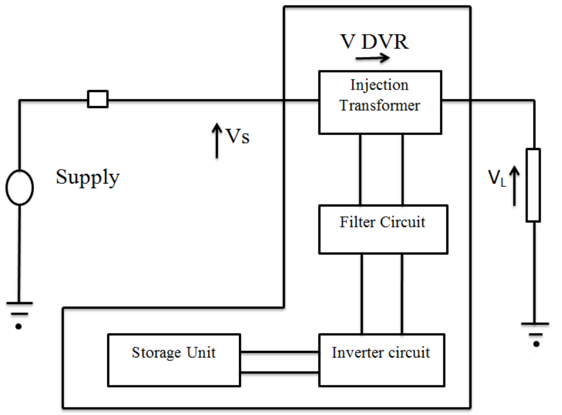

Fig1. Block diagram of DVR

The DVR consists of 6 major parts:-

1. Energy storage –

Energy storage devices used for DVR may be Batteries, flywheels or SMES can be used for the provision of real power for compensation. When large voltage sag occurs in the system, compensation using real power is essential.

2. Voltage Source Inverter (VSI)–

Voltage Source Inverter is used to convert DC voltage supplied by the energy storage device to an AC voltage. This AC voltage is injected into the main system by using coupled injection transformer. So the rating of VSI is sufficiently low.

3. Passive Filters–

Generated AC voltage is in PWM pulse waveform, so it must be converted into the sinusoidal waveform. For this purpose passive filter are used. It is the combination of an inductors and capacitors which are placed in between the inverter circuit and injection transformer. By placing filter circuit higher order harmonics are prevented from passing through the injection transformer. It will reduce stress on the injection transformer. When the higher order harmonic current penetrate to the secondary side of the transformer, a higher rating of the transformer is required

4. Injection Transformers–

The basic function of injection transformer is to inject voltage supplied by the filtered VSI output to the desired level. The secondary side of the injection transformer is connected in series with the distribution line. In this study three phase 1:1 injection transformer is used. This three phase transformer can be connected either in delta/open or star/open configuration.

5. Capacitor –

DVR has a large DC capacitor to ensure constant DC voltage input to inverter circuit.

6. By-Pass Switch–

Due to short circuit on the load or large inrush current, the DVR will be isolated from the system, for this purpose By-pass Switch is used. If the over current on the load side exceeds a specific limit then by using the bypass switches supply continued to another path.

III. OPERATION OF DVR

The DVR consists of series converter connected via a common dc link. The series converter is used to inject the voltage in series with line voltage. The voltage injection takes place with the help of injection transformer connected between the source and load. During voltage sag, energy from DC storage unit is extracted by the DC link and given to the series converter acts as inverter and generates constant ac output voltage. Generated AC output voltage has Square shaped sinusoidal nature. This is because of switching of inverter which produces harmonic in the supply. These harmonic are filtered by using shunt passive filter and given to injection transformer which inject voltage in series with the line voltage. Similarly, during voltage swell, additional power is absorbed by series converter circuit. That means the injected voltage is out of phase with the phase voltage so that excess voltage should be cancelled to each other. During voltage sag and voltage swell converter generate switching frequency which is in the range of KHz along with the fundamental component. To filter out these switching harmonics values of inductor and capacitor are properly tuned in LC filter circuit. In MATLAB/SIMULINK the DVR is designed to handle maximum load up to 30KW, 500VAR. The rating of the injection transformer is decided by the voltage to be injected and the load current flowing through the secondary of injection transformer. For the voltage compensation in the range of 270-560 V(rms), 15 to 20 KVA rating transformer is used for voltage injection.

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The injected voltage by DVR is given by,

$V_{INJ} = V_L - V_S$…………..(1)

Where,

V_L = Magnitude of desired load voltage.

V_S = Magnitude of source voltage during sag or swell.

The value of load current is given by,

$$I_L = \left[\frac{(P_L \pm J * Q_L)}{V_L}\right] \text{……………..(2)}$$

IV. CONTROL SCHEMES FOR DVR

(A).Discrete PWM based control scheme

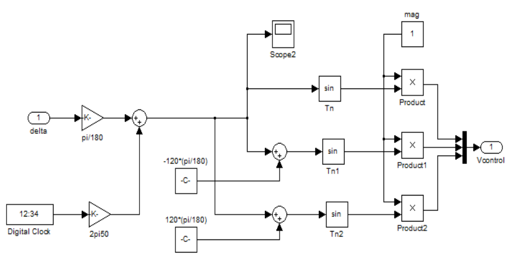

Fig.2. PWM based control scheme.

In practical application, for the mitigation or voltage sag or swell a discrete PWM-based control scheme is implemented. Figure (2) shows the DVR controller scheme implemented in MATLAB/SIMULINK. In this scheme an error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The PI controller processes the error signal and generates the required angle δ to drive the error to zero value. The modulating angle δ or delta is applied to the PWM generators in phase R, whereas the angles for phase Y and B are shifted by 240° or -120° and 120° respectively.

$VA = \sin(\omega t + \delta)$ … (1)

$VB = \sin(\omega t + \delta - 2\pi/3)$ … (2)

$VC = \sin(\omega t + \delta + 2\pi/3)$ ….(3)

IV. SYSTEM PARAMETERS-

In MATLAB /SIMULINK the DVR is designed for the three phase system to drive the maximum capacity of load. As shown in following table-1.

Supply voltage	415 V
Series injection transformer	1:1 , 20 KVA
DC link voltage	800 V
Inverter specification	IGBT based, 3-arm(6 pulse) 1080 Hz
Filter inductance	5mH
Filter capacitance	0.0175μF
Active and Reactive power of Load	30KW, 500 VAR

Table-1

SIMULATION MODEL–

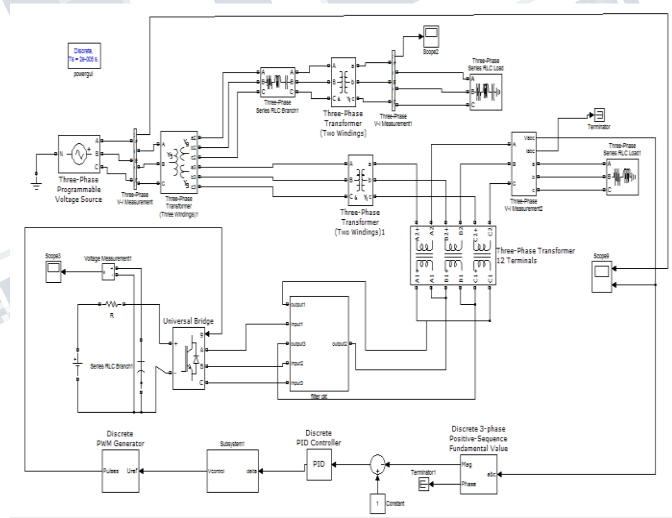

Fig.3. Simulink of PWM based DVR

A fig.3 shows simulation diagram of PWM based DVR designed in MATLAB/SIMULINK. A source of 415V line to line voltage is applied to load of 30KW, 500VAR through a series injection transformer of 20KVA, Delta/open connected. The output of three phase inverter bridge of 3-arm, 6 pulse is given to filter circuit to reduce the harmonics in the supply before injection into the mainline.

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(B).SPWM Based control scheme-

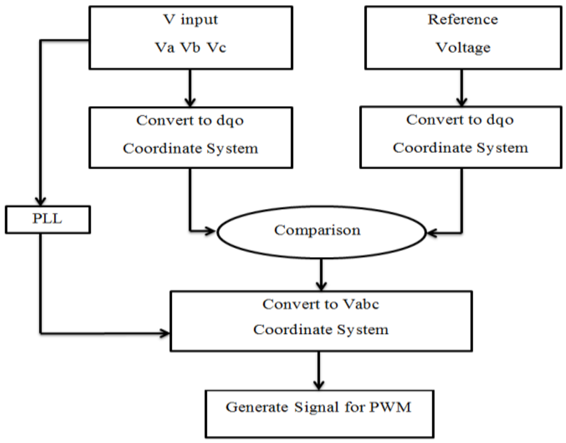

Fig.4. Block diagram of control technique for DVR

In this method, the dq0 transformation or the Park's transformation is used for voltage calculation where the three phase stationary co-ordinate system is converted to the dq rotating quantity. To get the information regarding of depth (d) and phase shift (q) of voltage sag with start and end time the dq0 transformation technique is used. The purpose behind the conversion of the three phase voltage Va, Vb and Vc into three constant voltages Vd, Vq , Vo three phase system is for the simplification of voltage calculations as well as the system should be easily controlled. The input for the DVR controller is taken from the output voltage measured by three-phase V-I measurement at load side. This load voltage is then transformed into the dqo transformation then if there is any voltage sag or voltage swell then the error signal is generated from the difference between the dq voltage and the reference voltage. The d reference is fixed to the rated voltage while the q reference is always set to zero. The gain values of controller such as Kp and Ki control the stability of the system. PI controller is a feedback controller which controls the system depending on the error signal. In PI controller the proportional response can be obtained by multiplying the error with constant Kp (proportional gain). This error signal is the actuating signal which drives the PI controller and the final output signal which is obtained controls the pulses for the Inverter. The output obtained from the PI controller is then again transformed back to Vabc. The error signal is used as a modulation signal that allows generating a commutation pattern for the power switches (IGBT's) constituting the voltage source converter. The generated commutation pattern is based on the sinusoidal pulse width modulation technique (SPWM.).

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & 1 \\ -\sin(\theta) & -\sin(\theta - \frac{2\pi}{3}) & 1 \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \ldots\ldots(4)$$

SYSTEM PARAMETERS-

In MATLAB /SIMULINK the DVR is designed for the three phase system to drive the maximum capacity of load. As shown in following table-2.

Supply voltage	415 V
Series injection transformer	1:1 , 15 KVA
DC link voltage	500 V
Inverter specification	IGBT based, 3-arm(6 pulse) 1080 Hz
Filter inductance	5mH
Filter capacitance	0.0175μF
Active and Reactive power of load	30KW, 500 VAR

Table-2.

SIMULATION MODEL –

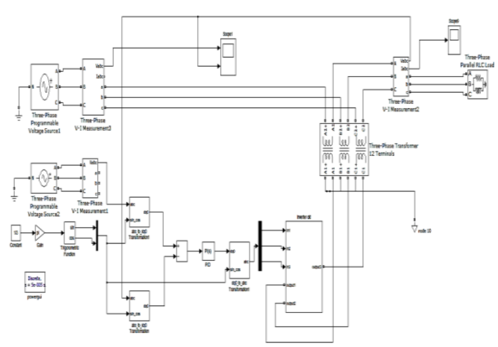

Fig.5. Simulink of SPWM based DVR

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A figure.5 shows simulation model of SPWM based DVR designed in MATLAB/SIMULINK. A source of 415V line to line voltage is applied to load of 30KW,500VAR through a series injection transformer of 1:1, 15 KVA , star/open connected .The output of three phase inverter bridge of 3-arm ,6 pulse is given to filter circuit to reduce the harmonics in the supply before injection into the line.

V. SIMULATION RESULTS

In MALTAB/SIMULINK, the source side voltage has voltage sag and swell of some value for the duration of 0.3 to 0.6 second. When the DVR comes in operating condition then voltage sag and swell are mitigated also DVR has additional feature that the Total Harmonic Distortion (THD) gets minimized to certain desired level as shown in below.

(A).PWM based DVR Results-

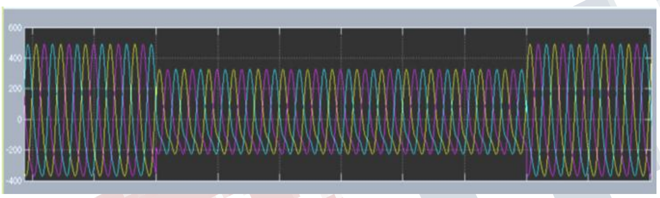

Fig.6. Load side voltage sag without DVR

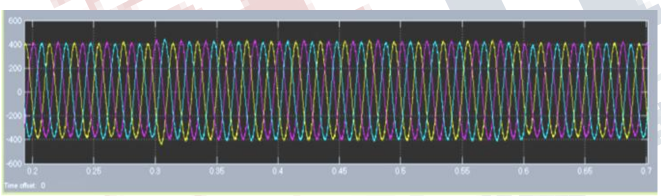

Fig.7. Load side voltage with DVR

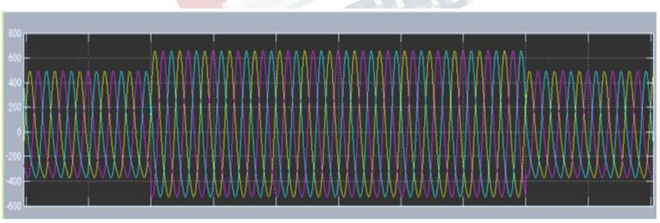

Fig.8. Load side voltage swells without DVR

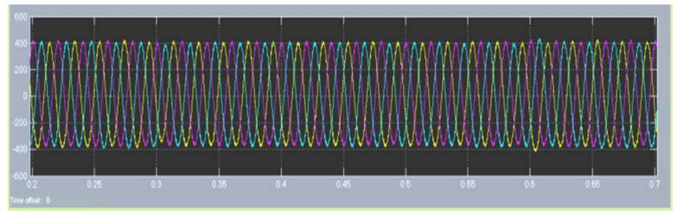

Fig.9. Load side voltage with DVR

(B) FFT Analysis of PWM control

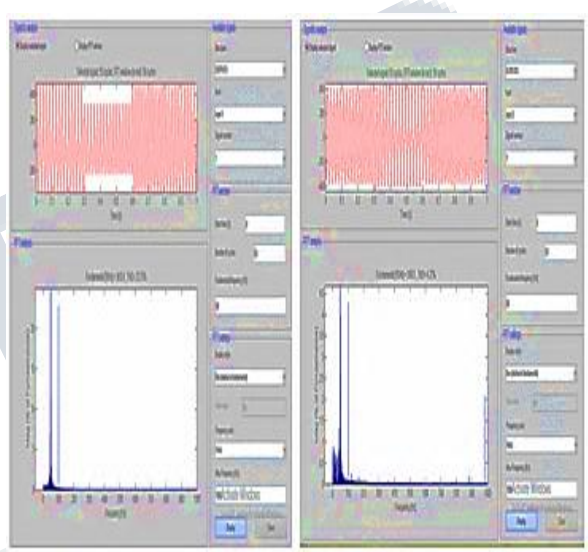

Fig.10. FFT Analysis of PWM control

(C).SPWM based DVR Results-

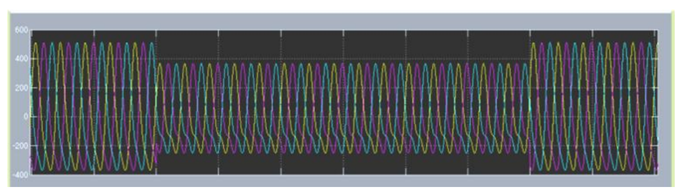

Fig.11. Load side voltage sag without DVR

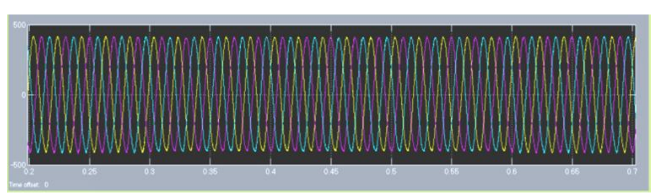

Fig.12. Load side voltage with DVR

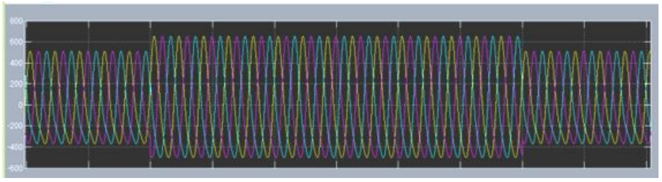

Fig.13. Load side voltage swells without DVR

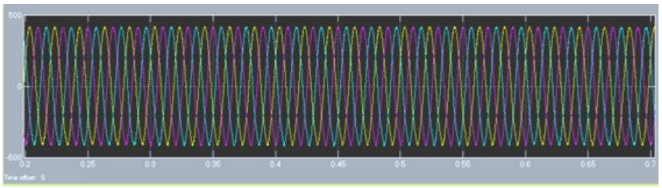

Fig.14. Load side voltage with DVR

(D) FFT Analysis of SPWM Control

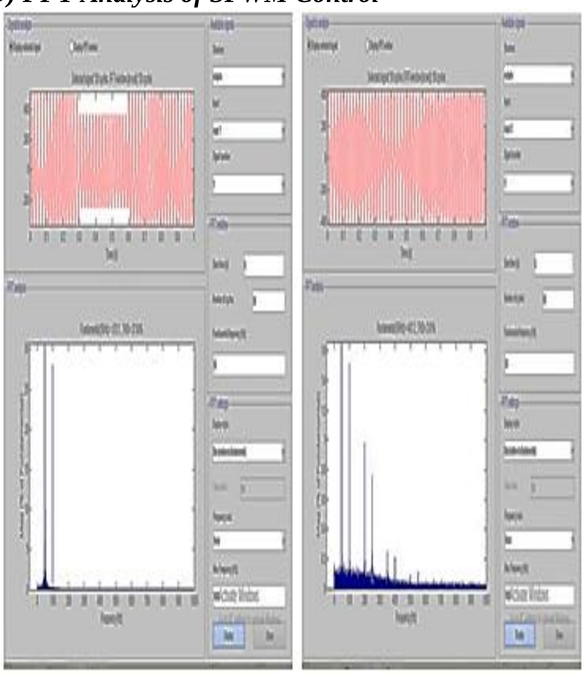

Fig.15. FFT Analysis of SPWM Control

VI. COMPARISON OF CONTROL METHODS

By using MATLAB/SIMULINK we are going to compare the PWM and SPWM method used for DVR control for same load connected in both the cases. A definite and perfect solution for DVR control is given by this comparative study.

Sr No.	Parameters	PWM Method	SPWM Method
1	Load	30KW,500 VAR	30KW,500VAR
2	Injection transformer rating required	1:1 , 20 KVA	1:1 , ,15 KVA
3	DC link voltage	800 V	500 V
4	Voltage profile improvement	Good	Very good
5	%THD (Sag)	4.27	2.01
6	%THD (Swell)	4.35	2.60

Table-3

VII. CONCLUSION

In this paper the design of DVR with PWM and SPWMcontrol strategy has been carried out in MATLAB/SIMULINK. The proposed DVR is able to protect the critical loads in distribution network**.** The performance of dynamic voltage restorer is satisfactory regarding to both the PWM and SPWM technique against voltage sag and swell. Voltage profile of loads are shown in above figure and the simulation is carried by using MATLAB/SIMULINK.The performance of DVR with PWM control strategy with reference to the voltage is good for mitigation of sag and swell. But as compaired to SPWM PWM has certain drawbacks which can be overcome by SPWM control strategy. In SPWM the accuracy is obtained by getting the error signal which will able to mitigate voltage sag and swell. In the above proposed technique we have observed that the Total Harmonic Distortion is less in SPWM as compaired with PWM control. The DVR has capability to injects the appropriate voltage component whether it may be positive or negative which will convert unbalancing condition to balancing conditions.

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