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Editorial Board

Title

A NEW PROPOSAL FOR VOLTAGE REGULATION MULTI FEEDERS/MULTIBUS SYSTEMS USING MC-DVR

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ABSTRACT:

This paper presents a new voltage regulation system multi converter dynamic voltage restorer (MC-DVR), capable of simultaneous compensation for voltage in Multibus/multifeeder systems. In this configuration two voltage-source converters (VSC) exist. The system can be applied to adjacent feeders to compensate for supply-voltage on the main feeder and full compensation of supply- voltage imperfections on the other feeders. In the proposed configuration, all converters are connected back to back on the dc side and share a common dc-link capacitor. Therefore, power can be transferred from one feeder to adjacent feeders to compensate for sag. The performance of the MC-DVR as well as the adopted control algorithm is illustrated by simulation. The results obtained in MATLAB/SIMULINK on a two-bus/two-feeder system show the effectiveness of the proposed configuration.

Keywords: Power quality, Distribution feeder, Custom power device, MC-DVR, Voltage sag, VSC, DVR.

1. INTRODUCTION:

Power quality is certainly a major concern in the present era; it becomes especially important with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply. Modern industrial processes are based on a large amount of electronic devices such as programmable logic controllers and adjustable speed drives. The electronic devices are very sensitive to disturbances [1] and thus industrial loads become less tolerant to power quality problems such as voltage dips, voltage sags, and harmonics.

In order to meet PQ standard limits, it may be necessary to include some sort of compensation. Modern solutions can be found in the form of active rectification or active filtering [2]. A shunt active power filter is suitable for the suppression of negative load influence on the supply network, but if there are supply voltage imperfections, a series active power filter

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In recent years, solutions based on flexible ac transmission systems (FACTS) have appeared. The application of FACTS concepts in distribution systems has resulted in a new generation of compensating devices. Custom power devices which are based on the voltage source converter (VSC) are mainly used for active filtering; load balancing, power factor correction and voltage regulation in distribution systems. The devices such as distribution static compensator (DSTATCOM), the dynamic voltage restorer (DVR) and the unified power quality conditioner (UPQC) have already been discussed extensively in [3-6]. A DSTATCOM is connected in shunt with the distribution feeder to protect the utility from the ration of compensating devices. Custom power devices which are based on the voltage source converter (VSC) are mainly used for active filtering; load balancing, power factor correction and voltage regulation in distribution systems. The devices such as distribution static compensator (DSTATCOM), the dynamic voltage restorer (DVR) and the unified power quality conditioner (UPQC) have already been discussed extensively in [3-6]. A DSTATCOM is connected in shunt with the distribution feeder to protect the utility from the ill effects of the loads and a DVR is connected in series to protect a sensitive load from disturbances in the source. A UPQC combines the functions of the DSTATCOM and the DVR in one unit, backed by common dc energy storage e.g,

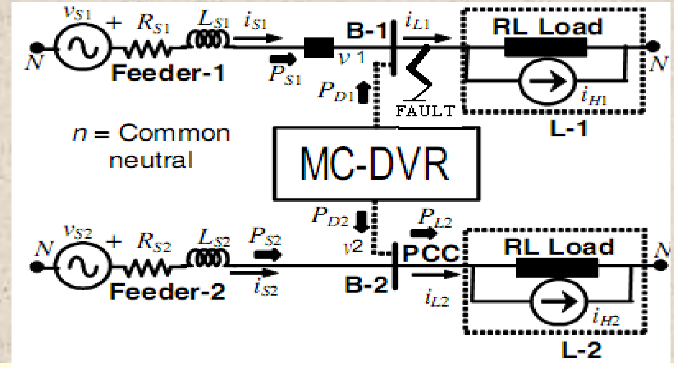


Fig. 1. Single line diagram of MC-DVR connected distribution system.

A capacitor. The UPQC consists of two VSCs. One of the VSCs is connected in series with a distribution feeder, while the other one is connected in shunt with the same feeder. These devices are placed on a single feeder.

This paper presents interline custom power devices can be connected between two neighboring feeders. In an interline custom power device, the two VSCs are connected back-to-back through a common dc capacitor to two neighboring feeders. These devices can be of series-series, shunt-shunt or series- shunt type. The advantage of these devices is that they can absorb power from one feeder and pass on to the other feeder in case of voltage sag or fault in the latter. An MC-DVR consists of two DVRs connected to different distribution feeders in the power distribution system. One of the DVRs compensates for the voltage sag while the other DVR maintains the dc link voltage to a specific level by absorbing real power from the ac system. A single line diagram of an MC-DVR connected to two parallel feeders is shown in Fig.1. Two feeders, Feeder-1 and Feeder-2, of 11 kV (L-L, rms) each with different impedances coming from different sources are sup- plying power to loads L-1 and L-2. A three-phase four-wire distribution system has been considered here. Both the loads are assumed to have two separate components - an unbalanced RL part and a non-linear part. The PCC terminal voltages of the two lines are indicated as v_1 and v_2. In between the feeders, the MC-DVR device has been connected. Various powers flowing in the system are also indicated in Fig.1. The MC-DVR consists of two shunt VSCs connected to different feeders through a common dc link. The main aim of the MC-DVR is to control or regulate the PCC bus volt- ages of the two feeders to pre-specified magnitudes.

This paper explores the operating principles and control characteristics of the MC-DVR. It will be demonstrated that bi-directional power flow between the two feeders is possible. This can be accomplished by supplying power from one feeder to the other load (and vice versa) through the common dc capacitor. A new bus voltage angle control strategy [9] has been proposed such that the voltage across the common dc capacitor remains constant. The limits of achievable performance of the MC-DVR have been computed. The performance of the MC-DVR has been evaluated through simulation studies using MATLAB/SIMULINK.

2. SYSTEM REPRESENTION:

The most usual application of a DVR is to protect sensitive loads from the effects voltage dips. A dip is usually taken as an event lasting less than one minute while the voltage decreases to between 0.1 and 0.9p.u. A DVR consists of a VSC placed in series with the load (via an injection transformer for higher voltages), which is controlled to inject a voltage in series with a depleted supply voltage to maintain the load voltage at a constant value. The DVR is a powerful controller that is commonly used for voltage sags mitigation at the point of connection. The DVR employs the same blocks as the D-STATCOM; but in this application the coupling transformer is connected in series with the ac system The VSC generates a three- phase ac output voltage which is controllable in phase and magnitude. These voltages are injected into the ac distribution system in order to maintain the load voltage at the desired voltage reference.

The converter generates the reactive power needed while the active power is taken from the energy storage. The energy storage can be different depending on the needs of compensating. The DVR often has limitations on the depth and duration of the voltage dip that it can compensate. Therefore right sized has to be used in order to achieve the desired protection. Options available for energy storage during voltage dips are conventional capacitors for very short durations but deep, batteries for longer but less severe magnitude drops and super capacitors in between. There are also other combinations and configurations possible. There are configurations, which can work without any energy storage, and they inject a lagging voltage with the load current. There are also different approaches on what to inject to obtain the most powerful solution. The main advantage with this method is that a single DVR can be installed to protect the whole plant (a few MVA) as well as single loads. Because of the fast switches, usually IGBT's, voltage compensation can be achieved in less than half a cycle [10]. Disadvantages are that it is relatively expensive and it only mitigates voltage dips from outside the site. The cost of a DVR mainly depends on the power rating and the energy storage capacity. The MC-DVR indicated in Fig. 1 consists of two shunt VSCs (VSC-1 and VSC-2) that are connected back to back through a common energy storage dc capacitor C_{dc}. Each of the VSCs is realized by three level inverters. The complete structure of a three-phase MC-DVR with two such VSCs is shown in Fig. 2.

The VSCs are connected in shunt with PCC buses B-1and B-2. The output of each three level inverter is connected to a single-phase transformer. One of the secondary terminals of each transformer is connected in shunt with the respective phase of the PCC bus. The other terminals of the secondary windings of each transformer are connected to the common load neutral N. The ac filter capacitors C_{F1} and C_{F2} are also connected at the PCC in each phase to prevent the flow of the harmonic currents into the distribution system generated due to switching. The VSCs are operated such that each of the PCC bus voltages are regulated. In Fig.3 represents the single line diagram of a DVR

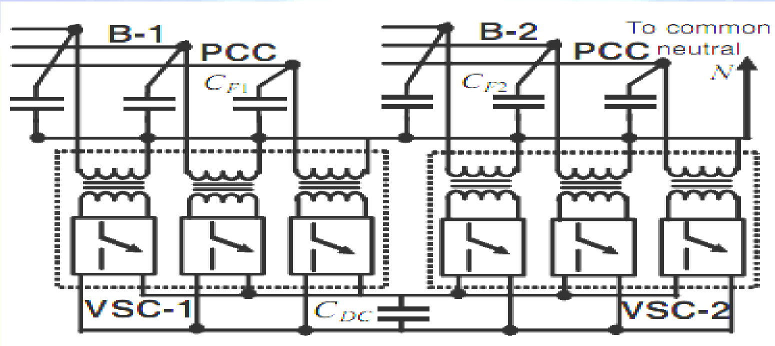


Fig. 2. The complete structure of an MC-DVR.

The circuit on left hand side of the DVR represents the Thevenin equivalent circuit of the system. The system impedance Z_{th} depends on the fault level of the load bus. When the system voltage (Vth) drops, the DVR injects a series voltage V_{DVR} through the injection transformer so that the desired load voltage magnitude V_L can be maintained [11].

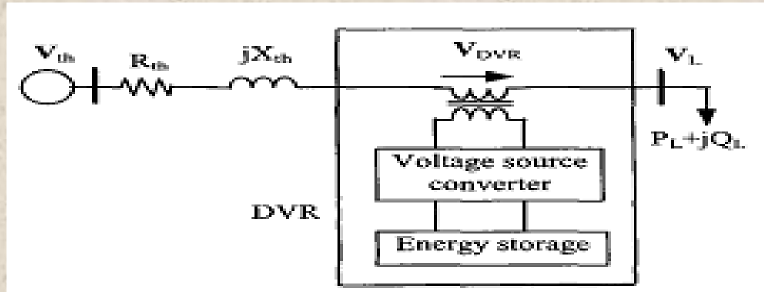


Fig. 3. The Schematic diagram of a Single Bus DVR

The series injected voltage of the DVR can be written as,

$$V_{DVR} = V_{TH} + Z_{TH}\, I_L - V_L \qquad (1)$$

V_L is the desired load voltage magnitude

V_{TH} is the system voltage during fault condition

Z_{TH} is the load impedance

I_L is the load current

The load current (I_L) given by

$$I_L = \left(\frac{P+JQ}{V_L}\right)^* \qquad (2)$$

When V_L is considered as a reference, eqn. (1) can be rewritten as,

$$V_{DVR}\angle\delta = V_L\angle 0 + Z_{TH}\, I_L\angle(\beta-\theta) - V_{TH}\angle\delta \qquad (3)$$

Here α, β and δ are the angle of V_{DVR}, Z_{TH} and V_{TH} respectively, and θ is load power factor angle,

$\theta = \tan^{-1}(P/Q)$.

The complex power injection of the DVR can be written as,

$$S_{DVR} = V_{DVR} I_L^* \qquad (4)$$

It may be mentioned here that when the injected voltage V_{DVR} is kept in quadrature with I_L, no active power by the DVR required correcting the voltage. It requires the injection of only reactive power and the DVR itself is capable of generating the reactive power. Note that DVR can be kept in quadrature with $I_L$only up to a certain value of voltage sag and beyond which the quadrature relationship cannot be maintained to correct the voltage sag. For such a case, injection of active power into the system is essential. The injected active power must be provided by the energy storage system of the DVR.

3. Control Strategy:

The aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. The control system only measures the rms voltage at the load point, i.e., no reactive power measurements are required. The VSC switching strategy is based on a sinusoidal PWM technique which offers simplicity and good response. Since custom power is a relatively low-power application, PWM methods offer a more flexible option than the Fundamental Frequency Switching (FFS) methods favored in FACTS applications. Besides, high switching frequencies can be used to improve on the efficiency of the converter, without incurring significant switching losses.

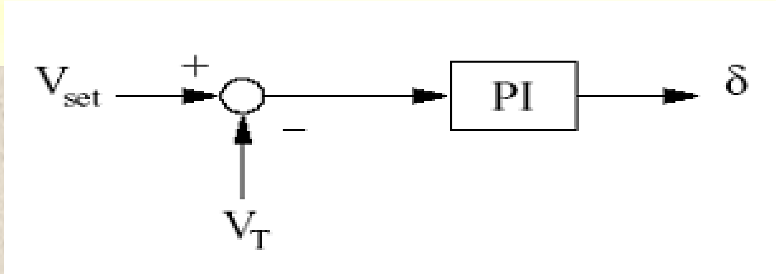


Fig. 4. Indirect Controller

In fig .4 shows that the controller input is an error signal obtained from the reference voltage and the value rms of the terminal voltage measured. Such error is processed by a PI controller and the output is the angle d, which is provided to the PWM signal generator. It is important to note that in this case, indirectly controlled converter, there is active and reactive power exchange with the network simultaneously: an error signal is obtained by comparing the reference voltage with the rms voltage measured at the load point. The PIcontroller process the error signal and generates the required angle to drive the error to zero, i.e., the load rms voltage is brought back to the reference voltage.

The sinusoidal signal $V_{CONTROL}$ is phase-modulated by means of the angle δ.

i.e.

$$V_A = \sin(\omega t + \delta)$$

$$V_B = \sin(\omega t + \delta - 120°)$$

$$V_C = \sin(\omega t + \delta + 120°) \quad (5)$$

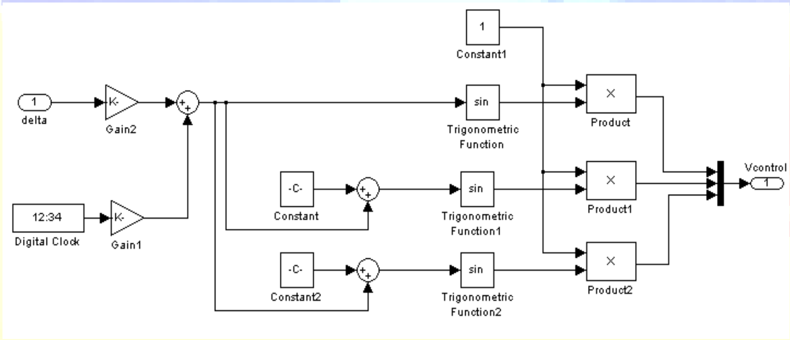
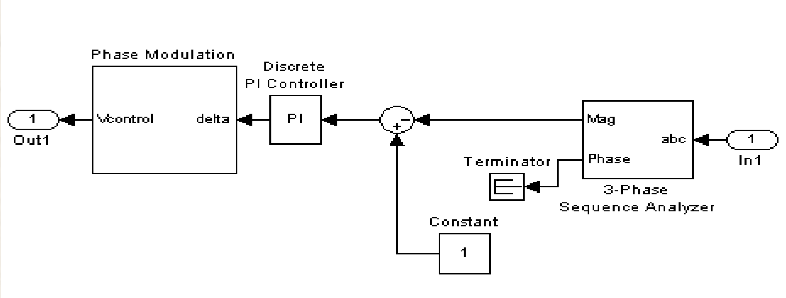


Fig. 5. The sinusoidal signal $V_{CONTROL}$

The modulated signal $V_{CONTROL}$ is compared against a triangular signal (carrier) in order to generate the switching signals for the VSC valves. The main parameters of the sinusoidal PWM scheme are the amplitude modulation index of signal, and the frequency modulation index of the triangular signal. The amplitude index is kept fixed at 1 p.u, in order to obtain the highest fundamental voltage component at the controller output.



Where

$V_{CONTROL}$ is the peak amplitude of the control signal V_{Tri} is the peak amplitude of the triangular signal the switching frequency is set at 450 Hz. The frequency modulation index is given by;

$$M_a = \frac{V_{CONTROL}}{V_{TRI}} = \text{I p.u}$$

$$M_f = \frac{f_x}{f_1} = 9 \qquad (6)$$

Where f_1 is fundamental frequency

The modulating angle is applied to the PWM generators in phase A. The angles for phases B and C are shifted by 240° and 120° respectively. It can be seen in that the control implementation is kept very simple by using only voltage measurements as the feedback variable in the control scheme. The speed of response and robustness of the control scheme are clearly shown in the simulation results. The Simulink block diagram of SPWM generator is as shown in fig.6

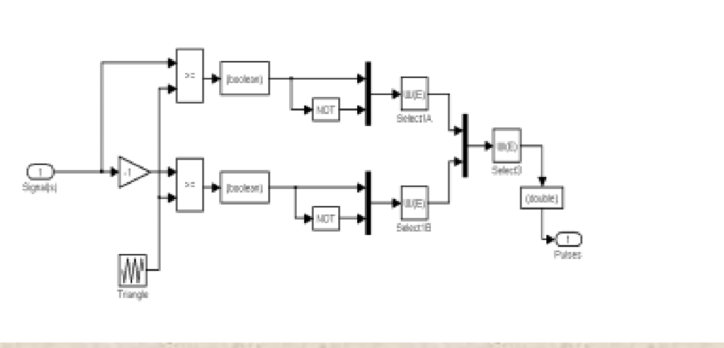


Fig.6.The Simulink block diagram of SPWM generator

4. SYSTEM MODELING:

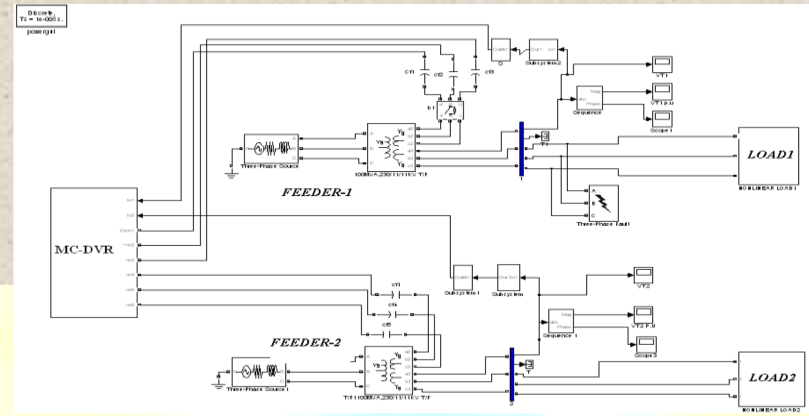


Fig.7.The Simulink block diagram of MC-DVR connected distribution system

With respect of Fig. 7, the feeder impedances are denoted by the pairs (R_1, $L1$) and ($R2$, L_2). The aim of the MC-DVR is to regulate the PCC bus voltages V_{T1}andV_{T2} to a prespecified magnitude against voltage sag/swell and/or disturbances in the system. The distribution system parameters used in the study are given in Table I.

TABLE I

System Parameters	Values
System frequency (f)	60HZ
Rated voltage	230KV
Voltage source v_{S1}	230KV,Phase angle 0^0
Voltage source v_{S2}	230KV,Phase angle 0^0
Feeder-1	0.1+j0.758Ω
Feeder-2	0.1+j0.758Ω
Load-1	A three-phase diode bridge rectifier with an resistor (500) Ω
Load-2	A three-phase diode bridge rectifier with an resistor (500) Ω

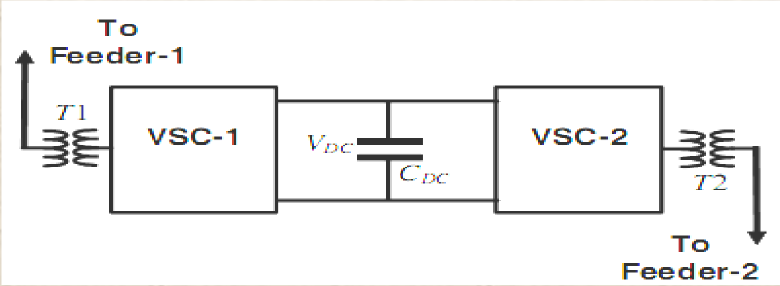


Fig.8.The Schematic diagram of MC-DVR

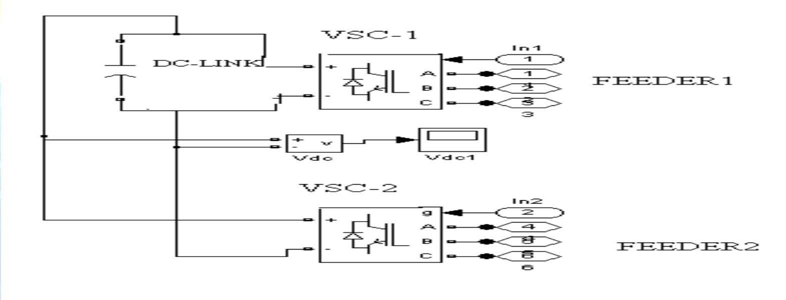


Fig.9.The Simulink converters block diagram of MC-DVR

MC-DVR PARAMETERS

TABLE II

System Parameters	Values
System frequency (f)	6oHZ
VSC-1 single-phase transformers ($T1$)	100MVA,230KV/11KV, 2% resistance and 8% leakage Reactance
VSC-2 single-phase transformers ($T2$)	100MVA,230KV/11KV, 2% resistance and 8% leakage Reactance

5. SIMULATION RESULTS:

A three-phase four-wire distribution system behavior without MC-DVR has been shown in fig. 10. The three-phase PCC bus voltages, VT1, V_{T2} and load currents I_{L1} and I_{L2} of the loads L_1 and L_2 respectively shown in below fig. 7.

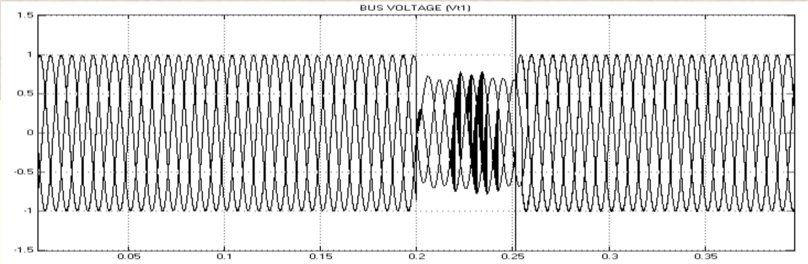


Fig. 10a. The three-phase PCC bus voltage, V_{T1}

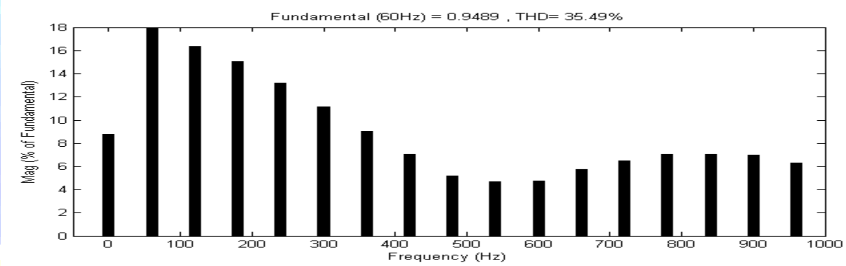


Fig. 10b. Total Harmonic Distortions(THD) at feeder1

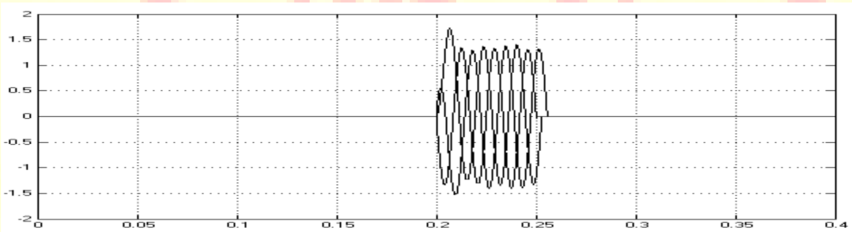


Fig. 10c. The three-phase Load Current, I_{L1}

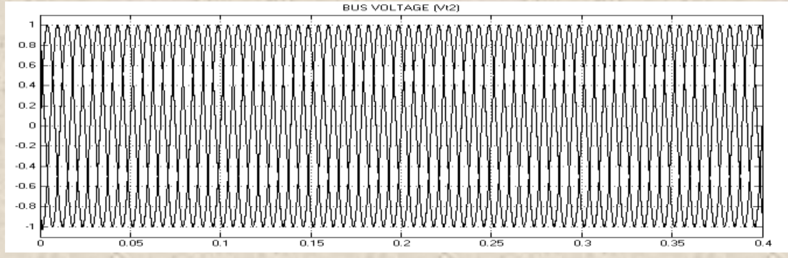


Fig. 10d. The three-phase PCC bus voltage, V_{T2}

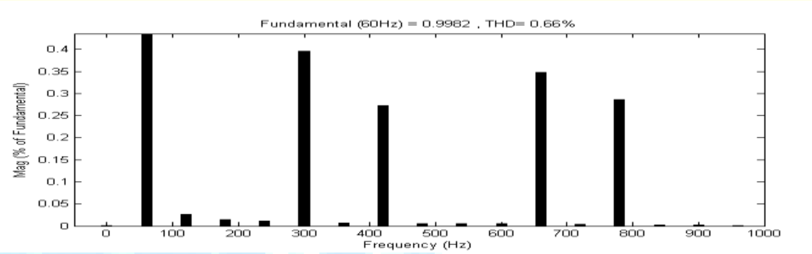


Fig. 10.d. Total Harmonic Distortions(THD) at feeder2

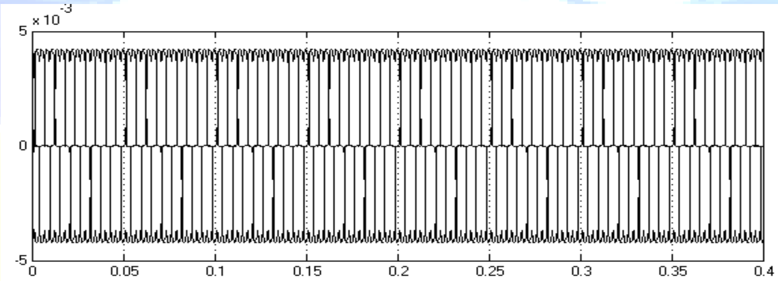


Fig. 10e. The three-phase Load Current, I_{L2}

A three-phase four-wire distribution system behavior with MC-DVR, The aim of the MC-DVR is to regulate the two voltages, V_{T1}, and V_{T2} to their reference magnitudes V_{REF1} and V_{REF2} respectively.

Case A: Voltage Sag in Feeder-1

With the system operating in the steady state the *Feeder-1* is subjected to deep voltage sag at 0.2s-0.25s(50ms) in which the supply voltage is reduced 60% nominal voltage and THD is 35.49% the system voltages in fig.10.a and 10.b

The voltage sag in *Feeder-1* limits its ability to supply the required power to the load L-1 and as a result of the control action, additional power is routed by the MC-DVR from *Feeder-2* into the load L-1and THD in feeder is 0.11%. It should be observed from Fig.12 and Table III.

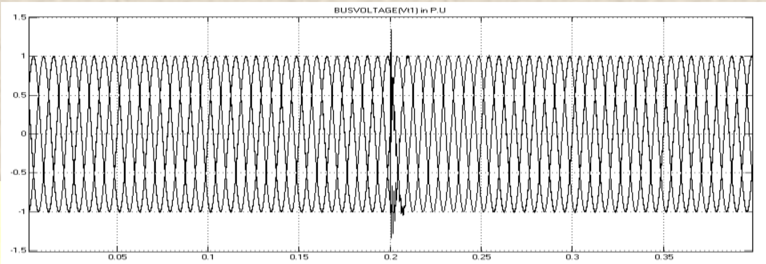


Fig.12a The three-phase PCC bus voltage, V_{T1} with MC-DVR

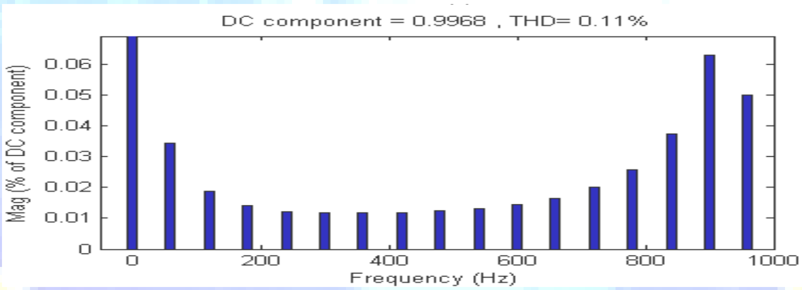


Fig.12b. Total Harmonic Distortions at feeder1 with MC-DVR

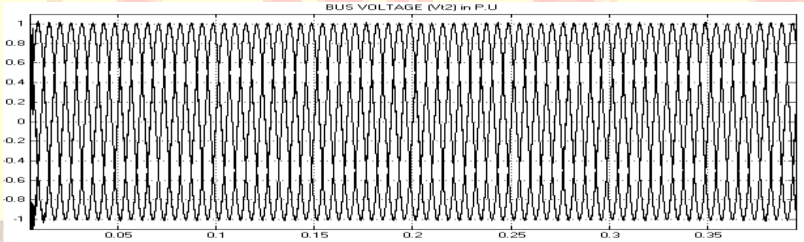


Fig. 12.c. The three-phase PCC bus voltage, V_{T2} with MC-DVR

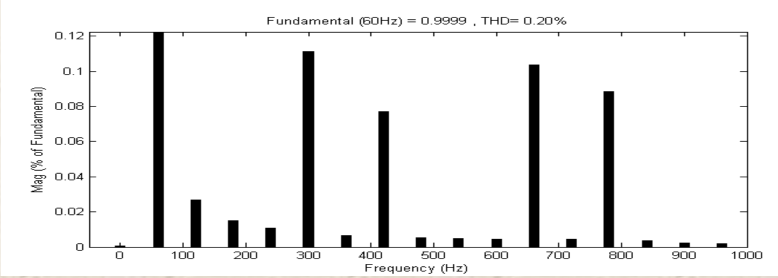


Fig.12.d. Total Harmonic Distortions (THD) at feeder2 with MC-DVR

III. RESULT TABLE

System observations	*% THD*	*Bus Voltages In P.U*
Without Controller Feeder -1	35.49	0.761
With Controller Feeder-1	0.11	0.999
Without Controller Feeder -2	0.66	1.000
With Controller Feeder -2	0.20	1.001

Similar simulation studies have been performed in case of a deep voltage sag in *Feeder-2*

Case B: Voltage Sag in Feeder-2

With the system operating in the steady state, the *Feeder-2* is subjected to deep voltage sag at 0.15s-0.2s(50ms) in which the supply voltage is reduced 42% nominal voltage and THD 37.03%.The system voltages in fig.13.a and 13.b

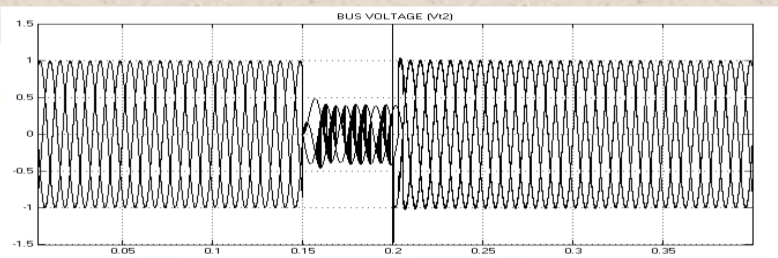


Fig.13.a The three-phase PCC bus voltage, V_{T2} without MC-DVR

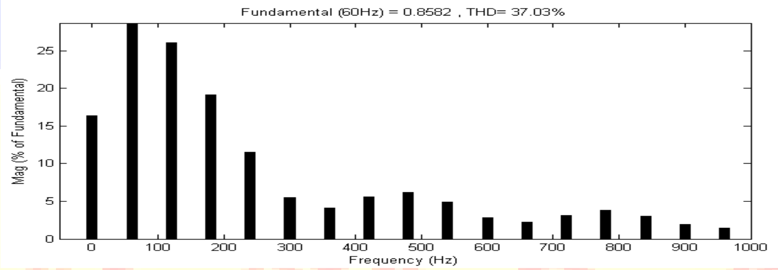


Fig. 13.b. Total Harmonic Distortions (THD) at feeder2

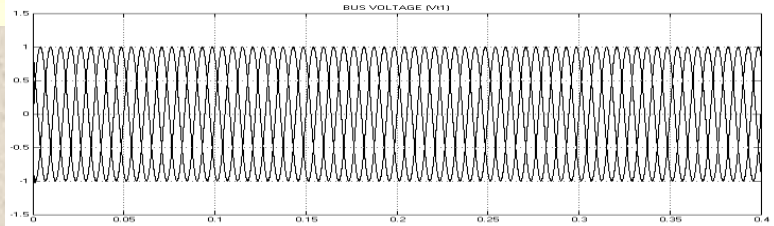


Fig.13c.The three-phase PCC bus voltage at, V_{T1} without MC-DVR

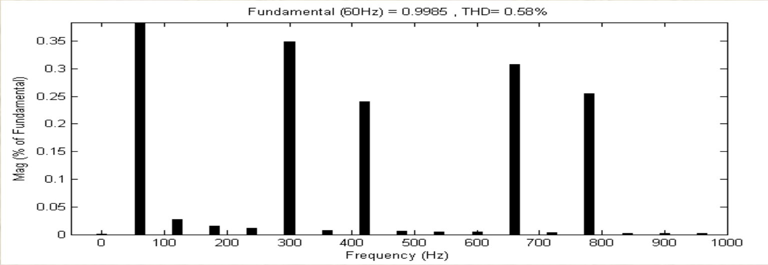


Fig. 13.d. Total Harmonic Distortions (THD) at feeder1

The voltage sag in *Feeder-2* limits its ability to supply the required power to the load L-2. And as a result of the control action, additional power is routed by the MC-DVR from *Feeder-2* into the load L-1 and THD is 2.45%. It should be observed from Fig. 14 and Table IV

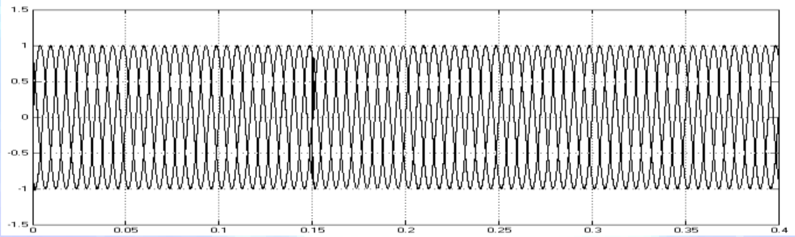


Fig.14a. The three-phase PCC bus voltage, V_{T2} *with MC-DVR*

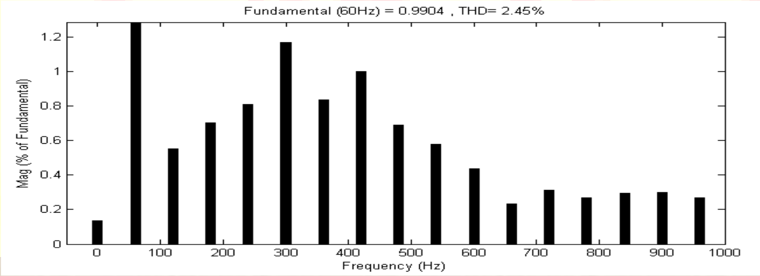


Fig.14a. Total Harmonic Distortions at feeder2 with MC-DVR

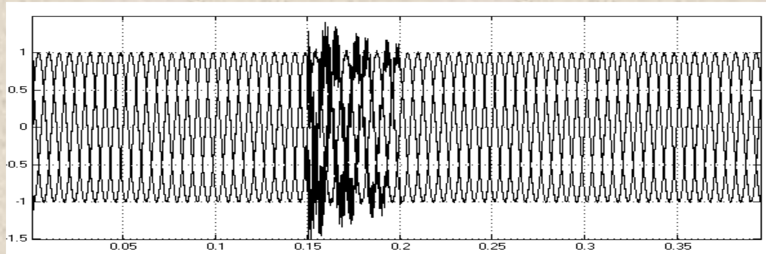


Fig.13.c. the three-phase PCC bus voltage at, V_{T1} with MC-DVR

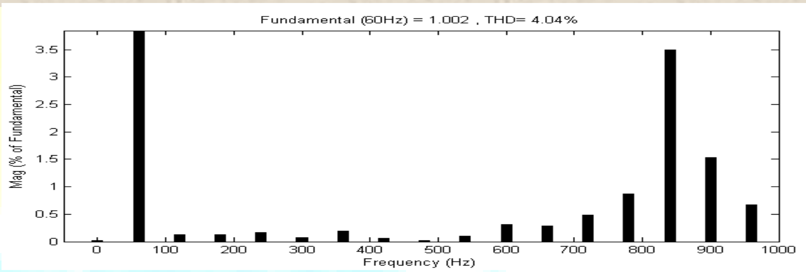


Fig.13.d. Total Harmonic Distortions (THD) at feeder2 with MC-DVR

CASE-B TEST RESULT

TABLE IV

System observations	% THD	Bus Voltages In P.U
Without Controller Feeder -1	37.03	0.621
With Controller Feeder-1	2.45	0.994
Without Controller Feeder -2	0.66	1.000
With Controller Feeder -2	0.20	1.002

6. CONCLUSIONS:

The paper presents voltage regulation in parallel distribution feeders by using multi converter dynamic voltage restorer (MC-DVR). The MC-DVR is connected in shunt between two parallel feeders coming from different substations. Two non-linear loads L-1 and L-2 are supplied by the two feeders. The phase angles of the PCC bus voltages are obtained such that the voltage across the dc link remains constant. The performance of the MC-DVR has been evaluated under the disturbance conditions such as voltage sags in either feeder. It has been demonstrated that bi-directional power flow between the two feeders is possible. This can be accomplished by supplying power from one feeder in case of deep voltage sag in the other feeder and vice versa.

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