Enhancement of Power Quality for 11-Bus Distribution Systems through Incorporating of DVR-Ultra Capacitor

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Abstract : Power Quality is the major concern in case of sensitive loads that are present in distribution system. In this paper, a new idea is presented to improve the power quality under sag,swell and harmonic condition, when the system connected to DVR-Ultra capacitor. The compensation capability of a dynamic voltage restorer depends on the maximum voltage injection ability and the amount of stored energy available within the restorer. Ultra capacitor has low energy density and high power density ideal characteristics for compensation of voltage sag/swell, which are both events that require high power for short span of time. The proposed system has active power capability and will be able to independently compensate temporary voltage sags ,swells and harmonics without relying on the grid to compensate for faults on the grid with less time period. The behavior of device is tested to 11-bus distribution system under a choice of loadings and verified through MATLAB/Simulink software.

IndexTerms – Power quality, d–q control, Dynamic Voltage Restorer (DVR), Ultra capacitor (UCAP), PI controller.

I. INTRODUCTION

In power system customer side susceptible loads day by day increased, which make the issues of power quality. Faults and sudden demand variations in distribution system can provide voltage sags and swells which are power quality issues. Which may degrade the equipment performance and sometimes it damages the equipment. FACTS devices are used to improve the power quality in distribution grid like UPQC, D-STATCOM etc. The reason for demanding high quality power is machine components are designed to be very sensitive for the power supply variations. Adjustable speed drives, automation devices, power electronic components are examples for such equipments. Failure to provide the required quality power output may sometimes cause complete shutdown of the industries. In [1], the authors proposed the usage of the DVR with rechargeable energy storage at the dc-terminal to meet the active power requirements of the grid during voltage disturbances. In order to avoid and minimize the active power injection into the grid, and also describe an alternative solution which is to compensate for the voltage sag by inserting a lagging voltage in quadrature with the line current. Due to the high cost of rechargeable energy storage, various other types of control strategies have also been developed in the literature [2]–[8] to minimize the active power injection from the DVR. The high cost of the rechargeable energy storage prevents the penetration of the DVR as a power quality product and has been decreasing drastically in the recent past years due to various technological developments and due to higher penetration in the market in the form of auxiliary energy storage for distributed energy resources (DERs) such as wind, solar, hybrid electric vehicles (HEVs), and plug-in hybrid electric vehicle (PHEVs) [9], [10]. Therefore, there has been renewed interest in the literature [10]–[14] to integrate rechargeable energy storage again at the dc-terminal of power quality products such as static compensator (STATCOM) and DVR.DVR is a solid state power electronic device which is connected in series with the system and is used to compensate the voltage sags, swells. In distribution system integration of power quality products for finding of weak bus can perform by forward sweep and backward sweep method [15-16].

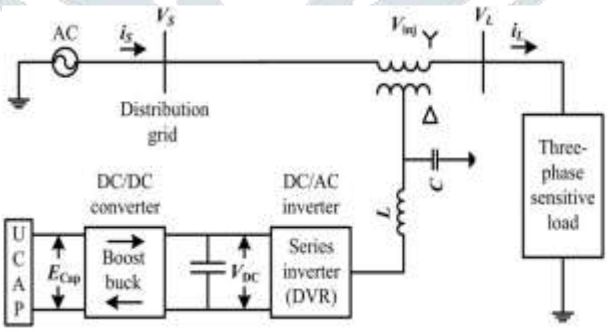

Fig.1: One line diagram of DVR with UCAP energy storage

In main theme of this work is followed by to incorporate the Ultra Capacitor to DVR system gives active power capability to the system and provides the good compensation for voltage sags , voltage swells and harmonics.

II. FORWARD AND BACKWARD SWEEP METHOD

The Forward and Backward sweep method involves the solution of simple algebraic equation in receiving end voltages. The impedance of a feeder branch is computed by the specified resistance and reactance of the conductors used in the branch construction.

Backward sweep: In this step, the load current of each node of a distribution network having N number of nodes is determined as:

$$[I]=\left[\frac{S}{V}\right]^{*}=\frac{P-jQ}{V^{*}} \tag{1}$$

Where, PL(m) and QL(m) represent the active and reactive power demand at node m and the over bar notation ($\bar{x}$) indicates the phasor quantities, such as IL ,V. Then, the current in each branch of the network is computed as:

$$\bar{I}(mn) = \overline{I_L}(n) + \sum_{m \in T} \overline{I_L}(m) \qquad (2)$$

Forward sweep: This step is used after the backward sweep so as to determine the voltage at each node of a distribution network as follows:

$$\bar{V}(n) = \bar{V}(m) - \bar{I}(mn)Z(mn) \qquad (3)$$

Where, nodes (n) and m represent the receiving and sending end nodes, respectively for the branch (mn) and Z (mn) is the impedance of the branch.

III. ULTRA CAPACITOR

Ultra Capacitor has high energy density and low power density as compared to batteries, which desirable for short duration of energy requirements. That is half cycle to one minute, life time of Ultra capacitors is also high, it is around 1,00,000 cycles. But Ultra Capacitors are not withstanding for high voltages, practically they designed for 12V, 24V, 48V which is a low voltage. Voltage rating of three phase load in LV-distribution system is 415Volts (line to line RMS value) to boost up the terminal voltage of capacitor to system level a boost converter is used, similarly to charge capacitor buck converter is used. R is equivalent series resistance; Rp is parallel resistance as shown in fig.2. Ultra Capacitor supports to system based on Time constant of discharging path. It is depends on the capacitance value, discharging path resistance and load resistance. But Ultra Capacitor having negligible resistance compared to load resistance.

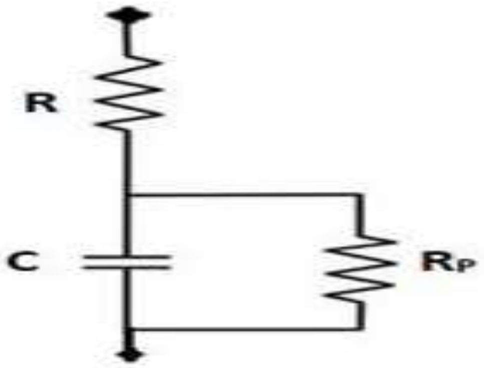

Fig.2: Equivalent circuit of Ultra Capacitor

IV. MATHEMATICAL MODELING OF COMPENSATION SCHEME AND CONTROL STRATEGY IMPLEMENTATION

The general principle of DVR is that whenever the system detects a voltage sag/swell, the DVR should react as fast as possible and inject an ac voltage into the grid. It can be implemented using the synchronous reference frame (SRF) technique based on the instantaneous values of the supply voltage. The control algorithm produces a three-phase reference voltage to the PWM inverter that tries to maintain the load voltage at its reference value. The voltage sag or swell is detected by measuring the error between the supply voltage and the reference value. The reference component is set to a rated voltage. The SRF method can be used to compensate all types of voltage disturbances, voltage sag/swell, voltage unbalance, and harmonic voltage.

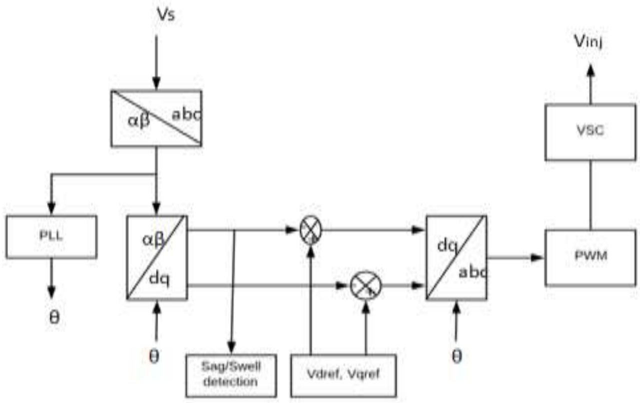

Fig.3: DVR control model

We have

$$V_d = \frac{2}{3}\left[V_a * \sin(wt) + V_b * \sin\left(wt - \frac{2\varphi}{3}\right) + V_c * \sin\left(wt + \frac{2\varphi}{3}\right)\right] \qquad (4)$$

$$V_q = \frac{2}{3}\left[V_a * \cos(wt) + V_b * \cos\left(wt - \frac{2\varphi}{3}\right) + V_c * \cos\left(wt + \frac{2\varphi}{3}\right)\right] \qquad (5)$$

$$V_o = \frac{1}{3}\left[V_a + V_b + V_c\right] \qquad (6)$$

Where w = rotation speed (rad/s) of the rotating frame
We have

$$V_a = \left[V_d * \sin(wt) + V_q * \cos(wt) + V_o\right] \tag{7}$$

$$V_b = \left[V_d * \sin\left(wt - \frac{24}{3}\right) + V_q * \cos\left(wt - \frac{24}{3}\right) + V_o\right] \tag{8}$$

$$V_c = \left[V_d * \sin\left(wt + \frac{24}{3}\right) + V_q * \cos\left(wt + \frac{24}{3}\right) + V_o\right] \tag{9}$$

The definition of proportional feedback control is

$$U = K_P e \tag{10}$$

Where
e = is the error, Kp= Proportional gain
The characterization of the essential feedback is

$$U = K_i \int_0^t e(t)dt \tag{11}$$

Where Ki =Integration gain factor
In the PI controller we have a combination of P in addition to PI control, that is

$$U = K_P e + K_i \int_0^t e(t)dt \tag{12}$$

$$U = K_P e + \frac{1}{t_i} \int_0^t e(t)dt \tag{13}$$

$$U = K_p \left(e + \frac{1}{t_i} \int_0^t e(t)dt \right) \tag{14}$$

Where Ti = Integration time, Tn = Reset time
In Proportional plus Integral Control action the actuating signal consists of proportional error signal with integral of the error signal. The block diagram is as shown in fig.1.5.

The input output relationship of PI control action when Kp = 1/t is

$$U(t) = e(t) + \frac{k_i}{t_i} \int_0^t e(t)dt \tag{15}$$

V. TEST SYSTEM

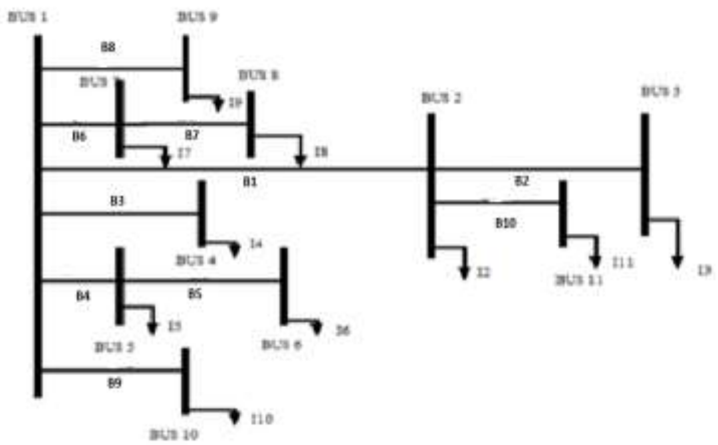

Fig.4: Single line diagram of IEEE 11 bus distribution system

Table 1.Bus data and line data of IEEE-11 bus

Bus	Real power (p.u)	Reactive power (p.u)	From	To	Resistance Ω	Reactance Ω
					(p.u)	(p.u)
1	0	0	1	2	0.04997	0.06644
2	1.22	0.916	2	3	0.02332	0.0331
3	0.032	0.024	1	4	0.04664	0.06201
4	0.778	0.584	1	5	0.02082	0.02768
5	0.673	0.595	5	6	0.025	0.03322
6	1.22	0.916	1	7	0.02665	0.03543
7	0.0488	0.0366	7	8	0.02748	0.03654
8	0.956	0.717	1	9	0.03331	0.0443
9	0.698	0.523	1	10	0.02082	0.02768
10	1.265	0.949	2	11	0.02082	0.02768
11	0.265	0.0949	-	-	-	-

VI. SIMULATION RESULTS

Table 2. Load Flows for 11-bus Distribution system

Bus No	Vbus	Ibus	Ploss	Qloss
1	1.0000	1.7701	0.0763	-0.0247
2	0.8204	0.0372	0.0356	-0.0115
3	0.8185	0.8300	0.0712	-0.0231
4	0.9208	2.1438	0.0318	-0.0103
5	0.9043	1.4152	0.0382	-0.0124
6	0.8301	1.1096	0.0407	-0.0132
7	0.9388	1.0583	0.042	-0.0136
8	0.8785	0.7260	0.0509	-0.0165
9	0.9510	1.3234	0.0318	-0.0103
10	0.9440	0.3178	0.0318	-0.0103
11	0.8100	--	--	--

At the buses 2,3,6,8 and 11 the voltage drop to 0.8 leads to voltage sag and the losses are increased for 10 iterations as mentioned in above table.2.

The proposed integrated dynamic voltage restorer-ultra capacitor design for enhancing power quality of the distribution system and its control circuit is implemented using MATLAB/ SIMULINK. Fig.4 shows the simulation model of the proposed system. The control system of the proposed system is shown in Fig.5 and output voltage waveforms are shown in following figures.

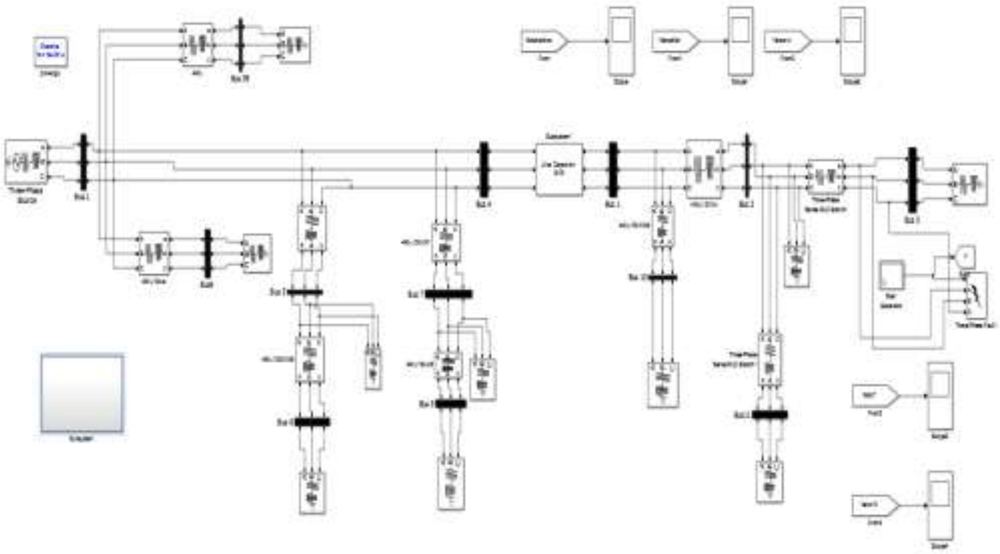

Fig.5: Simulation diagram of IEEE-11 bus system

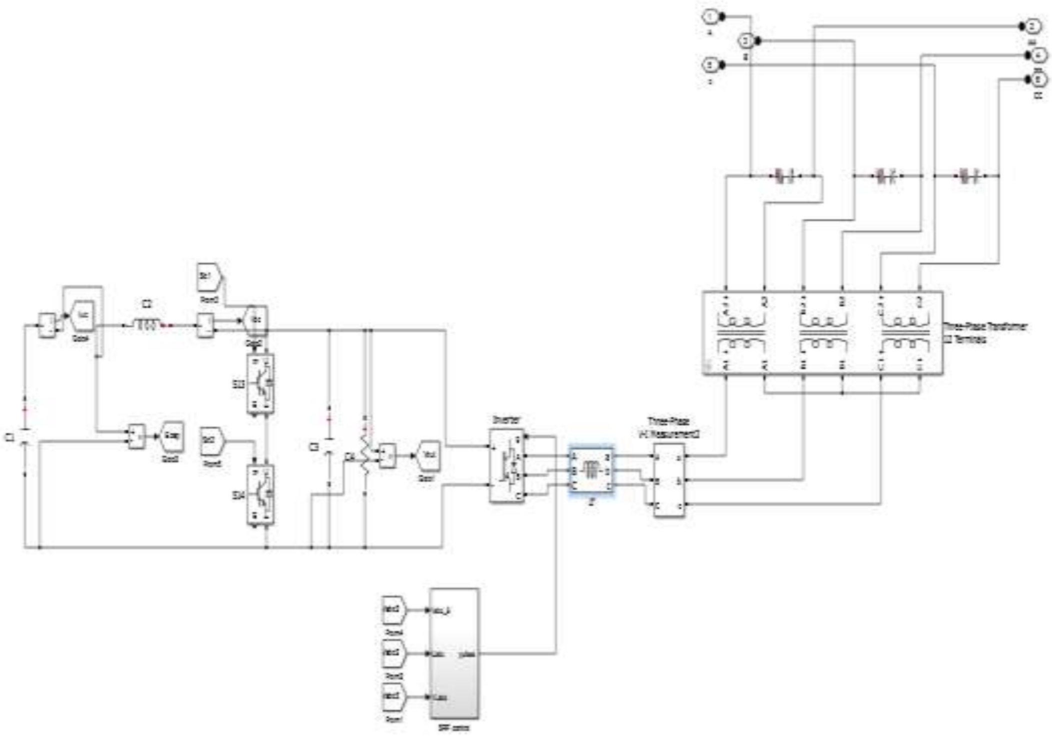

Fig.6: Simulink model for DVR-Ultra capacitor

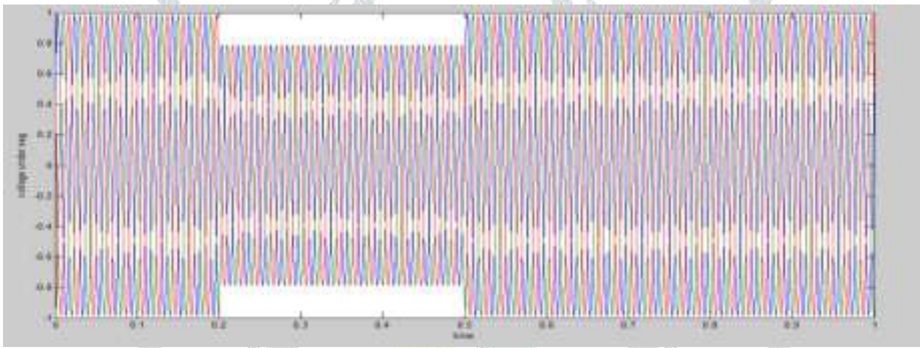

Fig.7: Voltage sag without compensation at bus-3

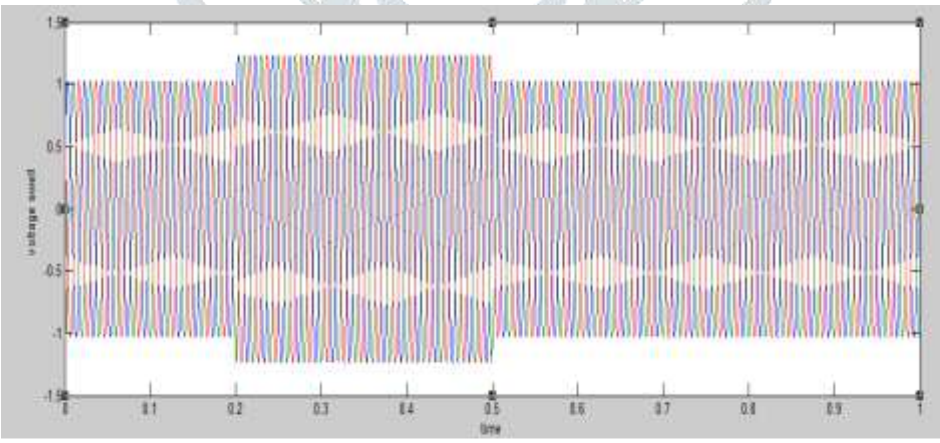

Fig.8: Voltage swell without compensation at bus-3

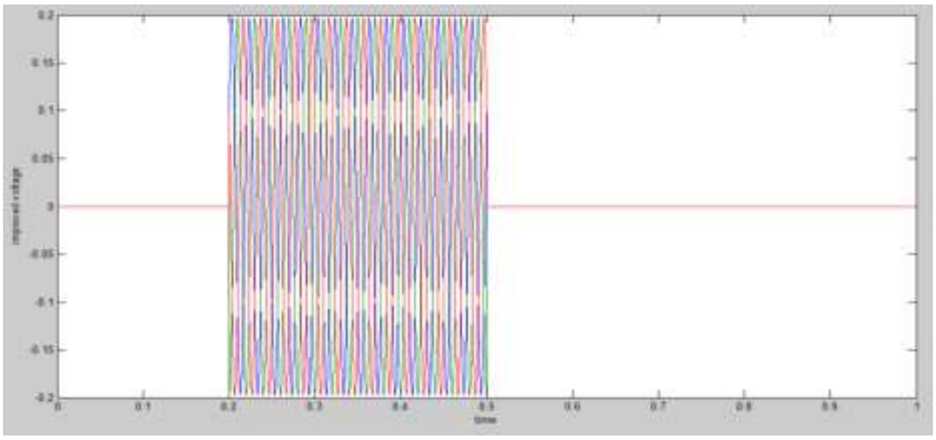

Fig.9: Injected voltage of DVR at bus-3

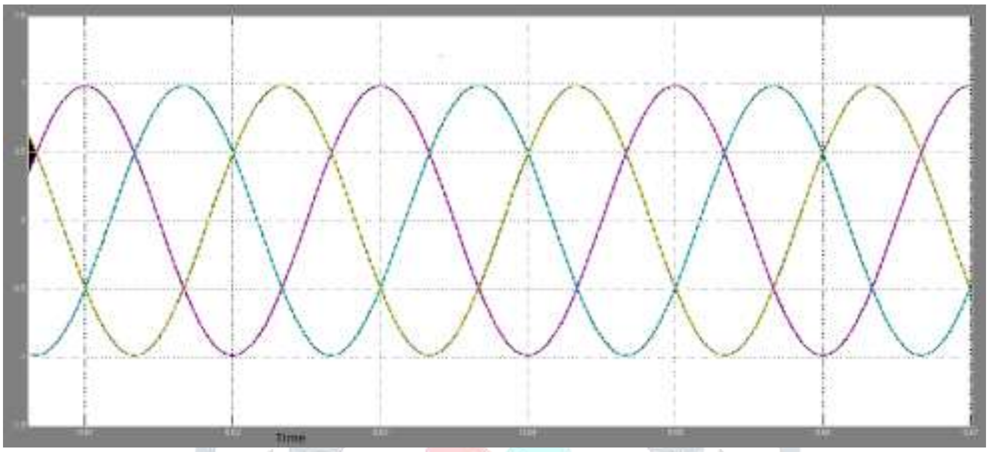

Fig.10: Output voltage Waveform with DVR-UCAP at bus-3

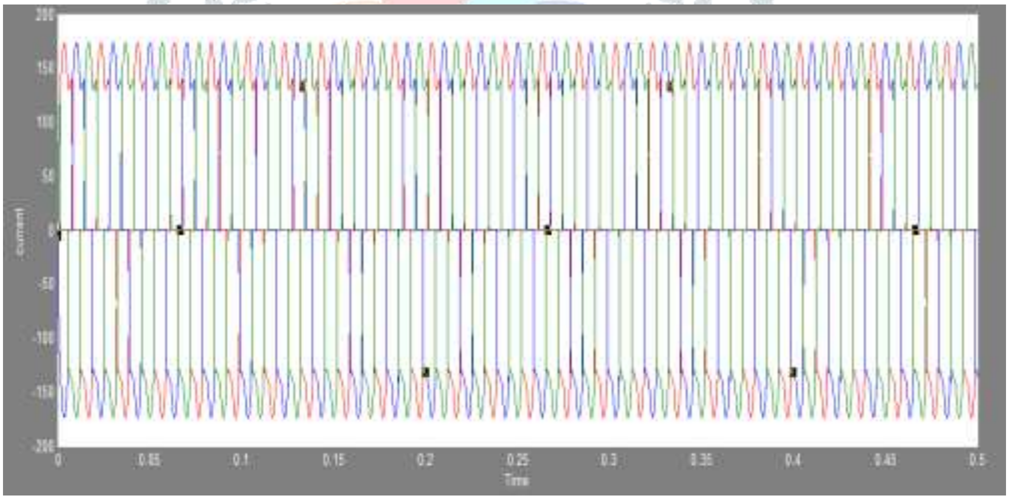

Fig.11 At bus 1 Current (Isabc) waveform of the 11 bus distribution system without DVR-UCAP

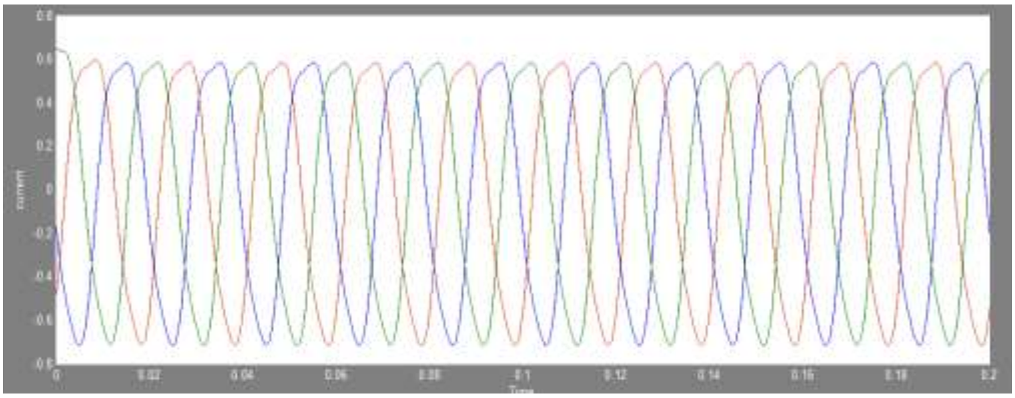

Fig.12 At bus 1 Current (Isabc) waveform of the 11 bus distribution system with DVR-UCAP

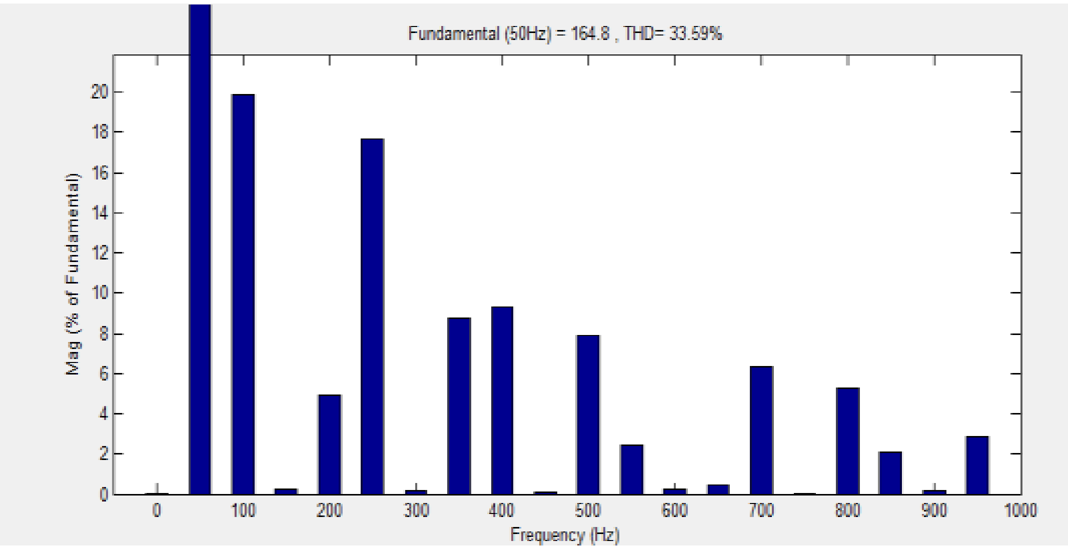

Fig .13 Total Harmonic Distortion (THD) of the bus3 Currents without DVR

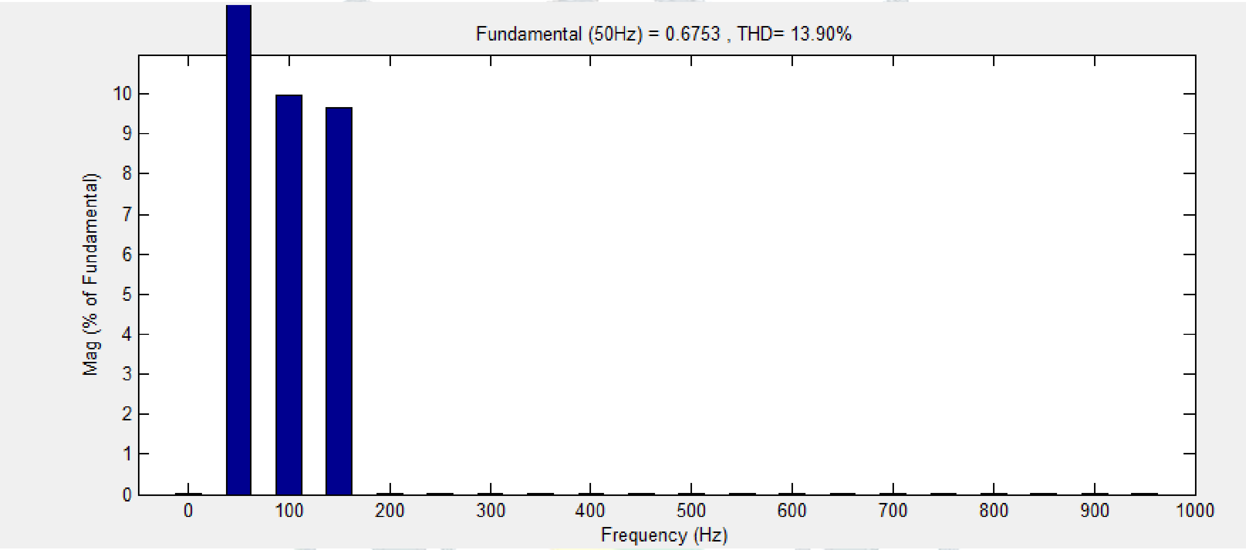

Fig.14 Total Harmonic Distortion (THD) of the bus4 Currents with DVR

From fig.13 &14 can shows the THD reduces from 33.59 to 13.9%.So,these topology used to makes the system is more reliable.

CONCLUSION:

In power system, mainly observed that to improve its voltage restoration capabilities was explored by integrating UCAP-based rechargeable energy storage to the DVR system. This system supplies the active and reactive powers to the load during sag/swell and maintains the load voltage at the rated value (1.0 p.u). The DVR will be able to independently compensate voltage sags ,swells and harmonics without relying on the grid to compensate for faults on the grid. The DVR control strategy is based on injecting voltages in-phase with the system voltage and also easier to apply when the DVR system has the ability to provide active power. The integration of DVR-UCAP the THD value of the distribution system reduces from 29.08% to 0.004% and probably the power quality enhanced.

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