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# Reduced Rating DVR & IDVR for Power Quality Enhancement using Particle Swarm Optimization Technique

KEYWORDS: Power Quality (PQ), Dynamic Voltage Restorer (DVR), Interline Dynamic Voltage Restorer (IDVR,) voltage sag, Synchronous Reference Frame (SRF) theory, Particle Swarm Optimization (PSO).

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**ABSTRACT** *One of the major concerns in electricity industry today is power quality problems to the sensitive loads. DVR is a device, used for improving the power quality (PQ) of the load voltage against voltage sags in the source voltage of three phase system. In order to maintain a balanced sinusoidal voltage at the load, DVR has to inject an amount of voltage which can be achieved using the Synchronous Reference Frame (SRF) theory. In this aspect, a method named as PSO is used to minimize VA rating of DVR. In this paper also presents operation and performance of interline dynamic voltage restorer. The proposed control strategy is validated through Simpower system tool box.*

## Introduction

Power quality problems in the distribution systems and their solutions are having much attention in the recent years due to incorporation of large number of sensitive loads and critical loads such as manufacturing processes, process industries, power electronics' based devices etc,. Apart from these loads, some system events like capacitor switching, motor starting, and faults may inflict the power quality problem. Power quality problems such as transients, sags, swells and other distortions affect the performance of these equipment pieces. In order to provide protection against power quality problems (PQ) a new technologies such as Custom Power Devices are emerged at consumer point. The problem of voltage sags are major impact on sensitive loads. The dynamic voltage is one of the custom power devices, is used for improving the power quality of the load voltage against the voltage sags.

A DVR is a Voltage Source Converter (VSC) based power electronic device. The DVR is connected in series between the supply and the loads, which are protected from the supply side abnormalities like voltage quality problems. Even though the source voltage is unbalanced and/or distorted DVR can restore a balanced sinusoidal load voltage of desired amplitude.

Now a day, researches focus on controlling the power flow of an entire line instead of portion of a line. So that to extend the DVR with the help of common dc link multi converters is connected to control the power flow of parallel lines. The basic block representation of Dynamic voltage restorer & Interline Dynamic Voltage Restorer is in figure 1&2 respectively.

In this paper, the Synchronous Reference Frame theory is used to control the DVR. It is used to generate the compensating voltages. DVR has to inject a required amount of VA into the system by using this theory in order to maintain a nominal balanced sinusoidal voltage at the load. The cost effective way of DVR is occur to minimize the VA rating of the DVR. In this aspect, a method is used in this work named as Particle swarm optimization technique (PSO). The optimal angle at which DVR voltage has to be injected in series to the line impedance so as to have minimum VA loading on DVR is computed by the PSO technique.

This paper deals with design of optimal parameters of PI controllers by using Particle Swarm Optimization (PSO) technique. The design aims is to minimize the volt-ampere (VA) loading of DVR and IDVR. In order to obtain minimum rating the optimal angle at which DVR voltage has to be injected in series to the line impedance is computed by the PSO technique.

The detailed explanation about DVR and IDVR is discussed as below sections. The control strategy for DVR and IDVR is depicted in section 2. The modeling and simulation results are presented in section 4.

## CONTROL OF DVR & IDVR

The voltage sags are compensated by injecting real or reactive power injected into the system. The DVR should not supply any real power in steady state. Because the phase difference between DVR voltages and line currents are in $90^{0.}$ Suppose the injected voltage ($V_{inj1}$ or $V_{inj2}$) is in phase with the supply voltage, the loads are not sensitive to the phase jumps which results optimum utilization of the voltage rating of DVR. The compensated voltages are obtained by using the Synchronous Reference Frame Theory (SRFT).

Fig.1. shows a control block of the DVR in which Synchronous Reference Frame Theory (SRFT) is used for generation of reference voltage signal estimation. The voltages at PCC represents $V_S$ are converted to rotating reference using Park's transformation in equation (1).

$$(f_{qd0s}) = KF_{abc} \qquad (1)$$

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$$K = \frac{2}{3}\begin{bmatrix} cos\theta & cos(\theta - \frac{2\pi}{3}) & cos(\theta + \frac{2\pi}{3}) \\ sin\theta & sin(\theta - \frac{2\pi}{3}) & sin(\theta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

By using low pass filters (LPFs) harmonics and harmonic components are eliminated and it gives dc components named as d- and q-axes. The voltage equations of d- and q-axes are

$$V_d = V_{ddc} + V_{dac} \qquad (2)$$

$$V_q = V_{qdc} + V_{qac} \qquad (3)$$

In order to maintain constant dc bus voltage a PI controller is used at dc bus voltage of the DVR. The output of the PI controller determines the amount of real voltage in to the system. The error between reference d-axis voltage and dc-link voltage will give the sag depth information. The amplitude of load voltage $V_L$ is controlled to its reference voltage $V_L^*$ using another PI controller. The load voltage is calculated as

$$V_L = [(2/3)*(V_{La}^2 + V_{Lb}^2 + V_{Lc}^2)]^{1/2} \qquad (4)$$

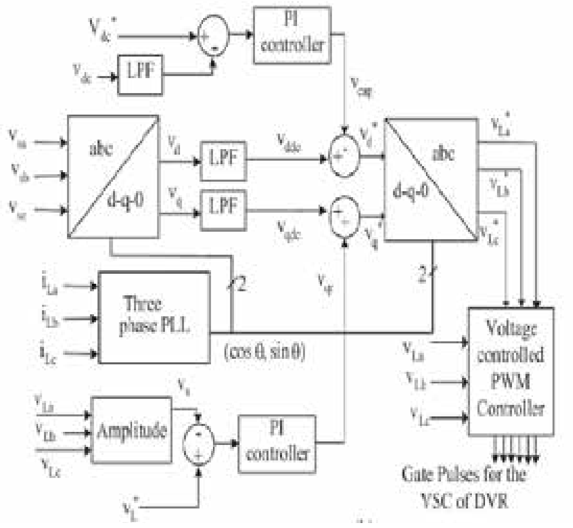

**Figure1: Control block of IDVR**

The reference load voltages ($V_{La}^*$, $V_{Lb}^*$,$V_{Lc}^*$) are obtained from the reverse parks transformation in equation (5). The error between reference load voltages ($V_{La}^*$, $V_{Lb}^*$,$V_{Lc}^*$) and actual load voltages ($V_{La}$ ,$V_{Lb}$ ,$V_{Lc}$) is used to generate gate pulses to control the VSC of DVR.

$$(F_{abc}) = K^{-1}(f_{qd0s})^T \qquad (5)$$

$$K^{-1} = \begin{bmatrix} cos\theta & sin\theta & 1 \\ cos\,(\theta - \frac{2\pi}{3}) & sin(\theta - \frac{2\pi}{3}) & 1 \\ cos\,(\theta + \frac{2\pi}{3}) & sin(\theta + \frac{2\pi}{3}) & 1 \end{bmatrix}$$

## SYSTEM CONFIGURATION

A 3-Φ, 415V, 50HZ supply with linear and DVR is developed inMATLAB/SIMULINK using Simpower system tool box.

*Design parameters of DVR & IDVR:* Design of the DVR consists of a voltage rating, current rating and KVA rating of the VSC of DVR, transformer rating, DC bus voltage and filter design is illustrated as below.

*A. Voltage rating of the VSC of DVR:* The voltage rating of VSC depends on maximum voltage to be injected under the case any voltage variations of the load. In case of self supported DVR the injected voltage is in quadrature with the load current so voltage rating of the VSC is calculated based on the load requirement. The injected voltage is estimated as;

$$V_C = \sqrt{(V_S^2 - V_L^2)} = V_{DVR}$$

*B. kVA rating of transformer*: the kVA rating of the injection transformer is same as that of the VSC rating of DVR. kVA rating of transformer is calculated as

$$S = (3V_{S*}I_S)/1000$$

*C. DC capacitor voltage:*

The DC capacitor voltage is calculated based on following relation

$$V_{dc} > 2\sqrt{2}*V_{DVR}$$

*D. DC bus capacitance of the VSC:* The DC bus capacitance is calculated based on how much of energy is required during the change in load, it is calculated as

$$E = 1/2*C_{dc}\,(V_{dc}^2 - V_{dc1}^2)$$

Where $V_{dc}$ is DC bus voltage and $V_{dc1}$ is change in bus voltage during disturbance.

$$P*\Delta t = 1/2*C_{dc}\,(V_{dc}^2 - V_{dc1}^2)$$

Where $P = 3*V_C*I_S$

*E. Ripple Filter:* In order to eliminate the switching frequency ripples from injected voltage the ripple filter is designed. Ripple filter consists a series connected $R_r$ and $C_r$. $f_r = 1/(2\,\pi\,*R_{r*}C_r)$

Where $f_r$ is taken as half of the Switching frequency. The range of switching frequency is from 5KHz – 20KHz.

**Table-1**
**Parameters of DVR**

| Parameters | Ratings |
|---|---|
| AC line voltage | 415V,50Hz |
| Line impedance | $L_s$ =3mH,$R_s$=0.01Ω |
| Ripple filter | $C_f$=10μF,$R_f$ =4.8Ω |
| DC voltage of DVR | 300V |
| PWM switching frequency | 10kHz |
| Series Transformer | 10kVA,200V/300V |

## DESIGN OF PI REGULATOR BY USING PSO

The fundamental equations that govern the design of PI regulator are presented as follows in equations (1) to (5). A mathematical model is required for the stability analysis and hence determines the parameters of PI controller. The block diagram of voltage control loop is shown in Figure 2, where G is gain of the PI controller.

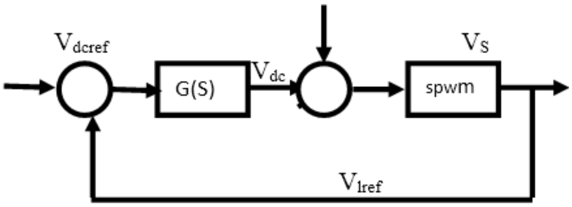

**Figure 2: Voltage control loop**

The dc-link capacitor is determined as

$$P_{dc\text{-}link} = \frac{d}{dt}(1/2*C_{dc}*V_{dc}^{2}) \qquad (6)$$

The power input to the PWM converter is

$$P_{Converter} = 3(V_{inj}*I_{sries}) \qquad (7)$$

Energy associate with the capacitor filter

$$P_{Filter} = 3[\frac{d}{dt}(1/2*C_{dc}*V_{dc}^{2})] \qquad (8)$$

The rate of change of energy is determined by using equations (6) to (8) is

$$P_{dc\text{-}link} = P_{Converter} - P_{Filter} \qquad (9)$$

The characteristic equation of the voltage controlled loop is used to obtain the PI regulator, which can be written as

$$1+(K_P+\frac{KI}{s})=0 \qquad (10)$$

## OPTIMIZATION OF PI CONTROLLER USING PSO

Particle Swarm Optimization (PSO) technique is a population based on computing technique[7-9]. The idea behind this algorithm was the behavior of the swarm such as bird flock and fish schools. Here each represents 'particle' in the swarm and flock is the fitness function. The fitness function is defined as

$$F = f_{THD} + \text{dc link error} \qquad (11)$$

In case of PI controller it is a problem to select a proper combination of $K_P$ and $K_I$. So that optimization techniques are used to find the $K_P$ and $K_I$. Tuning of PI controller with PSO is represented as Figure 3.

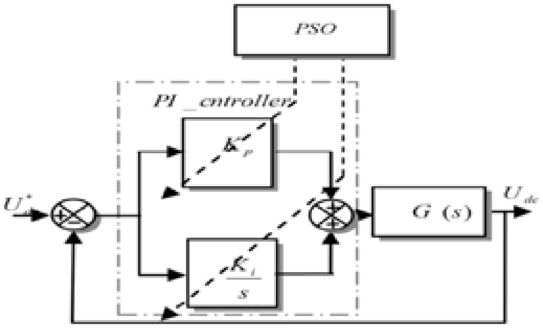

**Figure 3: Tuning of PI with PSO**

The particle position and velocity updating is given by eq (12) and eq (13)

$$V_s^{(t+1)} = W*V_s^{t} + C_1r_1*(P_{best}-X_s^{t})+C_2r_2*(G_{best}-X_s^{t}) \qquad (12)$$

$$X_s^{(t+1)} = X_s^{t} + V_s^{(t+1)} \qquad (13)$$

## RESULTS

This section describes the MATLAB/SIMULINK model of DVR & IDVR is as shown in Figure 6 & 7 respectively. The parameters considered for system simulation is given by table 1.

### Case I: Test results for voltage sag

Here voltage sag is created by adding a sudden load ($V_{load2}$) to the line through the circuit breaker with in the duration of 0.3 to 0.4 as shown in fig(6) where the simulation time is 0.6sec and supply is 415V,50Hz. Here by appling the sudden load the magnitude is reduces to 0.75 p.u, out of 1 p.u which is shown as fig.4. In the duration of 0.3-0.4S DVR will inject the 0.25p.u into the system in order to maintain the presag condition.

Incase of IDVR voltage sag is created at feeder1 is by adding a sudden load ($V_{load2}$) to the line1 through the circuit breaker with in the duration of 0.3 to 0.4 as shown in Figure 6. Similarly in the duration of 0.5 to 0.6 sag is created at feeder2. In the duration of 0.3 to 0.4 DVR1 in the IDVR will operate as voltage sag mode and DVR2 will be in power flow control mode. Similarly at feeder2 DVR1 does't inject any voltage in to the line and DVR2 in IDVR will be injects voltage into line2 is shown in Figure 5.

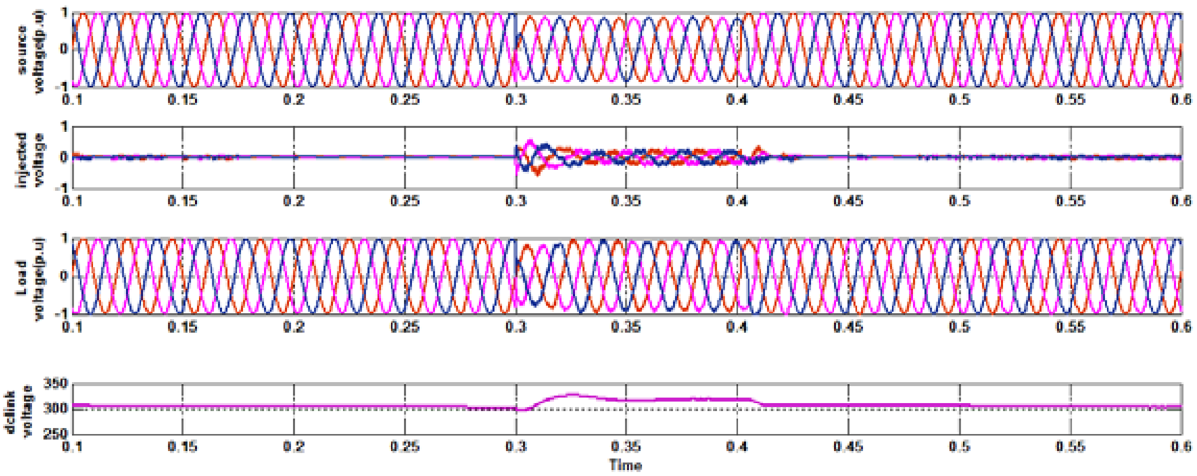

**Figure 4: Performance of DVR during voltage sag**

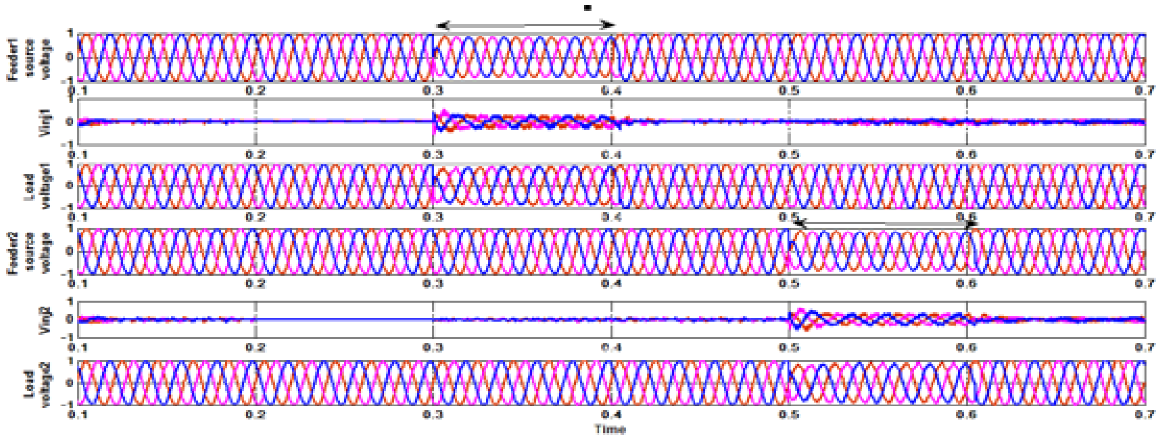

**Figure 5: Performance of IDVR during voltage sag**

**Case II: Implementation of proposed algorithm:**

The main objective of this proposed algorithm is optimization of PI components and generate reference compensate voltages, in such a way that minimum VA loading of Voltage Source Inverter (VSC) of DVR & IDVR is possible.

The proposed algorithm ensures that the minimum VA loading is obtained by controlling the dc-link error using PSO with constraints on THD of load voltages. The main problem of voltage control is to determine the duty cycle in such a way that the dc-link voltage remains constant and to produce suitable injected voltage to mitigate the load voltage problems. The main objective of controlling the injected voltage is accomplishing the precise compensation of the harmonic component.

This section describes the minimization of dc-link error. The convergence of dc-link error DVR with PSO and IDVR with PSO is illustrated as shown in fig.6. and fig.7. The optimization has been run for 0 to 100 iterations. The parameters of PSO are given in table 2.

**Table-2**
**Parameters of PSO**

| Parameters | Values |
|---|---|
| Population size | 10 |
| No.of iterations | 100 |
| $C_1$ and $C_2$ | 1 and 3 |

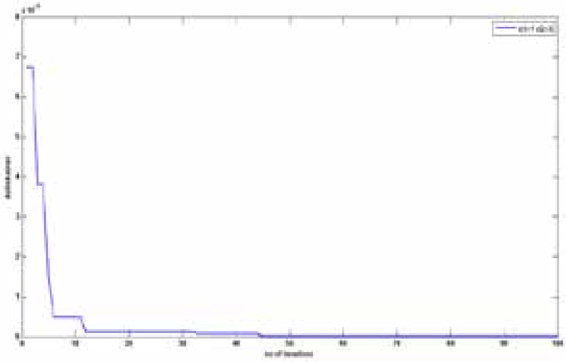

**Figure 6: convergence graph of dc-link error for DVR**

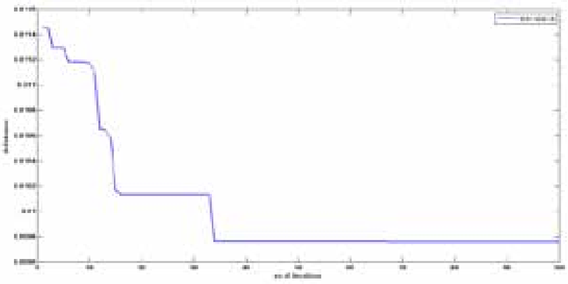

**Figure 7: convergence graph of dc-link error for IDVR**

The comparison of dc-link voltages for DVR with PI and PSO & IDVR with PI and PSO is illustrated as shown Fig.8 and Fig.9 respectively.

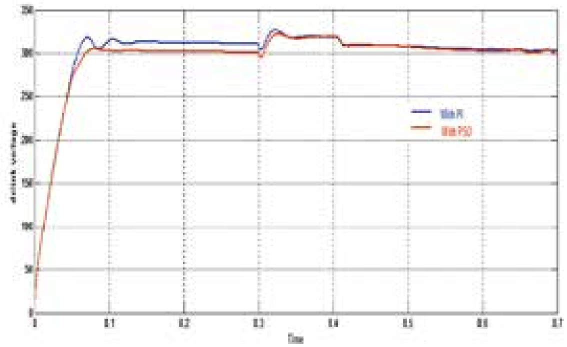

**Figure 8: dc-link voltage representation for DVR PI and PSO**

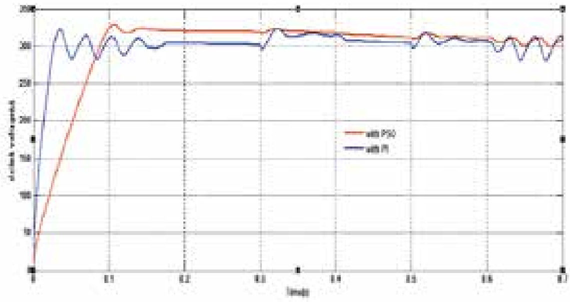

**Figure 9: dc-link voltage representation for IDVR PI and PSO**

In order to minimize the dc link error by using PSO tech-

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nique which results rating of DVR is reduced. The magnitude of the voltage injected by the DVR for mitigating the same kind of sag in the supply is observed. The injected voltage, series current and VA rating of DVR is given in table 3.

**Table-3**
**Comparison of DVR rating for sag mitigation**

| | With PI | With PSO |
|---|---|---|
| Injected Voltage($V_{ph}$) | 121 | 100 |
| Series Current ($I_{ph}$) | 13.91 | 13.91 |
| VA rating per ph | 1683.11 | 1391 |

## CONCLUSIONS

This paper has discussed design of optimized PI regulator components of $K_P$ and $K_I$ and minimizing the steady state error of the dc-link voltage in synchronous reference frame theory (SRFT) based DVR & IDVR in three phase system by using PSO technique. From the simulation results carried out as described above the following conclusions can be drawn.

The proposed DVR mitigates the voltage sag from0.75 p.u to 0.98 p.u with minimum real power injection.

The proposed IDVR mitigates the voltage sag and improves the load voltages in adjacent parallel feeders.

Comparative studies between the conventional PI controller and PSO showed that PSO has been proved to be better in terms of harmonic reduction in load voltage as well as minimization of dc-link error.

The proposed method is able to compensate voltage sags effectively by keeping the DVR voltage and power ratings at minimum values.

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