ANALYSIS AND COMPARISON OF PSO AND DE BASED OPTIMIZED DVR FOR MITIGATION OF SHORT DURATION VOLTAGE DISTURBANCE

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ABSTRACT*— Power quality problems are the major concern in this modern era. If the quality of supply is poor, it will greatly affect the equipment of the end users. The major power quality problems are voltage sag/swell, interruptions, harmonics, etc. The major consequences of voltage disturbances are malfunction and damage of equipment which in turn lead to loss of efficiency. The Dynamic Voltage Restorer (DVR) is a custom power device which is used to protect sensitive load against various short duration voltage disturbances such as voltage sag/swell. The existing DVR evidently mitigates voltage disturbances but it doesn't concern about the optimization of DVR energy storage. This paper deals with the Dynamic Voltage Restorer (DVR) used for the mitigation of short duration voltage disturbance. Here, dual control schemes are proposed, Particle Swarm Optimization (PSO) and Differential Evolutionary (DE) based DVR. In the proposed work, the Comparison results of PSO and DE based DVR determines the optimum phase angle so as to optimize the energy storage capacity of the DVR during the compensation of voltage sag.*

Key Words*: Dynamic Voltage Restorer (DVR); Differential Evolutionary (DE);Particle Swarm Optimization (PSO); Phase advance compensation technique; Phase angle controller; Voltage Sag;*

I.INTRODUCTION:

Power quality problems greatly affect the sensitive end user equipment. The power quality problems can be classified into voltage quality and current quality problems. The voltage quality problem includes voltage sag, voltage swell, interruptions and harmonics. The voltage quality problems can be mitigated by using custom power devices. The custom power devices improve the quality and reliability of power delivered to the end users. The major custom power devices are Distribution Static Synchronous Compensator (DSTATCOM), Dynamic Voltage Restorer (DVR), and Unified Power Quality Conditioner (UPQC). Among these, DVR provides the cost effective solution for the mitigation of voltage quality problems such as voltage sag/swell. A DVR is a series custom power device connected between the source and the load for compensating the voltage disturbances. The disturbance is compensated by injecting the required voltage from DVR energy storage. A novel control scheme has been proposed in [1] and [2] for dynamic voltage restorer to achieve fast response and effective sag compensation capabilities. The DVR proposed in [3]-[6] has demonstrated its ability to protect loads from the effects of voltage disturbances. DVR with neural network control has been used for detection and classification of disturbances. PI controller based DVRs are applied to mitigate the voltage disturbances. The optimal location in the network has been analyzed [7]. Single Phase DVR has been applied to compensate multiple voltage disturbances and limit the downstream fault current [8]. The voltage sag and voltage swell compensation using the DVRs in the medium voltage distribution systems has been explained in [9]. A scheme has been proposed for an optimum amount of energy injection from the DVR to correct a given voltage sag [10]. Particle Swarm Optimization (PSO) algorithm has been applied to optimize the energy storage capacity of the DVR only for mitigation of voltage sag [11]-[12] .The disturbance signal has been extracted using Widrow-hoff delta rule and disturbance is mitigated using series and parallel mitigating devices [13]. The DVR proposed in [14] can compensate the voltage unbalance and voltage harmonics with adaptive perceptron based control algorithm. The DVR based on super capacitor to compensate balanced and unbalanced voltages in the network has been experimentally demonstrated in [15]. The DVR with multifunctional emergency control has been implemented to compensate the disturbances in load voltage and protect the PCC voltage during downstream fault [16]. The multi-functional DVR using a quantitative feedback theory has been proposed in [17] to compensate voltage sag and also to limit the downstream fault current. The Self Adaptive Modified Bat Algorithm (SAMBA) and multi objective structure of human brain learning algorithm to regulate the emotional controller's coefficients have been discussed in [18].

The existing optimized controller uses multi loop control scheme with Kalman filter approach [19]. In this paper, PSO and DE based PAC controller is used for the optimization of energy storage capacity of DVR which is used for mitigation of voltage sag at faster rates.

2. OVERVIEW OF DYNAMIC VOLTAGE RESTORER

Dynamic Voltage Restorer (DVR) is a series connected device used to protect the sensitive equipment's against voltage Sag. It monitors the load voltage and injects the required voltage in case of voltage sag/swell. A DVR consists of Voltage Source Converter (VSC), Harmonic filter, an injection transformer, Energy storage and Control circuit.

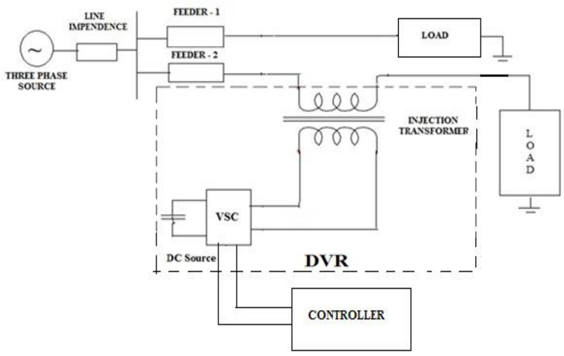


Fig.2.1.1. Block Diagram of Dynamic Voltage Restorer

2.1. Voltage source converter (VSC):

A voltage source converter consists of energy storage and a switching device. The switching device may be made of GTO, MOSFET and IGBT. It provides the sinusoidal output at required voltage, magnitude and frequency to compensate the voltage disturbance.

2.2. Harmonic Filter:

The output from the voltage source converter contains harmonics. The harmonic filter is used to suppress the harmonics present in the output.

2.3. An injection transformer:

An injection or booster transformer connects the DVR to the distribution network. It couples the incoming supply voltage with the voltage injected by the DVR energy storage.

2.4. Energy Storage:

The energy storage provides the required real power to the voltage source converter for the compensation of voltage sag/swell.

2.5. Control circuit:

The control circuit is used to regulate the load voltage under disturbances and it provides the constant voltage magnitude at the load point. There are different types of controllers used for the effective control of Dynamic Voltage Restorer.

3. OPERATING MODES OF DVR

The basic operation of DVR provides the injection of required injection voltage for the compensation of voltage sag/swell during disturbances. The magnitude, frequency and phase angle of the injected voltage are controlled by a separate control circuit. The DVR operates in three different modes they are.,

- Protection Mode
- Standby Mode
- Injection Mode

3.1. Protection Mode:

At the load side, when a short circuit fault occurs, the voltage and current exceed their predefined limits and hence, to protect the DVR from sudden inrush current, it is isolated from the system using bypass switches. Thus, the DVR stays protected, when it operates in protection mode.

3.2. Standby Mode:

In standby mode, there is no switching of VSC because, the converter legs are triggered such as to establish a short-circuit path for the transformer connection. The voltage injected by the DVR is relatively zero in this case. The DVR operates mostly in standby mode.

3.3. Injection Mode:

Whenever a voltage disturbance is detected, the DVR operates in Injection Mode.

The DVR injects the compensating voltage so as to mitigate the respective voltage Sag. In injection mode, the voltage across DVR is always greater than zero.

4. DVR CONTROL STRATEGIES

The existing DVR control strategies are the following,

- Pre-sag compensation technique
- In phase voltage injection technique
- Phase advance compensation technique.

4.1. Pre-sag compensation technique:

The pre-sag method tracks the supply voltage continuously and if it detects any disturbances in supply voltage, it will inject the difference voltage between the sag or voltage at PCC and pre-fault condition .Compensation of voltage sags in the both phase angle and amplitude sensitive loads would be achieved by pre-sag compensation method. Here there is no control over the injected active power.

4.2. In phase voltage injection technique:

Here, the voltage injected by the DVR in phase with the sag voltage. This method does not consider the phase shift of the voltage disturbances therefore, maximum power should be injected by the DVR energy storage unit into the distribution system. Hence, this method does not minimize the energy required for the voltage sag.

4.3. Phase advance compensation technique:

In phase advance compensation technique, the load voltage advance angle ‘α’ is adjusted in such a way that less real power needs to be injected by the DVR energy storage into the distribution system. The advancement of load voltage advance angle ‘α’ at the beginning of the compensation as well as the restoration of the phase angle and at the end of the sag must be carried out without interrupting the operation of sensitive loads. When compared to conventional In-Phase compensation technique, the phase advance compensation technique reduces the energy requirement of the DVR energy storage unit.

5. PARTICLE SWARM OPTIMIZATION – OVERVIEW

Particle Swarm Optimization (PSO) is an evolutionary algorithm developed by Eberhart and Kennedy. PSO consists of a population of particles called swarm. The particles move around the search space and it tracks the individual best positions.Each particle keeps track of its coordinates in the solution space which are associated with the best solution (fitness) that has achieved so far by that particle. This value is called personal best, pbest. Another best value that is tracked by the PSO is the best value obtained so far by any particle in the neighborhood of that particle. This value is called gbest. At each iteration, the particles update their position and velocity according to Eq.(1) and (2)

$$v_i(t+1) = w_{xi}(t) + c_1 r_1 (x_p(t) - x_i(t)) + c_2 r_2 (x_g(t) - x_i(t)) \quad (1)$$

$$x_i(t+1) = x_i(t) + v_i(t+1) \quad (2)$$

The velocity and position updating is done so as to stochastically move towards its local and global best positions.

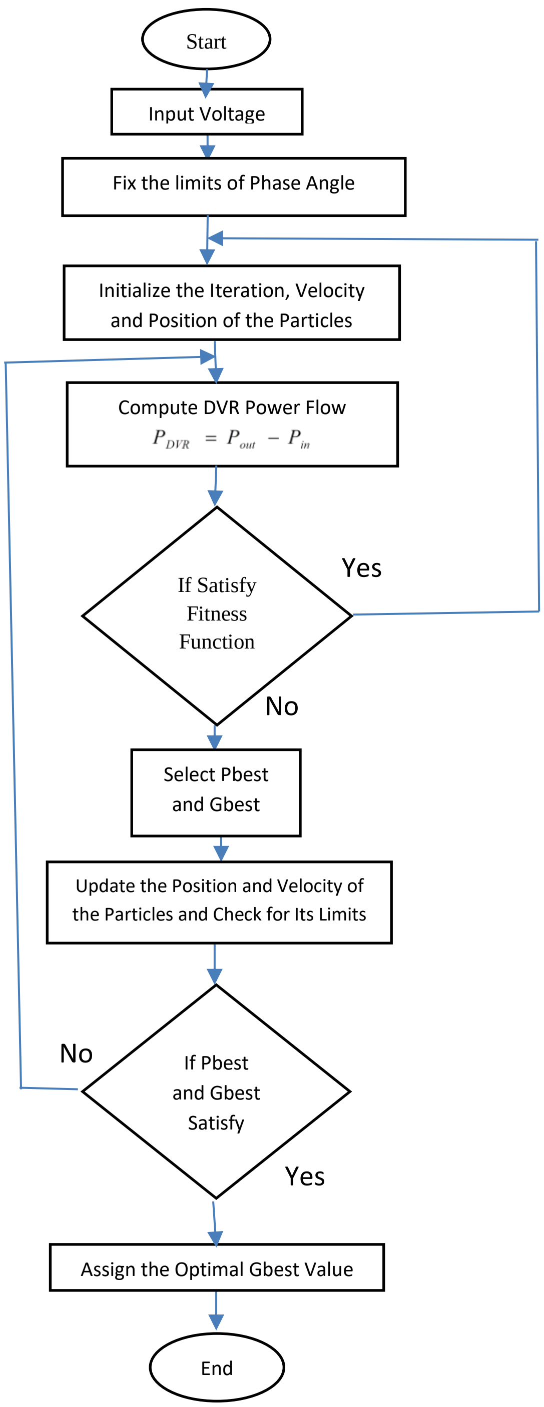
5.1. PROPOSED METHODOLOGY:

In the Proposed Work, the main objective is to optimize the energy storage capacity of the DVR using Particle Swarm Optimization Algorithm.

5.1.1. METHODOLOGY:

Particle Swarm Optimization (PSO) based Phase Advance Compensation (PAC) technique is used. In phase advance compensation technique, the load voltage advance angle ‘α’ is adjusted in such a way that less real power needs to be injected by the DVR energy storage into the distribution system. The proposed PSO based DVR control technique effectively determines the optimum phase angle for the optimized energy injection from the DVR Energy Storage. Under normal operating conditions the load voltage remains unaffected with the DVR operating in Standby mode (i.e. the energy injected from the DVR is relatively Zero) When a disturbance is detected, the terminal voltage is sensed and it is passed on to the optimized controller. The proposed algorithm determines the optimum angle and which in turn identifies the minimum power needed to be injected from the DVR Energy storage. Thus, the proposed methodology minimizes the real power requirement of DVR and also helps to reduce the cost of DVR Energy storage. In the proposed work, PSO based DVR is employed for the Compensation of Voltage Sag/Swell in Three Phase Test System.

5.1.2. FLOWCHART DEPICTING THE PROPOSED METHOD:



5.1.3. PROBLEM FORMULATION:

The objective function is to minimize

$$F = P_{DVR} = (P_{out} - P_{in}) \quad (3)$$

With the constraints of

$$-180 \le \alpha \le 180 \quad (4)$$

The power flow calculation of the DVR under the phase advance compensation technique is considered as follows: If P_{in} and P_{out} are the input power from the source and the load power respectively, then the Eq. (5) and (6) expressed as,

$$P_{in} = \sum_{\forall j} V_{1j} I_j \cos(\varphi - \alpha + \delta_j) \quad (5)$$

$$P_{out} = 3V_2 I \cos\varphi \quad (6)$$

The real power supplied by the DVR is

$$P_{DVR} = P_{out} - P_{in} \quad (7)$$

From the Eqs.(5), (6) and (7)

$$P_{DVR} = 3V_2 I \cos\varphi - \sum_{\forall j} V_{1j} I_j \cos(\varphi - \alpha + \delta_j) \quad (8)$$

Similarly Q_{in} and Q_{out} be the input reactive power from the source and the load respectively, and are given by Eqns.(9) and (10)

$$Q_{in} = \sum_{\forall j} V_{1j} I_j \sin(\varphi - \alpha + \delta_j) \quad (9)$$

$$Q_{out} = 3V_2 I \sin\varphi \quad (10)$$

Reactive power supplied by the DVR is,

$$Q_{DVR} = Q_{out} - Q_{in} \quad (11)$$

From Eqs.(9), (10) and (11) Q_{DVR} can be derived as ,

$$Q_{DVR} = 3V_2 I \sin\varphi - \sum_{\forall j} V_{1j} I_j \sin(\varphi - \alpha + \delta_j) \quad (12)$$

From the above equations, it is obvious that the control of real and reactive power exchange between DVR and the distribution system is possible only with the adjustment of phase angle 'α' for a given value of 'δ','φ','V_1','V_2'.

5.2. DIFFERENTIAL EVOLUTIONARY OPTIMIZATION – OVERVIEW

The Differential Evolution Algorithm has many strategies. Here simple DE strategy is applied. The steps involved in DE are

Initialization:

$$x_{i,j}(0) = x_j^L + rand(0,1).(x_j^U - x_j^L)$$

Mutation:

$$v_{i,j}(t+1) = x_{r1,j}(t) + F.(x_{r2,j}(t) - x_{r3,j}(t))$$

Crossover:

$$u_{i,j}(t) = v_{i,j}(t) \quad \text{if } rand(0,1) < CR,$$
$$= x_{i,j}(t) \quad \text{else}$$

Selection :

$$\vec{X}_{i,}(t+1) = \vec{U}_i(t) \text{ if } f(\vec{U}_i(t) \le f(\vec{X}_i(t)),$$
$$= \vec{X}_i(t) \text{ if } f(\vec{X}_i(t) < f(\vec{U}_i(t))$$

5.3. PROPOSED CONTROLLER FOR DVR:

5.3.1. PSO BASED PHASE ADVANCED COMPENSATION CONTROLLER CIRCUIT:

Conventional PI control method is used for the control of DVR [20]-[21]. Three phase terminal voltage is compared against the reference voltage. Its difference generates the error signal, which is fed into the PSO and DE based Phase angle controller. This Phase angle controller circuit drives the error signal to zero and corresponding gate signals are triggered for the control of DVR output. PWM control technique is applied for the inverter switching so as to produce a three phase 50 Hz sinusoidal load voltage at the load terminals.

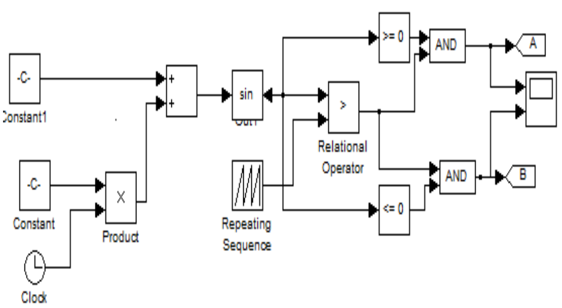


Fig.5.2.1.1. PSO based Phase angle controller circuit

6. TEST SYSTEM:

Single phase 230V, 50Hz test system with PSO and DE based DVR, and PI controller is simulated using MATLAB/SIMULINK. The above respective controller is advantageous in their own way. The PSOand DE based DVR effectively tracks the optimum power which identifies the minimum power to be injected by the DVR in case of short duration voltage disturbance. Under normal operating conditions, the voltage across the load is 230V. But when voltage disturbance is detected, the voltage across the load is never equal to the supply voltage. This condition may affect the sensitive loads at the utility side. So, to provide an unaffected voltage despite the disturbance, a DVR is connected with the distribution line. An injection transformer probably of 1:1 ratio is used to couple the DVR circuit to the distribution line. The real power requirement of DVR is supplied by the DC Energy storage of DVR. A single line diagram of the proposed Test system is depicted in fig 6.1

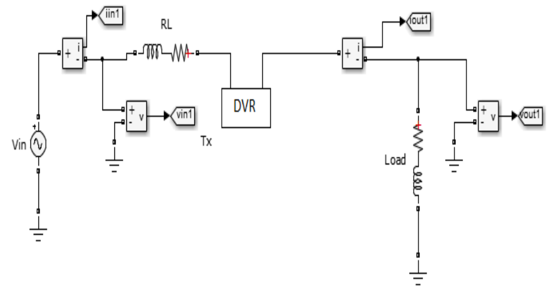


Fig.6.1. single line diagram of Test System with DVR

7. SIMULATION RESULTS:

DVR Injected Power (KW)			% of Power Savings	
From Existing method [10]	From the Proposed method(PSO)	From the Proposed method(DE)	From the Proposed method(PSO)	From the Proposed method(DE)
99.906	94.739	82.982	5.17%	16.924%

7.1. Single phase DVR test system with 230V, 50HZ with PSO based PAC controller is simulated in MATLAB/SIMULINK.

The optimum phase angle and respective DVR Injected Power obtained from PSO and DE for compensation of Single Phase voltage sag are highlighted in the Table 7.1.1.

Table 7.1.1 Comparison of Existing and Proposed (PSO) and Proposed (DE) method of DVR injected real Power for Voltage sag

The corresponding real power injected by the PSO based DVR and DE based DVR for compensation of voltage sag is 94.739 KW and 82.982 KW. Whereas the real power injected by the DVR using In-phase voltage injection method is 138.15KW [7]. In the existing method, real power required to mitigate the voltage sag is 99.906KW [10]. Thus, compared to the existing system, the real power requirement is further reduced 5.167KW and

16.924KW. Fig. 7.1.1 shows the Convergence curves for Proposed (PSO and DE) method of DVR injected Real Power. Fig.7.1.2 shows the reduced scale of Convergence curves for Proposed (PSO and DE) method of DVR injected Real Power.

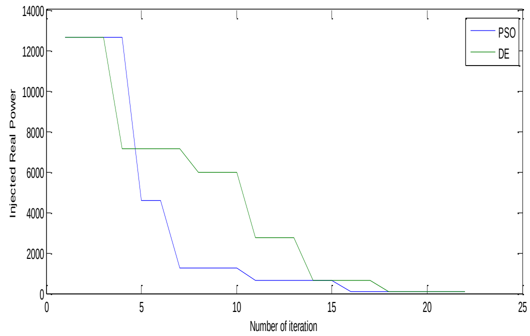


Fig.7.1.1. Convergence curve for Proposed (PSO and DE) method of DVR injected Real Power

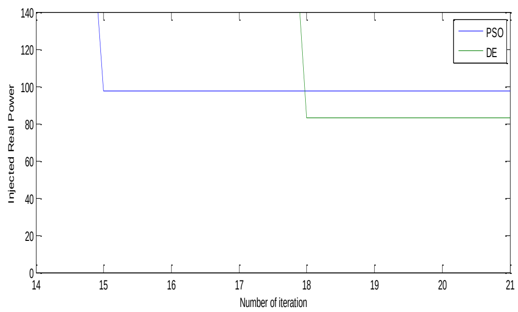


Fig.7.1.2. Convergence curve (reduced scale) for Proposed (PSO and DE) method of DVR injected Real Power

7.2. Three phase DVR test system with 230V, 50HZ with PSO based PAC controller is simulated in MATLAB/SIMULINK.

Fig. 7.2.1 shows the Single Phase Load Voltage Sag waveform under fault conditions. Here due to single phase fault, the voltage is reduced to 80V from nominal 230V. Fig.7.2.2. shows the DVR Injected voltage waveform and fig.7.2.3.shows the compensated load voltage waveform by injecting minimum real power from DVR energy storage.

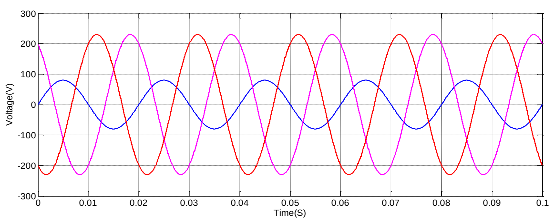


Fig. 7.2.1.Load Voltage Sag waveform under fault conditions

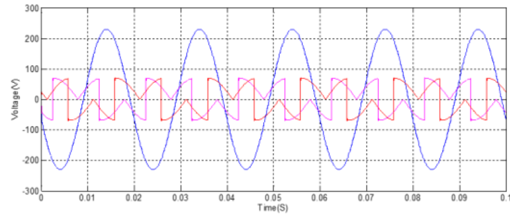


Fig.7.2.2. DVR Injected Voltage Waveform

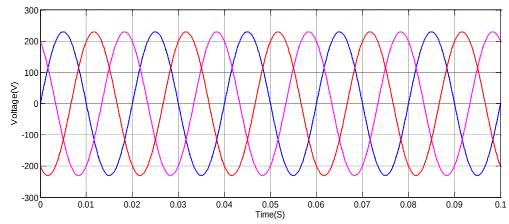


Fig.7.2.3. Compensated Load voltage waveform

8. CONCLUSION

The PSO and DE based phase advance compensation method clearly determines the optimum power for which the real power injection from the Dynamic voltage restorer is minimum. Thus the proposed work optimizes the energy injection of DVR. With the simulation results, the PSO and DE based phase advance compensation method is found to be good and improve the power quality in the distribution system when compared with the existing control strategies. In future, the proposed work can also be modified with advanced custom power devices and Optimization Techniques for effective mitigation of voltage disturbances.

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