BI-OBJECTIVE REGULATING OF DVR COMPENSATOR TO MODIFY POWER QUALITY'S INDICES OF LOAD

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ABSTRACT

This paper aims to present a control scheme based upon Particle Swarm Optimization (PSO) algorithm in order to compensate the key power-quality disturbances, particularly voltage sags and harmonic voltages, using a Dynamic Voltage Restorer (DVR). According to the aforesaid method, DVR's PI controller structure is regulated via multi-objective PSO algorithm. We introduce the method for distribution systems to modify both SAG and THD as major power quality indices in sensitive loads at fault conditions. Therefore, we apply the multi-objective optimization algorithm in order to attain a better performance in solving the related problems.

INTRODUCTION

Nowadays, the demand for accessing stable and high-quality electric power has been increased significantly due to a growth in the number of sensitive loads. Since the manufacturing units tend to utilize power electronic devices as well as computer processors and other non-linear loads; any interruption or deviation in delivered power quality exceeding the standard range will cause economic losses for them, especially in the current industrial competitive environment. Therefore, obtaining high power quality will play a key role in saving assets and also it will have economic advantages for an industrial organization. In addition, any kind of disturbances in electrical distribution systems will cause some deficiencies such as interruption, voltage sag, voltage swell, and flicker. Among the above-mentioned disturbances, the most important factor is voltage sag.

“Custom Power” devices have been introduced by experts in order to compensate the harmful effects of disturbances on sensitive loads. DVR, as a Custom Power device, has the ability to compensate voltage sag and swell effects in sensitive loads devices. Recognizing voltage sag in a feeder connected to the sensitive load, DVR generates proper voltage via a coupling transformer which is in series with the sensitive load and then injects proper voltage to the network and decreases voltage sag effects.

Since the DVR parameters are unchangeable, the classical PI method in DVR control system will have poor flexibility. Moreover, in power systems especially in fault conditions, suitable results can not be obtained in most cases. Therefore, different control strategies such as classical control like sliding mode [1] and intelligent control like emotional learning controller [2] must be used in order to control the injected voltage properly. In many sensitive loads such as medical equipment and adjustable speed motor drives, this level of sensitivity particularly THD index may be very important. In few researches, improving voltage THD index has also been considered as an objective and a control criterion as well. However, in the aforementioned studies, algorithms with high level of complexity have been used meanwhile they may cause some problems in practical implementation. Also, we can claim that [3] is the only research which has considered THD voltage as a second goal. This approach is one of the intelligent control methods that acts based on hebb learning control.

In order to have an appropriate performance during voltage flash and to be able to decrease the sensitive load voltage THD, a two-objective optimization has been proposed in this paper. Hence, in this method, voltage sag will be the first objective and voltage THD will be considered as the second objective in DVR control system. Both voltage sag and THD can be modified by the aforesaid algorithm. Also, we have utilized the Particle Swarm Optimization (PSO) algorithm for optimizing the objective functions in this paper. In order to make multi-objective algorithm, we have used fuzzification method for the objectives and fuzzy membership functions. On the other hand, to investigate the efficiency of the proposed algorithm; performance of DVR compensator during various faults in a typical network has been tested and compared with some controllers that were introduced before.

DVR operation, multi-objective optimization with fuzzy membership function, and PSO algorithm have been introduced and discussed in the following sections. After that, we have introduced the proposed method of the paper, and the final section contains the simulation results.

DVR’S STRUCTURE AND FUNCTIONALITY

DVR is one of the “custom power” devices in distribution network which is placed in series with transmission lines. Load voltage becomes balanced by injecting three controlled voltages when there's a disturbance in the power system. Thus, DVR works based on injection of necessary voltage to compensate voltage sag when it starts to occur [2].

In the presence of voltage sag, DVR injects appropriate voltage to a sensitive load. DVR circuit includes five main components: series transformer, voltage inverter, energy storage equipment, passive filter, and control system.

Control system uses the abc-dq transformation to calculate v_d and v_q. In balanced condition, the voltages v_d=1 and

v_q=0. But in fault condition, these voltages will change [2]. We can control the variations of these signals by comparing the voltages with their references and giving their error signals to a PI controller.

MULTI-OBJECTIVE OPTIMIZATION USING FUZZY MEMBERSHIP FUNCTION

In this research, we have defined each objective in the form of a membership function in fuzzy sets environment and then we have combined the objectives using proper weighting coefficients in the form of a satisfactory fuzzy objective function [4]. In case of using this optimization method, voltage THD and sag are our two objectives and the following objective function can be used:

$$F = w_1.\mu_T + w_2.\mu_D \tag{1}$$

Where μ_T is sensitive load THD membership function, μ_d is sensitive load voltage sag membership function. Also, w_1 and w_2 are weighting coefficients corresponding to the aforementioned objectives, respectively.

By determination of appropriate membership functions and weighting coefficients corresponding to each objective, this optimization problem can be resolved. Fuzzy membership functions of optimization objectives indicate the objective desirability variations in the interval [0, 1].

Membership Function of Voltage Sag

In presence of voltage sag, it is tried to minimize the difference between base bus voltage and real bus voltage. The voltage deviation can be calculated using the following equation (2):

$$D = \max|v_b - v_l| \tag{2}$$

Where v_b is the base voltage of sensitive load bus and v_l is the sensitive load voltage. If maximum value of bus voltage sag decreases, a higher desirability value will be assigned to it, and vice versa. The membership function is specified by equation (3) and its shape has been shown in Figure 1.

$$m_D = \begin{cases} \frac{D_{max} - D}{D_{max} - D_{min}} & for \quad D_{min} \le D \le D_{max} \\ 1 & for \quad D \le D_{min} \\ 0 & for \quad D \ge D_{max} \end{cases} \tag{3}$$

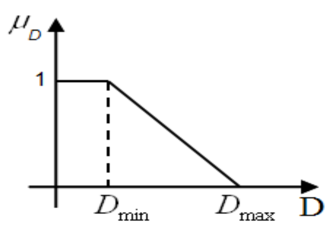

Figure 1. Voltage Sag Membership Function

According to IEEE-519 standard [5], bus voltage can have any value between 0.95 and 1.05. In this paper, we have considered D_{min}=0 and D_{max}=0.05.

Membership Function of Voltage THD

Voltage THD may cause irreversible effects on the sensitive load. Thus voltage harmonics minimization can be an attractive objective in this field. Also, THD has been considered as a harmonics index which its membership function can be specified by the equation (4) and its shape has been shown in Figure 2.

$$m_T = \begin{cases} \frac{T_{max} - T}{T_{max} - T_{min}} & for \quad T_{min} \le T \le T_{max} \\ 1 & for \quad T \le T_{min} \\ 0 & for \quad T \ge T_{max} \end{cases} \tag{4}$$

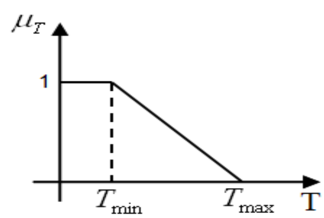

Figure 2. Voltage THD Membership Function

PARTICLE SWARM OPTIMIZATION ALGORITHM

The particle swarm optimization algorithm (PSO) was used for the first time in 1995, by Eberhart and Kennedy. This algorithm has been inspired by the social behaviour of animals such as flying birds or a flock of fishes searching for food. A community includes a number of particles (individuals) that can be a candidate solution for optimization problem and as time goes by, these particles constantly move towards the optimal solution. Like other evolutionary algorithms, initial population is generated randomly [6]. Details of this algorithm were explained in [6].

PROPOSED METHOD

Figure 3 is a flowchart that shows the application of PSO to solve the problem. Now we intend to explain more about this flowchart. First we can obtain results of Voltage sag and THD from SIMULINK software.

These values have been given to the both of fuzzy membership functions separately as defined by equations (3) and (4). Then, the values of the function related to the fitness function of optimization algorithm have been defined in equation (1). This process is being repeated for every particle relating to the iteration in optimization algorithm.

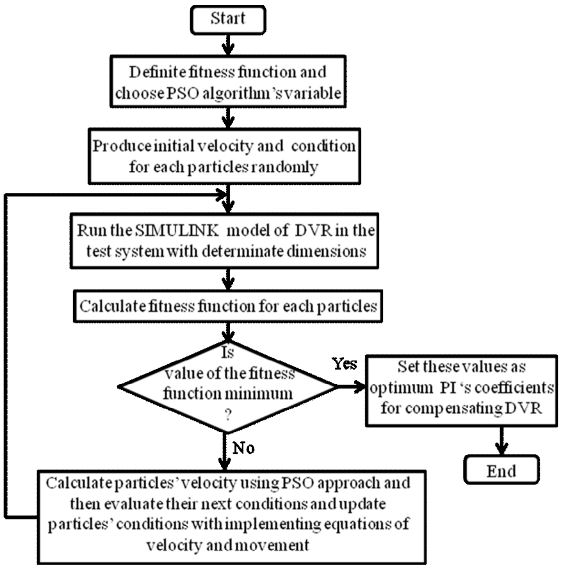

Figure 3. General optimization procedure for optimum PI's coefficients determination

SIMULATION AND RESULTS

The power distribution system case study consists of two load buses that one of them includes the sensitive load. This simple electrical network has been shown in Figure 4 and its parameters have been introduced in Table 1 (references [2-3]). This project has been simulated in the MATLAB/SIMULINK environment as well.

This problem initially can solve a single-objective problem in order to optimize the voltage sag caused by faults. Number of dimensions in the problem is four. These dimensions are the coefficients of two PI controllers so that one of them is aligned with the d-axis and the other is aligned with the q-axis. Each PI controller has two coefficients, i.e, proportional and integral gains.

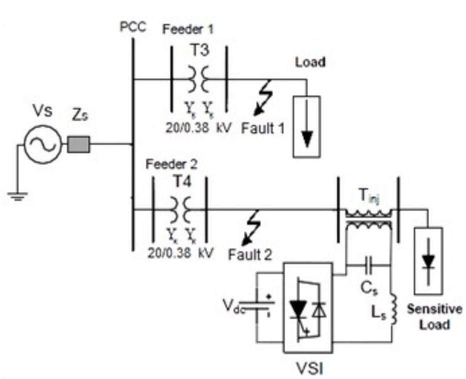

Figure 4. Power distribution system schematic

In order to simulate more critical conditions, two faults have been simulated. The first fault is just after series injection transformer with fault and earth resistances equal to 4.6Ω and 0.1Ω respectively, and the second one is near to a non-sensitive load with the same resistance values.

Table 1. Network parameters

PARAMETERS	VALUES
network frequency power supply voltage	Fn=50 (Hz), Vs=22500 (V)
active and reactive power for sensitive load	P=20 (kW) Q_l=4 (kVAR), Q_c=1 (kVAR)
active and reactive power for non-sensitive load	P=25 (kW) Q_l=4 (kVAR)
distribution transformer rated power and ratio	P_n=32 (kW), 20000/380
distribution transformer impedances	R_l=0.0003 (P.U.), X_l=0.001 (P.U.), R_m=X_m=500 (P.U.)
series transformer rated power and ratio	P_n=15 (kW), 100/1000
series transformer rated power and ratio impedances	R_l=0.00001 (P.U.), X_l=0.0003 (P.U.), R_m=X_m=500 (P.U.)
DVR switching frequency	f_S=10 (kHz)
DC voltage source	V_{DC}=200 (V)
impedances for shunt and series filter	R_S=0.2 (Ω), L_S=6 (mH) R_P=0.2 (Ω), C_s=20 (μF)

A PSO algorithm with 80 iterations and 20 particles had been used to solve the problem. Simulation results revealed an improvement in the voltage sag of sensitive load, but in terms of harmonic index (THD) the sensitive load was not in proper conditions. Therefore, it is been tried to use multi-objective algorithms. Figure 5 shows voltage signals at PCC, sensitive load voltage, injected voltage from DVR and sensitive load voltage deviation from the base voltage, respectively.

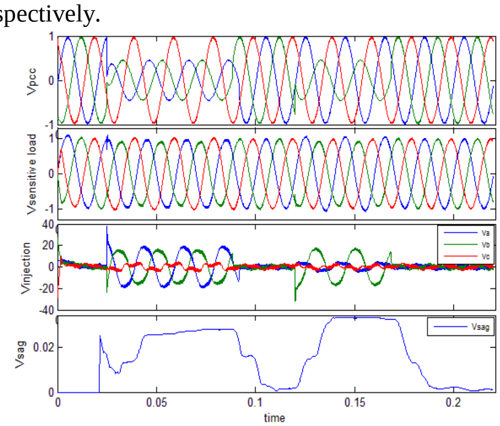

Figure 5. Voltage at PCC, the sensitive load voltage, injected voltage from DVR and the sensitive load voltage deviation signal from the base voltage in single objective case under fault conditions

Firstly, each objective was turned into a fuzzy membership function to solve this optimization problem. In solving process, both objectives have been considered to have the same importance degree. Therefore, the coefficients are set to w_1=w_2=0.5. This problem is solved using proposed algorithm with 20 particles and 80 iterations. The simulation results of PCC voltage, sensitive load voltage, injected DVR voltage and the sensitive load voltage deviation from its reference value as shown in Figure 6.

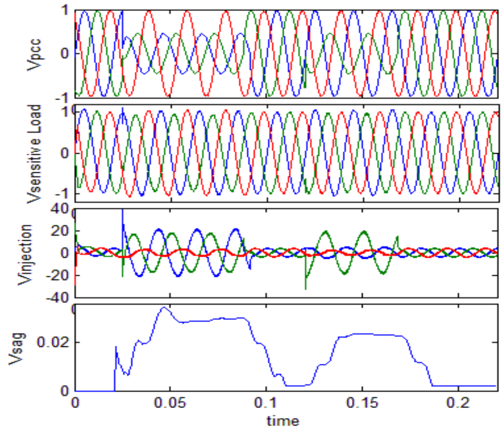

Figure 6. Voltage at PCC, the sensitive load voltage, injected voltage from DVR and the sensitive load voltage deviation signal from the base voltage in multi-objective case under fault conditions

Improvement in THD signal and also deviation signal in line voltage caused by network faults in the algorithm, have been studied. As it can be seen, during simulation the requirements of IEEE-519 standard have been considered. The result has been shown in Table 2. In addition, results of two other controllers that have been introduced in [9] and [10] are obtained in Table 4 as well.

Table 2. Comparison of results

		Voltage sag average		**THD (%)**	
Controllers	***states***	***value***	***Improve (%)***	***value***	***Improve (%)***
Classical PI	1	0.0205	-	4.87	-
	2	0.0273	-	3.94	-
Emotional Controller	1	0.0177	13.66	0.61	87.47
	2	0.0203	25.64	0.63	84.01
Modified hebb learning controller	1	0.0129	37.07	0.56	88.50
	2	0.0164	39.92	0.60	84.77
Single objective PSO	1	0.0177	13.66	1.46	70.02
	2	0.0203	25.64	1.59	59.64
Multi-objective PSO	1	0.0131	36.09	0.91	81.31
	2	0.0178	34.79	0.96	75.63

The first item describes a controller based on emotional learning. The second item explains single and bi-objective hebb learning algorithm for controlling DVR. These objectives are voltage sag and THD and in the Table these indices and their percentage of improvement rather than operation of classical PI controller have been mentioned. As it is clear, performance of proposed controller based on bi-objective PSO is improved in comparison with single objective type in term of both of power quality's indices. We can report that in proposed controller both flash and voltage THD indices have decreased in comparison to other controllers which have already been introduced. In other words, by considering control signal of voltage THD as second objective, we can guide PSO algorithm toward better answer for controlling and compensating DVR.

According to the results of Table 4, all of the controllers have proper results rather than classical controller. However modified hebb learning controller has operated more pleasant than emotional controller. Furthermore, we can observe multi-objective algorithm's preference rather than single-objective type. By considering these results, using multi-objective algorithm is more reasonable. Also, we can claim that PSO algorithm will have better performance than modified hebb learning controller, especially in major goal which is voltage sag.

CONCLUSION

New ideas presented in this paper can be analyzed from two points of view:

1. Presenting the idea of adjusting controller coefficients using heuristic algorithms:

In this paper, it is tried to achieve a better set of coefficients for PI controller using PSO algorithm. As the results show, the PI adjusted by this algorithm is better than classic PI controller.

2. Adjusting controller coefficients using a bi-objective optimization algorithm in order to improve THD and voltage sag indices:

In this paper a new bi-objective optimization algorithm is used for adjusting coefficients. This bi-objective algorithm is based on the fuzzification of aforementioned objectives. Simulation results revealed better performance of this bi-objective algorithm over the single-objective algorithm and classic control from voltage sag and voltage THD.

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