DVR Controlling by a Novel Method Based on Adaline Neural Network to Modifying power quality (voltage and THD) of load

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ABSTRACT

Having electricity with high quality is one of the more important aims in electrical systems. Disturbances in distribution systems can change voltage waveform. There are some methods to prepare high power quality for sensitive loads. In this research, we use "Dynamic Voltage Restorer" to compensate the harmful effects of disturbances on voltage. Since power systems fundamentally have complicated dynamic behavior especially during faults; adaline neural network self-tuning controller which is a powerful adaptive controller has been used. In order to improve the performance of this controller from point of view of power quality's indices such as flash and sensitive load voltage THD, a new structure is proposed for this controller with fuzzification method. The simulation results indicate better operation of system in case of using proposed controller. Voltage sag and harmonic in faulty conditions improve by this controller. According to simulation results, it works better than both classical PI controller and conventional Adaline NN controller.

Keywords: *DVR; sensitive load; Power Quality; adaptive control; fuzzy membership function; multi-objective Adaline NN algorithm; self-tuning controller*

1. INTRODUCTION

Nowadays by increasing the number of sensitive loads, demand for access to stable and qualitative electrical power has increased significantly. In industrial competitive environment, with development of enterprise production of power electronic devices, computer processors and nonlinear loads, any interruption or diversion from the standard range causes economic damages. The realization of this economic loss can be studied in such frameworks as production competition opportunity lose, efficiency reduction, increase of production cost, low-quality products, reduction of equipment lifetime, increase of repair cost, production interruption and energy losses. Thus, access to high power quality, applies a great influence on the asset savings and economic advantages for a firm [1].

Disturbance in power distribution system causes harmful defects in distribution system such as interruption, voltage sag, voltage swell, and flicker. Among the above disturbances the most important is voltage sag. According to the IEEE standard, it is a sudden voltage decrease in the range of %10 to %90 for 0.5 cycles to 1 min [2]. That is the result of natural phenomena such as system asymmetric errors and electromagnetic phenomena like start and inrush current.

"Custom Power" device has been introduced by experts in order to compensate the harmful effects of disturbances on sensitive loads. Among these devices, DVR is capable to compensate voltage sag and swell effects for sensitive loads devices. The structure of DVR in simple terms consists of: electrical storage source, voltage source inverter and coupling transformer. Recognizing voltage sag in feeder connected to the sensitive load, DVR generates proper voltage using coupling transformer which is in series with sensitive load and inject proper voltage to the network and decrease voltage sag effect.

The classical PID method has poor flexibility since its parameters are fixed for a special work point. Furthermore, when it applies to a complicated system as power system, results can't be acceptable for all conditions [3]. Therefore, control strategies such as predictive control [4], sliding mode [5] and robust control [6] are used in order to control injected voltage. Also in [7] and [8] are used $H\infty$ controller and a controller based on iteration respectively to have better operation in steady and transient states. Also emotional controller is implemented as an adaptive controller in [9] for DVR control. In [10] fuzzy controller is utilized. In [11] multi-level inverter with optimal predictive control structure is used. In [10-11], improving voltage THD index has been considered as an objective and a control criterion. However, in all of the aforementioned references, algorithms are complex. Although applied control strategies are capable to reduce impulses caused by voltage flash in sensitive loads, but most of these approaches don't consider reducing voltage THD. These approaches do not pay much attention to short voltage interruptions both abrupt holes and gaps or overshoot in the beginning and end of flash [11]. In many sensitive loads such as medical equipment and adjustable speed motor drives, this level of sensitivity can be very important .

In most of the aforementioned researches, it is tried to use a stable controller in order to make it capable of reacting to various fault conditions in the best possible way. Reference [12] is one the rare researches which has tried to improve sensitive load voltage THD in addition to improving voltage flash. In this research evolutionary algorithms have been used to optimize two-objective controller structure of DVR. This approach has two shortcomings. Firstly, power systems and compensators are completely nonlinear. This may cause these algorithms operate based on random search- encounter problems to find real optimum point of this structure and converge to a local optimum. Also, in real time applications, this search process takes long time. Secondly, power systems have different dynamic behaviors especially in fault conditions. Therefore, PID controllers which are optimized by off-line search algorithms may not have a good performance under these conditions. In this paper it is tried to solve these problems. Consequently, a relatively new adaptive method based on artificial neural network structure is introduced. This adaptive method which is inspired by a single neuron neural network is used as a self-tuning and robust PI controller. This method has been invented by combining neural network and classical PID in order to modify drawbacks of classical PID which mentioned in this section. The advantages are having simple structure, low computations time and self-tuning ability. Therefore, this control algorithm can be utilized in real time controller.

In order to have an appropriate performance during voltage flash and sensitive load voltage THD, a two-objective structure is proposed. In this method, voltage THD consider as second goal for DVR control system. Both of voltage sag and THD can modify by this algorithm.

To investigate the efficiency of the proposed algorithm, performance of DVR compensator during various faults in a typical network is tested and compared with conventional Adaline and classical PI controller. Also, in order to validate good operation of proposed method, we compare the controller with two presented controllers in [9] and [12].

DVR operation is introduced in section 2; PI controller based on Adaline NN algorithm is discussed in sections 3. Section 4 introduces the proposed method for making two-objective (two-input) with fuzzification, and the final section contains the simulation and results.

2. DVR; Structure and Description

DVR is one of the "custom power" devices in distribution network which is connected in series. Load voltage is stabilized through injecting three output voltages during disturbance in the power system and controlling voltage range, phase and frequency. Thus DVR is based on injection of necessary voltage when voltage sag occurs in order to compensate it. DVR functionality can be categorized as two modes: standby mode and injection mode [13]. In the standby mode a low voltage is injected into the network in order to cover voltage sag a cause to transformer reactance. In second mode, in presence of voltage sag, DVR injects voltage to sensitive load.

DVR circuit include in 5 main components. They are shown in Figure 1.

(1) Series transformer: that its primary winding is connected to the inverter and secondary winding is connected to the distribution network and sensitive load.

(2) Voltage inverter: The inverter is connected to the injection transformer. Energy storage equipment has been considered for inverter. This inverter includes IGBT switches self-commutation by shunt diodes and PWM technique is applied for control of it.

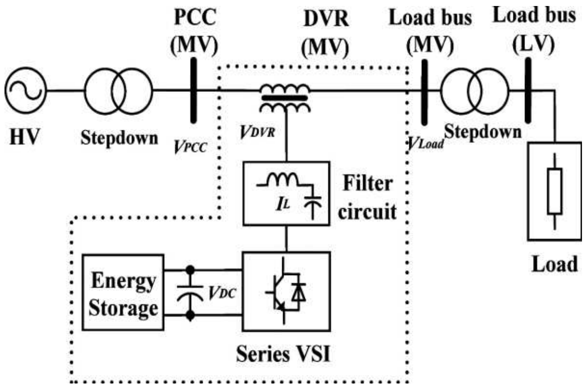

Figure 1. DVR unit structure

(3) Energy storage equipment: Power storage resources such as battery, capacitor banks, SMES and flywheels that have been used for providing adequate voltage and active power and compensating sag [14].

(4) Passive filter: With connecting to the high voltage side of inverter to eliminate harmonics produced by switching.

(5) Control system: Logical fundamental of control system is based on voltage sag detection, and providing appropriate switching strategies for inverter.

Control system uses the abc-dq transformation to calculate v_d and v_q. During normal and balance conditions, the voltages v_d and v_q are: $v_d=1$ and $v_q=0$. But in fault condition, these voltages change [10]. We can control the variations of these signals by comparing these voltages with their references and giving their error signals to a PI controller.

3. PI CONTROLLER BASED ON ADALINE NEORAL NETWORK ALGORITHM

Adaline, developed by Widrow and Hoff (1960), is found to use bipolar activations for its input signals and target output. The weights and the bias of the Adaline are adjustable. The learning rule used can be called as Delta rule, Least Mean Square rule or Widrow - Hoff rule. The derivation of this rule with single output unit, several output units and its extension has bean dealt already in section 3.3.3. Since the activation function is an identify function, the activation of the unit is its net input.

The Adaline is to be used for pattern classification , then, after training, a threshold function is applied to the net input to obtain the activation.

The Adaline unit can solve the problem with linear separability if it occurs[15].

3.1 Architecture

The architecture of Adaline is shown in fig 2

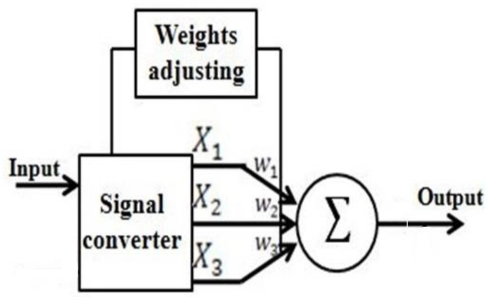

Figure 2. Structure of single neuron PID control system based on Adaline NN algorithm

The Adaline has only one output unit. This output unit receives input from several units and also from bias:l whose activation is always +1. The Adaline also resembles a single layer network. It receives input from several neurons. It should be noted that it also receives from the unit which is always +1 called as bias. The bias weight are also trained in the same manner as the other weights. In fig 2, an input layer with x1…xi…xn, and bias, an output layer with only one output neuron is present. The link between input and output neurons possess weighted interconnections. These weight get changed as the training progresses.

3.2 Algorithm

Basically, the initial weight of Adaline network have to be set small random values and not to zero, because this may influence the error factor to be considered. After the initial weights are assumed, activations for the input unit are set. The net input is calculated based on the training input patterns and the weights. The training process is continued unit the error, which is the difference between the target and the net input becomes minimum. The step based training algorithm for an Adaline is as follows:

Step 1: Initialize weights (not zero but small random values are used).

Set learning rate α.

Step 2: While stopping condition is false, do step 3-7.

Step 3: For each bipolar training pair, s:t, perform steps 4-6.

Step 4: Set activations of input units $x_i = s_i$, for i=1 to n.

Step 5: Compute net input to output unit **:**

$$y_{-in} = b + \sum_i x_i w_i \qquad (1)$$

Step 6: update bias and weights, i=1 to n.

$$w_i(new) = w_i(old) + \alpha(t - y_{-in})x_i \qquad 2)$$

$$b(new) = b(old) + \alpha(t - y_{-in}) \qquad (3)$$

Step 7: test for stopping condition.

The stopping condition may be when the weight change reaches small level or number of iteration etc.

3.3 Application Algorithm

The application procedure which is used for testing the trained network is an follows. It is mainly based on the bipolar activation.

Step 1: Initialize weight obtained from the training algorithm.

Step 2: For each bipolar input vector x, perform steps 3-5.

Step 3: Set activations of input unit.

Step 4: Calculate the net input to the output unit.

$$y_{-in} = b + \sum_i x_i w_i \qquad (4)$$

Step 5: Finally apply the activations to obtain the output y.

$$y = f(y_{-in}) = 1, \quad \text{if} \quad y_{-in} \geq 0 \qquad 5)$$

$$y = f(y_{-in}) = -1, \quad \text{if} \quad y_{-in} < 0 \qquad 6)$$

4. MULTI-OBJECTIVE MAKING WITH FUNCTION OF FUZZY MEMBERSHIP

There are several methods to analyze multi-objective (multi-input) neural networks. Up to now, multi-objective methods introduced [16-19]. In [16] there are three objectives. These three objectives are integrated into an objective function through weighting factors and the problem with minimum objective function value is solved. Also, in [17], fuzzification objectives are used. In [18-19], pareto base approach is used. Most of these methods have efficiency in evolutionary and off-line algorithms. It's possible that many of these inputs (objectives) aren't homogeneous and some of these methods aren't useful. Therefore, we should use special methods to making them homogeneous**.**

Hence, in this paper each objective is described in the form of membership function in fuzzy set environment. Combine those using appropriate weighting coefficients in the form of a satisfactory fuzzy objective function [20] are defined. We can use the objective function of Equation 7 to control the objectives of voltage THD and sag:

$$F = w_1.\mu_T + w_2.\mu_D \qquad (7)$$

Where μ_T is the rate of membership function; THD and voltage sag of sensitive load, μd is the rate of membership function and w_1 and w_2 are respectively weight coefficients equal to mentioned objectives.

By determination of appropriate membership functions and weighting coefficients associated in each objective, the process control can be employed. Fuzzy membership functions for the purpose of objectives control indicates the objective desirability changes in the interval [0, 1]. The proposed membership functions for each objective are described in continued.

4.1. Voltage sag Membership Function

In voltage sag, it is tried to minimize difference between base bus voltage and real bus voltage. This voltage sag is caused from system faults. The voltage error obtains as Equation 8.

$$D = \max|v_b - v_l| \qquad (8)$$

Where v_b is base bus voltage of sensitive load, v_l is sensitive load voltage. If the maximum bus voltage sag decreases, it takes more satisfier value and vice versa. According to IEEE-519 standard, bus voltage can have any value between 0.95 and 1.05. In this paper, we considered D_{min}=0 and D_{max}=0.05. The membership function is specified in Equation 9 and Figure 3.

$$\mu_D = \begin{cases} \frac{D_{max}-D}{D_{max}-D_{min}} & \text{for } D_{min} \le D \le D_{max} \\ 1 & \text{for } D \le D_{min} \\ 0 & \text{for } D \ge D_{max} \end{cases} \qquad (9)$$

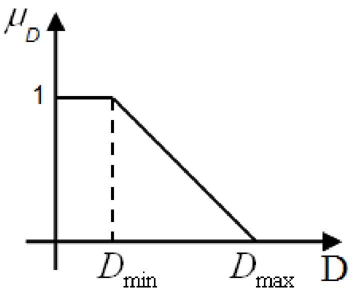

Figure 3. Voltage sag Membership Function

4.2. Voltage THD Membership Function

The THD may cause irreversible effects on the sensitive load. Thus voltage harmonic minimization can be an attractive objective. THD index is intended to determine the harmonic distortion that the membership function is specified in Equation 10 and Figure 4. In this function, T_{min}=0 and T_{max}=0.05. Since according to IEEE-519 standard, the value of acceptable THD voltage is determined under 5%.

$$\mu_T = \begin{cases} \frac{T_{max}-T}{T_{max}-T_{min}} & \text{for } T_{min} \le T \le T_{max} \\ 1 & \text{for } T \le T_{min} \\ 0 & \text{for } T \ge T_{max} \end{cases} \qquad (10)$$

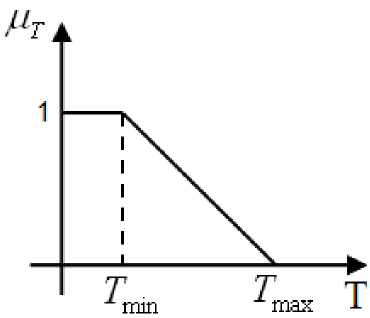

Figure 4. Voltage THD Membership Function

4.3. Proposed control algorithm

Firstly, each objective (input) convert to its special membership function fuzzy. Then by using mentioned objective function in Equation 7, input of Adaline NN algorithm create. Values of each weight coefficients can be consider with operator (designer) comment. Different values are tested for both of objectives in section 5.

5. Simulations and Results

The case study is a power distribution system consists of two voltage buses that one of them includes sensitive load[21-26]. The simple schematic of electrical network is shown in Figure 5 and its parameters introduced in Table 1.

The distractive effect of fault increases by decreasing distance between event locations to sensitive load. To simulation of more critical conditions, two faults are simulated. The first fault is occurred just after series injection transformer and the second one is occurred in near of non sensitive load. These faults led to decrease buses voltages about 50 percent of nominal line voltage of system. However, according to IEEE-519 standard, acceptable voltage sag and swell must not be over 5 percent. Therefore we have to compensate these voltages that stay in the range. In this research, to control the DVR, Adaline NN algorithm proposed. Then this method compared with two other controllers.

TABLE 1. Network parameters

PARAMETERS	VALUES
network ferquency power supply voltage	Fn=50 (Hz) Vs=22500 (V)
active and reactive power for sensetive load	P=2000 (W) $\begin{cases} Ql = 40\ (VAR) \\ QC = 10\ (VAR) \end{cases}$
active and reactive power for non-sensetive load	P=2500 (W) Q_l=40 (VAR)
distribution transformer rated power and ratio	P_n=3200 (W) 20000/380
distribution transformerimpedances	R_l=0.0003 (P.U.) X_l=0.001 (P.U.) R_m=X_m=500 (P.U.)
serie transformer rated power and ratio	P_n=1500 (W) 100/1000
serie 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 ferquency	f_S=10000 (Hz)
dc voltage source	V_{DC}=200 (V)
impedances for shunt and serie filter	R_S=0.2 (Ω) L_S=6 (mH) R_P=0.2 (Ω) C_P=20 (µF)

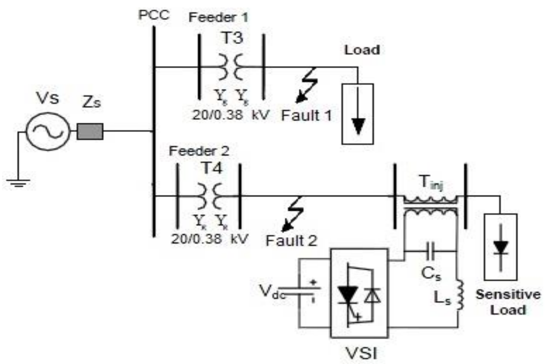

Figure 5. Power distribution system schematic

TABLE 2. Fault parameters

tates	fa ult point	fault period	fa ult resistance	eart h resistance
	1) A,B	[0.025 0.085]	4. 6	0.1
	2) A, B,C	[0.12 0.16]	4. 6	0.1
	1) A, C	[0.025 0.085]	4. 6	0.1
	2) B	[0.12 0.16]	4. 6	0.1

DVR Control has been carried out under different faults in network using classical PID controller, Adaline NN (single-objective) controller and proposed Adaline NN (two-objective) controller. Proposed Adaline NN controller is applied with weighting coefficients w_1=0.75 and w_2=0.25.

The voltage THD signal is as its second objective. Both mentioned cases in Table 2 are simulated and diagrams of PCC bus voltage, sensitive load voltage in the network, and injected voltage to the sensitive load by compensator and voltage flash signal are shown respectively in Figures (6-11). Voltage flash signal is obtained by subtracting real value of voltage from its desired value (one per-unit). Figures (6), (7) and (8) show the first fault condition in the system which is controlled by classical PI controller, Adaline NN controller and proposed Adaline NN controller respectively.

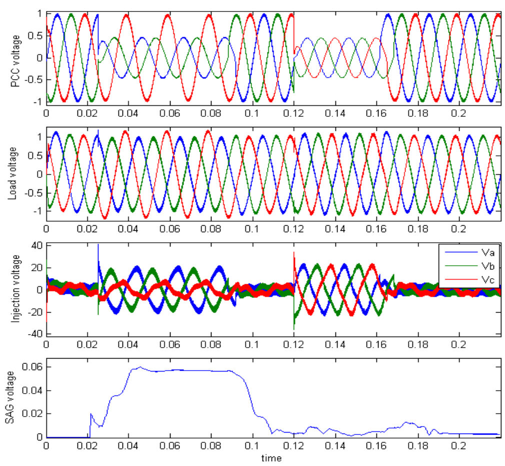

Figure 6. DVR control with classical PI in first state

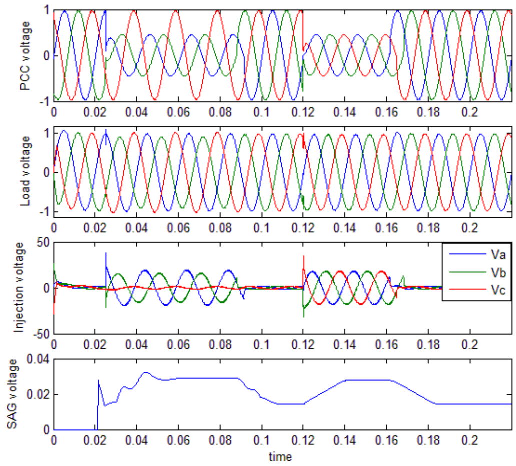

Figure 7. DVR control with Adaline NN controller in first state

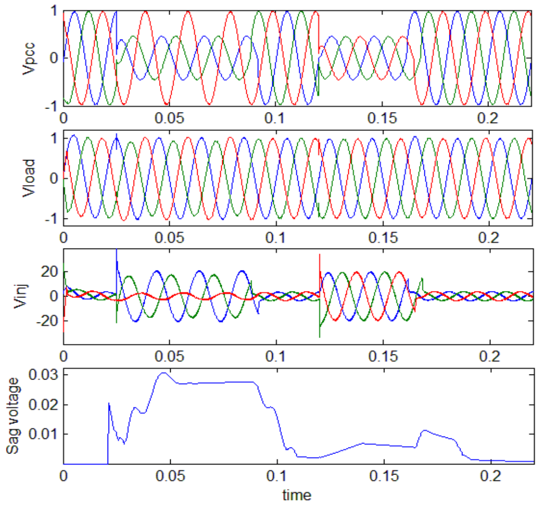

Figure 8. DVR control with two-objective Adaline NN controller in first state

Also, Figures (9), (10) and (11) show the second fault condition in the system which is controlled by classical PI controller, Adaline NN controller and proposed Adaline NN controller respectively.

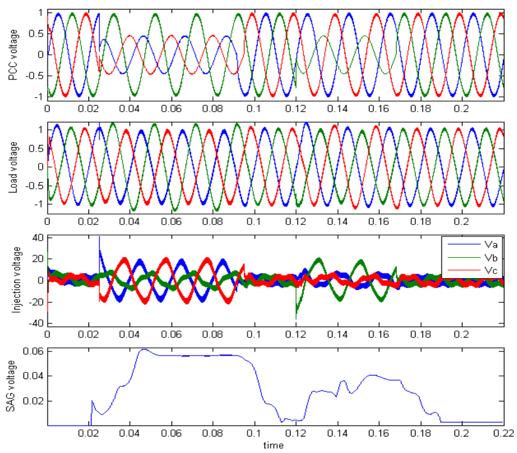

Figure 9. DVR control with classical PI in second state

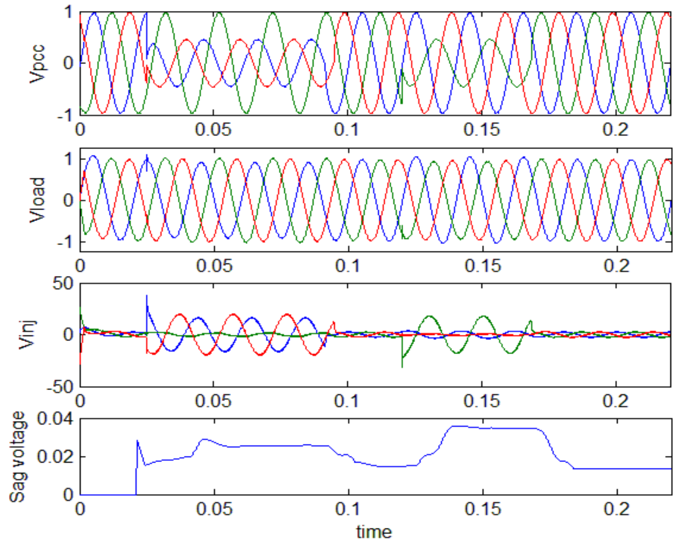

Figure 10. DVR control with Adaline NN controller in second state

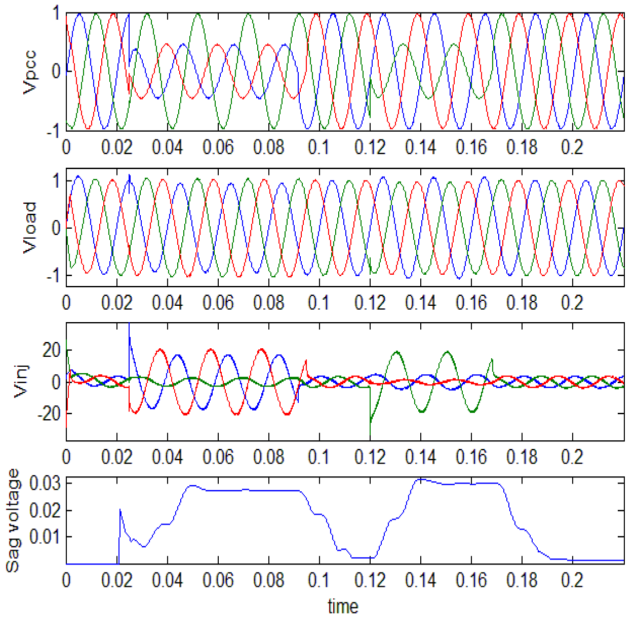

Figure 11. DVR control with two-objective Adaline NN controller in second state

Significant performance improvement of DVR with Adaline NN controller in comparison with PI classical controller is perceptible in both fault conditions. This improvement can be related to its high capability of responding to dynamic behaviors. This improvement can be seen not only in voltage flash compensating but also in voltage THD.

For more improvement of compensation, the modified Adaline NN controller can be used. From Table 3 one can get more detailed information about how power quality indices are improved in each of three control approaches. In this Table, two indices mentioned above and percentage of improvements of both (single-objective) and modified (two-objective) Adaline NN controller over classical PI controller are mentioned. In addition, results of two other controllers that have been introduced in [9] and [12] are obtained in Table 3. The first described a controller based on emotional learning. The second explained a PI controller which regulated with bi-objective PSO. These objectives are voltage sag and THD.

TABLE 3. Results of voltage THD and sag indice in each three control methods

		Voltage sag average		THD (%)	
controllers	tates	value	Improve (%)	alue	Improve (%)
Classical PI		0.0205	-	.87	-
		0.0273	-	.94	-
Emotional Controller		0.0177	13.66	.61	87.47
		0.0203	25.64	.63	84.01
Bi-objective PSO		0.011	46.34	.72	85.21
		0.0161	41.02	.74	81.22
Adaline NN controller		0.0198	3.41	.61	87.47
		0.0215	21.24	.65	83.5
Modified Adaline NN controller		0.0129	37.07	.56	88.50
		0.0164	39.92	.60	84.77

It is clear that performance of proposed Adaline NN controller is improved in comparison with Adaline NN controller. In proposed controller both voltage flash and voltage THD indices have decreased in comparison to the conventional Adaline NN controller. In the other words, by considering control signal of voltage THD as second objective, this index not only has been improved but also the main objective, voltage flash, has been reduced. Considering of voltage THD as second objective modify voltage sag and THD seriously.

The emotional learning controller has good performance on DVR compensating. However, according to results presented in Table 3, we can understand that modified Adaline NN controller (bi-objective) operated better than other methods.

Using PSO algorithm to regulate PI regulator has good compensation in voltage sag rather than proposed algorithm. But voltage THD with Adaline NN algorithm is lower than PSO algorithm. Although voltage sag compensation is better with implementing PSO algorithm, it is possible that the algorithm hasn't proper operation for different states and conditions. Whereas PSO algorithm indicate a good operation point of PI controller for a special state, it's possible that this regulator hasn't good operation in the other conditions. In fact, this effect reveals itself in large systems and faulty conditions which have more complicate dynamic. Also, in section one is quite discussed about the shortcomings of PSO algorithm.

In Equation 7, we saw that different weighting coefficients can be attributed to w_1 and w_2. The simulated cases are listed in Table 4. Also values of indices power quality such as voltage THD and sag have been mentioned in it.

TABLE 4. The values voltage THD and sag with different weight coefficients in two conditions

	First state		Second state	
Values of indices	Sag	THD	sag	THD
w_1=0.5 , w_2=0.5	0.0215	0.58	0.0264	0.56
w_1=0.6 , w_2=0.4	0.0157	0.57	0.0197	0.58
w_1=0.7 , w_2=0.3	0.0132	0.56	0.0169	0.58
w_1=0.75 , w_2=0.25	0.0129	0.56	0.0164	0.58
w_1=0.8 , w_2=0.2	0.0138	0.59	0.017	0.62
w_1=0.9 , w_2=0.1	0.0171	0.60	0.0194	0.65

According to the results in Table 4, by increasing w_1, the voltage sag and THD improve. There are an optimum point in w_1=0.75 and w_2=0.25. It is the best point for making fuzzification of suggested objectives (inputs).

As it can be seen, during whole period of simulation IEEE-519 harmonic standard requirements are observed. These requirements force load voltage THD to be under %5. It should be note that stability analyse is not our purpose in this research. Our study is in distribution systems. Consequently, it can be said that this controller can be an appropriate controller under different dynamic fault in the network and also it can improve power quality indices.

6. Conclusion

According to the results obtained by applying the proposed algorithm to the test network, it can be said that this algorithm is a good approach for improving power quality for customers. As it is clear, due to dynamic behaviors of power system under normal and fault conditions it is difficult to have a good model. So, to achieve fast and accurate performance of compensators, adaptive control algorithms should be used. The proposed controller has shown a very good performance under test cases. Also can been said that the Adaline NN controller and its proposed format are absolutely self-adjusting without any primary training and initializing. This controller mainly was designed to have a better performance in voltage THD index of sensitive load, but it was shown that by improving this index, a better compensation in voltage flash can also be achieved. Designing this controller does not have much complexity. It should be noted that the good performance of proposed approach is obtained without using specific additional equipment which can make it more cost-effective.

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