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A novel control strategy for DVR: Optimal bi-objective structure emotional learning

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ABSTRACT

There are different approaches to provide high power quality for sensitive loads in fault conditions. In this research, "Dynamic Voltage Restorer (DVR)" is used to compensate the harmful effects of disturbances on voltage. In order to improve the performance of DVR's controller from point of view of power quality indices, voltage sag and THD are considered as first and second object respectively so a new structure is suggested for this controller. The proposed controller is based on human brain learning which is a self-tuning PI controller that is called emotional controller. In that paper a bi-objective structure emotional learning is recommended. Also using this controller, system had better performance during fault conditions in term of both these power quality's indices. Furthermore, considering voltage THD as second goal influence on major goal considerably which is voltage sag. Power systems sometimes have complicated dynamic behavior especially during faults. Most controllers have difficulty doing their best performance in these situations. Therefore, in order to modify the performance of this controller from point of view of mentioned power quality indices, we make a decision to regulate this controller's parameters with an optimization algorithm. Self Adaptive Modified Bat Algorithm (SAMBA) is considered as a powerful optimization algorithm in this paper. This optimization algorithm is a modified version of Bat algorithm. The optimization algorithm can overcome to some problems which are common in other optimization algorithms. The algorithm has had a considerable performance rather than standard Bat and PSO algorithm. Also according to simulation results, this proposed method works significantly better than classic PI controller, bi-objective emotional controller and some intelligent controllers that have introduced in other researches already.

Introduction

Nowadays by increasing the number of sensitive loads, demand for access to stable and high quality electrical power has increased significantly. In industrial competitive environment, with the development of commercial production of power electronic devices, computer processors and nonlinear loads, any interruption or diversion from the standard range causes economic losses. The realization of this economic loss can be studied in such frameworks as production competition opportunity loss, efficiency reduction and production cost increase, low-quality products, reduced equipment lifetime and increased 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 defined as a sudden voltage decrease in the range of 10–90% for 0.5 cycles to 1 min [2]. That is the result of natural phenomena such as system asymmetric errors and electromagnetic phenomena such as start and inrush current.

"Custom Power" device have 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 injects proper voltage to the network and decrease voltage sag effect.

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The classical PID method has poor flexibility since its parameters cannot be changed. Furthermore, when it is applied to such complicated systems as power system in fault conditions specially, proper results can't be obtained in most cases [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 [7,8] H∞ controller and a controller based on iteration are used respectively for having better operation in steady and transient states. A multi-level inverter with optimal predictive control structure is used in [9]. These controllers are based on classical and nonlinearity control theory. The problems of control plants that arise in systems such as power systems and its components can be classified under three categories. There are such problems in DVR control. The first problem is complex computation of DVR control. Therefore these theories are rarely used in practical systems. The second is the presence of nonlinearities in these systems that make the control problem complicated. The last is uncertainty in these systems. Necessary information required in the mathematical model of these systems such as intensive dynamic behaviors in normal and special fault conditions is unknown. Most classic and nonlinear control methods are model based, hence it's possible that they have difficulty controlling these systems. Therefore, based on the nonlinear control theory as fine as the human ability to comprehend, reason and learn, intelligent methods may be used to overcome the these problems [10]. Thus some researchers investigated on intelligent techniques in order to control DVR compensator. Emotional controller is implemented as an adaptive controller in [11] for controlling DVR. In [12] fuzzy controller is utilized in DVR structure. In [13–16], improving voltage THD index has also been considered as an objective and a control criterion. In [13,14] is introduced a multi-objective PSO and multi-objective modified PSO algorithms to optimize voltage sag and THD. An adaptive neural network controller based on Hebb learning theory discussed in [15]. This controller was made bi-objective with fuzzification of goals. 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. In many sensitive loads such as medical equipments and adjustable speed motor drives, this level of sensitivity can be very important.

In most of the aforementioned researches, it is tried to utilize a stable controller in the system in order to make it capable of reacting to various fault conditions in the best possible way. References [13,14] 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 have a completely nonlinear nature. This may cause these algorithms which operate based on random search to encounter problems in finding real optimum point of this structure and finally converge to a local optimum. Also, it is necessary to note that in real power systems this search process takes long time [16]. Secondly, power systems have different dynamic behaviors especially during fault conditions. Therefore, PID controllers which are optimized by offline search algorithms may not have a good performance under these conditions [16]. In [15] a method was introduced which is similar to the mentioned requirement controller. This way is Hebb learning controller. However the adaptive neural network is not implemented in a easy manner in practical applications. Therefore, we try to create a controller that overcomes these drawbacks. This controller is based on emotions called emotional controller and it is adaptive based on intelligent control. In the following, we discuss about this controller.

The adaptive method which is inspired by learning nature of human brain is used as a self-tuning PI controller. In order to put capability of having an appropriate performance during voltage flash and sensitive load voltage THD in this controller, a two-objective structure was proposed in a last research. Furthermore, it was shown which by considering control signal of voltage THD as second objective, this index not only has been improved but also the main objective of this compensation, voltage flash has been reduced and also they argued this proposed controller have proper performance rather than other controllers that have introduced as DVR controller [16]. Proper regulating of emotional controller's parameters is enormous essential to have better performance [17]. Hence we decide to regulate these parameters with an optimization algorithm. Considering some drawbacks of most optimization algorithms, in this paper we use Bat algorithm (BA) for regulating these parameters [18]. BA is a numerical optimization approach that is simple, easy to implement, significantly faster than other algorithms, and robust. Furthermore, in order to enhance the search ability of this algorithm, a new Self-Adaptive Modified Mechanism (SAMM) is implemented in this paper. Most optimization methods require algorithm parameters that affect the performance of the algorithm. For instance, GA requires the crossover probability, mutation rate, and selection method; PSO requires learning factors, the variation of weight, and the maximum value of velocity. The proper tuning of the algorithm specific parameters is very crucial factor, which affect the performance of the above mentioned algorithms. The improper tuning of algorithm-specific parameters either increases the computational effort or yields the local optimal solution. Considering this fact, the proposed Bat algorithm (SAMBA) which does not require any algorithm parameters to be tuned, thus making the implementation of SAMBA simpler. Therefore in this paper, SAMBA is used for regulating bi-objective emotional controller's coefficients to have appropriate performance. Also we use standard PSO and Bat algorithm for regulate parameters of this controller to compare SAMBA. In order to investigate efficiency of the proposed algorithm, performance of DVR compensator is tested during various faults in a typical network and compared with versions of emotional controllers and classical PI controller and other controllers which are introduced in previous researches.

DVR operation is introduced in Section 'DVR's structure and functionality'; PI emotional controller and their multi objective structures are introduced in Section 'Structure of human brain emotional learning' and SAMBA algorithm is explained in Section 'Self Adaptive Modified Bat Algorithm (SAMBA)'. In Section 'Proposed method' we describe about proposed method in the paper. Final section contains the simulation and results.

DVR's structure and functionality

DVR is one of the "custom power" devices in distribution network which is series with transmission line. Load voltage becomes balance by injecting three controlled voltages during disturbance in the power system. 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 [16]. In the standby mode a low voltage inject into the network in order to cover voltage sag caused by transformer reactance. In second mode, in presence of voltage sag, DVR injects appropriate voltage to sensitive load. DVR circuit includes 5 main components. They are shown in Fig. 1.

(1) *Series transformer:* that its primary winding is connected to the inverter and its 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 control technique is PWM.