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An intelligent power factor corrector for power system using artificial neural networks

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ABSTRACT

An intelligent power factor correction approach based on artificial neural networks (ANN) is introduced. Four learning algorithms, backpropagation (BP), delta-bar-delta (DBD), extended delta-bar-delta (EDBD) and directed random search (DRS), were used to train the ANNs. The best test results obtained from the ANN compensators trained with the four learning algorithms were first achieved. The parameters belonging to each neural compensator obtained from an off-line training were then inserted into a micro-controller for on-line usage. The results have shown that the selected intelligent compensators developed in this work might overcome the problems occurred in the literature providing accurate, simple and low-cost solution for compensation.

1. Introduction

Reactive power compensation (RPC) is very important for industrial facilitates [1–3]. The purpose of RPC is to supply controlled reactive power by optimally fixed capacitors (FCs), thyristor controlled reactor-fixed capacitors (TCR-FCs), thyristor controlled reactors with thyristor switched capacitors (TCRs + TSCs), thyristor switched capacitors (TSCs) and synchronous motors (SMs) available in the system and installed in the electrical lines such that the voltage drop and real power loss is minimum. Fixed and switching capacitors are known as conventional methods and have some mechanical problems like slow responses, over or under compensation and harmonics in line voltage and current due to step changes of capacitor groups occurred during operation [4,5]. The changes of reactive power produced by variation of load or load switching on the line can cause adverse effects on voltage stability and system security. Nevertheless, TCRs and TSCs can give smooth reactive power compensation without step changes. TCRs (or TSCs) for reactive power compensation systems are faster and have not any mechanical problems. But they generate harmonics in voltage and current, and cause a stability problem in the system [6–11]. These problems can be overcome using a synchronous motor, if it is already available in the system [1,12–15].

The use of a synchronous motor as a reactive power compensator is a well-known method. If a synchronous motor is only used for the reactive power compensation, the system will be very inefficient and expensive in comparison with the group of capacitors [12–15]. Synchronous motors can operate at unity, lagging or leading power factor conditions but some problems also occur in this case, such as requiring manual control under variable loads [16]. In order to get rid of this problem, many different control techniques like proportional-plus-integral (PI), proportional-plus-integral-plus-derivative (PID), pulse width modulation (PWM) and fuzzy logic (FL), have been used in controlling the excitation voltage of the synchronous motor [13,15,17–22]. If a PI, PD or PID controller is used, a mathematical equation is required to represent the dynamic system [23,24]. To design a fuzzy logic controller, the information obtained from the operator is more important than the dynamic mathematical model of the system [21]. Even if fuzzy control reduces the error of the system to a minimum, the linguistic changes, the error and the change of error are used to give the decision according to the controller rules [25,26].

The problems encountered in the literature generally are summarized as: the mechanical problems, the harmonics in voltage and current waveform, the time delays and the step changes of excitation voltage, pole slip, kVA loading on plant transformer and voltage drop on the line, application and implementation difficulties. When these problems have been considered, accuracy, reliability, less power consumption, simplicity and the fast computation have been always required.

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Artificial neural networks (ANNs) have been very popular to achieve these requirements because of their fascinating features such as learning, generalization, faster computation and ease of implementation [27,28]. Therefore, ANNs have been recently applied for power system security, power system stability estimation and optimal static VAR compensation (SVC) [29,30], and controlling induction motors, direct current motors and SMs [31,32], and power factor compensations [33]. Sagiroglu et al. were proposed to handle power factor using neural compensator controlled by a synchronous motor. The neural structure was designed with two hidden layers having 10 and 5 neurons in the first and the second hidden layers, respectively. Using two hidden layers in the neural structures causes time delay, implementation difficulty, and larger computation time for microcontroller implementation [33].

This paper also focuses on controlling the excitation voltages of a synchronous motor with the help of simpler ANN structures to compensate the power factor of the line system. In order to get higher accuracy, lower energy consumption, faster computation and easier implementation of the neural controllers, the neural controllers designed with single hidden layers were trained with backpropagation with momentum, delta-bar-delta, extended delta-bar-delta, directed-random search learning algorithms. The parameters of each ANN controller were then inserted into a microcontroller for test.

In this paper, reactive power compensation in electrical systems was described in Section 2. The theory of artificial neural network was introduced in Section 3. The design and implementation of the neural controllers for the dynamic reactive power compensation were presented in Section 4. In Section 5, experimental study and measurements were introduced. The results were given in Section 6. The work was finally concluded in Section 7.

2. Reactive power compensation

Loads on electrical systems are known as resistive, inductive and capacitive. All inductive loads require two kinds of powers to function properly. Active power (P) actually performs the work but reactive power (Q) sustains the magnetic field.

The ratio of the active power to the apparent power (S) is known as the power factor. The relationship among apparent power, active power and reactive power is represented as

$$S = \sqrt{P^2 + Q^2} \quad (1)$$

The power factor is expressed as pf or $\cos\varphi$. The power factor is shown as [34,35]:

$$\text{pf} = \frac{\text{active power}}{\text{apparent power}} = \frac{P}{S} \quad (2)$$

Not only improvement of the power factor will save money, additionally, it also maximizes the capacity of power system, improves the quality of voltage, and reduces the power losses. In order to decrease the cost and to improve the efficiency, the reactive power drawn from the line has to be declined by supplying it from other reactive power source. Capacitors and synchronous motors have been mostly used to compensate the reactive power in applications [15,33].

3. Artificial neural networks

Artificial neural networks (ANNs) have been employed to various problems because of their fascinating features of learning, fast computation and ease of implementation [27,28]. ANN usually consists of an input layer, hidden layer and an output layer. General structure of an ANN is demonstrated in Fig. 1. An ANN contains very simple and highly interconnected processors called neurons. The neurons represented by rectangular in Fig. 1 are connected to each other by weighted links over which signals can pass. The input layer is represented by circles and behaves as a buffer. Each neuron receives multiple inputs from other neurons, except the neurons in the input layer, in proportion to their connection weights and then generates a single output in according with an activation function. An activation function can be linear or nonlinear form depending on applications.

Training a network consists of adjusting weights of the network using a different learning algorithm. ANNs in this work are trained with the three supervised and one reinforcement learning algorithms. In this work, the backpropagation with momentum (BP), the delta-bar-delta (DBD), the extended delta-bar-delta (EDBD) and the directed random search (DRS) were used to train the neural compensators. In addition, sigmoid and tangent hyperbolic activation functions were used to improve the performance of ANNs. The four

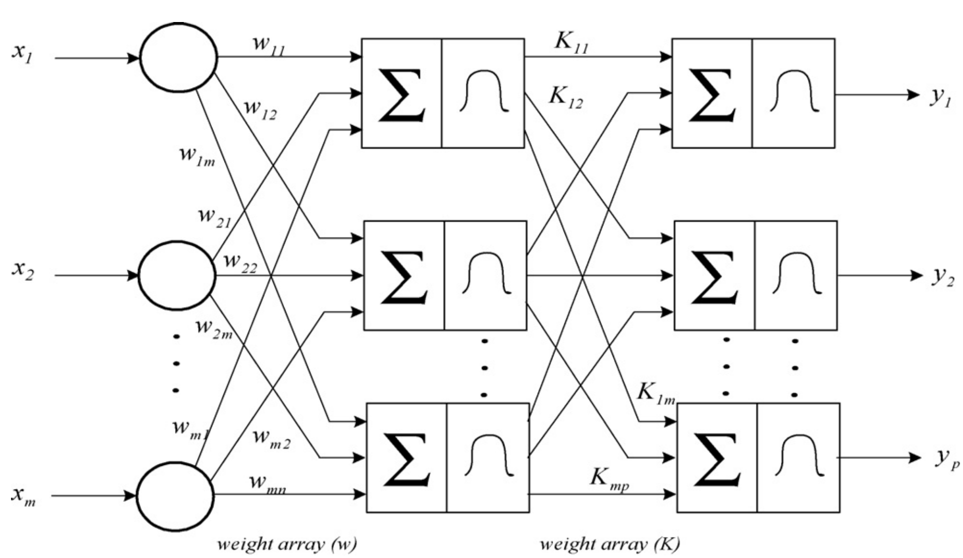

Fig. 1. An ANN structure.