# Modeling and Control of Three Phase Boost Rectifiers via Wavelet Based Neural Network

**FARZAN RASHIDI** **AMIR HOOSHANG MAZINAN**

School of Engineering
Islamic Azad University, South of Tehran Branch
Tehran, Iran

***Abstract: -*** In recent years, three-phase boost rectifiers, due to their high efficiency, good current quality and low EMI emissions are widely used in industry as Power Factor Correction (PFC) converters. Performance criteria of these converters significantly improve with increasing the switching frequency, and highly depend on the control strategy used.
This paper presents a new approach to control of three phase boost rectifiers. The proposed method is a hybrid of wavelet and neural network (WNN). Simulation results show that this control strategy is very robust, flexible and also the response of the system is very fast. With applying WNN to the three-phase boost rectifier, the system under control will has unity power factor, sinusoidal input currents and regulated output voltage.

***Key-Words:*** - Three phase, Wavelet, Neural Network, Boost Rectifier

## 1 Introduction

A variety of three-phase ac-dc PWM rectifiers are known, the most well known topology is the three-phase ac-to-dc boost rectifier. Three-phase boost rectifiers, due to their high efficiency, good current quality and low EMI emissions are widely used in industry as Power Factor Correction (PFC) converters [1]. For switching this type of converter, various modulation techniques have been already developed and implemented [2]. The simplest current control approach for three-phase boost rectifier is the Hysteresis Current Control (HCC). This technique combines the modulation and current control into a single function. It also provides the widest current–loop bandwidth among all control schemes. However, load dependence on switching frequency and phase interference problems in this technique, result in irregular converter operation and distorted current waveforms and cause excessive stress on switching devices [1]. The Predicted Current control with a Fixed switching Frequency (PCFF) strategy, known as the best fixed frequency method, has been proposed to maintain the advantages of other control strategies and has a very simple control structure. PCFF’s switching pattern reduces the switching losses and decreases the switching devices stress and improves the current waveforms, when compared to HCC and other analog techniques [3,4]. Although, PCFF is one of the well-known control strategies used in boost rectifiers, the need of three separate modulators for three phases is considered as a drawback [5,6].
This paper presents a new approach to control of three-phase boost rectifier. The proposed method is a hybrid of wavelet and neural network (WNN). Simulation results show that this control strategy is very robust, flexible and also the response of the system is very fast. With applying WNN to the three-phase boost rectifier, the system under control will has unity power factor, sinusoidal input currents and regulated output voltage.

This paper is organized as follows: In section II, the whole structure of the wavelet neural network (WNN) is shown. Section III describes the boost rectifier and its mathematical model. Section IV shows the simulation results. Some conclusion and remark are discussed in section V.

## 2 Wavelet Neural network

Due to the similarity between wavelet decomposition and conventional neural networks, the wavelet neural network, which combines wavelets and neural networks, has been proposed in various works. Many studies have reported that the wavelet neural network shows better approximating performance than conventional neural network does [7,8]. The wavelet neural networks (WNN) which have similar structure to the conventional RBF networks have the strengths such as free-selection of the basis functions and capability of setting the initial values of parameters systematically from the system's time-frequency characteristics and the wavelet theory. Thus, the WNN is the structure, which can compensate for the weakness of the RBF networks, while preserving most of the advantages of the RBF network. Fig.1 shows the whole structure of Wavelet neural network, which we have used in this paper. As shown in Fig.1, the proposed network has a feedforward structure consisting of a single hidden layer. The activation functions of the hidden layer units are the wavelets and the weights connecting the hidden layer units to the output layer units are the local linear models. The training of all of the parameters at the layers is performed by gradient-descent method. If the wavelet functions at hidden layers were as $\psi_i$, then the output of the *kth* unit in the output layer of the proposed network will be as follow:

$$y_k = \sum_{i=1}^{M} u_i \psi_i (X) \qquad (1)$$

Where $u_i = w_{i,0}x_0 + w_{i,1}x_1 + ... + w_{i,N}x_n$ and $X = (x_1, x_2, ....., x_N)$.

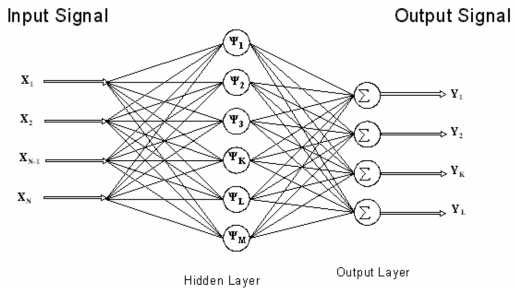


**Fig.1: The structure of Wavelet Neural Network**

## 3 Three Phase Boost Rectifier

Three-phase boost rectifier requires six SPST current bidirectional two-quadrant switches. The inductors and capacitor filter the high-frequency switching harmonics, and have little influence on the low frequency ac components of the waveforms. The switches of each phase are controlled to obtain input resistor emulation, either with a multiplying controller scheme employing average current control, or with some other approach. To obtain undistorted line current waveforms, the dc output voltage *V* must be greater than or equal to the peak line-to-line ac input voltage $V_{L,pk}$. In a typical realization, *V* is somewhat greater than $V_{L,pk}$. This converter resembles the well-known voltage-source inverter, except that the converter is operated as a rectifier, and the converter is controlled via high-frequency pulse-width modulation. The main objective of three-phase boost rectifier is to generate three-phase sinusoidal input currents in phase with the input phase voltages. To design the control law, dynamic equations of three-phase boost rectifier are derived. The first step in the analysis of the boost rectifier is the derivation of state space equations. Fig. 2, shows the schematic diagram of three phase boost rectifier. From fig. 2, the following equations are written as a representation of the circuit model [9],

$$\begin{bmatrix} v_{AB} \\ v_{BC} \\ v_{CA} \end{bmatrix} = L\frac{d}{dt}\begin{bmatrix} i_a - i_b \\ i_b - i_c \\ i_c - i_a \end{bmatrix} + \begin{bmatrix} v_a - v_b \\ v_b - v_c \\ v_c - v_a \end{bmatrix} \tag{2}$$

$$i_{dc} = C\frac{dv_{dc}}{dt} + \frac{v_{dc}}{R} \tag{3}$$

The line-to-line currents and voltages are defined as follows in terms of phase variables,

$$\vec{i}_{l-l} = \begin{bmatrix} i_a - i_b \\ i_b - i_c \\ i_c - i_a \end{bmatrix}, \vec{v}_{L-L} = \begin{bmatrix} v_A - v_B \\ v_B - v_C \\ v_C - v_A \end{bmatrix}, \vec{v}_{l-l} = \begin{bmatrix} v_a - v_b \\ v_b - v_c \\ v_c - v_a \end{bmatrix} \tag{4}$$

Equations (2) and (3) can be rewritten using the above definitions as follows:

$$\frac{d}{dt}\vec{i}_{l-l} = \frac{1}{3L}\vec{v}_{L-L} - \frac{1}{3L}\vec{v}_{l-l} \tag{5}$$

$$\frac{dv_{dc}}{dt} = \frac{1}{C}i_{dc} - \frac{v_{dc}}{RC} \tag{6}$$

Line-to-line voltages and dc current are related to the switching function, $\vec{s}_{l-l}$, $v_{dc}$ and $\vec{i}_{l-l}$ in the following manner,

$$\vec{v}_{l-l} = \vec{s}_{l-l}v_{dc},\ i_{dc} = \vec{S}^T_{l-l}\vec{i}_{l-l},\ \vec{S}_{l-l} = \begin{bmatrix} S_a - S_b \\ S_b - S_c \\ S_c - S_a \end{bmatrix} \tag{7}$$

These definitions of $v_{L-L}$ and $i_{dc}$ are substituted into (5) and (6) to obtain:

$$\frac{d}{dt}\vec{i}_{l-l} = \frac{1}{3L}v_{L-L} - \frac{1}{3L}\vec{S}_{l-l}v_{dc} \tag{8}$$

$$\frac{dv_{dc}}{dt} = \frac{1}{C}\vec{S}^T_{l-l}\vec{i}_{l-l} - \frac{v_{dc}}{RC} \tag{9}$$

By applying an average operator to the switching model, (8) and (9), equations that represent the average model are obtained,

$$\frac{d}{dt}\bar{\vec{i}}_{l-l} = \frac{1}{3L}\bar{\vec{v}}_{L-L} - \frac{1}{3L}\vec{d}_{l-l}\bar{v}_{dc} \tag{10}$$

$$\frac{d\bar{v}_{dc}}{dt} = \frac{1}{C}\vec{d}^T_{l-l}\bar{\vec{i}}_{l-l} - \frac{v_{dc}}{RC} \tag{11}$$

Using (10) and (11), the *dq* model in phase variables is developed as follows:

$$L\frac{di_d}{dt} = v_d + \omega L i_q - d_d v_o \tag{12}$$

$$L\frac{di_q}{dt} = v_q + \omega L i_d - d_q v_o \tag{13}$$

$$C\frac{dv_c}{dt} = \frac{3}{2}(d_d i_d + d_q i_q) - \frac{v_o}{R} \tag{14}$$

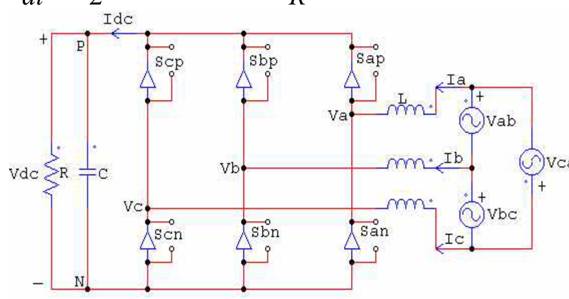


**Fig. 2. Three-phase boost rectifier.**

## 4 Simulation Results

Fig.3 shows the control block diagram of the three-phase boost rectifier. The proposed control strategy and the rectifier power circuit are simulated on MATLAB software. Sample simulation results are shown in Figs.4-7. Fig.4 shows the output voltage of boost rectifier. As it is clearly obvious, result is very satisfactory. On the other hand, the system response is very fast and it hasn't any overshoot. Figs.5 shows the performance of the boost rectifier, when load has step change. As shown figure 5, the WNN shows the excellent control performance in terms of settling time, overshot and rise time. Figure 6 and 7, show transient waveform of input voltage and current taken during a step load changes from full-load to its half and vice versa. It is seen that the line current obtain is nearly sinusoidal with unity power factor. The rapid change in the input line current shows that the proposed control scheme has a very good dynamic response to the load variations. Also, during this critical load change the output voltage remains almost constant with a minimum overshoot.

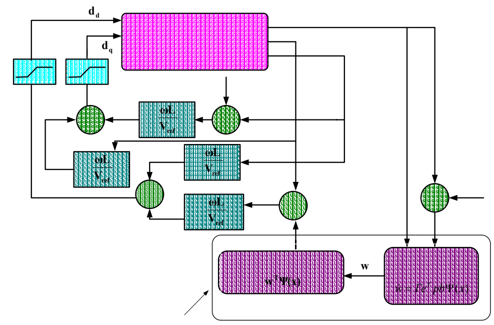


**Fig.3: Control Block Diagram of the Three-Phase Boost Rectifier.**

## 5 Conclusion

In this paper, a simple, fast and robust Wavelet Neural Network (WNN) based control strategy to enhance the operating performance of three-phase boost rectifiers is proposed. The controller presented in this paper possessed excellent tracking speed and robustness properties. The proposed method maintains the advantages of the other schemes, including fast dynamic response, unity power factor, suitable switching pattern and sinusoidal input currents. Simulation results confirm the validity of the analytical work.

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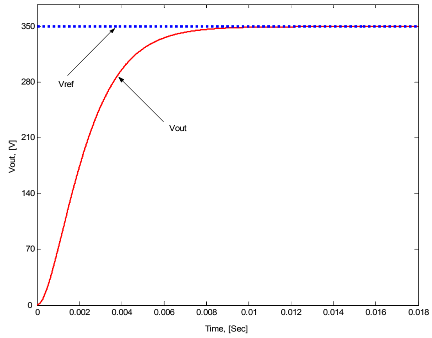


**Fig.4: Output voltage of three phase boost rectifier**

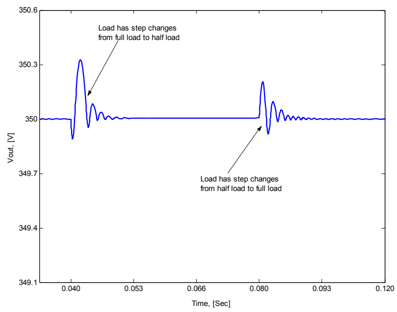


**Fig.5: The performance of boost rectifier when load has step changes from full-load to its half and vice versa**

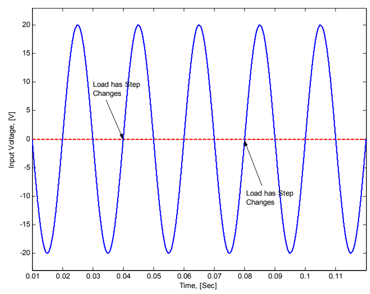


**Fig. 6: Input voltage during a step-load change**

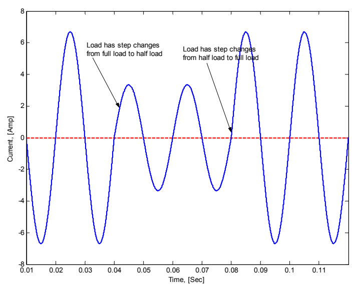


**Fig. 7: Input current during a step-load change**