Optimal Power Quality Control in Process Industries using Neural Network & Intelligence Techniques

Jitendra Singh Jhala
Department of Electrical Engineering,
Career Point Technical Campus, Rajsamand, Rajasthan, India

Dr. R. R. Joshi
Department of Electrical Engineering,
College of Technology & Engineering (MPUAT), Udaipur, Rajasthan, India

Vinod Kr. Yadav
Department of Electrical Engineering
College of Technology & Engineering (MPUAT), Udaipur, Rajasthan, India

Abstract - The increased use of nonlinear devices in industry has resulted in direct increase of harmonic distortion in the industrial power system in recent years. This paper presents harmonic analysis of closed loop controlled direct converter fed Induction motor drive. To effectively reduce the current harmonics, neural network based switching strategy for an ac/ac converter is presented.

Keywords: power quality, neural network, induction motor, current harmonics.

I. Introduction

Estimation of harmonics in motor currents is necessary when the input voltages are non-sinusoidal. It enables identifications of the limits on the operating conditions, if any, of the drive. In particular, considering unbalanced input voltages, most of the modulation strategies introduce low-order harmonics in the output voltages. Modern Converter has low input current THD (Total Harmonic Distortion) characteristics but in some application areas much lower THD level is required.

When the bus voltage is adjusted relative to the motor speed and the voltage drop of the resistance and inductance, a better performance of the drive system can be obtained. Therefore, a neural network to study the relationship between the bus voltage and the operating condition of the induction motor drive is investigated. There are three different types of bus voltage: the high bus voltage, the middle bus voltage, and the low bus voltage. Their voltage waveforms are shown in Fig. 1. The high bus voltage varies between VPK and 0.866 VPK; the middle bus voltage varies between 0.866 VPK and 0.5 VPK and the low bus voltage varies between 0 and 0.5 VPK.

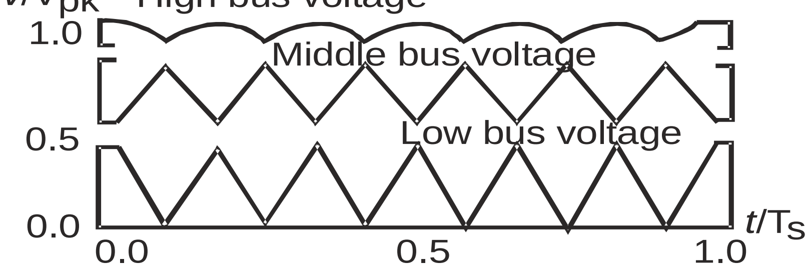

Fig 1: Indirect switching method: three types of bus voltages

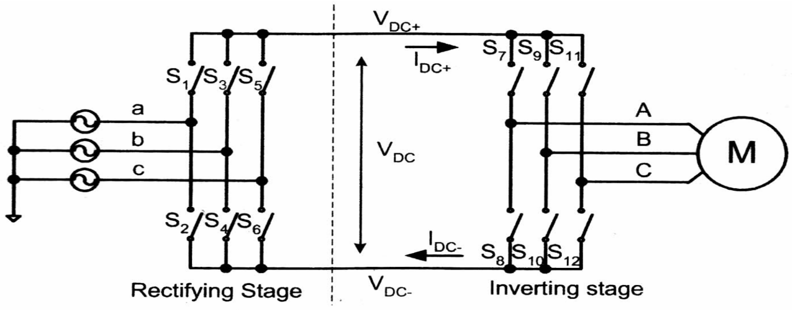

Fig 2: Indirect switching method: virtual equivalent dc-link converter and inverter circuit

In any converter system, the input voltage to the converter will be distorted by the switching of the converter. The extent of this distortion depends on the switching frequency and the degree of filtering used. Since it is desirable to make the filter as small as possible, it is necessary to determine the effects of input voltage distortion (at or about the switching frequency) on the performance of the converter. Current harmonics due to input LC filter resonance is one of main source that deteriorates current THD. Suppressing resonant current by additional damping resistor is a simple solution but power loss is not negligible in high power range.

Therefore, in light of above fact, an active input harmonics damping circuit is developed utilizing existing voltage clamp circuit to achieve very low input current THD level. Since the damping filter compensates mainly resonant current ripple, much smaller current rating devices are needed to achieve harmonics damping control than main MC power circuit.

II. HARMONICS IN CONVERTERS AT PROCESS INDUSTRIES

As the matrix converter has no dc-link energy storage, any disturbance in the input voltages will be reflected in the output voltages. In particular, considering unbalanced input voltages, most of the modulation strategies introduce low-order harmonics in the output voltages. An SVM (Space Vector Modulation) algorithm for matrix converters allows balanced output voltages to be generated, even under unbalanced supply conditions. As is known, in the case of unbalanced supply voltages, the negative sequence components of the voltage system causes variation in magnitude and angular velocity of the input voltage vector. As a consequence, a simple synchronization with the input voltages, as under balanced conditions, is no longer applicable and the input voltages have to be measured at each sampling instant. The harmonic profile of matrix converter system depends upon nature of power supply, whether balanced power supply, unbalanced power supply or balanced non-sinusoidal power supply. It can be noted that in the balanced conditions, the output voltages and input currents do not contain low-order harmonics. It is observed that unbalance in input supply results in abnormal harmonics in the matrix converter output. However, if the input power supply voltages contains the harmonics with the order of k, the harmonic components with the frequency of (k - 1) wi ± w0 and (k + 1) wi ± w0 will be introduced in output voltages .

III. NEURAL NETWORK BASED STRATEGY FOR OPTIMAL POWER QUALITY:

A neural network based switching strategy for matrix-converter induction motor drive system is proposed here. The new neural network based switching strategy for an ac/ac matrix converter fed induction motor drive can effectively reduce the current harmonics of the motor.

There are two major frequency conversion methods for a matrix converter: direct and indirect. By using the direct method, the sinusoidal input and output waveforms with unity input displacement power factor can be obtained. However, this method requires a lot of complicated computations to increase the voltage gain by injecting a third harmonic of the input and output frequency into the desired output-phase voltage. The indirect switching method is based on the basic principle of the switching strategy of the conventional converter and inverter. By using this method, the ac-dc and dc-ac conversion signals are generated separately. Then, all of the switching patterns of the matrix converter can be obtained by synthesizing the signals of the converter and inverter. This method, however, produces higher and fractional harmonic components. In addition, it may require a lot of computing time for a digital signal processor to execute a real-time algorithm to reduce the harmonic components. That increases the sampling interval of the current-loop control, and the performance of the drive system deteriorates. In order to solve this problem, a simple method based on neural network to reduce the output current harmonics of the matrix converter is proposed.

Here, a current controlling inverter regulates the current. The basic circuit of a three-phase current regulator is depicted in Fig. 2, which has already been discussed at page no. 113 of this chapter. By suitably selecting the switches S7-S12 current regulation can be achieved. The inverter has three legs. Each leg independently controls one phase current. In addition, each leg can switch and connect to the upper side or lower side. As a result, the three pairs of switches provide eight conduction modes. However, when the switches are all situated on the upper legs or lower legs, the motor is disconnected from the inverter. These two modes are called free-wheeling periods. The other six conduction modes provide six non-zero voltage vectors. By properly controlling the three-phase firing signals, the resultant stator current vectors will interact with the rotor flux to provide the required electromagnetic torque.

In this work, the three-phase independent current controller determines the three-phase firing signals. Taking the a-phase as an example. When the a-phase current command is larger than the a-phase current, which means Δ ias is greater than zero, the upper leg S7 is turned on. On the other hand, when Δ ias is less than zero, the lower leg S8 is turned on. The operations of the other two phases can be obtained analogously.

A. Structure of Neural Network

A multi-layer neural network is used here to determine the bus voltages of the matrix converter. It is possible to compute the required voltage vector of the motor, and then determine the optimal selection of the bus voltage. This method, however, requires a lot of computations and is difficult to implement. An off-line learning neural network is therefore proposed. Fig. 3 shows the structure of the proposed neural network which includes an input layer, a hidden layer, and an output layer. Table 1 states parameter of the neural network model.

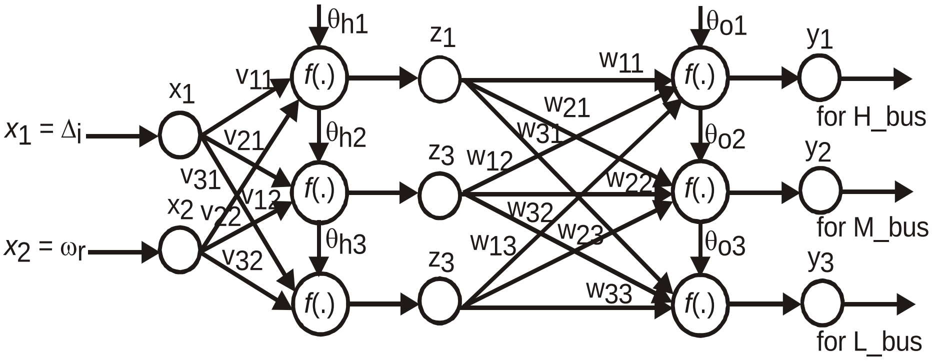

Fig. 3 Structure of neural network

A. Table 1 Parameters of the neural network model

S.No.	Parameters	Parameter values
1	Input	1. Motor speed (w_r) 2. Max absolute value of three phase current deviation (□ I)
2	Output	1. High bus voltage 2. Middle bus voltage 3. Low bus voltage
3	Maximum input value	W_r = 1 (p.u.) □I = 1 (p.u.)
4	Minimum input value	W_r = 0 (p.u.) □I = 0 (p.u.)
5	Maximum output value	High bus voltage = V_{pk} Middle bus voltage =0.866* V_{pk} Low bus voltage = 0.5 * V_{pk}
6	Minimum output value	High bus voltage =0.866* V_{pk} Middle bus voltage =0.5 * V_{pk} Low bus voltage = 0

7	Functions	Tansigmoidal + Linear
8	Layers	Input, hidden and output layers (3)
9	Hidden layer nodes	3
10	Input layers nodes	2
11	Output layer nodes	3
12	Number of samples	1000
13	Learning rate (□)	0.1 - 1.0
14	Momentum	0.6
15	Iterations (Epochs)	6270
16	Mean Squared Error	$6.57 * 10^{-5}$

IV. TRAINING OF NEURAL NETWORK:

Training is the procedure for modifying the weights and biases of a network. The purpose of learning rule is to train the network to perform some task. Once the networks weights and biases have been initialized, the network is ready for training. The parameters of the synaptic weights are off-line trained. The input state variables are the motor speed and current deviation because they are related to the bus voltage. For example, a higher speed range requires a high bus voltage to produce the required current regulation. In addition, the current deviations during transient response and steady-state conditions appear different and thus require different bus voltages to reduce the deviations.

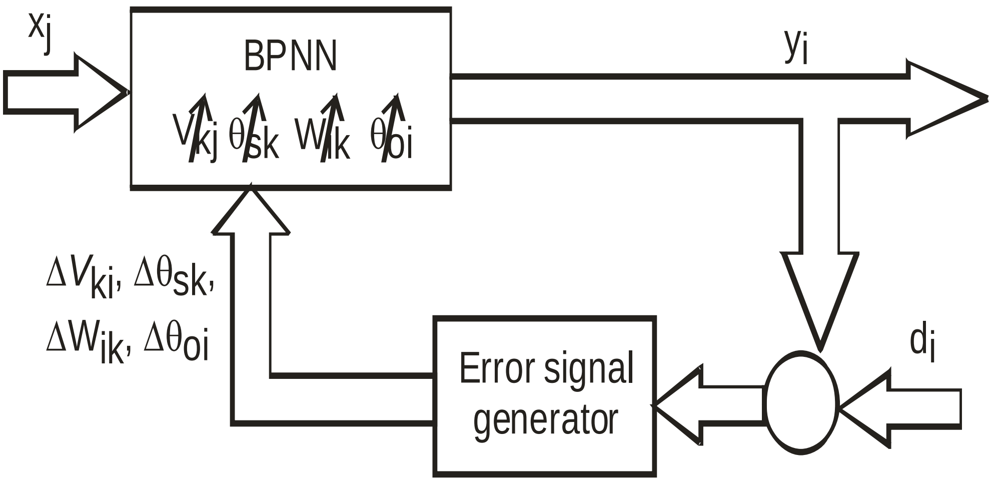

Fig. 4 Off-line learning algorithm

A. Testing of Neural Networks

For performance validity of the so designed neural network system, it is tested with both the known and unknown cases. Table 2 shows sufficiently high percent accuracy for known cases while Table 3 presents some typical unknown cases. These and host of other cases show very good testing results. Considering, a typical operating condition with speed command 520 r/min and current error 0.28 amps, the percentage accuracy obtained for bus voltage is 98.82 % for the known case. For a typical operating condition with speed command 840 r/min and current error 0.19 amps, the percentage accuracy obtained for bus voltage is 99.68 % for the known case.

Similarly, referring another typical operating condition with speed command 530 r/min and current error 0.20 amps, the percentage accuracy obtained for bus voltage is 98.75 % for the un-known case

Table 2 Testing of Neural Networks (Known Cases)

S. No.	Known cases of neural networks			Measured output	Percentage accuracy
	Speed commands: NN input	**Current error: NN input**	**Bus voltages: NN output**		
1	0 r/min	0.00 amps	00.00 V	00.00 V	100
2	40 r/min	0.11 amps	45.51 V	45.41 V	99.77
3	80 r/min	0.12 amps	46.74 V	46.70 V	99.91
4	120 r/min	0.13 amps	47.15 V	47.00 V	99.68
5	160 r/min	0.14 amps	47.56 V	47.00 V	98.82
6	200 r/min	0.15 amps	47.97 V	47.50 V	99.02
7	240 r/min	0.21 amps	48.38 V	48.30 V	99.83
8	280 r/min	0.22 amps	89.38 V	89.30 V	99.80
9	320 r/min	0.23 amps	114.39 V	114.30 V	99.81
10	360 r/min	0.24 amps	149.24 V	149.14 V	99.93

Table 3 Testing of Neural Networks (Unknown Cases)

S. No.	Unknown cases of neural networks			Measured bus voltage	Percentage accuracy
	Speed commands: NN input	**Current error: NN input**	**Bus voltages: NN output**		
1	30 rpm	0.10 amps	41.72 V	41.70 V	99.95
2	50 rpm	0.11 amps	45.51 V	45.49 V	99.94
3	70 rpm	0.12 amps	46.74 V	46.69 V	99.89
4	90 rpm	0.13 amps	47.15 V	47.10 V	99.88
5	110 rpm	0.14 amps	47.56 V	47.52 V	99.95
6	130rpm	0.15 amps	47.97 V	47.92 V	99.94
7	150rpm	0.21 amps	48.38 V	48.32 V	99.89
8	170rpm	0.22 amps	89.38 V	89.33 V	99.88
9	190rpm	0.23 amps	114.39 V	114.33 V	99.89
10	210 rpm	0.24 amps	149.24 V	149.19 V	99.88

IV. RESULTS AND DISCUSSIONS

As the matrix converter has no dc-link energy storage, any disturbance in the input voltages will be reflected in the output voltages. In particular, considering unbalanced input voltages, most of the modulation strategies introduce low-order harmonics in the output voltages. An SVM algorithm for matrix converters allows balanced output voltages to be generated, even under unbalanced supply conditions. Here, ISVM is employed for matrix converter control.

The drive is run under steady state and on full load at different frequency setting. The waveforms of matrix converter phase voltage, line voltage and motor line current are recorded in each case and their hardware FFT spectrums are obtained with the help of FFT analyzer facility of the storage oscilloscope and power quality analyzer. Fig 5 (a) shows a compensation current of the proposed harmonic damping filter. The damping filter generates compensating current that has the same frequency as the LC resonance frequency. The magnitude of the compensation current is about fifteen percent of the main power current. Thus harmonic damping circuit can be implemented with small power rating devices. Fig. 5 (b) depicts matrix converter output voltage and current in presence of proposed harmonic filter and shows almost sinusoidal waveform, with insignificant harmonic components. The proposed damping filter doesn’t deteriorate output control performance of matrix converter. Fig. 5 (c) shows the output voltage and current of matrix converter in absence of proposed damping controller. Here, presence of LC resonance frequency harmonic component may cause instability.

To have further insight into the harmonic performance, FFT harmonic spectrum is recorded. FFT result in Figs. 6 (a) and (b) show that output voltage has some 5th and 7th order harmonics. Large harmonic current near LC resonant frequency region (from15th to 21st) is observed which are significantly reduced by the harmonic controller. There also exists switching frequency harmonics of 4.2 KHz. Thus, with presence of proposed input harmonic damping circuit, which compensates resonant current ripple, the component of LC resonant frequency got substantially reduced. Figs. 6 (c) and (d) show that the harmonic components are so small that no appreciable differences are seen amongst them at different operating conditions.

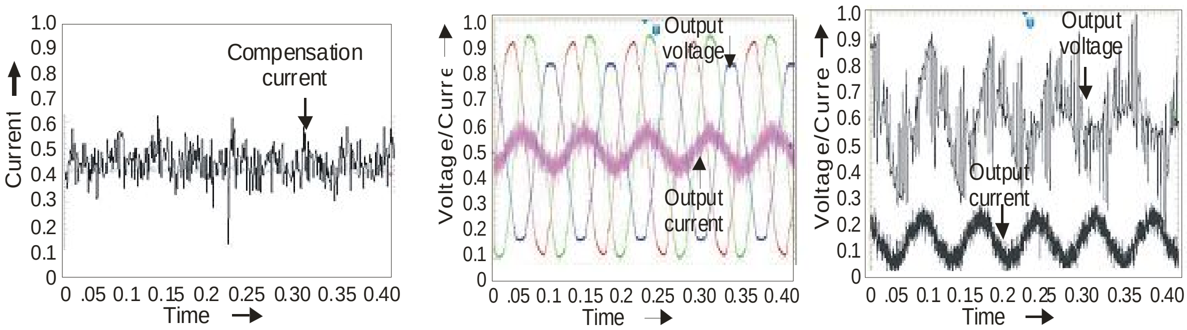

Fig. 5 Experimental waveforms (a) compensation current with harmonic filter (b) output voltage and current in presence of harmonic filter (c) output voltage and current of matrix converter in absence of harmonic filter, scale: 10 ms/div, 100 ma/div,10V/div

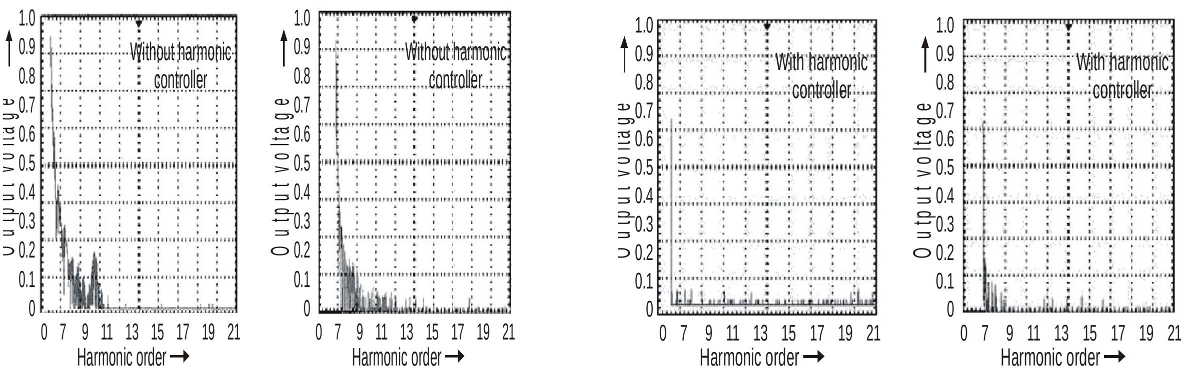

Fig. 6 FFT of output voltage: (a&b) without harmonic damping circuit (c&d) with harmonic damping circuit, scale: 30 V/div

These results show that, for practical value of the input voltage unbalance and voltage distortions, the harmonic damping controller achieves good accuracy. Similar results have been obtained with different set of input voltage disturbances.

V. CONCLUSION

A harmonic damping controller has been successfully implemented having small current rating devices (15%) than main power circuit. Results show that with the proposed method, input LC resonant current ripple is suppressed effectively from input current total harmonic distortion of 7.23 % to 1.25 %. Further, a neural network based switching strategy for matrix-converter induction motor drive system has been successfully implemented. The proposed neural network based switching strategy for an ac/ac matrix converter fed induction motor drive has effectively reduced the current harmonics of the motor.

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