A Neural Network Control for Voltage Balancing in Three-Phase Electric Power System

Dana M. Ragab, Jasim A. Ghaeb

***Abstract*—**The three-phase power system suffers from different challenging problems, e.g. voltage unbalance conditions at the load side. The voltage unbalance usually degrades the power quality of the electric power system. Several techniques can be considered for load balancing including load reconfiguration, static synchronous compensator and static reactive power compensator. In this work an efficient neural network is designed to control the unbalanced condition in the Aqaba-Qatrana-South Amman (AQSA) electric power system. It is designed for highly enhanced response time of the reactive compensator for voltage balancing. The neural network is developed to determine the appropriate set of firing angles required for the thyristor-controlled reactor to balance the three load voltages accurately and quickly. The parameters of AQSA power system are considered in the laboratory model, and several test cases have been conducted to test and validate the proposed technique capabilities. The results have shown a high performance of the proposed Neural Network Control (NNC) technique for correcting the voltage unbalance conditions at three-phase load based on accuracy and response time.

***Keywords*—**Three-phase power system, reactive power control, voltage unbalance factor, neural network, power quality.

I. INTRODUCTION

ELECTRICAL power systems are usually designed to operate efficiently within balanced conditions. However, although the voltage produced in central generation sites is highly symmetrical, several reasons can lead to unbalance condition. A primary cause for voltage unbalance is irregular distribution of single-phase loads over the three-phase system [1]. Dissimilar inter phase coupling of impedances and asymmetrical transformer windings normally lead to network asymmetries [2], [3]. The power quality is affected by voltage unbalance, because of its both technical and economic consequences. A perfect power quality means the ability of the power supply to be always available within rated voltage and frequency and with pure sinusoidal wave [4].

There are many indices for the voltage unbalance assessment. The National Electrical Manufacturers Association (NEMA) defines the line voltage unbalance ratio as the maximum deviation from the average of three-line voltages, referred to the average of three line voltages [5]. According to IEEE Std.1159-1195, the voltage unbalance factor is defined as the ratio of negative-sequence voltage and positive-sequence voltage [6].

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Many problems are associated with the voltage unbalance. As a result of unbalance, negative sequence voltage, current and impedance components that oppose the original phase sequence are created. The negative sequence component of current produces a negative torque that resists the effective torque and thus reduces the useful torque and causes speed disturbance [7], [8]. Also, voltage unbalances can cause excessive energy losses, heating up the system equipment, and the possibility of system instability [9], [10].

Several techniques can be considered for three-phase voltage balancing, such as load reconfiguration which is performed by transferring loads among the circuit to balance the distribution system by feeder switching manually and automatically [11], [12]. Another, technique that provides a satisfactory performance in load balancing is the employment of static Volt-Ampere Reactive (VAR) compensators and Static Synchronous Compensators (STATCOM) which are widely used for unbalance mitigation [13]-[15]. Enhancement of Static-VAR Compensator (SVC) performance based on minimizing harmonics generated by the compensator was discussed in [16]. It is proposed to reduce the Third Harmonic Distortion (THD) by introducing a new technique called Iterative Volt Ampere Technique (IVAT). The use of SVC for load balancing and power factor improvement was discussed in [17]. Symmetrical component theory was considered to develop the mathematical model for control purposes. A neural network based SVC for load balancing with harmonic minimization is introduced by [18]. The required firing angles were calculated based on real and reactive power requirements for each phase.

In this work, A NNC is proposed for voltage balancing in three-phase electric power system. The AQSA electric power system of 328 km length and 400kV voltage is considered and modelled in the laboratory as a real case study. To guarantee accurate and real system response, the AQSA transmission line is represented in the laboratory model by three nominal pi-sections. The Aqaba-Qatrana transmission line of 245 km is divided into two pi-sections, while the Qatrana-South Amman transmission line of 83 km is represented by one pi-section. The load voltages and the Voltage Unbalance Factor (VUF) are collected and they are used to determine the required firing angles for the Thyristor-Controlled-Reactor (TCR) compensator to restore balance condition. These data are used to train, validate, and test the Neural Network (NN). Several test cases were examined to validate the proposed technique.

The paper is organized as follows: Section II introduces the NNC employed for reactive power compensation. Section III represents the practical model of three phase AQSA electric power system. Section IV represents the effect of unbalanced load changes on the three load voltages, together with the simulated results. Finally, conclusions are introduced in Section V.

II. NN Based Reactive Compensator

The three-phase electric power systems are ideally balanced and the related distribution systems are designed in the way to reach the overall balance three phases. For any balanced electric power system, the three voltages are equal in magnitudes and with equal phase difference. This system can be represented by a per-phase impedance diagram as shown in Fig. 1 [19]. The electric power transmission lines connect power plants to multiple consumers through different number of substations.

If an unsymmetrical fault is taken place in the transmission line, or any unbalanced change is made in the load, an unbalance between phases is produced. This imbalance causes unbalanced currents and voltages to emerge in the power system. The indication of unbalanced conditions in the electric system is the generation of negative-sequence and zero-sequence components, besides the original positive-sequence components.

The general structure of multilayer feed-forward NN consists of an input layer, one or more hidden layer and an output layers; each layer contains neurons that are connected by weighted links, as shown in Fig. 2. The size of the network depends on application and available data.

The available data of three-phase load is usually divided into three sets: training set which is used to update weights and biases. The error in validation set can be used to indicate an over-fitting in the network during training phase. Finally, the test set which is not involved in training phase; this set is used to validate the network performance when new data are presented. In order to guarantee a good performance, the training data must cover the range at which the network will operate at.

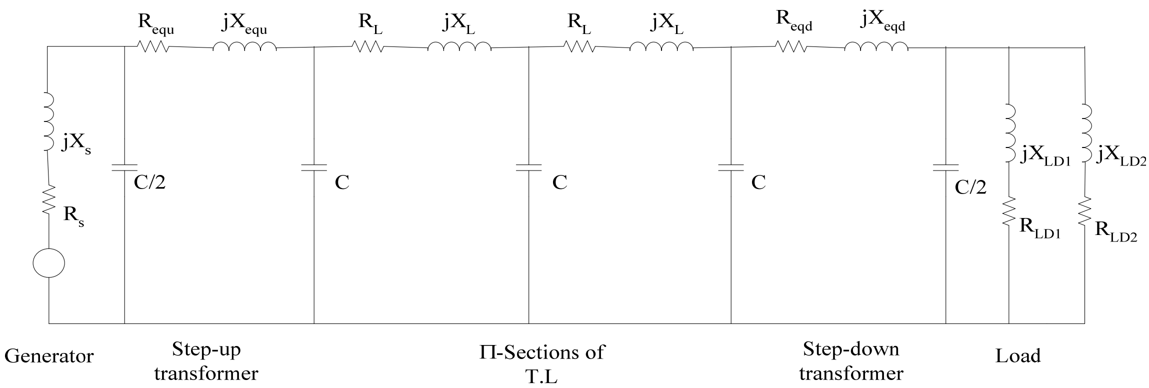

Fig. 1 The per-phase impedance diagram of an electric power system [19]

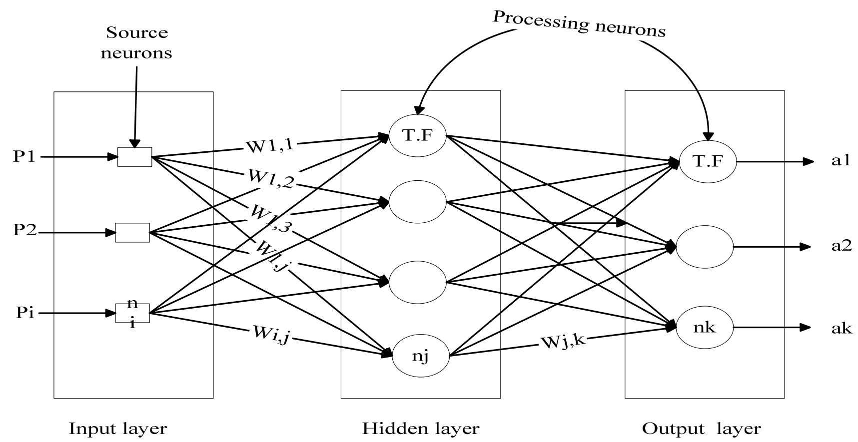

Fig. 2 Feed-forward NN with one hidden layer

III. Practical Model

The parameters of AQSA electric power system are considered in the practical model and several test cases have been conducted to test and validate the proposed NNC. Fig. 3 shows the details of the laboratory model of AQSA system.

The Aqaba-Qatrana transmission line of 245 km is divided into two pi-sections of 1.5 Ω resistor, 20 mH inductor and 0.3 μF capacitor. The Qatrana-South Amman transmission line of 83 km is represented by one pi-section of 1 Ω resistor, 15 mH inductor and 0.22 μF capacitor. Delta connected Thyristor-

Controlled-Reactor (TCR) is connected in parallel with the three-phase variable inductive load. A step-down transformer is connected at load point for Data Acquisition (DAQ) process.

Fig. 3 Laboratory model of AQSA electric power system

IV. Results and Discussions

The NN is examined for 109 cases of voltage unbalance; 99 cases are used for training and validation and 10 cases are obtained for testing purpose. The proposed NN is trained by TRAINBR training algorithm. The NN consists of one hidden layer with 10 neurons. TANSIG transfer function is considered for both hidden and output layers. The NN is irrigated by the data of the load at unbalance conditions. The performance of the NN is almost ideal during training phase and the regression factor for training is 0.99826 and for validation is 0.99121 as shown in Fig. 4.

Table I shows the test cases which are obtained from the laboratory model. The table shows the RMS values of the three load voltages before the correction with the associated VUF% for each case before and after correction. The average VUF% before correction is 5.51% and it is 0.56% after correction.

Fig. 5 shows the response for the three load voltages obtained from the practical model for case-6 in Table I, which has 4.48% VUF. The control action of the NNC is carried out at 0.1 s and the VUF% after the correction is 0.47%. Fig. 6 shows the response for the three load voltages for case-4 in Table I, which has 4.28% VUF. The VUF% after the correction becomes 0.20%. According to results shown in Figs. 5 and 6, it is reasonable to conclude that the proposed NNC is able to correct voltage unbalance at load accurately and quickly.

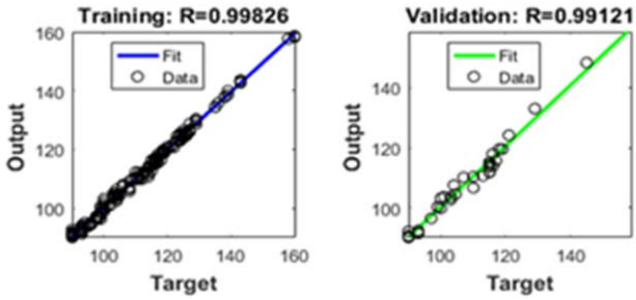

Fig. 4 Regression factor for training and validation

TABLE.I
VUF Before and After NNC Action

Unbalance case No.	V_{ab}	V_{bc}	V_{ca}	VUF % before NNC action	VUF % after NNC action
1	82.78	80.9	75.1	5.75%	0.67%
2	74.73	77.29	69.84	5.89%	0.24%
3	78.06	78.59	74.04	3.70%	0.26%
4	80.5	78.23	74.75	4.28%	0.20%
5	77.6	76.7	68.36	7.79%	0.73%
6	73.44	74.84	69.39	4.48%	0.47%
7	81.7	74.41	73.07	7.15%	1.26%
8	82.1	80.19	73.18	6.83%	0.49%
9	78.67	76.59	71.99	5.17%	0.18%
10	79.79	76.5	74.37	4.11%	1.13%
Average VUF				5.51%	0.56%

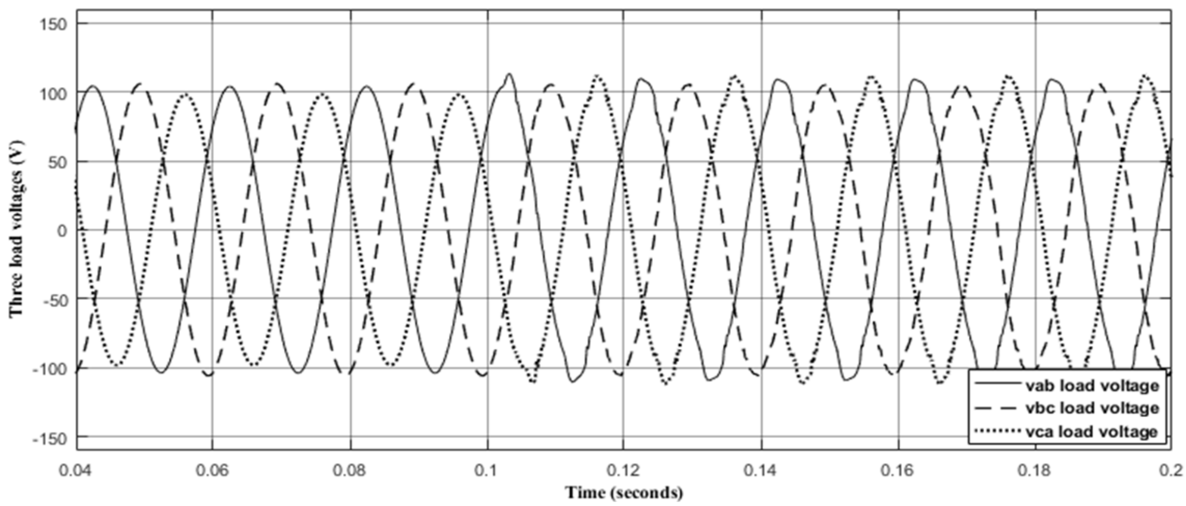

Fig. 5 Unbalanced three load voltages with 4.48% VUF and unbalance mitigation at .1 sec

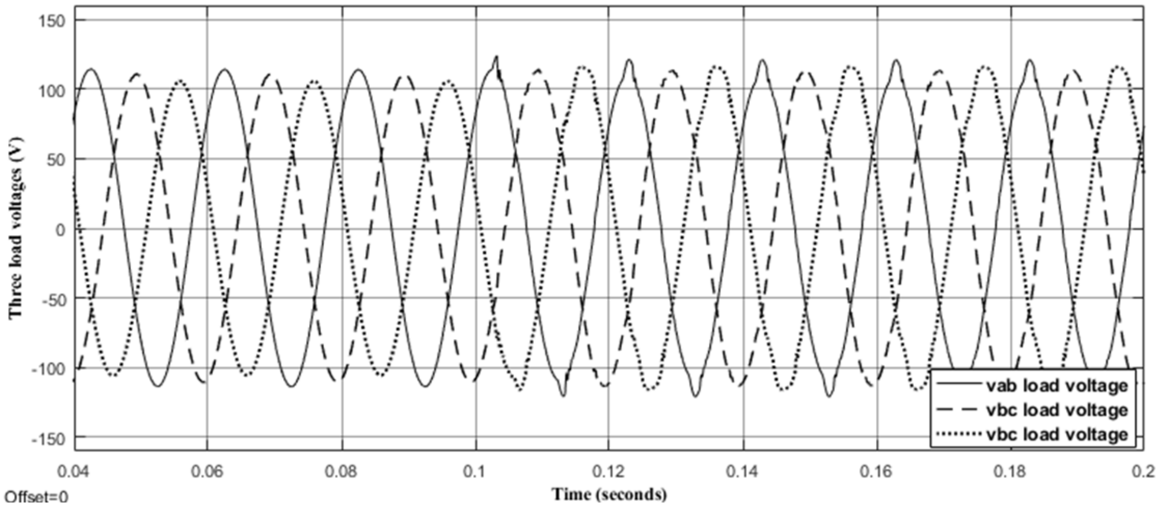

Fig. 6 Unbalanced three load voltages with 4.28% VUF and unbalance mitigation at .1 sec

V. Conclusions

A novel technique has been proposed to correct the voltage unbalance in the three-phase power system. The AQSA electric power system of 328 km length and 400 kV voltage is considered and modelled in the laboratory as a real case study. A NNC is proposed for voltage balancing at load which depends on measuring the of the three load voltages. The NNC determines the required firing angles of the TCR reactive compensator to restore voltage balance at load. The results have shown a high performance of the proposed NNC technique for correcting the voltage unbalance conditions at three-phase load based on time and response time.

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