An Artificial Neural Network Based Real-time Reactive Power Controller

Carl John O. Salaan and Noel R. Estoperez

Abstract - **This paper aimed to introduce a real-time reactive power controller based on artificial neural network. A feed-forward employing back-propagation was used as training algorithm. The inputs to the ANN were real and reactive power of each load. The targets were to switch ON/OFF the capacitors during normal and abnormal conditions. The network was trained and the weights corresponded to minimum (MSE) error were fed to the microcontroller unit. This method was tested in a radial distribution system model and implemented using Zilog Microcontroller. The results were monitored using MATLAB software. The method was validated and results were satisfactorily obtained.**

Index Terms - Reactive Power Control, Artificial Neural Network

I. INTRODUCTION

In the operation of a distribution system, reactive power control is very essential to reduce system losses by means of control device such as shunt capacitors. Inattention to the system configuration can lead to increase in reactive power which results to a decrease in power factor and high current flows of the system resulting to significant line loss.

In the past, many techniques have been employed including artificial intelligence methods.

In this study, an artificial neural network is applied to control the reactive power of the distribution system without human intervention. A Feed-forward ANN employing Back-propagation is trained to provide a proper control action required by the system. The training data is obtained from actual operation of radial distribution system prototype, initially without the controller which is subjected to different load conditions (normal or abnormal conditions). The trained data is then fed to microcontroller unit which will automatically control the system ensuring acceptable power factor level.

This study aims to develop a real-time reactive power controller through an artificial neural network on a radial distribution system configuration.

A neural network, once established (trained), is more efficient and accurate in circumstances where complex decision is required.

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Thus, this method will provide an immediate sensible response to any abnormal conditions. Subsequently, since the system will automatically react, this will allow least need of operator for control and let them engage in more challenging work.

II. THEORETICAL FRAMEWORK

2.1 Reactive Power Control

In a distribution system, reactive power control is very important since system loss can be reduced through proper dispatch of reactive power control device. Shunt capacitors installed on a distribution system will reduce energy losses in every part of the system between capacitors and generators. The scheme is that shunt capacitors are installed at low-voltage bus to switch on and off minimizing the reactive power of the system.

2.2 Artificial Neural Network

Artificial neurons are similar to their biological counterparts. It has input connections which are summed together to determine the strength of their output, which is the result of the sum being fed into an activation function. Though many activation functions exist, the most common is the sigmoid activation function, which produces a number between 0 (for low input values) and 1 (for high input values). The resultant of this function is then passed as the input to other neurons through more connections, each of which are weighted. These weights determine the behavior of the network [7].

Typical artificial neural network consists of three layers: input layer, hidden layer and output layer. Figure 1 shows an ANN with hidden layer.

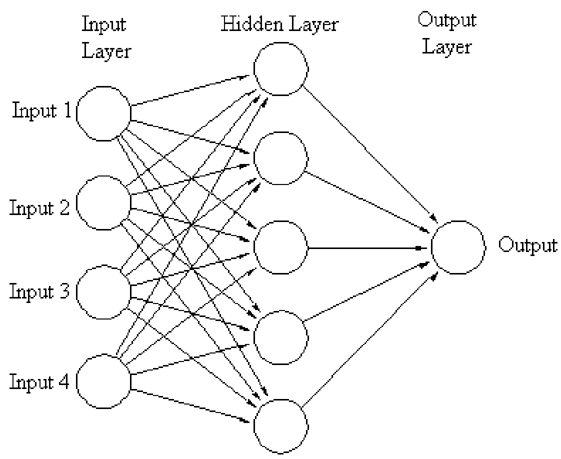

Fig. 1 Artificial Neural Network Diagram

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III. RELATED LITERATURE

3.1 Conventional Method of Reactive Power Control

The main objectives of reactive power control are to improve the voltage profiles and to minimize the system losses [5].

Capacitors have been commonly used to provide reactive power compensation in distribution systems. It is provided to minimize power and energy losses, maintain best voltage regulations for load buses and improve system security [2].

3.2 Reactive Power Control Using ANN

Artificial neural networks possess several properties that make it particularly attractive for applications to modeling and control of complex non-linear systems. ANNs represent the promising new generation of information processing networks. ANNs can supplement the enormous processing power of the digital computer with the ability to make sensible decisions and to learn by ordinary experience. ANNs have widely been used in electric power engineering [4].

In the past, several techniques have been employed using sensitivity relationships and gradient search approaches to overcome power system problem. In these approaches, the bus voltage violations are alleviated one by one. In case of many violations, the method may run into an infinite number of iteration. To avoid these difficulties, ANN has been proposed to control the actions. The method can handle complex problem and does not require computational effort in determining the required adjustments to control variables [5]. The study suggests the application of ANN technique in real-time and implement it to real power system.

The above studies are supported by the following simulation studies on reactive power control using ANN:

- Voltage and Reactive Power Control Simulations Using Neural Networks [1].
- Regulation of reactive power and voltage by artificial neural network [6].
- ANN-based reactive power compensation [8].

Similarly, a voltage control study based on artificial neural network presented as new method of control successfully and correctly identified the data. The proposed method conforms with the method presently employed in the substation [3].

The ANN technique was implemented in ANN Based DSPIC Controller for Reactive Power Compensation by R. Jayabarathi and N. Devarajan. The paper describes the methodology adopted for training an ANN network for reactive power compensation without human intervention. The ANN is implemented using a DSPIC 30F2010 and verified on a simulated laboratory network.

Based on these related studies, the researcher formulated a solution to several recommendations and suggestions from previous studies. A real-time reactive power controller will be developed using artificial neural network and will be implemented in real power system model.

IV. METHODOLOGY

4.1 Flow Chart of the Study

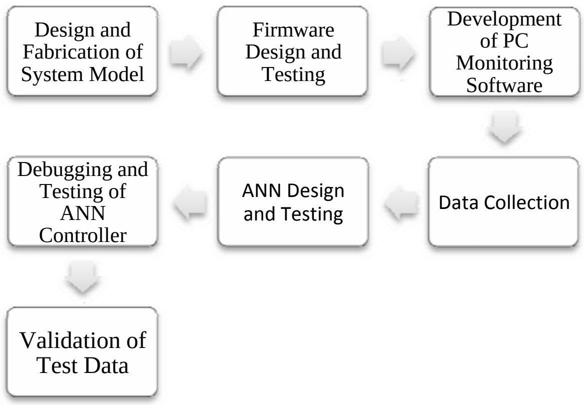

Fig. 2 Overall Flowchart of the Study

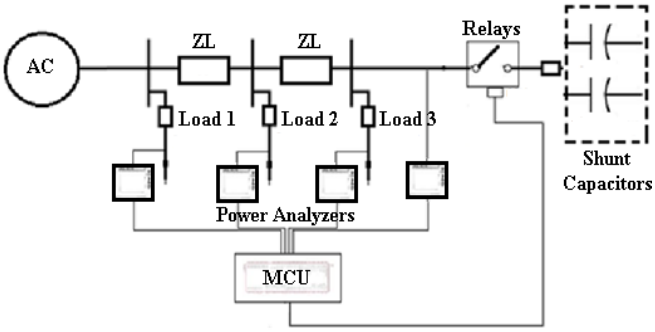

Fig. 3 Proposed System

4.2 Design and Fabrication of System Model

The proposed system is shown in Figure 3. The system consists of radial distribution model, control devices, switching devices, power analyzers, and microcontroller unit. The system is subjected to different load combinations of different power factor value based on actual distribution system. The value of shunt capacitor(s) to be installed is designed to maintain the overall power factor of the system in normal condition. Actual data from the load are collected from power analyzer in digital form. The microcontroller unit embed with ANN program is to control the system given its digital input from power analyzer and then response through the action of the relay. Any abnormal condition will automatically trigger the control devices. A special type of relay is needed to ensure system stability against voltage spike. The capacitor placement is based on rule of thumb; the capacitors are installed in parallel with the highest load.

4.3 Firmware Design

To control the pins in multiplexer (MUX) for power analyzer selection, to receive and transmit data in microcontroller (MCU), and to control the switching of relay, a program will be coded in ZDS II development software. The program will be loaded in microcontroller (servo sequencer) using the debug pins called dongle.

The functionality of microcontroller for switching is tested using Light-Emitting Diodes (LEDs).

4.4 Power Monitoring Software Design

The software is implemented using MATLAB environment employing Graphical User Interface (GUI) tools. GUI shows updated measured value of real power: reactive power and voltage on each load. The computed value of overall system; real power, apparent power and power factor are shown. The capacitor status such as the energized value of capacitor and number of capacitor energized are added also in the GUI. The software will receive the data from communication port while ensuring matched settings between microcontroller and PC (e.g. Port, Baud rate, Frequency, etc.).

4.5 Data Collection

Training and test data are collected from the actual operation of radial distribution system model. The data are composed of different combination of the three (3) loads. First, data are collected without capacitor(s) on the system and data are automatically generated and stored in excel file using *xlswrite()* function added in power monitoring software. Then, data are investigated and the combinations that need to be corrected are separated for another data collection. Those data are tested with the capacitor(s) on the system for correction. A new set of data are now manually collected and recorded which include the capacitors response either on or off (0 or 1) and the corrected pf. Finally, the data are re-arranged as needed for ANN training and testing. Data are randomly selected for training and test data.

Based on a preliminary study, the two (2) 1-uF capacitors used for power factor correction have no significant effect on bus voltages.

4.6 ANN Design & Training

ANN network will consist of input layer, one (1) hidden layer, and an output layer. The program is coded in MATLAB employing Graphical User Interface for a user-friendly approached output. GUI will show the trained weights, training and test errors, and number of iteration after the simulation. At the same time, the weights are automatically-generated and stored in excel file. In addition, the corresponding simulated training and test output are also generated in excel file for analysis and validation of result.

The ANN network is trained using the 3rd set of data. The data in excel format are converted into array of numbers using csvread() MATLAB function into array of numbers. The inputs to the ANN are real and reactive power of each load. Reactive power (Q2) data in Load 2 are excluded in the training since Q2 remains zero throughout combination. Figure 4 shows the proposed ANN architecture which composed of five (5) input nodes, three (3) nodes in hidden layer, and two (2) nodes in output layer..

The ANN targets are to switch ON/OFF the capacitor(s). The network is trained and the weights that correspond to minimum Mean-Squared Error (MSE) are obtained. The weights are fed to microcontroller unit (MCU) for control.

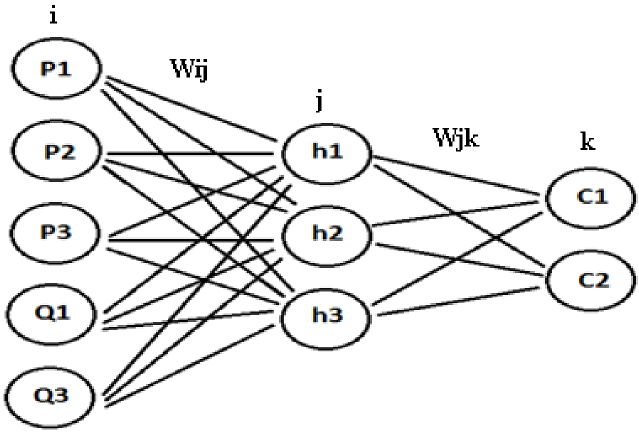

Fig. 4 Proposed ANN Architecture

4.7 Debugging and Testing of ANN Controller

The debugging phase is used to fix any problem that will arise in the system. The debugging stage is focused mainly on two programs; firmware program in MCU and software program in power monitoring. The system is subjected to debugging period until it will provide a correct real-time data and respond to any abnormal conditions in the system.

The system is tested using several samples of the collected data. Testing focuses on triggering of relay and transferring of data.

4.8 Validation of Target Output to the ANN Controller Output of Test Data

In order to check the reliability of the ANN controller, its output is subjected to validation using the target output of test data. The two output data are placed in a graph, compared and analyzed. The incorrect controller output is then subjected to second validation using the exemplified power factor of the system. The second validation is then analyzed if it is within the range of normal power level.

V. RESULTS AND DISCUSSIONS

5.1 Hardware

The whole hardware set-up is shown in Figure 5 with the following main components: (1) Loads, (2) Line Impedances, (3) Power Analyzers, (4) Multiplexer Circuit, (5) Microcontroller, (6) Relay Driver Circuit, (7) Serial TTL to USB converter, (8) Relay, (9) Capacitors, (10) VAC supply.

5.2 Firmware

The firmware is designed to cover the three function of microcontroller. The following are power analyzer selection control, transferring of data, and relay control.

In order to maximize the memory of the microcontroller, additional techniques are implemented. (1) The elements of each weight are converted from number with decimal points into whole numbers, and (2) the operation following Feed-Forward process was minimized by producing the same response directly at hidden layer.

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Fig. 5 Hardware Set-up

5.3 Power Monitoring Software

Figure 6 shows the designed power monitoring software employed with Graphical User Interface (GUI). GUI shows the updated measured values of power and voltage, and capacitor status. The computed values for overall system status are also shown in the diagram.

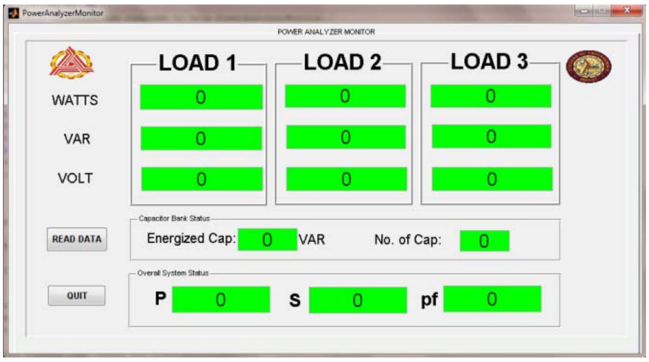

Fig. 6 Power Monitoring Software

5.4 Data Collected

The data are automatically generated and stored in excel file in same folder location as with the monitoring program. A total of 59 data are collected.

Table 1 Sample of Data Collected

P1	Q1	P2	Q2	P3	Q3	Uncorrected PF
0	0	0	0	34	19.2	0.871858
0	0	0	0	64.5	36.7	0.873015
0	0	0	0	92.3	50.1	0.88079
0	0	14.4	0	0	0	*0.99772
0	0	14.4	0	34	19.7	0.929917

The data are randomly distributed for training and test data. The data are subdivided: 47 data or 80% for training and 12 or 20% for test data.

5.5 ANN Design & Training Result

The following components visible to user are inputs, weights, and training results. At the start of the training, all needed parameters are fed into the ANN trainer. Successive training is done by adjusting the learning rate, or/and momentum until it provided a good result for mean-squared error (MSE).

The following final parameters are fed into the ANN trainer:

No. of Training Data = 47
No. of Test Data = 12
No. of Input Nodes = 5
No. of Hidden Nodes = 3
No. of Output Nodes = 2
Learning Rate = 0.04
Momentum = 0.2
Epochs = 2000

After training, the program automatically displayed the corresponding results. Figure 7 shows the final result of training. Subsequently, weights are auto-generated in excel file for further use.

Using the threshold for capacitor's action: 0, for output less than 0.5 and 1, for output greater than or equal to 0.5, Table 2 shows a sample of the training output data with corresponding capacitor's action.

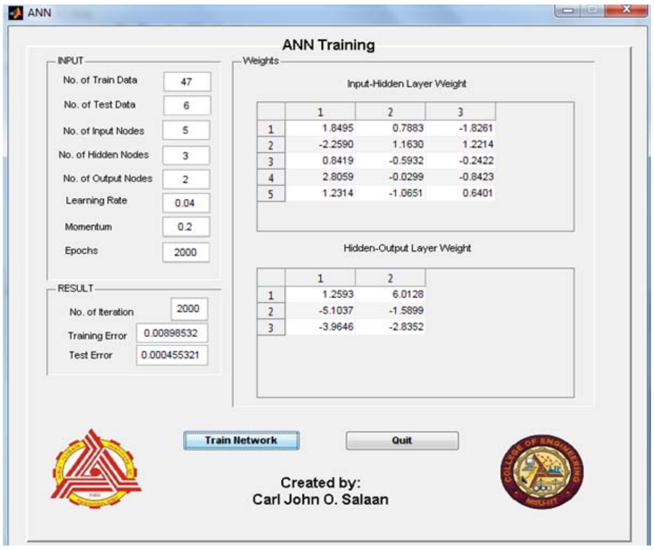

Fig. 7 Training Result

Table 2 Sample of Training Output Data with Corresponding Capacitor's Action

Training Output Data		Capacitor's Action	
C1	C2	C1	C2
0.0003	0.0315	0	0
0.0003	0.0315	0	0
0.1564	0.9851	0	1
0.1537	0.9849	0	1
0.1534	0.9849	0	1

5.6 Testing of ANN Controller

The system is energized after embedding the corresponding weights to the microcontroller and completed all necessary settings. By clicking READ DATA push button, the program starts to acquire data from MCU. The whole system is debugged and tested for several times until it provides a good result. All action controlled by MCU is being monitored in power monitoring software.

Figure 8 is a sample of energized system.

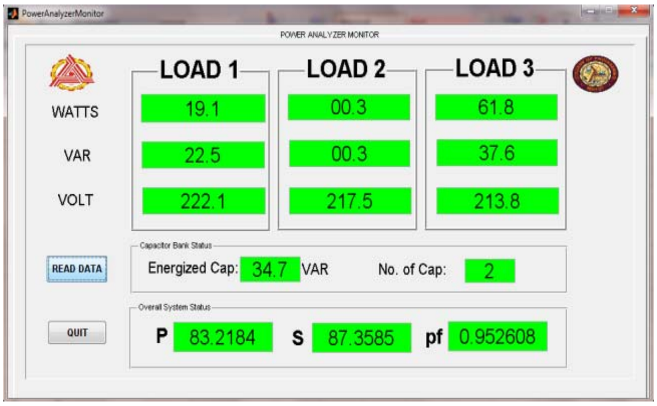

Fig. 8 Sample of Working Controller with Two (2) Capacitors Energized

Figure 9 &10 show the graph of target output vs. controller output of test data. As shown in Figure 9, 2 out of 12 data responded incorrectly or 83.33% properly responded. In Figure 10, 12 out of 12 data or 100% responded correctly.

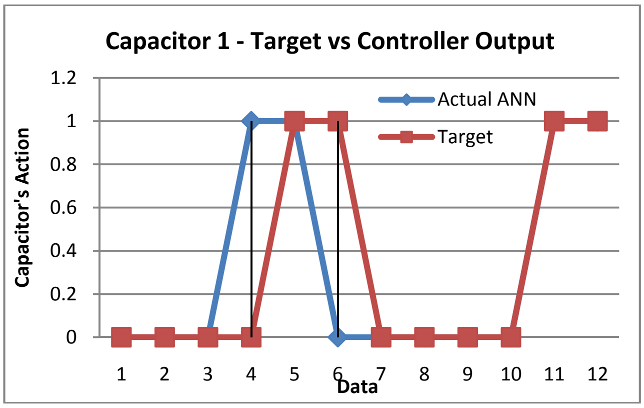

Fig. 9 C1 – Target Output vs Controller Output

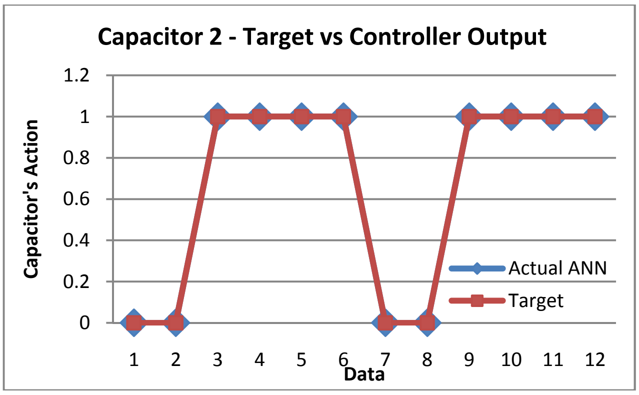

Fig. 10 C2 – Target Output vs Controller Output

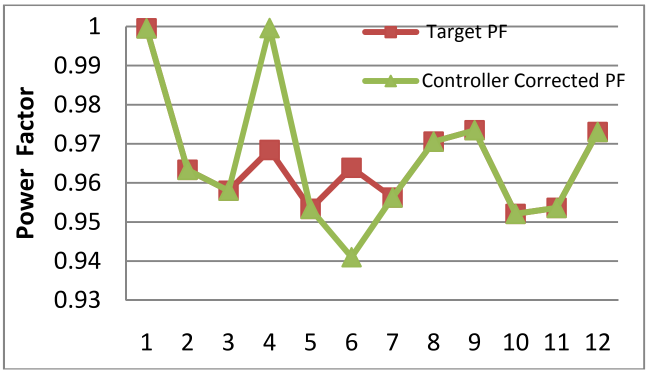

Fig. 11 PF of Test Data

Figure 11 shows the power factor of test data. The graph shows that one of the incorrect responses (data no. 4) is still within the normal range of power factor. Another incorrect response (data no. 6) which is below 0.95 (minimum level of normal pf) is still an acceptable outcome. Generally, the ANN controller is satisfactory in reactive power compensation.

VI. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the presented results and findings, the researchers arrived with the following conclusions:

- The radial distribution system can be modeled and fabricated using lighting bulbs as loads.
- The data for different load combinations are gathered using digital power analyzers and data acquisition software.
- The ANN trainer is created using MATLAB software employing with feed-forward and back-propagation algorithm.
- ANN output is satisfactorily trained as confirmed by a mean-squared error (MSE) for training equal to 0.00898532 and for test error of 0.00045532.
- Power monitoring software employed with Graphical User Interface is excellent in monitoring real-time data.
- The ANN based real-time reactive power controller is successful in responding capacitor's action as exemplified by power factor within the normal range.

6.2 Recommendations

The researchers would like to recommend the following:

- A more complex system must be modeled to verify the reliability of ANN to a real complex power system.
- A large data must be collected to have an accurate training of ANN network.
- The microcontroller to be used must have maximum memory capacity to avoid memory problem.
- A combination of voltage and reactive power control must be applied for a more efficient power system.
- Improving the model by including the variations of the voltages when capacitor is connected.

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REFERENCES

[1] Abdallah, J. and A. Al-Zyoud. *Voltage and Reactive Power Control Simulations Using Neural Network*. IJSSST. Vol. 10. No. 5.

[2] Ellithy, K., A. Al-Hinai, and A. Moosa. *Optimal Shunt Capacitors Allocation in Distribution Networks Using Genetic Algorithm – Practical Case Study*. International Journal of Innovations in Energy Systems and Power. Vol. 3. No. 1. pp. 18-45. April 2008.

[3] Estoperez, Noel R. (1999). Development of an Artificial Neural Network Based Voltage Control. *Special Project*. Iligan: Mindanao State University – Iligan Institute of Technology.

[4] Jayabarathi. R.A and N.B Devarajan. *ANN Based DSPIC Controller for Reactive Power Compensation*. American Journal of Applied Sciences. 508-515. 2007.

[5] Joorabian, M. and R. Hooshmand. *Application of Artificial Neural Networks in Voltage and Reactive Power Control*. 2005.

[6] Lyubchenko, V.Ya. and D.A. Pavlyuchenko. *Reactive Power and Voltage Control by Genetic Algorithm and Artificial Neural Network*. Transactions on Power Engineering. Vol.1. No.1. December 2009.

[7] Nissen, Steffen. *Neural Network Made Simple*. www.software20.org. 2005.

[8] Said, I. and M. Pirouti. *Neural Network-Based Load Balancing and Reactive Power Control by Static VAR Compensator*. International Journal of Computer and Electrical Engineering. Vol. 1. No. 1. April 2009.