2018 International Conference on Intelligent Autonomous Systems

Automated Power Factor Improvement Based on Artificial Neural Networks

Sonish S
UG Scholar
Government Engineering College , Thrissur
APJ Abdul Kalam Technological University
Email : sonishs13@gmail.com

Abstract—**This paper addresses the basic issues related to voltage instability considering the characteristics of transmission systems and thereby introducing a power factor improvement tool based on artificial neural networks focusing on the compensation of reactive power, consequently improving the voltage stability. A two layered feed-forward neural network employing back propagation algorithm was used to train the IEEE 22 bus system on a MATLAB environment.The capacitance to be introduced is predicted by the NN fitting tool and the predicted capacitance is to be switched to the load lines. The load flow of the system before and after the introduction of the capacitance has been analyzed and verified on an ETAP environment.**

Keywords—power factor, reactive power,ANN,MATLAB, ETAP

I. Introduction

Voltage stability issues are one of the ineluctable issues affecting heavily loaded power transmission and distribution system around the globe which might ultimately result in a total black out in extreme cases and although their reasons may be due to different contingencies, the underlying issue is mostly the weaknesses in the power system. Power factor correction and reactive power elimination has become an essential factor in diminishing the power losses and thereby enhancing the efficiency and stability of the system by increasing the current flow significantly augmenting the line losses in the T&D system. Control devices such as capacitors and switching devices such as thyristors controlled by a microcontrollers can be employed to correct the power factor in the circuit thereby controlling the reactive power in the system.

This study aims to improve the voltage stability in the power systems by correcting the lagging power factor thereby decreasing the reactive power and increasing the efficiency of the system, using capacitors from a capacitance bank. The reactive power compensation device is responsible for maintaining the power factor around unity by switching the respective capacitance to the circuit by means of thyristors. The real power and apparent power in the various load lines of an IEEE 22 bus system are analyzed and the respective compensation capacitance is introduced to the line by the switching device being used. A two layered feed forward ANN employing back propagation and mean square error reduction algorithm outputs the capacitance which when introduced in the load line compensates the reactive power by improving the power factor to unity approximately. The microcontrollers used are responsible for predicting as well as switching the respective capacitance in the circuit automatically on the basis of the trained data fed to the device.

The power factor plays an important role in the AC circuits since the power consumed depends on this factor. It is highly undesirable since it demands equipments with higher kVA ratings making the equipments more expensive, larger conductor size and equipment size, reduced handling capacity, increased copper loss owing to the increase in the current flowing through the conductors at low power factor, and poor voltage regulation resulting in a reduced voltage availability at the receiver’s end ultimately affecting the performance of the system.[1]. This method provides an automated, immediate and real time solution to issues regarding low power factor in the power systems leading to power losses in the form of reactive power resulting in a system with low efficiency and poor stability negating the need for an operator.

II. Literature Survey

Sensitivity relationship and gradient search approach was used by Joorabian M and R. Hooshmand (2005) in their work to alleviate bus voltage violations. When a large number of such violations are involved, it runs into an infinite, complex and time consuming loop as it requires adjustments to control variables making it inefficient for real-time applications.[2]

Similarly in 2011, a voltage control ANN based method was developed by O. Salaam and Estoperez to switch ON and OFF capacitors during normal and abnormal conditions of the power system on real-time using a zilog microcontroller. Two capacitors were employed in such a way that capacitor 1 was switched ON when the power factor in the system exceeds 0.5 and the capacitor 2 was switched ON when the power factor was less than 0.5.[1]

An identical method was used by Ellithy K.,A. Al-Hina and A. Moosain 2008 for allocation of shunt capacitances in the power distribution system using genetic algorithm for the prediction of the capacitance to be introduced to the system for the power factor correction.[3]

An embedded systems drive was developed in 2012 to switch static capacitors during peak load hours and switch off the capacitors during lightly loaded hours by M.Ravindran and V. Kirubakaran. Zero crossing detectors were employed to convert waveforms of voltage and current in the power system to TTL compatible square waves which were fed into the microcontroller. The phase angle between the waveforms were analyzed by the in-built computers in the microcontrollers to determine the power factor in the power system.[4]

In 2011, Jalal M.Abdullah and Abdullah R. Al-Zayoud developed a device implementing load tap changers and shunt capacitors to minimize the power loss in the system and thereby maintain the voltage profile within the permissible range at the consumer terminals. As the load at the consumers end is variable, an optimal operation mode is attained by controlling the regulation device by means of on- load tap changers. But these tap changers cause a significant power loss in the system due to the transformation ratio.[5]

An economic and dynamic power factor correction device to be employed in heavy load industries was proposed in 2016 by Sudha S., Dr. Gowrisankar P., RajkumarR.,andBalaprakash V. in their work. FACTS (Flexible AC Transmission System) devices were used to control the flow of active and reactive power in the system. It improves the limits of static as well as transient stability and voltage quality enhancing the efficiency of the system thereby increasing the power being generated. FACTS devices are capable of controlling the real and reactive power in the system independently. It dampens the oscillations which otherwise limits the usable line capacity. But this method can be used in high voltage transmission systems only[6]. AwasthandHuchche (2016) describes a method of reactive power compensation in their paper using custom power devices like D-STATCOM which are very similar to FACTS devices to inject the required reactive power to the distribution line.[7].

III. Theoretical Framework

The voltage stability and reactive power are interdependent entities which are individually controlled by the power factor in the system which are indirectly controlled by the capacitive and inductive elements in the power system. Trained artificial neural networks which usually have an accuracy of more than 95% are used to predict the power factor correction capacitance required to reduce the reactive power thereby improve the power factor, enhancing the efficiency of the system.

A. Power Factor

In an AC circuits the phase difference between the voltage and current in the system results in a lag or lead accordingly emphasizing the capacitive or inductive load in the system responsible for the reactive power and the power factor in the system. An Inductive load implies a lagging power factor owing to the lagging current compensable by switching the respective capacitance to the system and similarly a capacitive load implies a leading power factor compensable by the introduction of corresponding inductance. Most of the loads are inductive in nature and hence produce a lagging power factor which is highly undesirable as it causes an increase in the current flowing through the system resulting in additional loss of the active power in all the elements in the power system from the power station where power is generated to the load distribution. Hence from an economical standpoint, it is important to maintain the power factor as close as possible to unity though it is practically nearly impossible as some power system elements require a fixed amount of reactive power to start its operation.

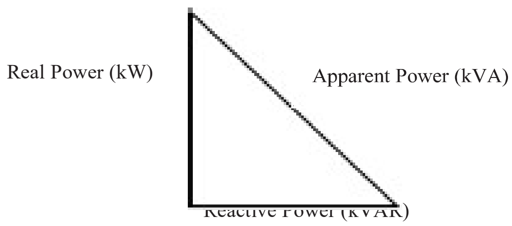

Figure 1.Power factor triangle

$$(kVA)^2 = (kW)^2 + (kVAR)^2 \text{ [2]}$$

$$\begin{aligned} \text{Power factor} &= \text{active power / apparent} \\ &= kW/kVA \\ &= \cos\varphi \end{aligned}$$

B. Power Factor Improvement

Power factor correction is the process of counteracting the undesirable effects on the various electrical loads when the system encounters a low power factor by supplying the necessary reactive power so as to improve the power factor to unity approximately [8]. There exists several means for the same including the usage of static capacitors which draws a leading current neutralizing the lagging reactive component of the load current in the system partially or completely, usage of synchronous condensers which involves a synchronous motor neutralizing the lagging reactive component by taking a leading current on being over excited, and usage of phase advancers involving induction motors.

A consumer pays the electricity charges for his maximum demand in kVA added to charges incurred due to the units consumed. On improving the power factor at the consumer's end, there will be a reduction in his max kVA owing to the reduced reactive power ultimately resulting in a decrease in the electricity charges incurred. The generators at the generating stations are rated in kVA whereas the output is in kW. Since kW = kVA x cos φ , the units supplied by it

depends directly on the power factor which implies that higher the power factor, more will be the kWh delivered to the system by the generating station enumerating the fact, higher power factor increases the earning capacity of the power station.

C. Artificial Neural Networks

Artificial Neural Networks are composed of several neurons which are similar to their biological counterparts, training themselves based on the input data and their desired outputs [9] by assigning weights to each neuron in the whole network by means of an activation function which is the sigmoid function in the case. The resultant of this function is then input to other neurons through more connections, each of which are weighted. These weights determine the behavior of the neural network.[10].

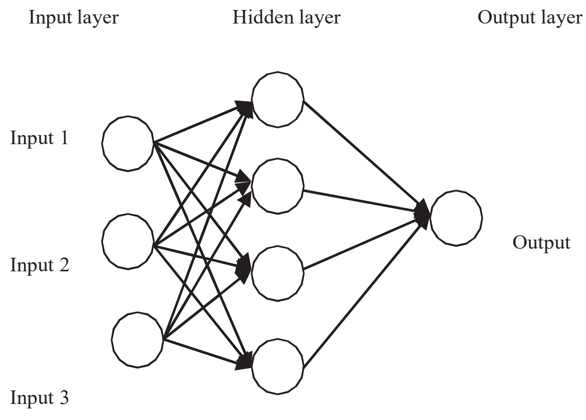

Figure 2.ANN Representation

The two-layered neural network used here predicts the capacitance accepting the real power and the reactive power in the circuit as their inputs characteristics. The ANN has a hidden layer having 25 neurons, and an output layer which gives the respective capacitance to be switched to the circuit from the capacitance bank so as to correct the power factor to unity approximately and thereby reduce the reactive power. The neural network was trained using IEEE 22 bus system data. The training was done using the Levenberg-Marquardt back propagation algorithm and the performance was analyzed using mean square error reduction method with an error minimization plot [11].

The artificial neural network tends to find and consider better relations between the sample data set and the output and hence the predicted data are found to be very close to the desired value with an accuracy of about 95%.[2]. ANNs are considered to be the most promising prediction tools it is based on experiences linking input and output sets and learning concepts.

IV. Methodology

A. Data

The training and testing data were taken from a standard IEEE 22 bus system with the real and reactive power as input characteristics to the activation function with a manually calculated output data set. Bus 1 and bus 8 data were not used to train the ANN since they were generator side data and hence the reactive power was zero. Bus 4 data were not used since the reactive power was negative which means the load is capacitive.

B. ANN Design and Testing

The ANN was implemented on a MATLAB environment using the Graphical User Interface. The GUI shows the trained weights, test error, and the number of iterations after training. The hidden layer of the ANN is set to contain 25 neurons [12].

The whole input data was divided at random into training, cross validating and testing data sets as 70%, 15% and 15% respectively to train the ANN as per the requirement to predict the desired capacitance in MVAR. On training the available 22 bus data on MATLAB environment, the following regression plots were obtained.

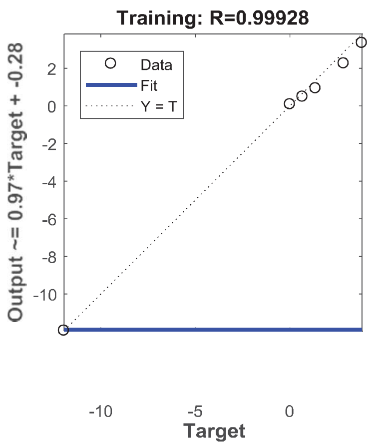

Figure 3. Regression plot of training data

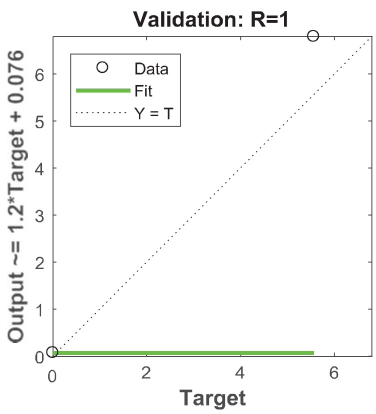

Figure 4.Regression plot of validation data

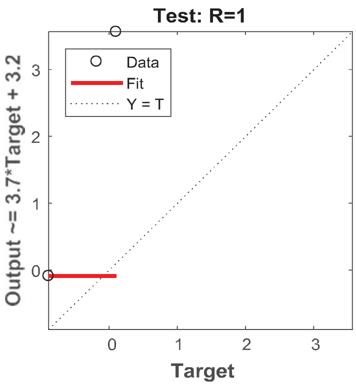

Figure 5. Regression plot of testing data

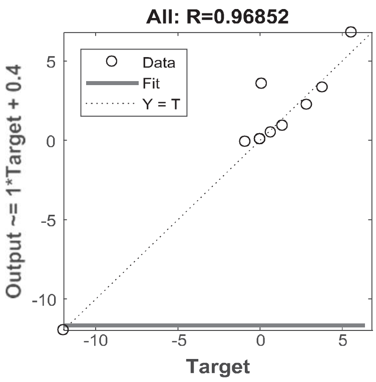

Figure 6. Regression plot of the entire data

Regression R value measure the correlation between outputs and targets. An R value of 1 means a close relationship between outputs and targets. An R value of 1 means a close relationship whereas a value of 0 refers to a random relationship[14]. Here the plot has R value of 0.96852 which implies that a close relationship exists between the outputs and the targets. The validity of the trained neural network which was used here to predict the shunt capacitance to be introduced in the circuit to make the power factor close to unity (0.95) has been proven.

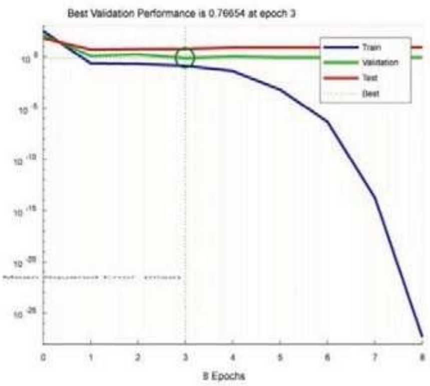

Figure 7. Overall performance plot of the ANN

C. Simulation

The Simulation of the bus system before and after the introduction of the predicted capacitance was carried out on an ETAP environment [13]. Load flow analysis was carried out before and after the introduction of the capacitance equal to the predicted capacitance. It was found that there was an improvement in the power factor to 0.95. The ANN had predicted that a 6.923 MVAR was to be introduced to the bus 12 where the real and reactive powers were 6.1 MW and 9.1 MVAR respectively. On the introduction of the capacitance, the power factor was improved from 0.55 to 0.95 and the reactive power was reduced to 1.391 MVAR. Increase in the voltage stability and improvement in the power factor was observed on the load side as well, bus 6 and bus 13.

TABLE II. Bus 12 1 kV Line Data before the Introduction of the Predicted Capacitance to the System.

Voltage		Load			Load Flow			
% Mag.	Ang.	MW	MVAR	% pf.	ID	MW	MVAR	% pf.
104.48	-14.7	6.1	9.1	0.55	Bus 6 L_6	-7.172	-6.83	72.4
					Bus 13 L_13	1.072	-2.27	42.7

TABLE II. Bus 12 1 kV Line Data after the Introduction of the Predicted Capacitance to the System.

Voltage		Load			Load Flow			
% Mag.	Ang.	MW	MVAR	% pf.	ID	MW	MVAR	% pf.
105.55	-15.1	6.1	1.391	0.95	Bus 6 L_6	-7.728	-2.218	96.1
					Bus 13 L_13	1.6	-0.8	89.1

V. Conclusions and Recommendations

A. Conclusions

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

- The data from an IEEE 22 bus system was considered and it was observed that a particular bus (bus 12) had a power factor of 0.55 which is a very low.
- An ANN was trained on a MATLAB environment employing feed-forward and back-propagation algorithms having 25 neuronsto predict the capacitance to be introduced to the circuit in MVAR so as to improve the power factor thereby reduce the reactive power.

- The ANN predicted that a capacitance of 6.923 MVAR was to be injected to the bus to improve its power factor to 0.95 (approximately unity).
- Load flow analysis was done before and after the introduction of the predicted capacitance on an ETAP environment to verify the correction in the power factor and reduction in the reactive power
- The improvement in the power factor of Bus 12 resulted in an improvement in the power factor of its load bus systems as well as per the ETAP analysis
- The ANN based power factor improvement tool is an accurate power factor correction meanto induce the necessary capacitance in the system.

The automated power factor improvement tool based on artificial neural networks was successfully implemented on a MATLAB environment and analyzed on an ETAP environment.

B. Recommendations

The researchers recommend the following:

- More complex systems with more data can be analyzed with this tool.
- Reactive power control must be implemented in the power systems around the globe for better voltage stability and reduced power loss.
- The same can be implemented on real time by using data digital power analyzers and data acquisition software. It can be used on large scale at power stations and other generating stations to correct the power factor.
- Capacitance banks can switch the predicted capacitance to the hardware installation using microcontrollers and thyristors.

REFERENCES

[1] Carl John O. and Noel R. EstoperezAn Artificial Neural Network based Real-Time Reactive Power Controller. Proceedings of the World Congress on Engineering and Computer Science 2October 19-21 2011.

[2] Joorabian M and R .Hooshmand. Application of Artificial Neural Networks in Voltage and Reactive Power Control.01October 2005

[3] Ellithy K., A. Al-Hina and A. Moosa. Optimal Shunt Capacitance Allocation in Distribution Networks using Genetic Algorithm-Practical case study. International journal of innovations in energy systems and power, 2008.

[4] M. Ravindran and V. Kirubakaren. Electrical Energy Conservation in Automatic Power Factor Correction by Embedded Systems. Energy and Power, 2012.

[5] Jalal M Abdullah and Abdullah R Al-Zyoud, Voltage and Reactive Power Control Simulations using Neural Networks. IJSST, Vol 10, No.4. 2011.

[6] Sudha S., Dr. Gowrisanker P., Rajkumar R., and Balaprakash V., Analysis of Implementation of FACTS Devices in Power Factor Improvement. International journal of engineering and computer science, 2016.

[7] Vinay M Awasth and V.A. Huchche. Reactive Power Compensation using D-STATCOM. International Conference on Energy Efficient Technology for Sustainability,2016

[8] D.P. Kothari and J.Nagrath Power System Engineering 4(e), McGraw Hill publications.

[9] Ethan Alpaydin, Introduction to Machine Learning 2(e), The MIT Press.

[10] Nissa and Steffen. Neural Networks Made Simple. www.software20.org, 2005

[11] James A. Freeman and David M Skapura, Neural Networks Algorithms, Applications and Programming techniques. Pearson Education.

[12] R. Sarijini and S.Jayalalitha , Power Factor Impovement and Harmonic Compensation using ANN.ARPN Journal of engineering and applied sciences.

[13] Stephen Philip Tubbs, SKM,ETAP and ADSA Power System Analysis Tutorials, Illustrated Edition.

[14] SS. Chen, B. Mulgrew, and P. M. Grant, “A clustering technique for digital communications channel equalization using radial basis function networks,” IEEE Trans. Neural Networks, vol. 4, pp. 570–578, July1993.