Recognition of Power Quality Events Using Artificial Neural Networks

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Abstract - This paper presents two stages of a research work concerned with power quality issues in electric power distribution networks. The first one the power quality research works on the distribution system of the residential city. The Energy Technology Assistance Program (ETAP) is used in modeling the distribution system components and simulating the processes of overvoltage and undervoltage caused by system faults changes in loads and switching of capacitor banks. The simulation results are analyzed and compared with relevant standards for evaluating the quality of power in the distribution system. The second stage is the recognition of power quality disturbances using neural networks. The simulation results work as learning data to neural networks to detect and classify different power quality signal types efficiently. Various steady state events are tested, such as overvoltage and undervoltage. Recognition of power quality events by analyzing the voltage waveform disturbances is a very important task in the power system monitoring.

Index Terms – distribution system, power quality, overvoltage, undervoltage, neural network

1. Introduction

Classically, the aim of the electric power system is to generate electrical energy and to deliver this energy to the end-user equipment at an acceptable voltage. The constraint that was traditionally mentioned is that the technical aim should be achieved with reasonable costs. The optimal level of investment was to be obtained by means of a trade-off between reliability and costs. A recurring argument with industrial customers is concerned with the definition of reliability: should it include only long interruptions or also short interruptions or even voltage dips. The term power quality came in use referring also to the other characteristics of the supply voltage. But, immediately, the first confusion started as utilities included the disturbances generated by the customers in the term ‘power quality’. This difference in emphasis will be discussed in more detail below. The main complaint of domestic customers concerned the costs which were perceived too high, especially where cross-subsidizing was used to keep prices low for industrial or agricultural customers. This classical model of the power system is shown in Fig. (1).

Fig. 1. Classical model of the power system.

In Fig. (2), the electric power network connects some or many customers. Customers may generate or consume electrical energy or even both albeit at different moments in time. Different customers have different demands on voltage magnitude, frequency, waveform, etc. The technical aim of the power network becomes one of allowing the transport of electrical energy between the different customers, guaranteeing an acceptable voltage and allowing the currents taken by the customers. With an ideal network each customer should perceive the electricity supply as an ideal voltage source with zero impedance. Whatever the current is, the voltage should be constant. As always, reality is not ideal. Power quality is concerned with this deviation between reality and ideal [1].

Fig. 2. Modern model of the power system.
LOAD equipment, such as power electronic devices and microprocessor based systems widely used in modern industries, one more sensitive to power quality variations than equipment applied in the past. The quality of electricity supplies, therefore, has become a major concern of electric utilities and end-users. Up until now, considerable efforts have been focused on this area, for instance, assessing impacts brought about by deterioration of power quality, monitoring variant disturbances occurring in transmission and distribution networks, and seeking measures for power service improvement [2]. As the prerequisite of solutions to power quality problems, an initial investigation is necessary for identifying the exact circumstances utilities have experienced as well as verifying the countermeasures to adopt. In practice, electric power delivered at certain customer sites is monitored continuously, which can produce yearly gigabyte size data files [3]. Thus, it could be a real challenge to identify different disturbances from the site measurements, either on-line or off-line. Obviously, conventional visual inspection method is laborious and time consuming. It is desirable to develop more sophisticated automatic recognition techniques.

2. Power Quality

The quality of electric power is becoming a matter of increasing concern to both power utilities and their customers. There are a number of major reasons for this they are:

1. Customer equipment today are more sensitive to power quality variations than equipment used in the past. Modern microprocessor based controllers and power electronic devices are very sensitive to various disturbances in the power supply.

2. Customers are becoming better informed about power quality problems and are challenging the utilities to improve power quality.

Power quality or, in fact, lack of quality is a term used to describe the most important aspect of the electricity supply. Power quality can be defined as any problem manifested in voltage, current, or frequency deviation that results in failure or mal operation of electric equipment [2]. It covers several types of problems of electricity supply and power system disturbances; we focus here on long duration variation:

- **Overvoltage**: When used to describe a specific type of long duration variation refers to a measured voltage having a value greater than the nominal voltage for a period of time greater than 1 min. Typical values are 1.1-1.2 p.u.

- **Undervoltage**: When used to describe a specific type of long duration variation refers to a measured voltage having a value less than the nominal voltage for a period of time greater than 1 min. Typical values are 0.8-0.9 p.u. [4].

3. Description of Methodology

3.1 Load flow

The great importance of load flow studies arises mainly in planning stages for the future expansion of existing systems. Load flow calculations provide power system subject to the regulating capability of utility, capacitors & tap changing under loaded transformers as well as specified net interchange among individual operating systems. The load flow problem consists of the calculation of power flows & voltages of a network for specified terminal or bus conditions. Associated with each bus are four quantities. These are:

a. Real power.
b. Reactive power.
c. Voltage magnitude.
d. Voltage phase angle.

At each busbar, on solving a load flow problem, two of these four quantities must be specified. In addition, buses of any power system must be classified according to the following categories:

- Slack bus, where voltage magnitude and angle must be given. This bus is necessary to provide the additional real and reactive power to supply the system losses. i.e. this type is unique in the system and is free to provide real and reactive power with no theoretical limits.
- Voltage controlled bus, where the real power and voltage magnitude are specified.
- Load bus, where the real and reactive power load power are known.

Two considerations must be taken when developing a computer program to solve load flow problems. These are:

- The formulation of a suitable mathematical model describing the network and the problem.
- The application of numerical method for the solution.

The mathematical formulation of the load flow problem [5] results in a system of algebraic non linear equations. These equations can be established by using either bus or loop frame of reference. The coefficients of the equation depend on the selection of the independent variables (voltage and currents).

3.2 Artificial Neural Networks

ANNs are among the oldest AI techniques; they have been around the power research arena for quite some time. Neural networks have been applied extensively in power quality (PQ). Main applications include [6, 7]:

- identifying PQ events from no power quality ones;
- modeling the patterns of harmonic production from individual fluorescent lighting systems;
- estimating harmonic distortions and PQ in power networks;
- identifying and recognizing PQ events using the wavelet transform in conjunction with neural networks;
- identifying high-impedance fault, fault-like load, and
normal load current patterns;
- analyzing harmonic distortion while avoiding the effects of noise and sub harmonics;
- developing a screening tool for the power system engineer to use in addressing PQ issues.

ANNs mimic the neural brain structure of humans. This structure consists of simple arithmetic units connected in highly complex layer architecture. ANNs are capable of representing complex (nonlinear) functions, and they learn these functions through example [8, 9].

To train a network the historical input and output training patterns are shown to the network repeatedly. With each presentation an input pattern is passed forward through each layer of the network. The output value from each neuron is multiplied by the respective interconnection weight to arrive at the input value for the next neuron. In the hidden and output layers each neuron's output is determined by the sum of its inputs and its transfer function. Each input vector is calculated. During training, the network's output is compared to the actual historical observations, and an error term is created. This error is fed backwards through the network from the output layer through the hidden layer(s) and back to the input layer. The interconnection weights between each layer are adjusted based on the computed error and learning rate parameter. The learning rate governs the rate which the Higher learning rates speed the convergence process but can result in overshooting or non-convergence. Slower learning rates produce more reliable results at expense of increased training time. This process of presenting input data passing it forward through the network and back propagating the error is repeated for each observation in the historical training set. The training set is shown to the network many times until the output values converge to a solution or the maximum number of iterations is reached. Fig (3) shows the steps of designing the ANNs.

Fig. (4) represents ANN structure which contains one input voltage sample, 2 hidden layers everyone having 12 neurons, and the network has 3 outputs.

Fig. (3) Steps of Designing ANN

Fig. (5). The output of ANN
The outputs of ANN are:

- Normal case 0 0 0
- Critical undervoltage. (CUV) 0 1 1
- Marginal undervoltage. (MUV) 1 0 0
- Marginal overvoltage. (MOV) 0 0 1
- Critical overvoltage. (COV) 1 0 0

3.3 Case Study

The power distribution system of the residential city [10] consists of one utility with nominal voltage of 33 kV, 3 step down transformers 33/11 kV & many loads. The objective of this paper is to formulate the model of residential city components and simulate several processes related to power quality problems with the help of ETAP which include overvoltage & undervoltage. The single line diagram of the residential city supply is shown in Fig. (6). this utility is responsible for supplying power to a number of loads.

The case studies, which are generated from the ETAP program, are loaded into NeuDesk program version 2.11 which is used to train and test the different ANNs. The initial weights are random values. Fig (7) shows the program flow-chart.

3.4 Simulation Results

The proposed method is performed using ETAP program. The randomly selected case from 560 cases of each disturbance type is used to test the neural networks. The proposed method is able to detect and classify the 2 types of power quality disturbances. Each one is divided into 2 types:

- Critical undervoltage.
- Marginal undervoltage.
- Marginal overvoltage.
- Critical overvoltage.

All disturbance types tested are different from pure sinusoidal case.
The output is a correct detection of the disturbance occurring on one bus. Fig. (8.1) represents the training of the ANN and Fig. (8.2) represents the results of testing the ANN under and the cases respectively. It shows the normal operation can be achieved unless the change in tap changer and switching off loads and switching on loads and switching capacitor banks show an overvoltage and undervoltage events.

4. Conclusion

This paper proposed a prototype load flow-based neural network classifier for power quality disturbance recognition and classification. The simulation results showed that the proposed method has the ability of recognizing and classifying different power disturbance types efficiently. This work has lead to believe that load flow analysis together with neural structure, as a new tool, offers a great potential for diagnosis of electrical power systems in the area of power quality problems.

5. References

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