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Prediction of Voltage Dip Frequency in Turkish Energy Transmission Lines Based on Artificial Neural Networks

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ABSTRACT: *Increasing usage of sensitive loads in industry due to rapid growth of power electronic equipment, give rise to focusing on power quality (PQ) phenomena. Voltage sag (voltage dip) is one of the most important PQ problems that utilities and customers are faced. Voltage dips may cause disoperation at sensitive loads of the power utility which could result not only loss of process but also economical damages, especially in paper, iron-steel and rubber industries. Therefore; elimination or reduction of this problem is significant. This paper presents a new approach for predicting the voltage dip frequency due to line fault of per km per month for rehabilitation of Turkish Transmission System. A neural network with feed forward structure has chosen as the prediction method and monitored data sets belonging to Turkish 380 kV voltage level transmission system have been used. It was seen that the approach can predict voltage dip frequency per km per month accurately.*

Keywords- *Artificial neural networks, pattern recognition, power quality, transmission lines*

1. Introduction

Power Quality phenomena has become more important on last decades due to increase usage of power electronic based equipment which is not only more sensitive to power quality problems but also these kinds of loads have become the one of the disturbing factor of Power Quality.

Power Quality is defined by C. Sankaran as “a set of electrical boundaries that allows equipment to function in its intended manner without significant loss of performance or life expectancy” [1]. The power quality phenomena in holds lots of subtitles among all aimed to voltage and frequency variations, like voltage imbalance, long duration - short duration variations, transients, waveform distortion [1-2]. The most frequent type of PQ problems is voltage dip in transmission and distribution systems [3-4].

Voltage dip is a decrease of the root mean square (rms) voltage to between 0.9 and 0.1 per unit at the power frequency for duration from 0.5 cycles to 1 minute [2]. Voltage dips are generally caused by faults on the system and starting of large loads.

Researches about voltage dip on power systems are becoming increasingly common. There are many relevant papers written relating to the voltage dip and its impact in practical system networks [5-9].

Utilities have been faced with rising numbers of complaints about the quality of power due to dips. The most important reason is customers in all sectors (residential, commercial and industrial) have more sensitive loads because of increasing usage of power electronic equipment in order to provide fast response, controlling flexibility of voltage and frequency. Increase of sensitivity requires reliability on electrical power system as a prior condition. Determination of the problem with reasons clearly is the first step for providing reliability. Power quality monitoring is an useful and realistic tool for identifying the disturbances, assessment of quality of power in overall and behavior of the electrical system [10-11]. Determination of the problem not only helps to improve existing structure but also provides planning for future which could be done by some methods. One of these methods is Artificial Neural Networks (ANNs). The ANNs enables the inclusion of expert knowledge into recognition and classification of signals. Therefore; this method has been used for voltage dip evaluation.

Generally it has been used to control of Dynamic Voltage Regulator (DVR) Systems, detection of voltage dip and classification of power system disturbances [12-15].

In this paper, ANNs has been used as a prediction method for detection of voltage dip frequency per km per month in 380 kV level by using monitoring data sets. The used data sets were obtained from Turkish transmission lines. For this purpose overall of all transmission system, weak busses regarding voltage dip phenomena were determined and parameters that may affect to the dip were defined.

The paper is organized as follows. Section 2 gives details about voltage dip problem like reasons, classifications, characteristics, and frequency. Turkish transmission system's structure and the current PQ project were analyzed in Section 3. In Section 4, proposed neural strategies were described and network results were presented. Finally in Section 5, conclusions and assessment of the method applicability were given.

2. Voltage Dip and Dip Frequency

According to IEEE 1346 (IEEE Std 1346, 1998) Standard a sag is "a decrease in rms voltage or current at the power frequency for duration of 0.5 cycle to 1 minute". The International Electrotechnical Commission, IEC, has the following definition for a dip (IEC 61000-2-1, 1990). "A voltage dip is a sudden reduction of the voltage at a point in the electrical system, followed by a voltage recovery after a short period of time, from half a cycle to a few seconds". It is evident that both voltage dip and voltage sag refer to the same disturbance which is recognizing as the most important power quality problem that affecting industrial customers thus affecting industrial production losses.

Determinations of the dip include two important parameters, which are magnitude of the positive sequence voltage and voltage dip duration [5-6]. The RMS voltage is the magnitude of retained voltage during the event. The duration of voltage dip is the time between voltage (downwardly) crossing the dip starting threshold and the voltage (upwardly) crossing dip ending threshold. It is also possible to define voltage dip as a temporary reduction of the voltage at a point in power system below a threshold.

System faults, transformer energizing and motor starting are the common reasons of voltage dips. The most common voltage dips are due to faults and the cause of the majority of power supply related production stoppages for many industrial installations. In this point propagation of voltage dip through the system comes into prominence. In the literature there are several studies defining propagation of voltage dip through lines and transformers. Those studies also emphasize the importance of transformer winding connection reason for changing fault type by transformer connection [16-18]. While a fault in high voltage level always affects lower parts opposite is not always possible. From the out of this point, this paper is focused on dips due to faults in transmission level. It is possible to predict voltage dip magnitude of a customer by using long termed power quality monitors. Fig. 1 shows voltage dip for 400 kV, 154 kV and 36 kV due to balanced fault at 400 kV.

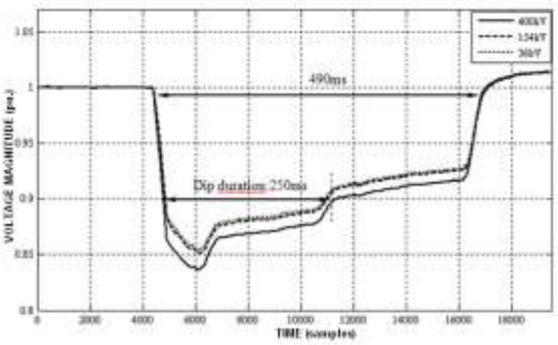

figure 1 Voltage magnitude at 400 kV (Solid), 154 kV (dashed) and 36 kV (dot) due to balanced fault at 400 kV

Voltage dip magnitude is 0.84 pu., while the defined voltage threshold of the system is 0.9-1.1 pu. The magnitude of the dip depends on fault distance to considered point or bus bar. The closer faults result decrease of the system voltage, and vice versa. Therefore; it could be said that the fault is not too much close to the related bus bar for Fig. 1, but still causes exceeding at the threshold. It is hard to give exact distance due to interconnected of 400kV voltage level. If the magnitude were almost zero then the fault would have been at the considered location.

The other parameter that is as important as the voltage dip magnitude is the voltage dip frequency, which is known as how often a particular voltage dip occurs at a given location, has significance to define dip severity of a system and interaction between systems in case of well-known system configuration. The dip frequency depends on several factors which are system configuration, generation scheduling, number of lines connecting the load bus, line length between buses, etc. So, it is necessary to use a prediction method to determinate the voltage dip frequency.

In this study, artificial neural network algorithm was used as a prediction method for determining the dip frequency. Data sets recorded in 380kV voltage level Turkish transmission system was used for training and testing the proposed NNet model. It is well known that short circuit power of the bus is important in terms of voltage dip. And also, seasonal conditions affect this power. So, they were considered as descriptive factors for dip frequency.

In this study voltage dip frequency data sets are refer to dip frequency per km per month. To show the effectiveness of the line length on dip frequency, one year data sets of 25 points of Turkish Transmission System were used. Used data sets were obtained from 400 kV cardinal type overhead line. In Fig. 2, it is seen that there is a logarithmic relation between line length and voltage dip frequency.

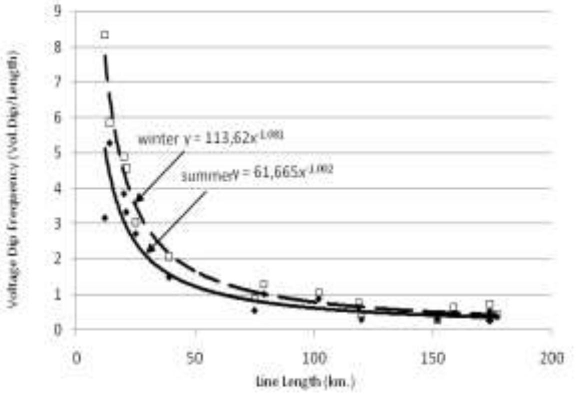

figure 2 Voltage dip frequency per kilometer during summer and winter periods in 400 kV cardinal type over-head line

Defined equations are calculated by using trend line function to acquire estimation for variation of voltage dip frequency and line length. As seen from the Fig. 2, length and also seasonal period are effective significantly on the voltage dip frequency. Therefore voltage dip frequency number was used as per km per month in performed study.

Elimination or reduction of power quality problems, which occur in system are the indicators of the power system deficiency or weakness. Future growth of power systems will rely more on increasing capability of already existing transmission systems, rather than on building new transmission lines and power stations, for economic and environmental reasons. So in this study, voltage dip that is one of the most important PQ problems is addressed for rehabilitation of Turkish Transmission System. For prediction of the dip frequency a NNet model was generated by using recorded data sets in energy monitoring system.

3. Monitoring and Turkish Transmission System

Power quality problems cost business billions of euros annually in lost revenue, process interruptions, and scrapped product. Power quality monitoring has traditionally been used for reacting to problems, by characterizing them to identify possible solutions. While that methodology will always be useful, continuous and permanent power monitoring has emerged as an integral part of overall system performance assessment. The greatest benefit of continuous power monitoring is that it puts users in a proactive position by increasing their knowledge and giving them the tools to increase system reliability.

By installing sensors on key points and presenting the resulting data and analysis on real-time screens and in historical reports, the owner and operators were able to immediately slash their utility costs changes in operation and control as well as other management actions.

And also by analyzing the collected data and historical reports, a lot of significant information like about energy wasting, hidden problems in energy system, system continuity and stability may be obtained. These information and data sets may be used for eliminating or decreasing the deficiency or weakness of the energy system.

In this study, for rehabilitation of Turkish Transmission System a PQ problem was examined. And then, a model was proposed for prediction of this parameter (voltage dip frequency) in the case of making some additions in the energy system.

3.1 Turkish Transmission System

Installed capacity of Turkey is approximately 60.000MW at 2013. Hydroelectric plants supply 36,2% of demand and the most of the rest from thermal sources. However Turkey is considered to have a large amount of wind, geothermal and solar power potential. Currently wind power capacity is around 3,5% of demand. Turkish transmission system which is among the largest transmission systems in Europe, has 21 transmission regions and connects to the European grid (Bulgaria connection) in Hamitabad Bus at the 1st region (Fig. 3).

figure 3 Monitored points in Turkish Transmission System

A quantitative overview of Turkish Electricity Transmission System is given in Table 1 [19]. The values in Table 1 increases every passing year due to upsurge in Turkey economy.

Table 1 Overview of Turkish Transmission System

Transmission	O/H	Number of	Number of
380	13976	58	145
220	85	-	-
154	31030	452	920
66	719	15	56

Total	45810	525	1121

The Turkish electrical energy sector was governed by the state owned company, called Turkiye Elektrik Kurumu (TEK). The Turkish government made the first attempts to bring private companies into the energy sector in the 1980's. In 1993 the Turkish government divided TEK into two independent companies: Turkiye Elektrik Uretim Iletim A.S. (TEAS), responsible for generation, transmission and wholesale of electrical energy and Turkiye Elektrik Dagitim A.S. (TEDAS), responsible for distribution activities and retail sales to consumers.

The rapid growth of electrical demand causes privatization of Turkish electrical energy sector in distribution area. The primary objective is to ensure the delivery of electricity (which has a significant role in our economic and social life) to consumers in an adequate, quality, continuous and low-cost manner. Turkey's distribution network was divided into 21 distribution regions based on geographical proximity, managerial structure, energy demand and other technical/financial factors and all of them have being privatized.

3.2 Monitoring of Turkish Energy System

Power quality monitoring system improved to carry out extensive power quality measurements in nationwide. A properly designed and installed monitoring system offers deeper understanding of the operational parameters of the power system. A better knowledge of how energy is used within a facility allows you to identify an array of prospects to improve efficiency, minimize waste, and reduce energy consumption, thereby allowing the facility to be a better steward of its allotted natural resources and evaluation of data from the monitoring system can reveal existing or imminent issues that can help to locate and correct both acute and chronic problems, resulting in increased productivity [20]. With this regard, a new project, aimed to installation power quality monitors, has been started named as National Power Quality Project in Turkey. The project of the Scientific and Technological Research Council of Turkey, TUBITAK, is based on to measure PQ parameters (voltage, voltage dip frequency, and active-reactive power, harmonic) in Turkey Transmission-Distribution System [21].

PQ data sets have been regularly recorded in 85 substations for one year. Monitoring points in overhead lines and transformers are given in Table 2. Fig. 4 shows a screenshot from PQ monitor for 380kV overhead line.

In this work data sets recorded in 380kV voltage level transmission system was used to predict voltage dip frequency per month per line. Buses in which the problem occurs and parameters that may affect to this condition were determined and then ANNs has been used for prediction method.

Table 2 Number of recorded data points

Description of point	Number of recorded
Overhead Lines in 380 kV	25
Overhead Lines in 154 kV	20
Primary side of 154/34.5 kV Transformers	25
Primary side of 380/34.5 kV Autotransformers	15

figure 4 Screenshot from PQ monitoring in case of data collection

4. Artificial Neural Networks

The artificial neural network represents a parallel, multilayer information processing structure which enables the inclusion of expert knowledge into recognition and classification of signals.

Among the various artificial neural networks, the multilayer perception (MLP) can be considered as an information processing system whose function is defined from a set of examples describing both the inputs and the desired output. After a training step, the MLP is able to compute the right output not only from the input vectors of the examples set, but also from any unknown input vector [22].

4.1 Generating Data for Training and Testing

By using developed system for the project "Electrical Transmission System Supply Reliability and Quality" sampled three phase voltages and currents have been collected. The sampling rate per channel is 512 samples per one cycle of the 50 Hz system. Using these data sets PQ parameters have been computed as indicated on the standard IEC-61000-4-30 [23].

Monitored data of overhead lines in 380kV voltage level have been collected from 25 substations.

Used data sets for evaluation of the method include duration of April-September 2012 as summer period. Significant changes occur in the summer period in terms of loading. So this six-month period is examined in the first stage of the study.

Because of the hardness of archiving full sampled data sets, 10-min averages of PQ parameters have been collected by the monitors. So these average values were used in this work.

Recorded data of voltage dip frequency is per month. So PQ parameters that is stored as 10-min average had to be reduced to a simple state. For this purpose the average value of 10-min PQ data sets per month were calculated. Afterwards the input parameters were determined to have true voltage dip frequency.

The input parameters of the proposed network were determined as line length, short circuit powers of connected buses of line (Ssc main and end bus), average active and reactive power flow per month and a number that represents the month. It means that the network has six inputs. The output of the network was voltage dip frequency per km per month. A sample of used data sets is seen in Table 3. Active power and reactive power values are kW and kVAR, respectively. And the short circuit power (Sk) values are MVA.

Table 3 A sample of used data sets

1. Alibeykoy Bus Number	1	1	1	1	1	1	1. Alibeykoy Bus Number	1	1	1	1	1	1
1. Umraniye Bus Number	6	6	6	6	6	6	1. Umraniye Bus Number	5	5	5	5	5	5
P (average)	234173	181798	138504	139980	158640	150648	P (average)	139640	128760	113788	125430	141780	167028
Q (average)	42419	34866	32505	37585	40080	34639	Q (average)	41116	38298	29996	34754	31373	38738
Length (km)	39	39	39	39	39	39	Length (km)	25	25	25	25	25	25
S (short circuit power at bus-1)	21703	21703	21703	21703	21703	21703	S (short circuit power at bus-1)	21703	21703	21703	21703	21703	21703
S (short circuit power at bus-6)	19005	19005	19005	19005	19005	19005	S (short circuit power at bus-5)	17612	17612	17612	17612	17612	17612
Month numbers	4	5	6	7	8	9	Month numbers	4	5	6	7	8	9
Monthly voltage dip number	13	8	9	4	6	8	Monthly voltage dip number	27	4	18	4	5	8

4.2 Proposed Network Architecture

Data sets of 14 points were used for training and 8 points were used as test data. Since there were some problems in three monitors, all 25 points data could not be used. Six-month data sets were used for each point. All inputs and outputs were normalized to the highest magnitude of the parameters.

The initial weights were selected as small random numbers. The activation functions for the hidden layer neurons were tangent sigmoid functions and for the output layer were pure linear functions. After the network parameters were determined, the network was ready for training. The error back propagation technique is used for training ANN. The criterion function for the mean square error is minimized according to the gradient descent procedure. Levenberg-Marquardt algorithm in Matlab Toolbox was used for training because it is the fastest training algorithm for networks of moderate size and has a memory reduction feature [22].

There is no particular formula to choose suitable network architecture for an application. The suitable network size is found by trial and error. Small sized network may not be enough to map the function, but bigger sized network may not be a better choice as well. It was seen that the network size of [6 9 7 4 1] is good choice for training time and performance. The proposed neural network architecture is shown in Fig. 5.

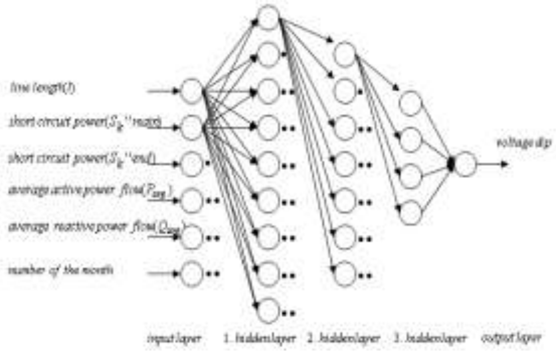

figure 5 Network architecture of the proposed system

The network was trained until the mean squared error is less than 1e-6. At the end of the 260th epoch mse of 1e-6 was achieved (Fig. 6).

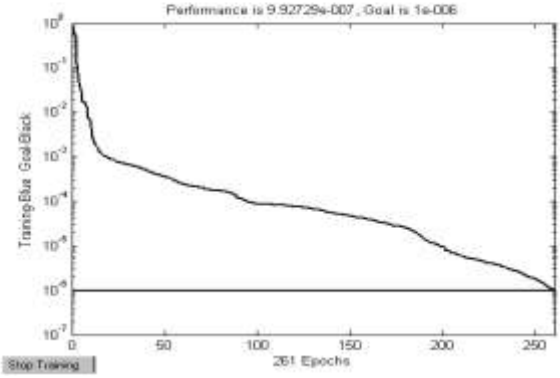

figure 6 Performance curve of the network

4.3 Response of Proposed ANN for Training and Testing Simulations

Normalized inputs were applied to proposed ANN and the output of the network has been attained. In Fig. 7 input-target set and input-training results are shown.

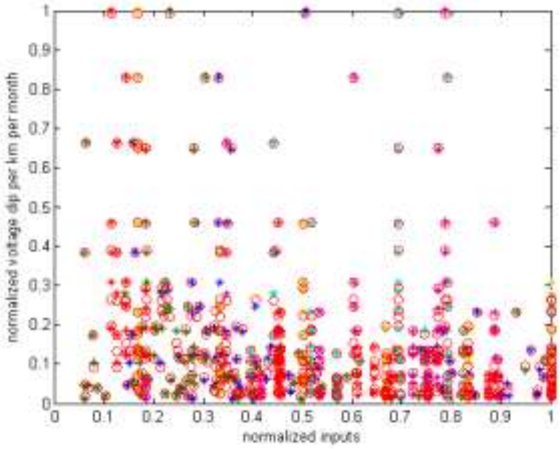

figure 7 Training input- target (*) and training input-network output (o) data sets

It is seen in Fig. 8 that network can predict voltage dip frequency per km per month accurately. It is observed that expected output is nearly same as actual output.

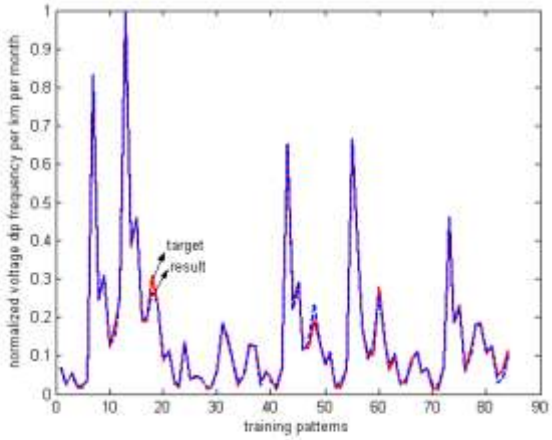

figure 8 Target and training result curves of the network

After neural network is trained with training samples, it is required to test the proposed network In Fig. 9 and Fig. 10 the testing input-target (actual output) and testing input-output (expected output) data set are given respectively and the results show that the proposed network is successful.

It is known that voltage dip frequency is depend on a lot of system parameters like active-reactive power, line parameters, seasons, etc. But network outputs show that defined input parameters is sufficient for predicting voltage dip frequency per km per month. It means that proposed network is well trained despite of having to use limitedly data sets.

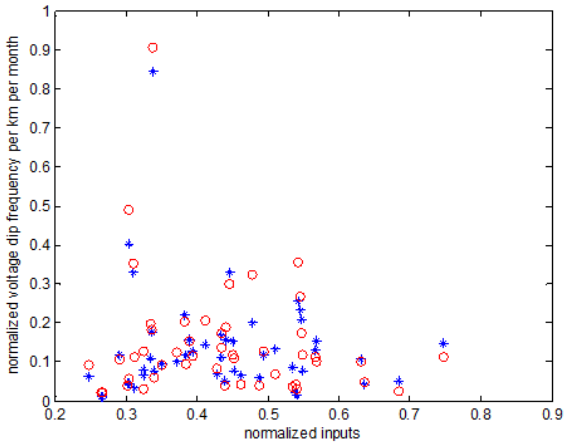

figure 9 Testing input- target (*) and training input-network output (o) data sets

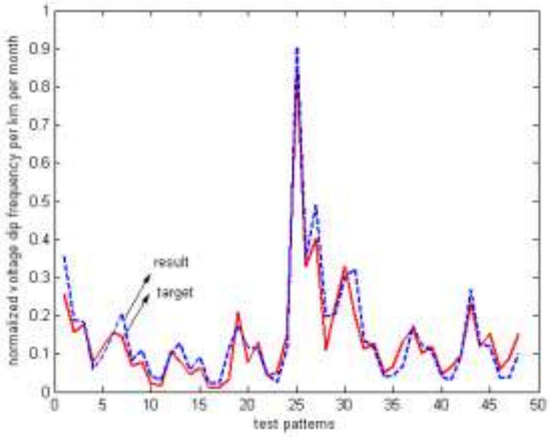

figure 10 Target and testing result curves of the network

5. Conclusion

The results obtained in this paper are summarized as follows:

An artificial neural-net based method has been presented for predicting voltage dip frequency per km per month in 380kV level transmission system The 4-layered neural network was constructed with the back propagation algorithm. Lots of network constructions were tried and the most accurate one is selected.

Using proposed network, voltage dip frequency per km per month predictions have been obtained for summer period accurately.

This proposed network can be used for energy system planning. These values can help system planners to decrease voltage dip frequency.

It may be necessary to add a new transmission line to supply increasing energy demand. In such a case the substations that can be used for transmitting energy to the needed one are determined. For each selected substations PQ parameters are obtained by using power flow analysis. Then obtained parameters are used in proposed ANN system for finding the most reliable substation. As a result, more uninterruptable energy can be transmitted to distribution regions.

In the following study, same method will apply for 400 kV voltage level transmission lines using winter period data sets.

6. Acknowledgement

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