

ANN based On-Load Tap Changer for Distribution Network with Distributed Generation

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Abstract—Number of distributed generation (DG) plants integrated to utility network increases due to rising of electricity consumption. DG plants have a big impact on voltage level of network in accordance with this increasing. Especially DG plants based on renewable resources may cause voltage rise and drop because of their intermittently energy generation. Generally, the voltage level is regulated by reactive power control technique and On-load tap changer (OLTC). Generally, HV/MV transformers use OLTC to regulate the voltage level under load. The conventional voltage control techniques depend on current of the branch at the main substation end. If the rising of DG installation is taken into consideration, the conventional methods can be inadequate. Artificial intelligence techniques can be used to mitigate this problem. In this paper, an Artificial Neural Networks (ANN) model is designed for determination of OLTC best tap position. ANN model is trained by using different values of network voltage level, DG generation values and amount of load demand. Designed model is applied on electrical network of Selcuk University. The electrical network of Selcuk University is modeled by using PSCAD/EMTDC. 1MW Photovoltaic (PV) power plant is determined as DG plant.

Keywords—Distributed generation; voltage regulation; OLTC; ANN; artificial intelligence; photovoltaic power plant.

I. INTRODUCTION

Nowadays, electricity consumption is rapidly growing due to technological improvements, urbanization and industrialization all over the world. In connection with this rise, installation of distributed generation (DG) plants based on renewable resources increases. The integration of these plants has different impacts on voltage profile of distribution networks. These impacts can be positive or negative according to type of DG and operating characteristic of distribution network [1]. Generally, control of voltage and frequency isn't expected from the integrated DG plants. This control is ensured by generation plants in transmission system. However, it's expected that these plants contribute to the control of voltage and frequency, as the number of DG plants integrated to distribution networks increases. In addition that, especially DGs including renewable energy plants inherently generate intermittent electrical energy, which causes to decrease or increase of DGs' voltage [2].

In classical power systems, direction of power flow is from high voltage side to low voltage side. At the same time power flowing causes to voltage drop. The voltage drop depends on loads and reactance of line. If load demand and reactance of line increase, the voltage drop increases or vice versa. Contrary to this, voltage level can be raised based on generated power, number of integrated DGs and their connection point. The voltage level of radial distribution networks can be regulated by On-load tap changer (OLTC) or reactive power control. The voltage level cannot be adjusted by the conventional voltage control methods, because they depend on current of branch at the main substation end. If the increasing of DG integrated to distribution networks is considered, these methods can be inadequate for indication of the feeder status [3].

Artificial intelligent techniques are used to provide the control of voltage level and transformer OLTC system. In [3], the control strategy of voltage level of distribution networks in Saudi Arabia is investigated. The investigated network includes small-scale distributed solar Photovoltaic (PV) power plant. Fuzzy logic method is used to determine the best tap position. Load conditions and total PV generation are determined as membership functions. An adaptive fuzzy based control of OLTC is presented in [4]. The impact of high penetration of DG which includes solar and wind power because of their intermittent nature on voltage regulation is considered. This impact is mitigated by OLTC controller. Maximum and minimum voltages are determined as adaptive fuzzy reference. The voltage regulation of unbalanced distribution networks is investigated in [5]. In case of PV and wind generators are integrated to distribution system, OLTC operation is analyzed. The voltage regulation is provided by PV and wind turbine in order to reduce the OLTC operation. Different scenarios are applied on IEEE 13 bus system and analyzed. Artificial Neural Networks (ANN) is used to find optimum tap ratio of OLTC in [6]. Real and reactive power values at each load bus are determined as input layer of ANN. The output layer consists of transformer tap changing ratio and real power losses. This technique is tested on IEEE 6 bus system. An Automatic Voltage Control (AVC) based on Fuzzy logic method is presented in [7]. Secondary voltage of transformer and phase angle are determined as input membership functions and AVC relay voltage is determined as

output membership function. Designed system is tested on a distribution system. Effective voltage control is provided with fuzzy logic controller based AVC.

This paper presents an ANN model to determine the optimum tap position of transformer OLTC. When DG plants are integrated to utility network, system behavior may change. The ANN model is designed and trained in accordance with DG integration. 1MW PV power plant is determined as DG plant. Designed ANN model is used for transformers of Selcuk University Medical Faculty (MF). The electrical system of University is modeled by using PSCAD/EMTDC.

II. METHODOLOGY

A. Voltage Regulation

Voltage level of distribution networks may reduce or rise according to power demand of consumers. When power demand is high or extreme, voltage level can decrease below of lower limit. On the contrary, when power demand is reduced and light load situation occurs, voltage level can increase above of upper limit. Power flow direction can be reversed, when DG power plants are integrated to distribution network [8]. Figure 1 represents a simple diagram of distribution network including DG.

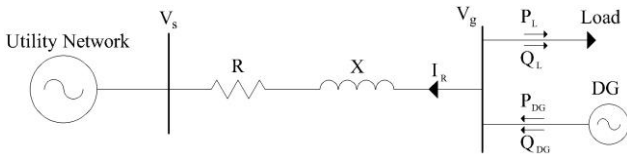


Fig. 1. Simplified model of network including DG

where R and X represents the line impedance, P_L and Q_L are active and reactive power respectively, demanding by the load. P_{DG} and Q_{DG} are active and reactive power respectively, supplying by the DG. The voltage drop (ΔV) between the DG voltage (V_g) and the source voltage (V_s) is calculated by:

$$\Delta V = V_s - V_g = \frac{R(P_{DG} - P_L) + X(Q_{DG} - Q_L)}{V_g} \quad (1)$$

Due to the DG effect on power flow, voltage increasing may occur at V_g . Exceeding the voltage limits can damage to the customers. Generally, HV/MV transformers use automatic tap changer and AVC to regulate the voltage variation. The output voltage of transformers can be easily regulated with OLTC under load. In addition to this, fixed or variable capacitor banks are used to improve voltage profile [9].

In this paper PV power plant whose capacity is 1MW is determined as DG. The voltage level of system can be increases or decreases due to the installation of high capacity PV and variable loads. The sensitive and better detection of optimum tap position with artificial intelligence techniques can mitigate this impact of DG.

B. Artificial Neural Network

ANN is an approach trying to create a new system similar with operation of human brain. At the same time it is a simplified model of human brain and a computational method using to get an efficient model for different problems. This system has the capacity for learning of system behavior, gaining experience and solving new problems by using clusters of inputs and outputs data. Linear and nonlinear connections between inputs and objective results are modelled. Acceptable and satisfying solutions can be produced about different issues by using this method. ANN is used to solve complicated problem in engineering field by means of advantages such as learning ability, be able to get result with less data, feasibility for different problems [10].

In an ANN model, there are generally different layers which are input, output and hidden. The optimum neuron number in these layers is determined by trial and error method.

C. Design of ANN Model

ANN model is created to estimate the best tap position of step-down transformer. The tap position is determined by voltage level. If the voltage level of network is high, tap position should be increased or vice versa. However some variables may affect the voltage level of network. The one of the most important variable is DG integration. Especially in the case of high DG penetration, the voltage level of system may exceed its upper and lower limits. Another variable is load demand of system. When load demand increases, voltage level can decrease depending on system parameters. This is an undesirable situation. Therefore the best tap position should be determined carefully to regulate the voltage level. The designed ANN model is shown in Figure 2.

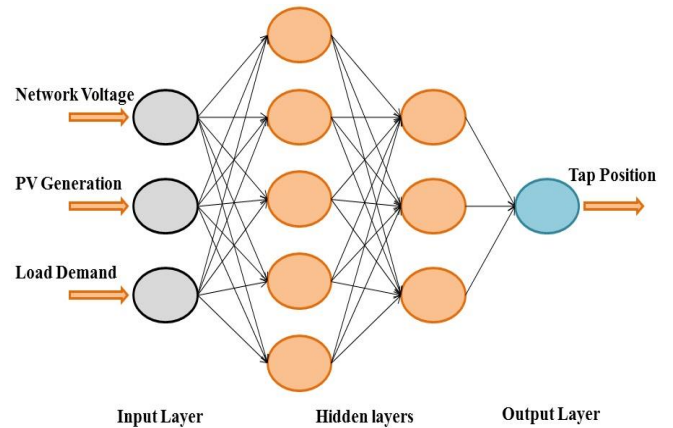


Fig. 2. Designed ANN model

The input layer consists of the voltage level of network, PV generation and load demand of system. The optimum tap position is determined as output layer.

The ANN model was trained with varied levels of network voltage, PV generation and load demand. For network voltage, 5 different voltage levels which are 1.05, 1.025, 1.0, 0.975 and 0.95 per unit are taken into consideration. For load demand, 5

different demand types which are extreme load (125% of peak load), peak load, average load (75% of peak load), low load (50% of peak load) and light load (25% of peak load) are considered. For PV generation, a lot of assumption can be considered. In this study, PV generation values are determined by starting from no PV generation to full PV generation (100% capacity) by 10% increment (0%, 10%, 20%, ..., 90%, 100%). The combinations of these situations mentioned above are created and determined as training data of ANN. The training data of ANN are shown in Table 1.

TABLE I. Training data of ANN

Network Voltage	PV generation (%)	Load demand
1.05 p.u.	100	Extreme
1.05 p.u.	100	Peak
1.05 p.u.	100	Average
1.05 p.u.	100	Low
1.05 p.u.	100	Light
1.05 p.u.	90	Extreme
1.05 p.u.	90	Peak
.	.	.
.	.	.
.	.	.
0.95 p.u.	10	Low
0.95 p.u.	10	Light
0.95 p.u.	No PV	Extreme
0.95 p.u.	No PV	Peak
0.95 p.u.	No PV	Average
0.95 p.u.	No PV	Low
0.95 p.u.	No PV	Light

All combinations are taken into consideration. ANN model is training data consisting of 275 sample. ANN can gain

enough experience and find the connections between the inputs and output by using these data.

III. SYSTEM DESCRIPTION

Electrical network of Selcuk University Campus is modeled by using PSCAD/EMTDC. In case of 1MW PV power plant to be building at Campus supplies MF, this plant will have an impact on voltage level of MF. 1MW PV power plant is designed as similar to an installed PV power plant located in Konya Organized Industrial Zone. The installation parameters and equipment of plant are determined according to a real grid connected PV power plant. The modeled system is shown in Figure 3.

Selcuk University campus and MF are supplied by 3 feeders. One of these feeders connecting Campus Distribution Center supplies the MF via $3(1x50+16mm^2)$ XLPE cable.

In order to supply different loads, MF has 4 distribution transformers whose features are 31.5/0.4kV and 1.6MVA. The main bus of MF is called as Point Common Coupling (PCC) because of utility feeder and designed PV power plant connect to this bus together.

The voltage level of MF transformers is crucial because of MF has many sensitive devices and equipment. When PV power plant is integrated to MF, the voltage level of system may change depending on PV generation and load demand. Therefore a new control strategy is necessary for more reliable system. The OLTC mechanism of MF transformers can be enhanced with modeled ANN architecture

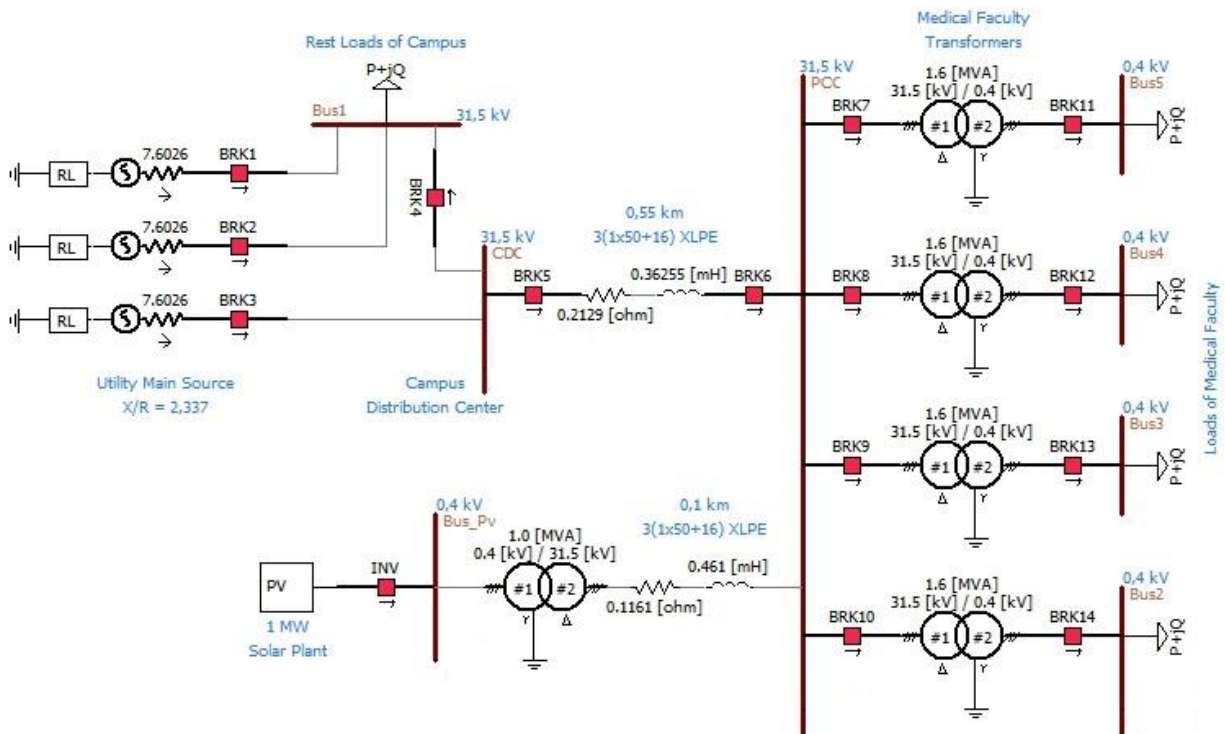


Fig. 3. Single Line Diagram of Selcuk University Campus

IV. CASE STUDY

In this paper, transformers of Selcuk University Medical Faculty are investigated from the point of voltage level and tap position. ANN technique is used to determine the optimum tap position of these transformers.

Designed ANN model is trained by using simulation values of electrical system of Selcuk University Campus modeled by PSCAD/EMTDC. The voltage level of utility main source is first input variable of ANN. The generation values of 1MW PV power plant and load demand of MF are other input variables. The optimum tap position of OLTC is determined with 95.3% accuracy rate. Change of classification accuracy and iteration numbers for training are shown in Figure 4.

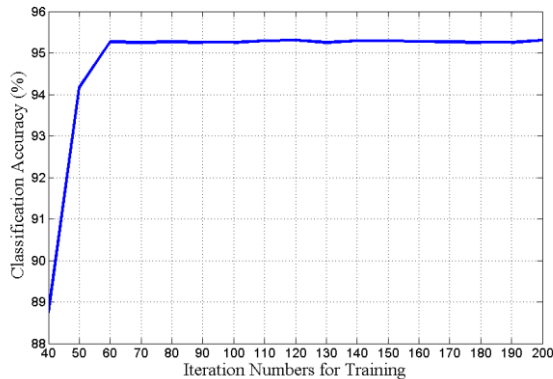


Fig. 4. Accuracy rate of classification

Fig. 4 illustrates that all of classification accuracy are acceptable after 60 iterations. After this iteration number, accuracy rate is changed between 95.2% and 95.3%. Mean squared error of this model is shown in Figure 5.

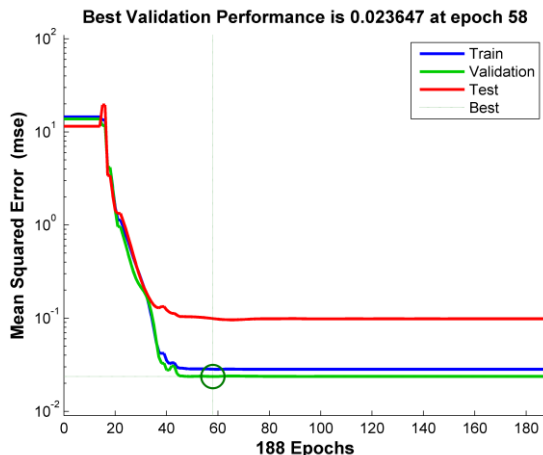


Fig. 5. Change of mean squared error

Fig. 5 illustrates that minimum error of model is not changed after iteration 58. Therefore the number of iteration

between 60 and 70 is adequate to determine the tap position for this model.

V. CONCLUSIONS

In this paper, an ANN model was proposed to regulate the voltage level of distribution network with distributed generation. The optimum tap position of OLTC used to regulate the voltage in HV/MV transformers was determined with designed ANN model according to different values of network voltage, DG generation and load demand.

Designed ANN model was applied on electrical network of Selcuk University. The electrical network of Selcuk University was modeled by using PSCAD/EMTDC. 1MW PV power plant was determined as DG plant. In case of 1MW PV power plant to be building at University supplies to Selcuk University MF, behavior of MF transformers' OLTC was analyzed. The optimum tap position of transformers was successfully determined with designed ANN model. It was seen that ANN is an adequate artificial intelligent technique to determine the best tap position.

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