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Energy Procedia 117 (2017) 209–215

Energy Procedia

www.elsevier.com/locate/procedia

1st International Conference on Power Engineering, Computing and CONtrol, PECCON-2017, 2-4 March 2017, VIT University, Chennai Campus

Voltage Profile Assessment in Power Distribution System Using Generalized Regression Neural Network

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Abstract

The planning and operation of distribution system requires the values of voltage magnitude at different sections of the system. Penetration of Distributed Energy Resources (DERs) in the power system improves the voltage profile especially during the peak load periods. The DERs in the conventional power system provides more options for voltage control mechanisms. The voltage control mechanism will be chosen based on the voltage profile of a particular section during given time period. Hence it is essential to estimate and update the voltage magnitudes of the system at pre specified time intervals. Many methods have been proposed to estimate the voltage profile of a radial distribution system. This paper proposes a new method for voltage profile assessment using Generalized Regression Neural Network (GRNN). The proposed method uses the influential load as inputs to estimate the voltage magnitudes with lesser computation time.

Peer-review under responsibility of the scientific committee of the 1st International Conference on Power Engineering, Computing and CONtrol.

Keywords: Distributed Energy Resources (DERs); Generalized Regression Neural Network (GRNN); voltage control mechanisms

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1. Introduction

Planning and operation of electric power system requires information about the Power flow, voltage magnitude and power loss. Load flow analysis is a basic and necessary tool for any electrical system in order to carry out steady

Peer-review under responsibility of the scientific committee of the 1st International Conference on Power Engineering, Computing and CONtrol.
10.1016/j.egypro.2017.05.124

state operating condition. The load flow solution provide the real (kW) and reactive power (kVAr) losses of the system and voltage magnitudes and angles at different nodes of the system subject to the regulating capability of generators, condensers and tap changing of transformers under load as well as specified net interchange between individual operating systems. These analyses require the calculation of numerous load flows for both normal and emergency operating conditions. Short circuit analysis used for calculating the switch gear rating uses the load flow studies. These studies should also be used to confirm adequate voltage profiles during different operating conditions, such as heavily loaded and lightly loaded system conditions. Load flow studies can be used to determine the optimum size and location of capacitors for power factor correction. The results of load flow studies are also starting points for other system studies. The distribution power flow involves, first of all, finding all of the node voltage as given by Short T.A. From these voltages, it is possible to directly compute currents, power flows, system losses and other steady state quantities. Some applications, especially in the fields of optimization of power system, distribution automation (i.e., VAR planning, network optimization, state estimation, etc.) need repeated fast load flow solutions. In these applications it is important that the load flow problem is solved as efficiently as possible.

A method is proposed [1] a method for estimating voltage profile of unbalanced distribution systems using backward/forward sweep load-flow analysis method with secant predictor. A method for Voltage stability analysis of radial distribution networks using catastrophe theory is given in [2] . Probabilistic voltage stability assessment considering renewable sources with the help of the PV and QV curves is proposed in [3]. Voltage stability analysis in unbalanced power systems by optimal power flow is proposed in [4]. Real-Time Voltage Regulation in Power Distribution System Using Fuzzy Control is explained in [5]. Reliability assessment of electric distribution systems using fuzzy logic is proposed in [6,7]. The conventional methods reported in the literature uses complex computation whereas the AI based methods the number of input required is proportional to the system size. In this paper GRNN based method is proposed to estimate the voltage magnitude using few influential loads as inputs. GRNN model is developed using the data obtained from simple method for distribution load flow solution which solves a simple algebraic expression of voltage magnitude. The convergence characteristics and the effect of voltage dependency are analyzed. A simple algorithm based on circuit theory using algebraic recursive expression to solve radial distribution networks. Load flow solution to distribution system is obtained by using bus injection to branch current matrix and branch current to bus voltage matrix and a simple multiplication. A Load flow technique to solve distribution networks based on sequential branch numbering scheme by considering committed loads. A backward/ forward sweep load flow solution for three phase radial distribution systems is used. A load flow solution including voltage dependent load models based on forward – backward sweep method for solving the load flow problem of a distribution system. The proposed method is tested by taking 28 bus radial distribution systems by using backward forward sweep method of load flow for radial distribution system

2. The Distribution load flow

The effective active (P_i) and reactive (Q_i) powers that of flowing through branch ‘j’ from node ‘i' to node ‘i+1’ can be calculated backwards from the last node and is given as,

$$P_i = P'_{i+1} + r_j(P'^2_{i+1} + Q'^2_{i+1}) / V'^2_{i+1} \qquad (1)$$

$$Q_i = Q'_{i+1} + r_j(P'^2_{i+1} + Q'^2_{i+1}) / V'^2_{i+1} \qquad (2)$$

where $P_{i'+1} = P_{i+1} + P_{L\,i+1}$ and $Q'_{i+1} = Q_{i+1} + Q_{Li+1}$

P_{Li+1} and Q_{Li+1} are loads that are connected at node ‘i+1’.

P_{i+1} and Q_{i+1} are the effective real and reactive power flows from node ‘i+1’.

The voltage magnitude and angle at each node are calculated in forward direction. Consider a voltage $V_i \ \delta_i$ at node ‘i’ and $V_{i+1} \ \delta_{i+1}$ at node ‘i+1’, then the current flowing through the branch ‘j’ having an impedance, $z_j = r_j + j$

$x_j$connected between 'i' and 'i+1'is given as,

$$Ij = (V_i\delta_I - V_{i+1}\,\delta_{i+1}) / z_j = r_j + j\,x_j \tag{3}$$

$$Ij = P_i + j\,Q_i / V_i\ \delta_i \tag{4}$$

On equating the equations (3) and (4), we have

$$(V_i\delta_I - V_{i+1}\,\delta_{i+1}) / z_j = r_j + j\,x_j = P_i + j\,Q_i / V_i\ \delta_I \tag{5}$$

$$V_i^2 - V_i V_{i+1} (\delta_{i+1} - \delta_i) = (P_i - j\,Q_i)(r_j + j\,x_j) \tag{6}$$

By equating real and imaginary parts on both sides of equation (6), we have

$$V_i V_{i+1} \cos(\delta_{i+1} - \delta_i) = V_i^2 - (P_i r_j + Q_i x_j) \tag{7}$$

$$V_i V_{i+1} \sin(\delta_{i+1} - \delta_i) = Q_i r_j - P_i x_j \tag{8}$$

Squaring and adding equations (7) and (8), we get

$$(V_i V_{i+1})^2 = [V_i^2 - (P_i r_j + Q_i x_j)]^2 + [Q_i r_j - P_i x_j]^2 \tag{9}$$

$$(V_i V_{i+1})^2 = V_i^4 - 2\,V_i^2 (P_i r_j + Q_i x_j) + (r^2_j + x^2_j)(Pi^2 + Q^2_i) \tag{10}$$

$$V_{i+1} = V_i^2 - 2(P_i r_j + Q_i x_j)) + (r^2_j + x^2_j)(Pi^2 + Q^2_i)^{1/2} / V_i^2 \tag{11}$$

and voltage angle, δi+1 can be derived on dividing equations (8) and (7)

$$\tan(\delta_{i+1} - \delta_i) = V_i^2\ ((Q_i r_j - P_i x_j\ / V_i^2 - (P_i r_j + Q_i x_j)\ ) \tag{12}$$

3. $$\delta_{i+1} = \delta_i + \tan^{-1} V_i^2 ((Q_i r_j - P_i x_j\ / V_i^2 - (P_i r_j + Q_i x_j)\ ) \tag{13}$$

The magnitude and the phase angle equations can be used recursively in a forward direction to find the voltage and angle respectively of all nodes of radial distribution system.

The real and reactive power losses of branch 'j' can be calculated as,

$$Ploss\,(j) = r\,j\,(Pi^2 + Q^2_i) / V_i^2 \tag{14}$$

$$Q\,loss\,(j) = x_j\,(Pi^2 + Q^2_i) / V_i^2 \tag{15}$$

The total real and reactive power loss of radial distribution system can be calculated as,

$$TPL = \text{€}\ r\,j\,(Pi^2 + Q^2_i) / V_i^2 \tag{16}$$

$$TQL = \text{€}\ x_j\,(Pi^2 + Q^2_i) / V_i^2 \tag{17}$$

Initially, a flat voltage profile is assumed at all nodes i.e., 1.0 pu. The branch powers are computed iteratively with the updated voltages at each node. In the proposed load flow method, powers summation is done in the backward walk and voltages are calculated in the forward walk. The maximum difference of voltage magnitudes in successive iterations is taken as convergence criteria and 0.0001 is taken as tolerance value. The algorithm for load flow solution of radial distribution system is explained in the following section.

3. Algorithm for Load Flow Calculation

Step 1: Read distribution system line and load data. Assume initial node voltages are 1 pu and set $\varepsilon = 0.0001$.

Step 2: Start iteration count, IT =1.

Step 3: Initialize real power loss and reactive power loss vectors to zero.

Step 4: Calculate the effective real and reactive power flow in each branch

Step 5: Calculate node voltages, real and reactive power loss of each branch

Step 6: Check for convergence i.e.$\Delta Vmax< \varepsilon$ in successive iterations. If it is converged go to next step otherwise increment iteration number and go to step4.

Step 7: Calculate the real and reactive power losses for all branches and also total real and reactive power loss.

Step 8: Print voltage at each node, the real and reactive power losses of all branches and total loss.

Step 9:stop.

4. Proposed Method

The accuracy and computation time of the AI based methods depends on the size of the input vector. Hence the AI based methods which gives accurate results for smaller systems, may give erroneous results for practical power system with more number of buses. This paper proposes a method to reduce the size of the input vector. In the practical power system the load variation in a bus may not have significant effect on the voltage magnitude of all the buses. Hence to estimate the voltage magnitude of few buses it is sufficient to include the buses which are having significant effect on the voltage magnitude. The proposed method for voltage profile assessment using influential loads has two parts. The first part will be to identify influential loads and generate data patterns that reflect all possible operating conditions of the test system using the algorithm explained in the preceding section. The second part will develop the GRNN model for voltage profile assessment.

Procedure to identify influential bus:

- Select the buses for which voltage magnitude to be estimated.
- Change the load of the bus and estimate the voltage magnitudes by running power flow
- Check the buses which are having significant change in the bus voltages.
- The influential buses are 11,12,13,14,15.
- After selecting the influential buses, generate data sets which reflects all possible operating conditions of the system.
- Different data set patterns are generated by random numbers.
- Influential busloads of IEEE 28 bus system are identified through off-line power flow studies.

4.1 Generalized Regression Neural Network (GRNN)

A schematic of the Generalized Regression Neural Network (GRNN) is shown in Fig. 1. The GRNN consists of four layers: an input layer, a pattern layer, a summation layer and an output layer.

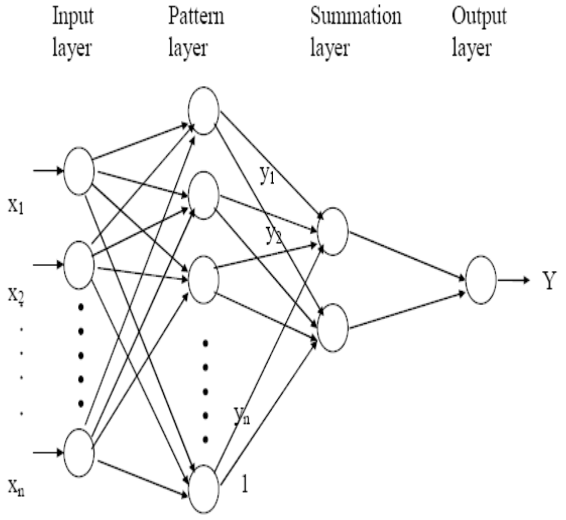

Fig. 1 Schematic diagram of GRNN

The first layer is connected to the second, pattern layer, where each unit represents a training pattern and its output is a measure of the distance of the input from the stored patterns. Each pattern layer unit is connected to the two neurons in the summation layer: S-summation neuron and D-summation neuron. The former computes the sum of the weighted outputs of the pattern layer while the later calculates the outweighed outputs of the pattern neurons. The connection weight between the ith neuron in the pattern layer and the S-summation neuron is y_i; the target output value corresponding to the ith input pattern. For the D-summation neuron, the connection weight is unity. The output layer merely divides the output of each S-summation neuron by that of each D-summation neuron, yielding the predicted value to an unknown input vector x as

$$\hat{y}_i(x) = \frac{\sum_{i=1}^{n} y_i \exp[-D(x, x_i)]}{\sum_{i=1}^{n} \exp[-D(x, x_i)]} \tag{18}$$

where n indicates the number of training patterns and the Gaussian D function is defined as

$$D(x, x_i) = \sum_{i=1}^{p} \left(\frac{x_j - x_{ij}}{\zeta} \right)^2 \tag{19}$$

where, p indicates the number of elements of an input vector. The terms $x_j$and x_{ij} represent the j^{th} element of x and x_i respectively. The term ζ is generally referred to as the spread factor. The GRNN method is used for estimation of continuous variables, as in standard regression techniques. It is related to the radial basis function network and is based on a standard statistical technique called kernel regression. The joint probability density function (pdf) of x and y is estimated during a training process in the GRNN. Because the pdf is derived from the training data with no preconceptions about its form, the system is perfectly general. The success of the GRNN method depends heavily on the spread factors. The larger that spread is, the smoother the function approximation. Too large a spread means a lot of neurons will be required to fit a fast changing function. Too small a spread means many neurons will be required to fit a smooth function, and the network may not generalize well. GRNN needs only a fraction of the training samples that a back propagation neural network would need. GRNN is advantageous due to its ability to converging to the underlying function of the data with only few samples available. This makes the GRNN very useful and handy for the problems with inadequate data.

5. Test system and results

The technical feasibility of the proposed method is tested using IEEE 28 node distribution system. The voltage obtained using conventional load flow algorithm and the GRNN model is given in Table.1. From the Table.1 it is observed that the proposed method estimates the ATC value with reasonably good accuracy in lesser computation time.

Table 1. Voltage magnitude obtained from load flow and GRNN model

Bus No	Voltage by Load flow	Voltage by GRNN model	%Error
1	-	-	
2	0.992	1.01	1.8
3	0.98	0.94	4.0
4	0.97	0.966	0.4
5	0.957	0.9	1.7
6	0.951	0.963	1.2
7	0.940	0.942	0.2
8	0.96	0.94	2.0
9	0.961	0.94	2.1
10	0.95	0.94	1.0
11	0.966	0.962	0.4
12	0.97	0.961	1.0
13	0.98	0.96	2.0
14	1.01	0.96	4.9
15	0.99	0.96	2.0
16	0.98	0.956	2.4
17	0.93	0.947	5.3
18	0.95	0.946	0.4
19	0.98	0.945	3.5
20	0.95	0.945	0.5
21	0.94	0.944	0.4
22	0.95	0.94	1.0
23	0.927	0.938	6.2
24	0.95	0.937	3.6
25	0.94	0.937	0.3
26	0.97	0.937	3.4
27	0.98	0.94	4.0
28	0.98	0.94	4.0

The proposed model is tested with IEEE 28 bus distribution system. Twenty data sets are generated and GRNN model is developed using the influential real power loads as inputs and voltage magnitudes as outputs. The GRNN model developed is tested with five data sets which were not used for training the model. The test result of one data set is presented in Table 1.

From Table 1 it is observed that the maximum error was found to be 6.2% and the minimum error was 0.2%. Hence it is clear that the GRNN model can estimates the bus voltages accurately. The proposed GRNN model uses very less computation to estimate the voltage magnitudes. Whereas the conventional methods uses iterative methods to obtain voltages. Hence the computation time of GRNN model will be much lesser than the conventional methods. With the high penetration of renewable energy resources in the distribution system, the load flow need to be carried out frequently to obtain information about generation requirement, reactive power support etc. Hence the proposed GRNN model can be widely used for voltage magnitude estimation of distribution system.

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