International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-8 Issue-2, July 2019

Voltage Profile Assessment in Distribution Substation using Generalized Regression Neural Network

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Abstract: – ***Power system stability is one of the major factors for the reliable operation of electric utilities. Factors resulting power system instability are the sudden increase in load or insufficient reactive power support. Efficient Voltage regulation methods enable the system to operate in a stable operating condition. Many methods reported in the literature for voltage stability assessment of the power system such as optimization method, continuation power flow method, Indices based method and Artificial Intelligence based methods. Several iterative methods are used for the solution of load flow problems. The major disadvantages of iterative methods are larger iteration and increase in convergence time which depends on size of the power system. This paper proposes new method for voltage profile assessment on distribution system using Generalized Regression Neural Network. The Power System Analysis Toolbox (PSAT) is used for Distribution power flow solution. The proposed method is tested using 52 buses, distribution system of Tirunelveli, Tamil Nadu India. The technical feasibility of the proposed method is verified by comparing the results of proposed method and PSAT***.

Index Terms: ***Generalized Regression Neural Network (GRNN), Voltage Stability, Distribution System Studies.***

I. INTRODUCTION

The electric power systems under went so many changes from its inception. The penetration of Distributed Energy Resources has many technical and commercial advantages. But the intermittent nature of renewable energy sources poses technical challenges to power system engineers. Sudden addition or loss of renewable energy generation will affect the stable operation of distribution system. It is necessary to continuously monitor the power system parameters. Power flow analysis is one of the important studies for planning and operation of power systems. It is used to calculate voltage, real power and reactive power flows and line losses for the given system. Different types of algorithms are proposed to solve the power flow studies of radial distribution system. Many works have been carried out for voltage instability problems based on conventional methods. [1] Aleksandar M. Stanković, and AndrijaT.Sarić proposed a method of dynamic voltage stability assessment for power systems with optimized topology. [2] Guo-yunCao, Luo-nan Chen and Kazuyuki Aihara suggested a method of saddle node bifurcation in Power System Voltage Stability Assessment Based on Branch Active Powers.[3] Han Wang and Sijie Chen suggested a stochastic response surface method for Power System Voltage Stability Evaluation Considering Renewable Energy with Correlated Variability's. [4]Denis HauAik suggested a Jacobian matrix method for Voltage Stability Assessment Using Equivalent Nodal Analysis. [5]Fengkai Hu, Kai Sun, Di Shi, Zhiwei Wang proposed an online measurement method for voltage stability assessment on load areas. [6] Bai Cui, Zhaoyu Wang proposed an improved coupled single-port method for Voltage stability assessment. [7] Tukaram Moger and Thukaram Dhadbanjan suggested a method of Fuzzy logic approach for reactive power coordination in grid connected wind farms to improve steady state voltage stability Literature survey shows that the conventional methods have very complex computation. The power system with renewable energy penetration requires faster estimation voltage magnitudes. This necessitates a method with less computational time and iteration count. A simple Artificial Intelligence based technique is proposed in this paper. The Proposed Generalized Regression Neural Network is used to calculate the voltage Profile with lesser inputs and lesser computation. The influential bus loads are the inputs to GRNN model and the voltage magnitudes are the outputs. The proposed GRNN model is developed using the data obtained from power flow studies conducted in PSAT. The proposed GRNN model is tested in 52 buses, 62 Transmission Lines, 51 loads Tirunelveli Distribution System.

II. PROPOSED METHOD

From the literature review it is inferred that the voltage magnitude assessment using the conventional power flow methods requires complex computations. Further the Artificial Intelligence based methods the number of inputs increases with system size. This paper proposes an Artificial Intelligence based method to compute voltage magnitudes with lesser computation and inputs. Generalized Regression Neural Network is used to estimate the voltage magnitudes of the distribution system. Power System Analysis Toolbox is used to obtain the power flow results of distribution system. In the AI based methods for voltage magnitude estimation, all the bus loads were given as inputs. This increases the data pattern size unnecessarily which increases the computation time.

Revised Manuscript Received on 30 July 2019.

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Hence in the proposed method only the influential bus loads will be used as inputs. The influential bus loads will be identified using the following procedure. Identify the buses for which voltage magnitudes have to be estimated. Hereafter these buses will be termed as chosen buses. Vary the real and reactive loads of any one of the buses say bus number 1, of test system by 20% from its base value. Run Power Flow analysis for the new data set. From the power flow results, check the bus voltages. If the voltage magnitudes of the chosen buses had significant change in their magnitude for the variation of a bus load, choose the bus 1 as influential bus. Repeat the procedure for remaining buses and identify influential bus loads. The data sets to train the GRNN model will be generated by changing the real and reactive power loads of influential buses. The procedure to obtain the data sets for training and testing the GRNN model is given in the following section.

Step1: Select a maximum load condition which causes no limit violation as base case.

Step2: Change the real and reactive loads of influential buses by multiplying the base case values with random numbers (preferably less than 1)

Step 3: Run power flow using PSAT and obtain the voltage magnitudes and check for no limit violations.

Step 4: The real power loads of influential buses are the inputs and the bus voltages are the outputs. This forms one data set. Generate load pattern by multiplying the real and reactive loads of each bus by random numbers.

Step5: Repeat the process and generate more number of data sets for training and testing the GRNN model.

The PSAT output and test results of two sample data set generation are presented in Table 1 and Table 2.

III. POWER FLOW ANALYSIS ON PSAT

PSAT MATLAB toolbox is used for electrical system analysis and control .PSAT consists of Power Flow, continuation power flow, optimal power flow, and small signal stability analysis and time domain simulation. All calculations can be done by graphical user interfaces (GUIs) and a Simulink-based library provides a user friendly tool for network design. There are many methods in PSAT to solve Power flow analysis such as Newton Raphson method, fast decoupled method and simple robust method. In this paper simple robust method is used for power flow solution. To calculate accurate power system analysis, PSAT provides various static and dynamic component models such as Power flow, Continuation power flow; optimal power flow; Small signal stability analysis; Time domain simulations, Phasor measurement unit (PMU) placement.

A. Algorithm for PSAT MATLAB Toolbox

Step1: Representation of Power system components.

Step2: Create the single line diagram of Distribution system using PSAT Simulink Library.

Step3: Enter all the Input data in the given file format. In PSAT, all the Inputs are in Per-unit.

Step 4: Save the single line diagram in MDL format.
Step 5: Load the data file.

Step 6: Solve the power flow analysis using simple robust method.

Step 7: Calculate Voltage magnitude, Phase angle, Real and reactive power generation, real and reactive power load and also total generation, total load, total losses

Step 8: Run the simulation.

Step 9: Print the results of Voltage magnitude, total generation, total load, total Losses.

IV. GENERALISED REGRESSION NEURAL NETWORK

General Regression Neural Network (GRNN) is a type of Probabilistic neural network model. The Probabilistic neural network requires only few training samples as input. GRNN gives accurate results even with lesser number of training data sets. GRNN calculates the output based on weights. GRNN has four layers such as input layer, pattern layer, summation layer and output layer. Each Layer has neurons with Training Parameter and its output. The main advantage of GRNN is high accuracy when compared to other methods.

A. GRNN model for Voltage magnitude estimation

Step 1: Select the training data sets in such a way, it covers all the possible operating conditions of the system

Step 2: The GRNN model is trained with Influential bus loads and total load as inputs and the corresponding bus voltages as output.

Step 3: GRNN model is developed in MATLAB/Simulink

Step 4: The GRNN model is tested with test data sets. Test data contains the influential bus loads. These bus loads were given as input to GRNN model and the bus voltages were obtained from GRNN model,

Step 5: Compare the bus voltages obtained from GRNN model and PSAT. The percentage error were calculated using the formula

$$\%Error = \frac{\{v(PSAT) - v(GRNN)\}}{v(PSAT)} * 100 \qquad (1)$$

V. TEST SYSTEM AND RESULTS

The proposed method is tested on 52 bus Tirunelveli, Tamil Nadu, India, distribution system.

The voltage magnitudes of buses 6 to 15 need to be estimated. The influential bus loads are identified as per the procedure explained in earlier section. The influential bus loads are16, 18, 21, 24,26,27,28, 31to 40, 42, 44 to 51. Load flows were conducted to obtain the data sets for training and testing of GRNN model. The GRNN model was developed using the training data sets. The influential bus loads from the test data were given to GRNN model and the voltage magnitudes were obtained. For a data set the voltage magnitudes were obtained by both PSAT and GRNN model. The voltage magnitudes obtained using GRNN were compared with PSAT values. The percentage error was calculated. From the test results it is inferred that the proposed GRNN model can estimate the voltage magnitudes with lesser computation and reasonably good accuracy. Hence the proposed method can be used for the estimation of voltage magnitudes of distribution system especially the system with more renewable energy source penetrations.

Fifteen data sets are generated and GRNN model is developed using the real power loads as inputs and voltage magnitudes as outputs. Here fifteen data sets are given as input for training the GRNN model. In GRNN model, the Influential bus loads and total load is given as Input. The following Fig.2 shows GRNN Model. The test result of one data set is presented in Table 3.

The - PSAT model-52 bus Tirunelveli Region Distribution Substation is shown in (Fig .1).

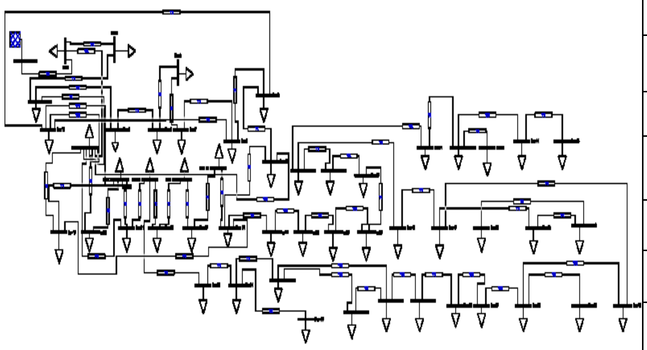

Fig. 1- PSAT Model-52 bus Tirunelveli Region Distribution Substation

Bus	Volt. Magnitude [p.u.]	Real P load [p.u.]	Reactive [p.u]	Bus	Volt. Magnitude [p.u.]	Real P load [p.u.]	Reactive [p.u.]
Bus0	1	0	0	Bus27	0.8646	0.05	0.02
Bus1	0.9054	0.025	0.01	Bus28	0.8880	0.05	0.02
Bus2	0.8826	0.025	0.01	Bus29	0.9151	0.05	0.02
Bus3	0.8819	0.025	0.01	Bus30	0.8995	0.025	0.01
Bus4	0.8794	0.025	0.01	Bus31	0.9257	0.025	0.01
Bus5	0.8759	0.025	0.01	Bus32	0.9558	0.025	0.01
Bus6	0.8726	0.05	0.02	Bus33	0.957	0.025	0.01
Bus7	0.8725	0.05	0.02	Bus34	0.9610	0.025	0.01
Bus8	0.8727	0.025	0.01	Bus35	0.9669	0.05	0.02
Bus9	0.8727	0.025	0.01	Bus36	0.9668	0.05	0.02
Bus10	0.8731	0.025	0.01	Bus37	0.9663	0.05	0.02
Bus11	0.8727	0.025	0.01	Bus38	0.9590	0.08	0.02
Bus12	0.8726	0.025	0.01	Bus39	0.9590	0.08	0.02
Bus13	0.8726	0.05	0.02	Bus 40	0.9267	0.014	0.006
Bus 14	0.8712	0.025	0.01	Bus41	0.9148	0.05	0.02
Bus15	0.8702	0.025	0.01	Bus42	0.9145	0.03	0.014
Bus 16	0.8709	0.025	0.01	Bus43	0.9145	0.015	0.007
Bus17	0.8707	0.05	0.02	Bus44	0.9145	0.03	0.014
Bus 18	0.8711	0.025	0.01	Bus45	0.9143	0.03	0.014
Bus19	0.8733	0.05	0.02	Bus46	0.9403	0.4	0.04
Bus20	0.8768	0.05	0.02	Bus47	0.9353	0.2	0.02
Bus21	0.8735	0.025	0.01	Bus48	0.9332	0.03	0.014
Bus22	0.8731	0.05	0.02	Bus49	0.9361	0.03	0.014
Bus23	0.8757	0.05	0.02	Bus50	0.9370	0.03	0.014
Bus24	0.8681	0.025	0.01	Bus51	0.9466	0.03	0.014
Bus25	0.8633	0.05	0.02				
Bus26	0.8603	0.05	0.02				

Table 1- Output of PSAT -52 Bus Tirunelveli Distribution Substation

Bus	Volt. Magnitude [p.u.]	Real P load [p.u.]	Reactive [p.u.]	Bus	Volt. Magnitude [p.u.]	Real Pload [p.u.]	Reactive [p.u.]
Bus6	0.8504	0.03	0.009	Bus6	0.9002	0.03	0.009
Bus7	0.8501	0.03	0.009	Bus7	0.9000	0.04	0.01
Bus8	0.8494	0.027	0.02	Bus8	0.8998	0.028	0.03
Bus9	0.8494	0.027	0.02	Bus9	0.8998	0.028	0.03
Bus10	0.85	0.024	0.009	Bus10	0.9002	0.023	0.008
Bus11	0.8492	0.026	0.02	Bus11	0.9	0.024	0.009
Bus12	0.8490	0.026	0.02	Bus12	0.9000	0.024	0.009
Bus13	0.8490	0.04	0.01	Bus13	0.9000	0.02	0.008
Bus 14	0.8470	0.026	0.02	Bus 14	0.8990	0.027	0.03
Bus15		0.024	0.009	Bus15		0.023	0.008
Bus26		0.04	0.01	Bus26		0.03	0.009
Bus27		0.04	0.01	Bus27		0.02	0.008
Bus28		0.06	0.03	Bus28		0.07	0.04
Bus31		0.024	0.009	Bus31		0.023	0.008
Bus32		0.026	0.02	Bus32		0.027	0.03
Bus33		0.024	0.009	Bus33		0.023	0.008
Bus34		0.026	0.02	Bus34		0.024	0.009
Bus35		0.04	0.01	Bus35		0.02	0.008
Bus36		0.04	0.01	Bus36		0.03	0.009
Bus37		0.06	0.03	Bus37		0.07	0.04
Bus38		0.09	0.03	Bus38		0.1	0.04
Bus39		0.07	0.01	Bus39		0.06	0.009
Bus 40		0.015	0.008	Bus 40		0.016	0.009
Bus42		0.02	0.013	Bus42		0.01	0.014
Bus44		0.04	0.015	Bus44		0.02	0.013
Bus45		0.02	0.013	Bus45		0.01	0.012
Bus46		0.3	0.03	Bus46		0.4	0.04
Bus47		0.3	0.03	Bus47		0.1	0.01
Bus48		0.02	0.013	Bus48		0.01	0.012
Bus49		0.02	0.013	Bus49		0.01	0.014
Bus50		0.05	0.016	Bus50		0.04	0.015
Bus51		0.01	0.014	Bus51		0.02	0.0

Table 2- Sample Data Set

BUS NO	VOLTAGE MAGNITUDE BY PSAT(p.u)	VOLTAGE MAGNITUDE BYGRNN(p.u)	%Error
Bus6	0.9072	0.8891	0.0181
Bus7	0.9073	0.8891	0.0182
Bus8	0.9086	0.8892	0.0182
Bus9	0.9087	0.8892	0.0194
Bus10	0.9090	0.8896	0.0194
Bus11	0.9089	0.8893	0.0196
Bus12	0.9091	0.8893	0.0198
Bus13	0.9091	0.8893	0.0198
Bus 14	0.9087	0.8884	0.0203
Bus15	0.9084	0.8878	0.0206

Table 3- Output comparison between PSAT and GRNN model

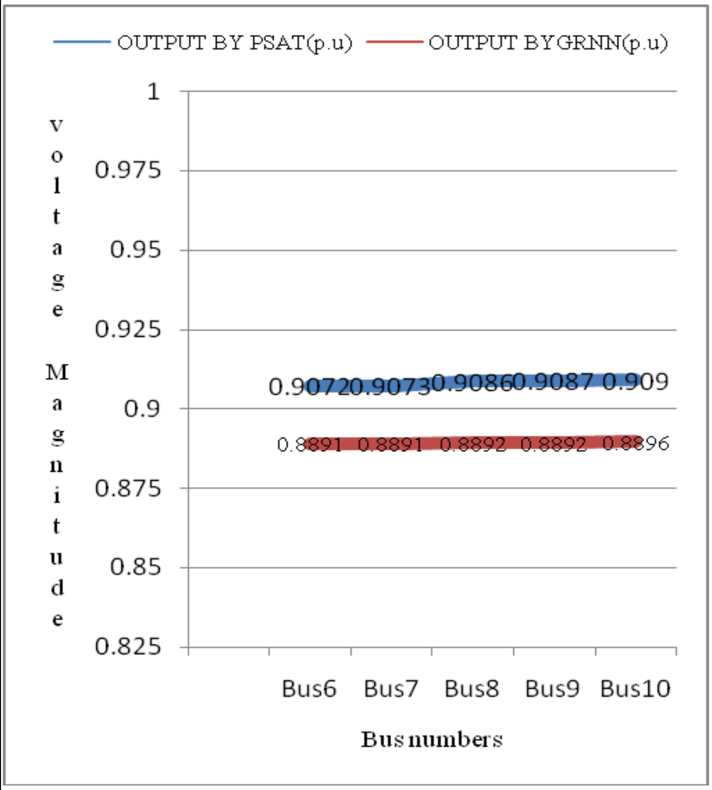

Fig 3: Voltage comparison between PSAT and GRNN

Retrieval Number: B3249078219/19©BEIESP
DOI: 10.35940/ijrte.B3249.078219
Journal Website: www.ijrte.org

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Blue Eyes Intelligence Engineering
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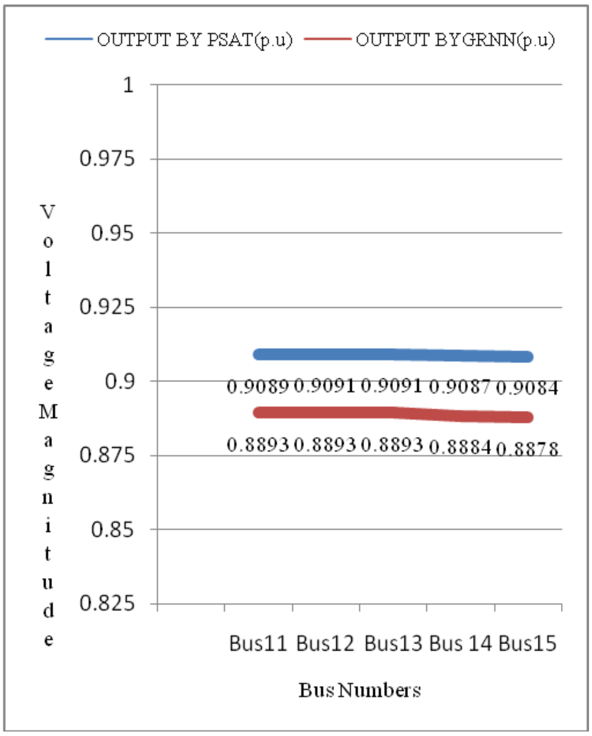

Fig 4: Voltage comparison between PSAT and GRNN

VI. CONCLUSION

This paper demonstrates the performance of both GRNN and PSAT for the voltage stability assessment with lesser inputs. The implementation of GRNN in MATLAB software gives best solution in faster speed and easy to use. The development of GRNN in MATLAB is to discover the best optimal results for voltage magnitude estimation. Here 15 set of data was used for training procedure and tested in PSAT and GRNN. In training data, the influential inputs are influential real power loads(buses 16,18,21,24,26,27,28,31 to 40,42,44 to 51) and the corresponding output voltages (buses 6 to 15)which is generated in PSAT are entered in training file. The training data sets are used in both PSAT and GRNN to show the performance of voltage profile assessment. The 15 data set is used to generate the GRNN. The computational time to generate GRNN model is **0.420308 seconds** and the CPU times of PSAT is **1.889 seconds**. The proposed GRNN model takes very less computation time to estimate the voltage magnitudes but in conventional methods, it takes iterative methods to solve the load flow problem. The computation time of GRNN model is lesser than other conventional methods. GRNN does not require any Iterative methods. Hence the proposed method can effectively be used for the estimation of voltage magnitudes of real time distribution systems.

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