Voltage State Estimation By ANNs with Reduction of PMUs

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Abstract. In this paper the estate estimation of voltage and phase of voltage has been presented. In this paper the PMU has been used to observe some part of power system and ANN (Artificial Neural Network) has been used to estimation. In this paper it is assumed that the power system is partly observable by PMUs and the network is not full observable. This method has been implemented on IEEE 14-Bus. The results show that this estimation is impossible and the error of estimation is negligible.

Key words

State Estimation, PMU, Incomplete Observability, Artificial Neural Network.

1. Introduction

Due to progress on Global Positioning System (GPS), the PMUs (Phasor Measurement Unit) become available and can be used to get data from different points of a power system. This data is necessary for the supervisory control applications or on-line states assessment of a large scale power system. PMUs are able to take the online phasor measurements. This simultaneous measurement is achieved with voltage and current waveforms sampled by GPS signals. The ability of simultaneous measurement of PMUs, improve the monitoring, control and in turn the security level of power networks [1].

In this paper, it is assumed that the power system is not fully observable. This situation may happen due to PMU failure or construction limits. In these states some buses are unobservable. In this paper the ANN has been used to estimate the voltage magnitude and voltage phase of unobservable buses. It is shown in [2] that the voltage magnitude and phase are the best parameters to the voltage stability assessment, so these parameters can be used to the voltage stability assessment. This method has been implemented on IEEE 14-Bus. The results show negligible error.

2. Estimation by ANN

In this paper, the ANN has been used to estimate the voltages of unobservable buses. The power network has been simulated by DIgSILENT software and the ANN has been carried out in MATLAB software. As it is mentioned before, this idea can be used when there is complete observability but one of PMUs or its communication system has failed.

The ANN should be trained by the results of the load flow analysis. The scenarios have been randomly selected for different load or generation levels, which are generated by using Mont-Carlo method. In this method, a random number (N) between 1 and N_b (the number of buses) is generated. This number determines the number of buses, which their parameters should be changed. If a bus is a PQ or PV bus, then in order to change its parameters, scenario 1 or 2 should be selected, respectively.

In the scenario 1, the load active power is randomly selected in the prespecified margin, as follows:

$$P_{L,i}^{PQ} \in \left[P_{L,i}^{\min} \quad P_{L,i}^{\max} \right] \tag{1}$$

In the scenario 2, one of the following three cases, is selected with equal probability, (i.e., 1/3):

Case 1: Only the load active power should be changed, as follows:

$$P_{L,i}^{PV} \in \left[P_{L,i}^{\min} \quad P_{L,i}^{\max} \right] \tag{2}$$

Case 2: Only the active power generation should be changed, as follows:

$$P_{G,i}^{PV} \in \left[P_{G,i}^{\min} \quad P_{G,i}^{\max} \right] \tag{3}$$

Case 3: Both, the bus load and generation should be changed by using the following constraints:

$$\begin{aligned} &P_{L,i}^{PV} \in \left[P_{L,i}^{\min} \quad P_{L,i}^{\max} \right] \\ &and \\ &P_{G,i}^{PV} \in \left[P_{G,i}^{\min} \quad P_{G,i}^{\max} \right] \end{aligned} \tag{4}$$

The ANN used in this paper has 13 nodes on the input and one hidden layer with 20 nodes. The Levenberg–Marquart back-propagation algorithm has been used to identify ANN parameters.

In this step, 1000 different load flow scenarios have been simulated by DIgSILENT. 900 of them have been selected to train the ANN, and 100 scenarios have been chosen to test the ANN. The error has been calculated for these 100 scenarios by the following equation:

$$Error(\%) = \frac{Actual\,Value - Estimated\,Value}{Actual\,Value} * 100$$

The maximum and the average values of error are calculated, to compare the different cases.

3. Installed PMU Number Reduction

In this section, the proposed algorithm has been applied to IEEE 14-Bus network.

A. IEEE 14-BUS Test System

It is shown in [3] that the IEEE 14-Bus system is observable by using 4 PMUs. To model the PMU failure, one of the PMUs should not be used. The candidate PMU has been selected by using the proposed index, named SORI. If the bus *i* is observed by n_i numbers of PMUs, then *System Observability Redundancy Index (SORI)* is expressed by the following equation:

$$SORI = \sum n_i$$

Based on this index, the PMU installed on bus 7 should be considered as a failed PMU. In t

his case, the bus 8 will be unobservable. But, the voltage of this bus can be estimated by the trained ANN.

Based on *SORI* index, the candidate bus can be selected and listed in Table-1.

Table-I: Eliminated PMUs in IEEE 14-Bus system

No. of eliminated PMUs	No. of PMUs	Installed on buses
0	4	2, 6, 7 and 9
1	3	2, 6 and 9

The error of the estimation of the bus 8 voltage magnitude (with 3 PMUs) is given in Table II and the error of estimation of the bus 8 voltage phase (with 3 PMUs) is given in Table III..

Table-II: Error of estimation of voltage magnitude of bus 8 (by using 3 PMUs).

	Error %
Maximum Error	0.0028
Average Error	$2.46 * 10^{-5}$

Table-III: Error of estimation of voltage phase of bus 8 (by using 3 PMUs).

	Error %
Maximum Error	0.0086
Average Error	7.93E-05

The errors represent the difference between the results calculated by ANN and simulated by DIgSILENT. Considering the Table-II and Table-III, it is obvious that the reduction of one PMU leads to a negligible error. It is clear that, the less the error, the more the cost.

As previously mentioned, there is a trade-off between the error of the estimation and the cost of the monitoring system. Therefore, considering an acceptable range of error, it is possible to reduce the number of installed PMUs.

4. Single Contingency Studies

In this section, it is assumed that the voltage of buses should be estimated by the proposed algorithm after occurrence of a single contingency. The IEEE 14-bus has been studied and the results have been given in Table-IV and Table-V.

Table-IV: Maximum error of voltage magnitude estimation of unobservable buses after occurrence of contingency in IEEE 14-bus system.

No. of installed PMUs	Maximum Error %	Average Error %
4	0	0
3	21.84	6.57

Table-V: Maximum error of voltage phase estimation of unobservable buses after occurrence of contingency in IEEE 14-bus system.

No. of installed PMUs	Maximum Error %	Average Error %
4	0	0
3	54.65	0.178

It can be seen in these tables that the errors are considerable and cannot be neglected. The main cause of this problem is the radial configuration of some parts of the network. In this case, the outage of one line can result in subnetworks without any generation (passive network). Therefore, the voltages of some buses are equal to zero.

Training with these types of data increase the nonlinearity of the problem and the wrong estimation probability by ANN.

This problem can be solved in a smart grid, which has sensors, like voltage transformers, for the detection of the outage of this type of transmission lines.

IEEE 14-bus test system has only one line with this condition, which is the line between bus 7 and bus 8. If a sensor, which can detect the line outage, would be installed on this line, then the results could be changed, as given in Table-VI and Table-VII.

Table-VI: Maximum error of voltage magnitude estimation of unobservable buses in IEEE 14-Bus smart grid

No. of installed PMUs	Maximum Error %	Average Error %
4	0	0
3	0.019	0.0035

Table-VII: Maximum error of voltage phase estimation of unobservable buses in IEEE 14-Bus smart grid

No. of installed PMUs	Maximum Error %	Average Error %
4	0	0
3	0.00054	7.93E-05

5. Conclusion

In this paper it has been shown that the reduction of installed PMUs and the application of ANNs for the estimation of unobservable buses increases errors in voltage magnitude and phase estimation, but decreases the cost of monitoring system. The system designer should find a trade-off between error and cost.

The proposed algorithm has been applied to IEEE 14-Bus test system. It is shown that for normal operation conditions, it is possible to reduce the number of installed PMUs, if there is an acceptable error range. But in case of single contingency, this solution does not have a good performance and the errors are unacceptable. By using voltage sensors, it is possible to change the test systems to smart grids. The voltages of unobservable buses of IEEE 14-Bus smart system can be estimated by ANNs with a good performance.

References

[1] B. Gou, "Generalized Integer Linear Programming Formulation for Optimal PMU Placement", IEEE Trans. on Power Systems, Vol. 23, No. 3, August 2008.

[2] D. Q. Zhou, U. D. Annakkage and A. D. Rajapakse, "Online Monitoring of Voltage Stability Margin Using an Artificial Neural Network" IEEE Trans. on Power System, Vol. 25, No. 3, August 2010.

[3] A. G. Phadke, “Synchronisedphasor measurements in power systems,” IEEE Comput. Applicat. Power, Vol. 6, No. 2, pp. 10–15, Apr. 1993.