A novel online monitoring system of frequency oscillations-based intelligence phasor measurement units

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ABSTRACT

In this paper, frequency oscillation has been present as it is an important issue in power systems, especially when it is joined to the new trend to use alternative energies as an energy source, as well as to be a big risk for the inter-connection of the modern electric power networks. Wind farm acts as alternative energy and connected to two buses on the Iraqi power system. Because the low-frequency oscillation monitoring needs be accurate and fast, the main objective is to propose a novel online monitoring system consisting of phasor measurement unit's (PMU) with artificial intelligence neural network (PMU-NN). The location of the phasor measurement units has been optimized using (graph-theoretic procedure algorithm) and the function for the artificial intelligence (NN) is radial basis function (RBFNN). The data information from phasor measurement units is the inputs to the artificial intelligence system then predictions are made Information on low-frequency oscillation (target). The MATLAB toolboxes (PSAT & NN) used to obtain results. Finally, from the results, the validity of the proposed (PMU-NN) system has been proven and tested on the Iraqi power grid (24 bus) in several cases and several places on the network and the comparison was made with the analysis model.

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1. INTRODUCTION

In modern electrical power systems, and with the development taking place in the world of industries that require ensuring the equipped capacity of these industries in terms of availability, quality, reliability, and protection, it has become imperative that this equipped capacity be monitored by an intelligent and rapid response system capable of predicting and giving very accurate data to ensure appropriate decisions are made in a failure occurs. The PMU's is most important devices used in electrical power systems network through which it is possible to evaluate any site for any event that occurred or will receive the network [1]–[3]. Previously, the case was evaluated without the need for a unit of measurement. But now, with the unit of measurement, the bus calculated as neighbors, as it makes all observations and measurements for both voltages and currents are available [4], [5]. In fact, in the major electrical power systems, all things are financially costly, with the installation of phasor measurement unit within the network devices, and because of its financial costs in terms of infrastructure and installation costs, and this is why major companies avoid installing it in all places [6], [7]. When alternative energies are used within the power system and represented by modern energy systems, the reaction of the power networks during event of a small breakdown fluctuating as if voltage regulators were used, which will reduce the risk of instability in power system [8], [9]. The main step to monitor oscillation is the power system electromechanical identification modes. We can divide the identification of technologies into two groups of methods, the first is modal analysis methods and the second is modal identification [10], [11]. Modal analysis methods are one of the greatest approaches for offline study, but for time-overwhelming and not performing well for very large systems. Modal identification methods of identification comprise analysis, pattern analysis meters, non-linear and non-fixed methods of analysis [12]. There is no size restriction nevertheless this requires some time field simulations to excite and differentiate all between the region's modes in the network [13]. Now that technology has advanced using everything necessary to make the power system a perfect system, therefore, the development of on line monitoring system has developed very important and useful to provide this goal [14], [15].

Finally, in this paper a new online monitoring system is built, (PMU-NN) proposed to achieve the objective of this paper, MATLAB toolboxes (PSAT and neural network) are used and tested on IRAQI power system (24 bus). The contributions of this paper as: i) Proposing a linear model of PMU as a valuable technique to get the input variables and then feed the neural network system to estimate the information of oscillations; ii) It is the first time to use computational methods such as integrated (PMU-NN) on the Iraqi power system as an online monitoring system; and iii) Providing a realistic integrated system PMU-NN within proficiency to be applied in big scale cases.

2. FORMULATION OF POWER SYSTEM INDICATORS

There are many indicators to expect the power systems state such as frequency oscillation, participating generation's units, mode index and localness. Power system indicators are measures used to assess the health and stability of a power system. Frequency is a critical power system indicator and deviations from the standard frequency can indicate potential problems. Participating generation units, mode index, and localness are additional indicators that can provide insight into the stability of the power system. These indicators help operators and engineers make informed decisions about managing and maintaining the power grid.

2.1. Damping index

As is expected in electrical power networks, the fluctuation that may be happens as a consequence of any sudden occasion is variable or that it is in varying degrees from one case to another according to the strength of the sudden event. The electric power systems monitoring system must be able to determine the strength or weakness of the impact value for that sudden event, for this the damping index (DI) is used [16] as in (1). The damping index rang between (0-1) if it was equal to 0 which means the system is very good damped if it is more than 0 to ≥ 1 which means well-damped, else it means poorly.

$$DI = \begin{cases} min\left(1, \left(\frac{\zeta}{\zeta_{\min,admissible}}\right)^{-n}\right) & \text{if } \zeta > \zeta_{\text{abs}}, if \zeta \geq \zeta_{\text{abs}}, \\ 1, & \end{cases} \quad (1)$$

Where: ζ :is the ratio of damping; $\zeta_{\min,admissible}$: is the min. acceptable damping limit; n is index norm; and ζ_{abs} is an absolute of the damping limit.

2.2. Mode index (MI)

The frequency ranges and the participating generation units, it is the points to show the differences between the local/inter-area modes. However, in the power grid system that have a large of buses the observation may difficult to define the mode if it is global or local. Local modes from 0.8 to 2 Hz include swinging the components at the generator concerning rest of power grid. Inter-area modes from 0.1 to 0.8 Hz are correlated with swing of machines in area of the power system against machines in other areas. MI ranks all the modes rendering to their localness [17], [18]. If the MI value is high that means it is a local mode or if it has a small value that is mean an inter-area mode. The MI of ith electromechanical mode is given in (2).

$$MI_i = \sum_1^{N_g}(1 - p_{ij})^n \quad (2)$$

Where: I_{th} = Electromechanical mode; N_{g} = generators No.; p_{ij} = normalized participation factor value; and n = clustering property.

3. PROPOSED METHODOLOGY (METHODS)

3.1. Optimal placements of phasor measurement units

Graph-theoretic procedure algorithm (GTP) [19], [20] has been used to reduce PMU devices that can connect to the Iraqi power network (24 bus) for full network observable. The details of (the 24 bus) Iraqi power system has been shown in Table 1. Figure 1 shows the algorithm of optimal placement. Figure 2 shows the single line diagram for an Iraqi power system with PMU installation and two wind farms are installations on 1-MUSP and 15-BGE4.

Table 1. Iraqi power system details (24 bus) with PMU bus location

Name	Bus NO	LINEs	Gen NO	Load NO
Iraqi power system	24	36	11	19
		PMU's NO.	PMU's Location	Time in (Sec.) Requirement
		8	4-BAJG, 10-HRTP, 12-MSL4, 13-BGW4, 16-BGN4, 18-BGC4, 20-KUT4, 21-QIM4	0.36341

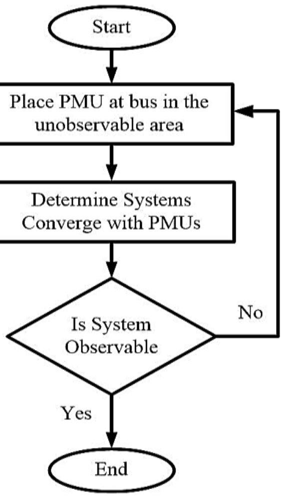

Figure 1. Flowchart of the GTPA PMU placement [21]–[23]

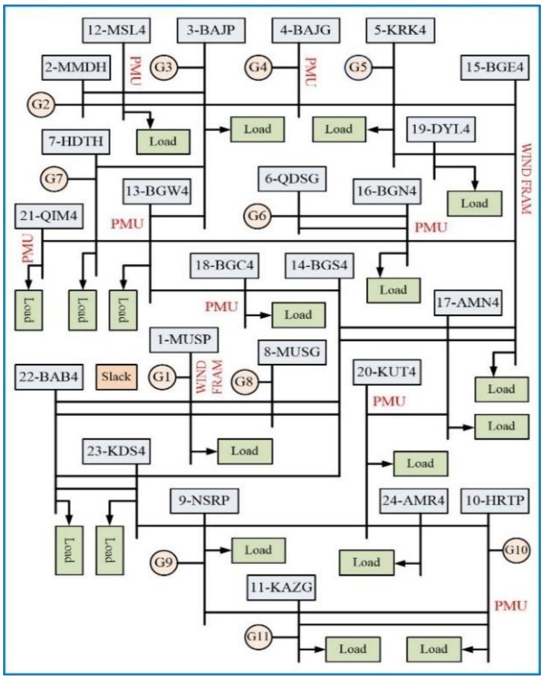

Figure 2. Iraqi power system single line diagram with PMU installation and wind farms [23]

3.2. Artificial intelligent neural network

The neural network acts as a process box where it manages inputs mathematically [24]. As it selects the mathematical operations in a way that suits the entry (variables) and works to create parallel relationships with all elements. The approximate values produced from these parallel relationships vary with precision. These results are obtained by training input variables. The artificial intelligence radial basis function

(RBFNN) has an input, hidden, and output layer (target). In this paper, the wide function used is the radial basis function (RBF) that produces the target ym (predicting or estimating the LFO information).

$$ym = exp\left|\frac{-\|X_i - U_j\|}{2\sigma^2 j}\right| \quad (3)$$

Where: $(X_i - U_j)$: square distance between the input feature vector (X_i) and center vector of (U_j) hidden node as measured by some norm for that radial basis function. Here in this paper, the hidden layer number is three of size 18 in RBFNN. The input vectors define as phase voltage values and angles as shown in Figure 3.

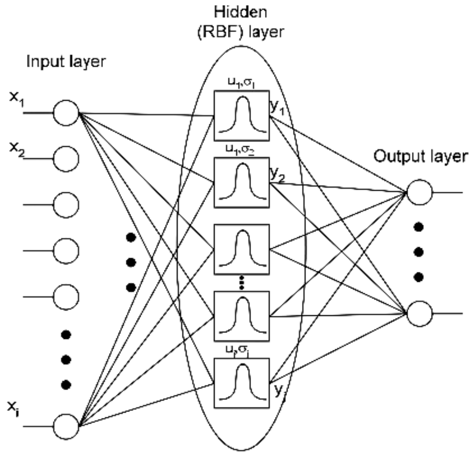

Figure 3. Radial basis function neural network (RBFNN) [4]

4. PMU_NN INTELLIGENT MONITORING SYSTEM

In this part of the paper, the phasor measurement units provide the input data, which includes both voltages and their angles [25], while the artificial intelligence (NN) works to treat the inputs as variables multiplied by weights and chooses a mathematical method and layers to extract the targets or the outputs and it is more than one output such as (MI, DR, and FI) mode index, damping ratio and frequency respectively, for each i_{th} mode, as shown in the Figure 4. Figure 5 shows the general algorithm for the proposed work (PMU-NN) based monitoring system.

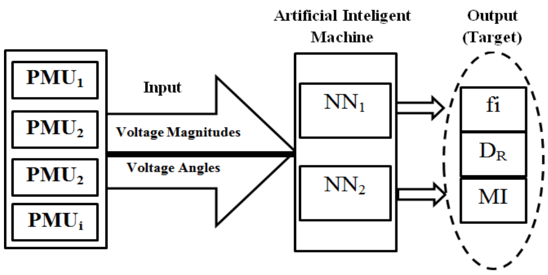

Figure 4. Block diagram for PMU-NN monitoring system

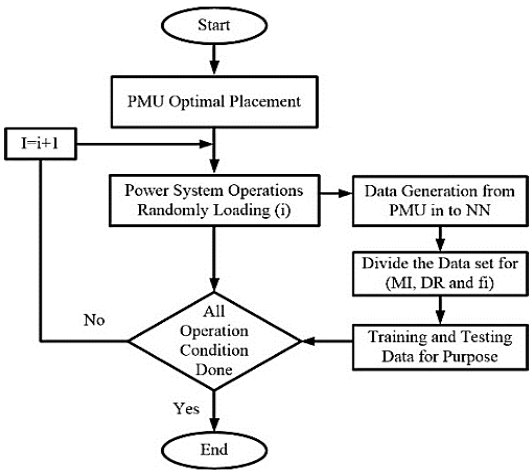

Figure 5. Flow chart of PMU-NN algorithm-based monitoring system

5. RESULTS AND DISCUSSION

The innovative technique in this paper has been tested on Iraqi network with (24 buses), (11 generators) and (17 lines) with the following features: The Iraqi power system high voltage 400 kV, popular base power of 100 MVA. A system total generation of 5835 MW and loading of 5800 MW were considered for the state of load flow analysis. Through the results, it was found that the method is effective. To generate the inputs that will feed the artificial intelligence, and about (variables system's bus voltage and the angle), multiple-layer intelligence operations were run as the inputs were calculated as the voltages and their angles for each bus except for a slack bus. The locations of the phasor measurement units have been improved, as in Table 1 about connecting two wind-mills on two buses, the first on Babylon high voltage and the second west of Baghdad high voltage. With the presence of air turbines, which were chosen randomly location leading to injected of harmonics into the electrical power system, which affects the value of the low frequency, and fluctuating it is contained in different values, which leads to instability the Iraqi electrical network. To generate a wide range for the system, we review the scenarios by randomly loading the system from 100% to 125%. During these operations, a process of outage line from the power network was entered. All about those scenarios, the values of our targets such as (MI, DR, and FI) are recorded.

Several cases for decoration vectors are 1500 cases, 1000 for the training of artificial intelligence function, and 500 of them are for testing purposes. After an outage of one line of the power grid lines, the data that should be inputted into the artificial intelligence network, which includes both voltages and their angles and coming through the phasor measurement units (8 * 4 * 3) 96 are used for each case. Because of the number of cases, which is a large number and mathematical process, it will be a matrix with many rows and columns, which if we want to analyze will require a long period for this. To reduce the number of variables in the required matrix, we use principal component analysis (PCA). To give a 90% reduction with an accuracy value of (0.995) and then the data was trained after the reduction using the artificial intelligence function (FFNN) to find the target or output of (MI, Fi, Dr) in real-time. The patterns are determined by whether it is (local from 0.8 Hz to 2 Hz) or (inter-area from 0.1 Hz to 0.8 Hz) by frequency value. Table 2 (see Appendix) show the values of each of (MIi, mode rank and mode type) were obtained through in (2) and using two methods, each of (PMU-ANN-based method and modal analysis), where they show the difference between the results varied in very few proportions. Nine patterns were obtained for each of the three cases. The first case 105% (an outage of line KDS-KUT): The loading rate is 105% and the line outage (KDS-KUT), as there are 7 cases for one and two who are within the Inter category and for both ways. The second case is 115% (an outage of line BAJG-KURK). The loading rate is 115% and the line outage (BAJG-KURK), as there are 7 cases for one and two who are in the inter category and for both ways. In a similar way for the third case, 125% (an outage of line HADYTH-BAGW) and different results for all cases. From Table 3 the values of (Freq.(fi)) and damping ratio (ζ i), where the values gotten from PMU-NN-based method was compared. From the results, it was found that the difference between them was very little and with very high accuracy to predict the objectives of them.

Through the results in Tables 2 and 3 (see Appendix), predictive results were obtained, which provides a good and accurate for selecting the type and method of control required in real-time to control the damping fluctuation at the frequency of the electric power grid. As is well known to those with specialization in electrical power systems, the behavior of the electrical model can change when overloading cases when the power system is dynamic. The oscillatory dynamics are obtained in real-time using the proposed method, regardless of device size and operating condition. An operator can concurrently figure out the main driver of that critical mode or most critical generator for the poorly damped situations, and can, therefore, apply effective helpful achievement and use of this approach in real-time also. The MSE (training data) is 0.0156 and MSE (test data) is 0.0172.

The MSE is employed as a performance function. From the result, the mean square error is very less for both the training and testing phase for the FFNN. The number of samples is 11000 samples. 10000 for training and 1000 for testing

6. CONCLUSION

In this paper, a new PMU-NN monitoring system for low-frequency oscillation is proposed, the linear valuable method is used to the optimal location of PMU to provide full observation of power system network buses and reduced the input data to make the convergence of the power system easy. The performance of the preparation was confirmed on large-scale power networks. Priority monitoring is given to the critical buses; the full information was provided from PMU as input data for FFNN. The artificial neural network aims to estimate the low-frequency oscillation, mode type, model index, and damping ratio. From the results the proposed method proved can work with high precision in off-line and real-time. The new method tested on the Iraqi power system high voltage (400 KV) by using MATLAB package toolboxes and compared with another method is modal analysis.

APPENDIX

Table 2. Different results of mode index and mode rank for model analysis and PMU_NN method for Iraqi power system (24 bus)

Scenario number	Loading (%)	Modal analysis				PMU-ANN-based Method		
		Mode No.	M_{Ii}	Mode rank	Type of mode	M_{Ii}	Mode rank	Type of mode
350 (Case I)	105% (Outage of line KDS-KUT)	1	7.263	1	Locally	7.2843	1	Locally
		2	6.7441	3	Locally	6.7654	3	Locally
		3	6.6123	4	Locally	6.6336	4	Locally
		4	6.8278	2	Locally	6.8491	2	Locally
		5	2.9075	7	Locally	2.9288	7	Locally
		6	5.1669	5	Locally	5.1882	5	Locally
		7	3.985	6	Locally	4.0063	6	Locally
		8	1.0301	9	(Inter-Area)	1.0514	9	(Inter-Area)
		9	1.0452	8	(Inter-Area)	1.0665	8	(Inter-Area)
		10	1.0202	10	(Inter-Area)	1.0211	10	(Inter-Area)
750 (Case II)	115% (Outage of line BAJG-KURK)	1	7.3036	1	Locally	7.3236	1	Locally
		2	6.5674	3	Locally	6.5874	3	Locally
		3	6.6188	2	Locally	6.6388	2	Locally
		4	4.2785	6	Locally	4.2985	6	Locally
		5	5.163	4	Locally	5.183	4	Locally
		6	3.8456	7	Locally	3.8656	7	Locally
		7	4.8868	5	Locally	4.9068	5	Locally
		8	0.9996	8	(Inter-Area)	1.0196	8	(Inter-Area)
		9	0.9965	9	(Inter-Area)	1.0165	9	(Inter-Area)
		10	0.9887	10	(Inter-Area)	0.9922	10	(Inter-Area)
1400 (Case III)	125% (Outage of line HADYTH-BAGW)	1	6.9912	1	Locally	7.4012	1	Locally
		2	6.3426	2	Locally	6.7526	2	Locally
		3	6.1593	3	Locally	6.5693	3	Locally
		4	4.0041	7	Locally	4.4141	7	Locally
		5	5.1446	4	Locally	5.5546	4	Locally
		6	4.8924	5	Locally	5.3024	5	Locally
		7	4.6537	6	Locally	5.0637	6	Locally
		8	1.008	9	(Inter-Area)	1.418	9	(Inter-Area)
		9	1.018	8	(Inter-Area)	1.428	8	(Inter-Area)
		10	1.007	10	(Inter-Area)	0.9936	10	(Inter-Area)

Table 3. Different values for (frequency, damping ratio and DI) of model analysis and PMU_NN method for Iraqi power system (24 bus)

Scenario number	Loading (%)	Mode No.	Modal analysis			PMU-ANN based method		
			Freq.	Damping ratio	Damping index	Freq.	Damping ratio	Damping index
350 (Case I)	105% (Outage of line KDS-KUT)	1	1.688	0.071	Poorly	1.6901	0.0742	Poorly
		2	1.5221	0.0652	Poorly	1.5501	0.0658	Poorly
		3	1.3672	0.0723	Poorly	1.3887	0.0732	Poorly
		4	1.3044	0.0765	Poorly	1.3673	0.0761	Poorly
		5	1.2012	0.0881	Poorly	1.2108	0.0877	Poorly
		6	1.0298	0.0863	Poorly	1.0293	0.0861	Poorly
		7	0.9612	0.149	Poorly	0.9379	0.0993	Poorly
		8	0.7594	0.4335	Poorly	0.7332	0.4271	Poorly
		9	0.6591	0.3998	Poorly	0.6461	0.3887	Poorly
		10	0.7903	0.3852	Poorly	0.7863	0.4015	Poorly
750 (Case II)	115% (Outage of line BAJG-KURK)	1	1.7725	0.0794	Poorly	1.781	0.0758	Poorly
		2	1.572	0.067	Poorly	1.5618	0.0615	Poorly
		3	1.3943	0.0685	Poorly	1.419	0.0844	Poorly
		4	1.3925	0.0666	Poorly	1.3801	0.0639	Poorly
		5	1.2164	0. 0574	Poorly	1.2915	0.0911	Poorly
		6	1.0023	0.0899	Poorly	1.006	0.0869	Poorly
		7	0.9316	0.0912	Poorly	0.9458	0.0859	Poorly
		8	0.7903	0.3852	Poorly	0.7863	0.4015	Poorly
		9	0.7133	0.3961	Poorly	0.7001	0.4006	Poorly
		10	0.9692	0.179	Poorly	0.9379	0.0993	Poorly
1400 (Case III)	125% (Outage of line HADYTH-BAGW)	1	1.7695	0.0801	Poorly	1.7692	0.0822	Poorly
		2	1.5615	0.0620	Poorly	1.5626	0.0627	Poorly
		3	1.3937	0.0855	Poorly	1.3872	0.0861	Poorly
		4	1.2833	0.0630	Poorly	1.2825	0.068	Poorly

Table 3. Different values for (frequency, damping ratio and DI) of model analysis and PMU_NN method for Iraqi power system (24 bus) (continue)

Scenario number	Loading (%)	Mode No.	Modal analysis Freq.	Damping ratio	Damping index	PMU-ANN based method Freq.	Damping ratio	Damping index
1400 (Case III)	125% (Outage of line HADYTH-BAGW)	5	1.2111	0.102	Poorly	1.1893	0.1018	Poorly
		6	1.0548	0.0741	Poorly	1.0632	0.0758	Poorly
		7	0.9311	0.0896	Poorly	0.9385	0.0906	Poorly
		8	0.7036	0.0472	Poorly	0.6808	0.0424	Poorly
		9	0.7011	0.0422	Poorly	0.6900	0.0414	Poorly
		10	0.6581	0.3798	Poorly	0.6431	0.3897	Poorly

REFERENCES

[1] D. I. Kim, A. White, and Y. J. Shin, “PMU-Based event localization technique for wide-area power system,” *IEEE Transactions on Power Systems*, vol. 33, no. 6, pp. 5875–5883, 2018, doi: 10.1109/TPWRS.2018.2824851.

[2] S. S. Mousavi-Seyedi, F. Aminifar, M. R. Rezaei, and R. Hasani, “Optimal fault location algorithm for series-compensated transmission lines based on PMU data,” *Smart Grid Conference, SGC 2015*, pp. 105–109, 2017, doi: 10.1109/SGC.2015.7857418.

[3] H. I. Hussein and A. M. Ghadhban, “A hybrid model for state estimation prediction composed of neural network and PSO algorithm for Iraqi national super grid system,” *1st International Scientific Conference of Engineering Sciences - 3rd Scientific Conference of Engineering Science, ISCES 2018 - Proceedings*, vol. 2018-Janua, pp. 50–55, 2018, doi: 10.1109/ISCES.2018.8340527.

[4] Y. Tang, F. Li, C. Zheng, Q. Wang, and Y. Wu, “PMU measurement-based intelligent strategy for power system controlled islanding,” *Energies*, vol. 11, no. 1, 2018, doi: 10.3390/en11010143.

[5] P. K. Ghosh, S. Chatterjee, and B. K. S. Roy, “Optimal PMU placement solution: Graph theory and MCDM-based approach,” *IET Generation, Transmission and Distribution*, vol. 11, no. 13, pp. 3371–3380, 2017, doi: 10.1049/iet-gtd.2017.0155.

[6] D. Dua, S. Dambhare, R. K. Gajbhiye, and S. A. Soman, “Optimal multistage scheduling of PMU placement: An ILP approach,” *IEEE Transactions on Power Delivery*, vol. 23, no. 4, pp. 1812–1820, 2008, doi: 10.1109/TPWRD.2008.919046.

[7] C. D. Patel, T. K. Tailor, S. K. Shukla, S. Shah, and S. N. Jani, “Steiner Tree-Based Design of Communication Infrastructure With Co-Optimizing the PMU Placement for Economical Design of WAMS,” *IEEE Transactions on Instrumentation and Measurement*, vol. 71, 2022, doi: 10.1109/TIM.2022.3179510.

[8] P. Kundur, *Power System Stability and Control*. CRC Press, 1994.

[9] M. H. Velayati, N. Amjady, and S. A. Hosseini, “Prediction of Generators’ Participation Factors and Oscillation Types for Dominant Oscillatory Modes of Power System,” *Electric Power Components and Systems*, vol. 43, no. 15, pp. 1727–1740, 2015, doi: 10.1080/15325008.2015.1057779.

[10] I. Tyuryukanov, M. Popov, M. A. M. M. Van Der Meijden, and V. Terzija, “Slow Coherency Identification and Power System Dynamic Model Reduction by Using Orthogonal Structure of Electromechanical Eigenvectors,” *IEEE Transactions on Power Systems*, vol. 36, no. 2, pp. 1482–1492, 2021, doi: 10.1109/TPWRS.2020.3009628.

[11] H. Huang, Z. Xu, and W. Hua, “Estimation of interarea modes in large power systems,” *International Journal of Electrical Power and Energy Systems*, vol. 53, no. 1, pp. 196–208, 2013, doi: 10.1016/j.ijepes.2013.04.016.

[12] M. S. Hasan, G. A. Salman, and H. I. Hussein, “Prototype of implementation SVPWM inverter in RTI with V/F control based reluctance machines application,” *International Review of Electrical Engineering*, vol. 13, no. 3, pp. 178–184, 2018, doi: 10.15866/iree.v13i3.14738.

[13] A. G. Phadke, “Synchronized phasor measurements in power systems,” *IEEE Computer Applications in Power*, vol. 6, no. 2, pp. 10–15, Apr. 1993, doi: 10.1109/67.207465.

[14] J. De La Ree, V. Centeno, J. S. Thorp, and A. G. Phadke, “Synchronized phasor measurement applications in power systems,” *IEEE Transactions on Smart Grid*, vol. 1, no. 1, pp. 20–27, 2010, doi: 10.1109/TSG.2010.2044815.

[15] U. Kerin, N. T. Trinh, E. Lerch, and G. Bizjak, “Small signal security index for contingency classification in dynamic security assessment,” *2011 IEEE PES Trondheim PowerTech: The Power of Technology for a Sustainable Society, POWERTECH 2011*, 2011, doi: 10.1109/PTC.2011.6019398.

[16] A. N. Abdullah, A. M. Ghadhban, H. S. Hameed, and H. I. Hussein, “Enhancement the stability of power system using optimal location of FACTS devices,” *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 18, no. 2, pp. 648–655, 2020, doi: 10.11591/ijeecs.v18.i2.pp648-655.

[17] A. K. Gupta, K. Verma, and K. R. Niazi, “Wide-area PMU-ANN based monitoring of low frequency oscillations in a wind integrated power system,” *India International Conference on Power Electronics, IICPE*, vol. 2018-Decem, 2018, doi: 10.1109/IICPE.2018.8709466.

[18] W. Li, D. Deka, M. Chertkov, and M. Wang, “Real-Time Faulted Line Localization and PMU Placement in Power Systems Through Convolutional Neural Networks,” *IEEE Transactions on Power Systems*, vol. 34, no. 6, pp. 4640–4651, Nov. 2019, doi: 10.1109/TPWRS.2019.2917794.

[19] F. Milano, “PSAT: Power System Analysis Toolbox, Documentation for PSAT version 1.0.0.” 2002. [Online]. Available:.http://www.uclm.es/area/gsee/Web/Federico.

[20] H. I. Hussein, “Neural network controller based dstatcom for voltage sag mitigation and power quality issue,” *International Journal of Engineering and Technology*, vol. 8, no. 1, pp. 405–420, 2016.

[21] M. Ghamsari-Yazdel, M. Esmaili, F. Aminifar, P. Gupta, A. Pal, and H. Shayanfar, “Incorporation of Controlled Islanding Scenarios and Complex Substations in Optimal WAMS Design,” *IEEE Transactions on Power Systems*, vol. 34, no. 5, pp. 3408–3416, 2019, doi: 10.1109/TPWRS.2019.2901748.

[22] H. Mohammadi and M. Dehghani, “PMU based voltage security assessment of power systems exploiting principal component analysis and decision trees,” *International Journal of Electrical Power and Energy Systems*, vol. 64, pp. 655–663, 2015, doi: 10.1016/j.ijepes.2014.07.077.

[23] I. Ibrahim Ali and M. Nasser Mohsen, "Enhancement Voltage Stability of the Iraqi Power Grid Using Shunt FACTs Devices," *Engineering and Technology Journal*, vol. 34, no. 13, pp. 2527–2550, 2016, doi: 10.30684/etj.34.13a.15.

[24] H. I. Hussein, G. A. Salman, and A. M. Ghadban, "Employment of PSO algorithm to improve the neural network technique for radial distribution system state estimation," *International Journal on Smart Sensing and Intelligent Systems*, vol. 12, no. 1, pp. 1–10, 2019, doi: 10.21307/ijssis-2019-005.

[25] J. Björk, K. H. Johansson, and L. Harnefors, "Fundamental Performance Limitations in Utilizing HVDC to Damp Interarea Modes," *IEEE Transactions on Power Systems*, vol. 34, no. 2, pp. 1095–1104, 2019, doi: 10.1109/TPWRS.2018.2876554.

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