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Identification of Coherent Generators for Dynamic Equivalent Studies- A Review

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Abstract— The structure of a modern power system is becoming more and more complex due to large interconnections of the network elements. This has posed a lot of challenges in providing a quick solution to power system problems and has been a growing concern to power system researchers, utilities and engineers in recent times. One of such problems which require quick solution is the identification of coherent generators for dynamic equivalence study in power systems. In solving this problem, various approaches have been proposed in the open literature and have been documented. This paper, therefore, provides a comprehensive review of the existing approaches for providing solution to the identification of the generators that swing together after the system has been subjected to a fault. The merits and the demerits of some of the reviewed techniques are also presented.

Index Terms— Clustering, Coherency, Dynamic equivalence, Dynamic modelling, Transient Stability.

1 Introduction

THe study of the complex power system dynamics requires modelling of the external system using dynamic in order to speed up the solution and consequently reduces the size of the problem required to be solved [1]. One good technique of doing this is by identifying the coherent generators within the external system [2]–[5]. The coherent generators can simply be referred to as the network generators having a similar waveform as well as rotor angle and can easily be represented by a single equivalent generator. In dynamic equivalent calculations, one main important task is the generator coherency identification [2]–[7]. The study of the generator coherency identification among the network generators has a significant applications in the control and operation of power systems [8]–[11]. The main objective of coherent generator study can be related to the study of the generator response, which is obtained by carrying out the time domain simulations, when the system is subjected to various perturbations [8], [12]–[15].

Studying the generator coherency in power systems involves determine the coherent structure of the network component through effective monitoring of the deviations in the rotor angle [16]. Furthermore, modern power system has been generally stressed. Consequently, for an effective preventive measure to be provided under this stressed condition, identification of coherent generators is of paramount importance [3], [17]–[19].

The approaches for classifying generator coherency can generally be categorized into two. The first approach is the Model Reduction-Based Method (MRBM). In MRBM, the eigenvalues and eigenvectors of the network are usually computed for the system analysis. A good example of this is demonstrated by Ramaswamy et al. (1997) in [16], where a synchronic modal equivalencing (SME), for preserving the dynamic equivalence of the network structure, is proposed. The second category of the methods are based on the perturbation in the system. This approach uses time domain simulations for determining the group of the generator coherency. This approach has been well applied and various methodology have been deployed in solving the problem. For instance, rotor trajectory index is proposed by Verma and Niazi (2013) in [2], , Fourier spectrum-based method by Lei et al. (2002) in [7], Fast Fourier dominant interarea mode by Jonsson et al. (2004) in [20]. Other methods include Principal Component Analysis (PCA) [21], Independent Component Analysis (ICA) [15], Hierarchical Clustering-based methods [14], [22], wavelet algorithm [23], Hilbert– Huang Transform (HHT) [13]. As a result of the variation in the level of generator and load (nongenerating) buses coherency buses, most of the techniques proposed in the literature are not suitable for all system applications, which include dynamic equivalent schemes, remedial action schemes, system protection schemes, controlled islanding schemes etc. Though, this may be varied for various disturbances occuring at different parts and conditions of the system, the real time transient stability assessment is the most appropriate method for predicting the network stability status. This real time assessment can easily be carried out by considering the behavior of the generator operating under a perturbed condition. Various technicques have benn deployed for this assessment in the open literature.

In this paper, various existing approaches for identifying the coherent generators within power systems are comprehensively reviewed. The new direction through which the identification could be carried out are also revisited in this paper.

2 Review of the Existing Studies on Coherent Generators Identification

Significant contributions have been made using model reduction-based methodology. This concept is based on the determination of the eigenvalues and eigenvectors of the system. For instance, Verdejo et al. (2014) in [9] presented an approach based on the modal analysis. The eigenvalues are represented by the oscillation modes of the system. These are obtained by linearizing the nonlinear expressions, which are used to model the behavior of the network. The inter-area modes are determined, which is then used to identify the network coherent groups. The authors of [24] presented a novel generalized technique, which can beused to define generator coherency determined by the coherency within the low-frequency inter-area modes. The spectrum analysis, due to the variations in the generator velocity, is used to determine the coherent generators based on the random load changes, which assumes distributed disturbance in the network. In refrence [8], an alternative approach of Transient Severity Index (TSI), for identifying coherent generators, is suggested. The effectiveness of this approach is tested using standard IEEE 39-bus of New England network. The results obtained based on the TSI are then used to construct a classifier based on the supervised learning. This approach uses the support vector machine (SVM) for carrying out the severity ranking of the network generators. These are then classified into vulnerable and non-vulnerable generators. The results show that the STI and the supervised learning-based methods align well with one another and with the ones published in the literature. Furthermore, a fuzzy clustering-based method for coherent groups recognition is proposed in [1]. The Fuzzy Similarity Matrix (FSM) is formulated using maximum-minimum algorithm and tested using the EPRI-36 bus network of PSASP. Although, the results obtained compared well with that obtained using time simulations method compared to A-K method, the proposed method identified coherent generator groups in quickly. A new approach for identifying the groups of coherent generators in a large large power system is proposed method in reference [25]. Two basic concepts are adopted in this method. First, the approach is based on two coherency criteria, which are formulated using the time response of the linearized model of power systems. Second approach solely depends on the application of Fuzzy C-Means clustering algorithm. The study also presented a new method for dynamic equivalence construction in power system. The proposed approach is tested using two different networks. The results obtained showed that the proposed approach is suitable for determining the group of generator coherency as well as in constructing of the dynamic equivalent of power network. In [26], a new method for identifying the group of generators that are coherent based on synchronization coefficients. The method applied a coherency criterion, which is based on the weighted complete graph model that presents the relationship between the integrity of the grid connections and the synchronization coefficient. The applicability of the method is tested using the standard IEEE 39-bus network. The results obtained revealed that the proposed approach is effective, simple and identifies the group of coherent generators quickly in power systems. More recently, as a result of the frequent vvoltage collapse experienced by many power grids, application of generator coherence identification for controlling network islanding is proposed by the authors of reference [4]. The approach is explored to determine the optimal cut-set to maintain the transient stability of the post-islanding power networks. The approach presented uses phasor measurement unit (PMU) data and dynamic time warping (DTW). The results obtained from the identification of coherency are then applied cluster the nongenerator buses based on the spectral clustering such that the power flow distruption is drastically minimized. The method is tested using the standard IEEE 39-bus system as well as WECC 179-bus system. It is shown that the approach is suitable for identifying the coherent group of generators within power systems. In reference [27], the application of a supervised learning-based model, for identifying coherent generators, is presented by the authors. The rotor angle, as well as predicting the transient stability status of the network, following a large distrubance, is predicted. Consequently, the coherent group of generators are identified based on the support vector machines, which is also proposed by the authors. The effectiveness of the method is tested on IEEE-39 bus test system. The real time state of the generator as well as the generator synchronism state are then determined.

3 Challenges with the Existing Approaches

Based on the foregoing, various approaches for identifying the coherent group of generators within the power systems have been holistically reviewed. Alhough, significant contributions have been recorded based on these methods, there exists some bothlenecks associated with these approaches. Some of these approaches are formulated as optimization problems while some employed meta-heuristic-based approaches. In solving the optimization-based problems, iterative procedures are required which could be time-consuming. Another challenge with this approach is the premature convergence; local optimal solution could be obtained instead of global optimal solution. This affect the accuracy of the solution significantly and hence not well suitable for a large-sized practical power system. Also, the computational time could be enormous and therefore affects the size of the memory required for the computations. This is also applicable to the meta-heuristic-based methods. Large computer space is usually required for the computations.

4 Suggested approach for Solving the Problem

In tackling the above-mentioned challenges, a non-iterative-based approach is suggested in this study. The approach is based on the structural interconnections of the network elements and the relative electrical distances between the network. This approach has been applied to solve various power system problems in the literature [28]–[31]. However, its application to identifying the coherent group of network generators has not been investigated. Advantages of this approach are as follows: it does not require a slack bus for its computations, it provides solution to the problem faster (in just a computational time) as it does not involve iteration, it saves time and does not require a large memory for storing the computations. Some of the problems, which this structura- based approach has been used to provide effective solution to loss allocation problem [29], identifying suitable location for TCSC placement in power systems to enhance the voltage profile as well as reduces the network losses [30], identification of critical buses and weaktransmission lines [28], etc. It is therefore, believed that the benefits derived in this new approach could be effectively explored to identify coherent generators within power system in a more effective manner.

4 Conclusion

In this paper, a comprehensive review of the existing studies for identifying coherent generators are presented. Various techniques in used for resolving this issue are presented. The merits as well as the demerits of each method are presented. The study also profer useful solution by suggesting a non-iterative-based procedure, which reduces the computational time without sacrificing the results accuracy and reliability. This study, therefore, serves as a good signal through, which new methods for identifying coherent generators for dynamic equivalencing in power systems, could be provided. This will also be helpful to power system operators and planners in determining the suitability of the methods for practical applications.

References

[1] T. Liu, J. Wen, X. Liu, and X. Li, "A fuzzy clustering method for coherent generator groups identification based on A-K," *1st Int. Conf. Sustain. Power Gener. Supply, SUPERGEN '09*, pp. 1–4, 2009.

[2] K. Verma and K. Niazi, "A coherency based generator rescheduling for preventive control of transient stability in power systems," *Int. J. Electr. Power Energy Syst.*, vol. 45, no. 1, pp. 10–18, 2013.

[3] S. Chittora and S. N. Singh, "Coherency based dynamic equivalencing of electric power system," *2014 18th Natl. Power Syst. Conf. NPSC 2014*, 2015.

[4] H. U. Banna *et al.*, "Online coherence identification using dynamic time warping for controlled islanding," *J. Mod. Power Syst. Clean Energy*, vol. 7, no. 1, pp. 38–54, 2019.

[5] E. Asumingfrimpong, "Prediction of Transient Stability Status and Coherant Generator Groups," no. August, pp. 46–56, 2015.

[6] E. J. S. Pires de Souza, "Identification of coherent generators considering the electrical proximity for drastic dynamic equivalents," *Electr. Power Syst. Res.*, vol. 78, no. 7, pp. 1169–1174, 2008.

[7] and O. R. X. Lei, D. Povh, "Industrial approaches for dynamic equivalents of large power systems," in *Proceedings of the 2002 IEEE Power Engineering Society Winter Meeting*, pp. 1036–1042.

[8] B. P. Soni, A. Saxena, V. Gupta, and S. L. Surana, "Assessment of Transient Stability through Coherent Machine Identification by Using Least-Square Support Vector Machine," *Model. Simul. Eng.*, vol. 2018, 2018.

[9] H. Verdejo, G. Montes, and G. Olguín, "Identification of coherent machines using modal analysis for the reduction of multimachine systems," *IEEE Lat. Am. Trans.*, vol. 12, no. 3, pp. 416–422, 2014.

[10] H. H. Wilfert, K. Voigtländer, and I. Erlich, "Dynamic coherency identification of generators using self-organising feature maps," *Control Eng. Pract.*, vol. 9, no. 7, pp. 769–775, 2001.

[11] R. S. Rashedur and H. Yeakub, "A New and Simple Approach to Coherency Identification for Multi-Machine Power System," vol. 3, no. 10, pp. 102–107, 2012.

[12] K. L. Lo, Z. Z. Qi, and D. Xiao, "Identification of coherent generators by spectrum analysis," *IEE Proc. Gener. Transm. Distrib.*, vol. 142, no. 4, pp. 367–371, 1995.

[13] N. Senroy, "Generator coherency using the Hilbert–Huang transform," *IEEE Trans. Power Syst.*, vol. 23, no. 4, pp. 1701–1708, 2008.

[14] and A. S. M. Davodi, H. Modares, E. Reihani, M. Davodi, "Coherency approach by hybrid PSO, K-means clustering method in power system," in *2008 IEEE 2nd International Power and Energy Conference, (PECon 2008)*, pp. 1203–1207.

[15] M. A. and B. C. Pal, "Coherency identification in inter- connected power system–an independent component analysis approach," *IEEE Trans. Power Syst.*, vol. 28, no. 2, pp. 1747–1755, 2013.

[16] and B. C. L. G. N. Ramaswamy, C. Evrard, G. C. Verghese, O. Fillatre, "Extensions, simplifications, and tests of synchronic modal equivalencing (SME)," *IEEE Trans. Power Syst.*, vol. 12, no. 2, pp. 896–905, 1997.

[17] F. Jabari, H. Seyedi, and S. N. Ravadanegh, "Online aggregation of coherent generators based on electrical parameters of synchronous generators," *30th Power Syst. Conf. PSC 2015*, no. November, pp. 8–13, 2017.

[18] G. Cai, J. Zhang, D. Yang, and K. W. Chan, "The identification of coherent generator groups via EMD and SSI," *2010 Int. Conf. Power Syst. Technol. Technol. Innov. Mak. Power Grid Smarter, POWERCON2010*, vol. 1, no. 1, pp. 7–11, 2010.

[19] F. I. Izuegbunam, E. C. Okafor, and S. O. E. Ogbogu, "Coherent generator based Transient Stability Analysis of the 16 machines , 330KV igeria Power System," vol. 2, no. 3, pp. 456–461, 2011.

[20] and J. D. M. Jonsson, M. Begovic, "A new method suitable for real-time generator coherency determination," *IEEE Transactions Power Syst.*, vol. 19, no. 3, pp. 1473–1482, 2004.

[21] and B. C. P. K. K. Anaparthi, B. Chaudhuri, N. F. Thornhill, "Coherency identification in power systems through principal component analysis," *IEEE Trans. Power Syst.*, vol. 20, no. 3, pp. 1658–1660, 2005.

[22] H. A. A. and R. Dunn, "Determination of coherent clusters in a multi-machine power system based on wide-area signal measurements," in *2010 IEEE Power and Energy Society General Meeting, pp. , IEEE, Minne- apolis*, pp. 1–8.

[23] and M. K. S. Avdakovic, E. Becirovic, A. Nuhanovic, "Generator coherency using the wavelet phase difference approach," *IEEE Trans. Power Syst.*, vol. 29, no. 1, pp. 271–278, 2014.

[24] A. Vahidnia, G. Ledwich, E. Palmer, and A. Ghosh, "Generator coherency and area detection in large power systems," *IET Gener. Transm. Distrib.*, vol. 6, no. 9, pp. 874–883, 2012.

[25] M. M. M. El-Arini and A. Fathy, "Identification of coherent generators for large-scale power systems using fuzzy algorithm," *WSEAS Trans. Syst. Control*, vol. 6, no. 6, pp. 229–238, 2011.

[26] H. Davarikia, F. Znidi, M. R. Aghamohammadi, and K. Iqbal, "Identification of coherent groups of generators based on synchronization coefficient," *IEEE Power Energy Soc. Gen. Meet.*, vol. 2016-Novem, pp. 891–896, 2016.

[27] B. P. Soni, A. Saxena, and V. Gupta, "Online identification of coherent generators in power system by using SVM," *2017 4th Int. Conf. Power, Control Embed. Syst. ICPCES 2017*, vol. 2017-Janua, pp. 1–5, 2017.

[28] A. S. Alayande, A. A. Jimoh, and A. A. Yusuff, "Identification of critical buses and weak transmission lines using inherent structural characteristics theory," *Asia-Pacific Power Energy Eng. Conf. APPEEC*, vol. 2016-January, 2016.

[29] A. S. Alayande, A. A. G. Jimoh, and A. A. Yusuff, "Inherent structural characteristics approach for solving loss allocation problems," *2015 4th Int. Conf. Electr. Power Energy Convers. Syst. EPECS 2015*, pp. 0–5, 2015.

[30] A. S. Alayande and N. Nwulu, "A Faster Approach for Identifying suitable Locations for TCSC Placement for Voltage Profile Enhancement and Loss Reduction," *Proc. Int. Conf. Comput. Tech. Electron. Mech. Syst. CTEMS 2018*, pp. 462–467, 2018.

[31] A. S. Alayande and N. Nwulu, "Influence of Critical Outage on Reactive Power Loss Allocation in a Deregulated Electricity Market," *Proc. Int. Conf. Comput. Tech. Electron. Mech. Syst. CTEMS 2018*, pp. 245–249, 2018.