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EMPLOYING PMU DATA, ANALYZE THE PERFORMANCE OF WIDE-AREA BACKUP PROTECTION

Kommuri Harinath Reddy, Research Scholar, Department of Electronics and communication Engineering, Monad University, Hapur, U.P.
Dr.Jaidev Sharma, Associate Professor, Supervisor, Department of Electronics and communication Engineering, Monad University, Hapur, U.P.

Abstract

Continued load growth without an associated rise in transmission resources has reduced operational profit margins for many power systems globally, pushed operation of power systems nearer to their stability limits, and resulted in power exchange in new patterns—all significant steps toward improving power system monitoring and performance. These problems, along with the ongoing global movement toward deregulation of the entire industry and the growing demand for more precise and effective network monitoring, force power utilities that are subject to this pressure to request new options for wide-area monitoring, protection, and control. Communication of specific-node information to a distant station is necessary for wide-area monitoring, protection, and control, but all information must be time-synchronized to cancel out any time differences. The power system is completely and simultaneously captured by it. The time-synchronized requirements of the electricity system cannot be met by the traditional system. Phasor Measurement Unit (PMU) transmits synchronized local information to distant stations, enabling time-synchronized measurement.

1 Introduction

The linking of regional power networks is one of the changes to the power system. This extensive integrated network efficiently utilizes scattered power resources from multiple locations as well as automated energy resource allocation. However, inter-area oscillations (IAO) of frequency (say, 0.2-0.8 Hz) have an impact on the operation of linked networks when subjected to load shedding or a line-to-ground failure. Such oscillations may cause instability in the linked lines and limit the electrical system's capacity for interconnection. It is crucial to monitor the dynamic activity of linked power systems and manage such oscillation patterns by employing the appropriate dampening controls. At the generation and transmission levels, the majority of integrated power systems use Energy Management System/Supervisory Control and Data Acquisition System (EMS/SCADA) units. These units receive measured signals in the form of branch currents, active power flow, and Root Mean Square (RMS) values of the bus voltages at a scanning rate of 1 sample every 2 seconds. At intervals of 5–10 minutes, the system states may be approximated. The calculated states may be utilized for stability analysis and for monitoring the power system's security. The SCADA/EMS may be used to do the offline-based mode analysis. Wide Area measuring Systems (WAMSs) in particular have seen a rise in use of measuring equipment in the electricity system in recent years.

The remote terminal units (RTUs) are used by the existing SCADA/EMS monitoring system to calculate the magnitudes of voltage and current as well as the active power flow in the lines. The RTUs generate measurement data at a refresh rate of 2 to 10 seconds. A control center that preprocesses the measured data from RTUs is required. Bad data processing and non-linear state estimation are both done at the preprocessing stage. These functions provide state estimate for a period of 5 to 10 minutes, which restricts the monitoring activity of SCADA/EMS to stability analysis solely in the event of a steady-state situation. It is highly challenging for SCADA to synchronize these readings in real-time monitoring because of the different locations of the measurements of the phase angle corresponding to the bus voltage. The SCADA cannot be used to analyze the integrated power system's dynamic behavior due to the slower measurement rate, and it can only provide the operator with a limited level of situational awareness. By using the global positioning system to synchronize current and voltage waveforms at widely separated places, PMUs were developed to alleviate this issue.

The advantages of the PMU over SCADA may be expressed in terms of performance, dependability, and speed. According to IEEE, a PMU is a monitoring device that offers time synchronizing signals, synchronized phasor, rate of change of frequency, and frequency estimations from current and/or voltage data. PMUs are able to provide real-time synchronized measurements from the power system with a one-millisecond synchronization precision using GPS signals. Positive sequence current and voltage measurements are made from the feeders and buses by the PMUs located at various points throughout the power system, and each measurement is GPS time-stamped. A unified representation of the condition of the power system may be created by organizing the time stamps of the measurements that have been obtained from the various substations and assembling them in the right location. High-end computation transforms the time-synchronized current and voltage waveforms (sinusoids) in the grid into a phasor representation before securely transmitting it to the central server. The use of PMU technology for tracing grid dynamics in real-time is extremely well suited; the measurements obtained can be used for wide-area monitoring and control, small-signal and transient stability analysis, dynamic system ratings, and accuracy in state estimation, grid protection, and control. It helps utilities to plan effective energy distribution and proactively minimize faults. The power grid's voltage and current waveforms, which are time-synchronized pulses (with an accuracy of one microsecond) utilizing GPS as illustrated in , are measured using the WAMSs monitoring system based on PMUs. When a measurement is time-synchronized with universal time via GPS, the technology known as a synchronphasor enters the scene. The use of Synchrophasor makes it possible to synchronize and time-align all PMU measurements made by various owners or at distant places. These synchronized readings may be used to provide a precise and thorough picture of the linked power system. Synchrophasors enable accurate information about the power grid's condition and also start corrective operations to maintain the interconnections' dependability. Phasor data is typically produced by PMU once every one to two cycles.

2 Litreature Survey

A PSS coupled to the excitation system is used to protect the stability of the power system against local area oscillations. By employing an exciter and extra signals to provide proper phase adjustment, as illustrated in Fig., the PSS serves as a damping torque component. 2.2. Both have been tweaked independently. Typically, speed, power, and frequency are used as additional feedback signals for PSS. Kpss stands for the gain offered for amplification of the damping signal. To mitigate the impact of other oscillating modes on PSS performance, a high pass wash-out filter is used. The PSS model may be expressed as follows:

It is important to develop a linearized model around an equilibrium point for stability analysis using singular perturbation theory after the dynamical studies of the system have been acquired [10]. System dynamics is characterized by:

The eigenvalues of the system matrix are provided by the nontrivial solution to the A =. For a non-trivial solution, det(A I) = 0 must be met. The system's free response is provided by the linear combination of the state matrix's eigenvalues. Eigenvalues reveal the specific state characteristics. The term "oscillating Mode" refers to eigenvalues with finite frequency. The mode's stability in the system relies on ; if it occurs in the left half-plane, it is stable; if it appears in the right half-plane, it is unstable. f = 2 and root = 2+2 are represented by the damping and frequency for each oscillation mode. For each eigenvalue, there is a column vector i that fulfills the condition Ai = ii and is denoted as the right eigenvector. An individual mode's eigenvector is represented by a mode shape. When the modes are aroused, mode shapes may be used to describe the dynamics of the states. The right eigenvector's constituent ki reveals the level of activity for a state xk in the ith mode. The Participation factor is used to represent how much a state contributes to a mode compared to other states. Assume P is a matrix with Pi standing for the i-th column. One may express themselves

8) in which = 1, also known as the left eigen vector. The pki element quantifies the relative contribution of the kth state variable to the ith mode. Participation factor analysis may be used to identify swing modes. The total of participation factors connected to a mode that are larger than participation from stay states is known as the swing mode. The mode shape gives a distinct representation of the various modes (such as local or inter-area). It indicates that i is swinging against j if the mode shape of i state is almost 180 phase different from j state with respect to a certain mode. Therefore, the machines i and j are said to be in local-area mode if they are both located in the same area. However, if they are located in separate areas, the machines are said to be in inter-area mode.

A two-area, four-machine Kundur's test system is shown in Fig. 2.3. Eleven buses, two regions, and four machines make up the system. Buses 7 and 9 are connected by a weak connection. At buses 7, 8, and 9, three loads are introduced to the test system. Additionally, two shunt capacitors are connected to buses 7 and 9. The test system's fundamental frequency was kept constant at 60 Hz. Power transmission of 400 MW occurs from Under the circumstances, from area 1 to area 2. In order to adequately dampen local modes, each area of the network has two generators and is equipped with a Local Power System Stabilizer (LPSS) at the G1 and G3 terminals. However, as previously mentioned, these local controllers are ineffective for enhancing inter-area damping. The operational point and nominal system characteristics without wide-area control are taken into consideration, as stated.

The system is modeled in MATLAB-Simulink and linearized around the operational point using the command linearize. The linear model placed 58th overall. The modes of the system will next be examined. Swing modes are classified using participation variables from the modes, as illustrated in Fig. 2.4. When compared to previous states, swing modes should have a greater

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involvement from the i and i of the ith generator. In Fig. (2.4(a)), it is shown that all machines engaging in M1 mode have i and i, while in Fig. 2.4(b), Fig. 2.4(c) only permits states from one region to participate concurrently. Therefore, swing modes M1, M2, and M3 are indicated here. Next, mode shapes are displayed as illustrated in Fig. (2.5) in order to determine local and inter-area in modes. Figure 2.5(a) demonstrates that the mode shapes of G1 and G2 are in opposition to those of G3 and M1 is the inter-area mode because of G4. G1 and G2 will fluctuate in opposition to G3 and G4 in M1. Additionally, it can be seen that machines close to the tie line are busier than machines farther away from the tie line in the same region. It is evident from the mode shape of M2 in Fig. 2.5(b) that G1 oscillates in opposition to G2. Fig. 2.5(b) shows the mode form for G3 and G4, however since it is a local mode of area 1, it is not particularly evident. Similar to this, G3 is shown oscillating against G4 in Fig. 2.5(c). In Table 2.4, the analysis's executive summary is shown.

3 Methodology

The off-line stability test analysis revealed the LFO options that the system uses to generate power. The reliability of the LMSSD algorithm can be confirmed by comparison with SSSA. Power systems are frequently affected by load and generation fluctuations, the tripping of switches and equipment, as well as the development of malfunctions. This constant, slow disruption within the system can lead to changes in frequency of the system and/or oscillations within the frequency. The causes of oscillations within the power system are detected using two distinct techniques, i.e. the conventional analytical method using models (off-line) while the other one is the measurement-based method (on-line) [15The measurement based approach is the most effective [15,16]. An innovative method of estimating LFOs modes using TLS-ESPRIT, a technique based upon LMSSD adaptive filtering is suggested. In the first place, with a low-pass FIR filter and high-frequency components of measured data samples that contain white noise generated by PMUs via sensors are taken out, leaving the lowest frequency components. The noise signal generated by the FIR low-pass filter transforms to highly

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correlated AWGN that reduces the precision of estimation mode by causing an error during estimation. LMSSD adaptive filtering can reduce the amount of AWGN quite effectively. The TLS-ESPRIT algorithm later is utilized to get the low-frequency models. The LMSSD adaptive filtering is much more resistant to AWGN which has fast computation time in comparison to other subspace techniques .

The method proposed uses the power on LMSSD adaptive filtering, as well as TLS-ESPRIT in order to determine the low frequency mode of the power system. The signal model utilized in the method of estimation proposed is a linear mixture of sinusoidal frequencies that are exponentially damped along with an AWGN. The method is based on the power that comes from LMSSD adaptive filtering as well as TLS-ESPRIT to calculate the low frequency mode of the power system. The model of signal used for the estimation procedure is a linear mixture of sinusoidal signal that is exponentially dampened along with an AWGN.

The signal that is used for the presentation of the power system model could be expressed as sinusoids that are exponentially dampened. In order to analyze the LMSSD TLS-ESPRIT method, we looked at the actual power i.e. p(n) that flows through the tie-lines of Kundur's test systems for two areas and the IEEE New england 39 bus. The model of power system signals could be described as follows:

$$p(n) = \sum_{k=1}^{K} a_k e^{b_k n} \cos(n\omega_k + \phi_k) \quad (3.1)$$

$$P(n) = p(n) + w(n) = \sum_{j=1}^{L} \alpha_j e^{\beta_j n} + w(n) \quad (3.2)$$

filter $\mathbf{P}(n)$ is given by:

$$\mathbf{P}(n) = [P(n)\ P(n+1)...P(n+M-1)]^T = \mathbf{p}(n) + \mathbf{w}(n) \quad (3.3)$$

$\mathbf{p}(n)$ is the signal vector and $\mathbf{w}(n)$ is the noise vector. The data matrix $\mathbf{Y}$ can be formed by utilizing the time window vector $\mathbf{P}(n)$.

$$\mathbf{Y} = \begin{bmatrix} \mathbf{P}^T(0) \\ \mathbf{P}^T(1) \\ \vdots \\ \mathbf{P}^T(n) \\ \vdots \\ \mathbf{P}^T(n-2) \\ \mathbf{P}^T(n-1) \end{bmatrix} = \begin{bmatrix} P(0) & P(1) & \cdots & P(M-1) \\ P(1) & P(2) & \cdots & P(M) \\ \vdots & \vdots & \vdots & \vdots \\ P(n) & P(n+1) & \cdots & P(N+M-1) \\ \vdots & \vdots & \vdots & \vdots \\ P(N-2) & P(N-1) & \cdots & P(N+M-3) \\ P(N-1) & P(N) & \cdots & P(N+M-2) \end{bmatrix} \quad (3.4)$$

$\mathbf{P}(n)$ can also be represented in form of time-window frequency vector V.

$$\mathbf{P}(n) = \sum_{k=1}^{L} \alpha_k \mathrm{v}(f_k) e^{\beta_k n} + \mathbf{w}(n) = \mathbf{V}\boldsymbol{\Phi}^n \boldsymbol{\alpha} + \mathbf{w}(n) \quad (3.5)$$

L columns of matrix V are length-M time-window frequency vectors of the complex exponential.

$$\mathbf{V} = [\mathrm{v}(f_1)\, \mathrm{v}(f_2) ... \mathrm{v}(f_p)] \quad (3.6)$$

where v(f) = [1 e β1 ... e(M−1)β1]. The each column vector of α contains the complex sinusoid vectors αk for k=1,2,3, …, L, at frequency fk. Φ is the unitary diagonal matrix of phase shifts between adjacent time samples of the independent, complex sinusoid of p(n).

4 Experiments & Evaluation

The answer to the OPP issue is found by employing a variety of heuristics and a meta-heuristic algorithms. Two different techniques from the previously mentioned algorithms are used and are implemented and coded for the purpose of evaluating the effectiveness of these algorithms. Minimum Spanning Tree (MST) algorithm is one type of tree search technique and is employed to achieve the purpose of ensuring that there is a perfect positioning of the PMU. The term "spanning tree" refers to a subgraph that is comprised of every vertice of the connected graph, or the graph that is not directed (Abdelaziz). The method is explained in the manner that the following.

Step 1: Start bus or node should be picked. The bus can be chosen from any place within the power system in question.

Step 2: Alternate designs of the location are explored. The site of the PMU is changed to buses connected to the original node. The visibility of the entire system is verified. 3. Observability is confirmed by the elimination of a PMU over the same time from a particular combination.

If the whole network can be observed it will be able to finish by completing the first step. If not, PMU is changed to another site and the process will continue until the system is fully observed.

OPP using Meta-Heuristic Technique

Genetic Algorithm (GA) is an algorithm that was inspired by Darwinian's Principle. It's an iterative procedure that incorporates the principles of evolutionary theory as well as natural selection. The basic principle is existence of the most fit people (Marin). The features in the GA add value addition to their advantages so they could be utilized in many real-time programs. Furthermore, numerous research projects were conducted to accomplish various goals (Aminifar). In this research, the GA is modified to address the task of determining the best location of PMUs. The GA is based on the belowactions: (i) Population initialization, (ii) Selection, (iii) cross-over (iv) mutation and (v) the Stopping Criteria.

The GA is mainly based on the randomly selected chromosomes that are generated from situations (Kolosak and colleagues. 2014). The chromosomes that are randomly generated contain information about the PMU places in a power system. The length of the set is likely to be equivalent to what number of busses within the n-bus system of power. In other words, if the value of a bit is that is '1' indicates that the PMU has been placed at the bus's location. If a bit has '0 number, it's described as an absence of PMU at that particular bus stop. The information about chromosome's chromosome's structure is determined using GA. However, when an optimization problem is addressed by using GA can provide a variety of options. What steps are involved in GA

5 Conclusion

To address the complex and high-dimensionality of the current power system architecture as well as improve the efficiency of the structure This thesis presents an D - n4sid algorithm that is a on a wide-area damping control system to control a vast-scale interconnected system. Each FACTS device and generator can be considered as subsystems that is identified using the D - the n4sid algorithm. FOPID controllers are designed offline by using PSO using parallel computing features to every subsystem. The efficiency of the developed the decentralized wide-area damping controller (DSC) can be verified using nonlinear simulations in time domains that show that damping can be improved by decreasing the sustained period of oscillations. Stability that the scheme has is improved and it remains steady for larger-scale disturbances. Multiple delay varying in time are considered as part of the wide-area signals that are fed to PSS as well as the external damping controller of FACTS devices. This suggests that the damping reduced in the absence of TDC. TDC is a TDC was designed using a an actual time-stamped technique employing SimEvents which proves that damping can be improved by TDC. The suggested DSC can be compared to LSC as well as CSC and shows that DSC is superior to LSC and is comparable with CSC and CSC, with less communications signal requirements. Subsystem autonomy, and the ability to damp oscillations between areas are improved. It also can prevent blackouts.

The primary benefits of this proposed wide-area damping control method to control LSS are:) A decentralized controller and identification layout for each subsystem require only measurements of the output and input disturbance details for every subsystem.) The need for a complicated mathematical model of the WECC system. Interconnection structures are also maintained. Iii) The damping effect of interarea oscillation within the WECC systems that do not stimulate other inter-area modes especially for contingency with wide-area coverage.

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