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Online Prediction of Transient Instability by Wide Area Measurement System

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Abstract

In this paper an online accurate prediction method is proposed to enhance the speed of Transactionient stability assessment. This method is the measurement basis technique resulted from wide area measurement systems (WAMS). In the proposed method, the generators with same dynamic behavior, referred as to coherent generators, are clustered as a same group and they can be considered as an equivalent bus. So the system will be reduced into a small scale system. The admittance matrix parameters of the reduced system can be identified with the least square algorithm. Then the trajectory prediction is performed by real-time simulations. Obtained results from simulations on New England test system show the high noticeable efficiency for performance of the proposed method, capable in predicting of the disturbed trajectory under existence of unknown parameters in grid structure.

Keywords: *Transactionient stability, wide area measurement system, phasor measurement units, coherent generators*

1. Introduction

Today, most modern power systems work very close to their secure dynamic limits. This has been caused by complexity in the structure, increasing Transactionferred power through long and tie lines, interdependence between interconnected systems and interaction between different controllers in the system, etc.

Therefore such systems are vulnerable in disturbances and instability problems are as the major threats for the power system stability, so that in some cases instability problems move the network to go to blackout.

Today, tracking of system dynamics is done more easily using phasor measurement units (PMUs) and new techniques of communications. In smart grid structure, PMUs Transactionfer all necessary data to a central control system to monitor the network in large scale (Wide Area). They have high capacity for data Transactionmitting into the control center and therefore they create good visibility of the network integrity [1].

Wide area measurement system (WAMS), including phasor PMUs, have been installed in many networks around the world to monitor the dynamic behavior of the power systems [2].

Because of the reasons like non-linear nature of Transactionient instability and its high speed and also intensity of destructive effects, today Transactionient instability is known as the most important type of stability studies. [3]

Transactionient stability is the ability of power system to maintain synchronism when is subjected to a severe Transactionient disturbance. Loss of synchronism because of Transactionient instability, if it occurs, will be usually evident within 2 to 3 seconds after the initial disturbance. So very fast detection of this phenomenon is very important [4].

Several approaches have been proposed for online Transactionient stability prediction by data received from WAMS because of reliability and simplicity in this solution.

This paper proposes an on-line Transactionient stability prediction method using PMU measurements. The method consists of measurement, clustering, reducing and prediction.

2. Identification Of Coherent Generators

When a fault occurs, this may cause a drift in the rotor angle of two or more number of generators. Therefore such generators show different dynamic behavior with respect to others.

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These different behaviors create the concept of coherent generators which means generators with same dynamic behavior are clustered in a same group [5].

Coherent generators interest to to swing together after a disturbance. Common methods determine the coherent generators via the swing curves generated by numerical integration of system dynamic equations [6].

But this technique has high computational complexity and is not suitable for online processing.

A pair of two generators is said to be coherent when there exist constant ε_0 as follows:

$$max|\Delta(t)-\Delta\delta j(t)|\leq\varepsilon_0 \qquad t\in[0,\tau] \tag{1}$$

Where ε_0 and t can be chosen as $5° \leq \varepsilon_0 \leq 10°$, $1s \leq t \leq 3s$.

If indices to be from type of signal changes, is fast and accurate. So the first and second derivatives of the power angle with respect to time (angular velocity and angular acceleration) can be used as good indicator for clustering of generators [7].

All the n generators can be grouped into several coherent generator groups [8] by using the following index:

$$d_{ij}(k)=\frac{d_{\omega ij}(k)}{\sum_{k=1}^{n_0} d_{\omega ij}(k)} \tag{2}$$

$$d_{ij}(k)=\frac{d_{\dot{\omega} ij}(k)}{\sum_{k=1}^{n_0} d_{\dot{\omega} ij}(k)} \tag{3}$$

Where:

$$n_0 = n(n-1)/2$$

$$d_{\omega ij}(k) = \sqrt{\sum_{t=1}^{k}\left(\Delta\omega_i(t)-\Delta\omega_j(t)\right)^2}$$

$$d_{\dot{\omega} ij}(k) = \sqrt{\sum_{t=1}^{k}(\Delta\dot{\omega}_i(t)-\Delta\dot{\omega}_j(t))^2}$$

If d_{ij} is less than ε_0 it means that two generators are placed into same groups, otherwise they belong to different groups.

3. Proposed Dynamic Aggregation

Since the generators belonging to a group have similar angular velocity and bus terminal voltage, they can be considered as an equivalent bus and then dynamic aggregation can be applied to the swing equation of the generator rotor.

The dynamic equation of the rotor of the jth generator can be written as:

$$M_j\frac{d\omega_j}{dt}=P_{mj}-P_{ej}-D_j\left(\omega_j-1\right) \tag{4}$$

Because the mechanical and electromagnetic powers of coherent generator group are equal to equivalent generator, the rotor equations of coherent generators can be aggregated as follows:

$$(\sum_{j=1}^{N} M_j).\frac{d\omega_j}{dt}=\sum_{j=1}^{N} P_{mj}-\sum_{j=1}^{N} P_{ej}-\sum_{j=1}^{N} D_j\left(\omega_j-1\right) \tag{5}$$

$$\frac{\mathrm{d}\theta^*}{\mathrm{dt}} = \omega^* \quad (6)$$

$$M^* \frac{\mathrm{d}\omega^*}{\mathrm{dt}} = P_m{}^* - P_e{}^* - D^*(\omega^* - 1) \quad (7)$$

Where

$$M^* = \sum_{\mathrm{j=1}}^{\mathrm{N}} \mathrm{M_j}\, , P_m{}^* = \sum_{\mathrm{j=1}}^{\mathrm{N}} \mathrm{P_{mj}}\, , P_e{}^* = \sum_{\mathrm{j=1}}^{\mathrm{N}} \mathrm{P_{ej}}\, , \qquad D^* = \sum_{\mathrm{j=1}}^{\mathrm{N}} \mathrm{D_j}\, , \omega^* = \omega_{\mathrm{j}}$$

N is number of generators in the group [6].
Identification of Reduced Network Model:
Assume the network is linear and loads are constant impedances. After integration, network node equation can be written as follows:

$$\dot{I}_t = Y_t \dot{E}'_t \quad (11)$$

Y_{tij} = G_{ij} + jB_{ij} and Gij and Bij are the elements of admittance matrix that constrict to the internal potential nodes of equivalent generator, $\dot{I}_t, \dot{E}'_t$, are electric potential vector for equivalent generator and current vector infused into the grid, respectively. These vectors can be calculated by combining the internal potential and terminal current of the coherent generators. The procedure of calculation is as follows:

The internal potential of generators can be calculated with the real-time information of terminal voltage and infused current measured by PMU:

$$\dot{\mathrm{E}}'_{\mathrm{j}} = \dot{\mathrm{U}}_{\mathrm{j}} + \mathrm{j}\dot{\mathrm{I}}_{\mathrm{j}}\mathrm{X}'_{\mathrm{d}} \quad (12)$$

$X_d{}'$ represents the Transactionient reactance of generators.
Magnitude and phase of $\dot{E}'_t$(equivalent internal potential of the generator) are defined as:

$$|\dot{\mathrm{E}}'_{\mathrm{t}}| = \frac{1}{\mathrm{N}} \sum_{\mathrm{j=1}}^{\mathrm{N}} |\dot{\mathrm{E}}'_{\mathrm{j}}| \quad (13)$$

$$\theta_{\mathrm{t}} = \frac{1}{\mathrm{N}} \sum_{\mathrm{j=1}}^{\mathrm{N}} |\theta_{\mathrm{j}}| \quad (14)$$

The conjugate value $\dot{I}_t$injected into the network can be expressed as follows:

$$I_t{}^* = \frac{\sum_{j=1}^{N} \dot{E}'_j I_j{}^*}{\dot{E}'_t} \quad (15)$$

The electromagnetic power of the ith equivalent generator is:

$$P_{ei}{}^* = E_{ti} \sum_{j=1}^{m} E_{tj} \left(G_{ij} cos\theta_{ij} + B_{ij} sin\theta_{ij}\right) \quad (16)$$

We can get least squares estimation of Y_t using information from m sample points of disrupted system, as follow:

$$\widehat{Y}_t = \dot{I}_t{}^* \dot{E}_t^*{}^T (\dot{E}_t^* \dot{E}_t^*{}^T)^{-1} \quad (17)$$

$\dot{I}_t^{\,*} = [\dot{I}_t(1), \dot{I}_t(2), \ldots., \dot{I}_t(n)]^T$is equivalent current vector matrix,
$\dot{E}_t^{*} = [\dot{E}_t'(1), \dot{E}_t'(2), \ldots.\dot{E}_t'(n)]^T$ is equivalent internal potential vector matrix,$\dot{E}_t^{*^{T}}$is no-conjugate Transactionpose of $\dot{E}_t^{*}$.

4. Prediction of Post-Fault Trajectory

After identifying the reduced-order admittance matrix, using WAMS data as initial conditions, the future post-fault trajectory of generators is obtained using equations (5) and (6) and therefore ω and θ can be predicted using modified Euler rule.

5. Studied Network and Simulation Results

The New England network has been studied all over this paper. The 39 bus grid includes 34 Transaction mission lines, 10 generators, and 12 Transactionformers at the frequency of 60 Hz [9]. For the dynamic simulation purposes, the fifth-order model of synchronous machines [10].

Simulation cases include the symmetric three-phase short-circuit fault on Transactionmission lines and bus network. Some of the most important examples of these studies are described and analyzed below in detail.

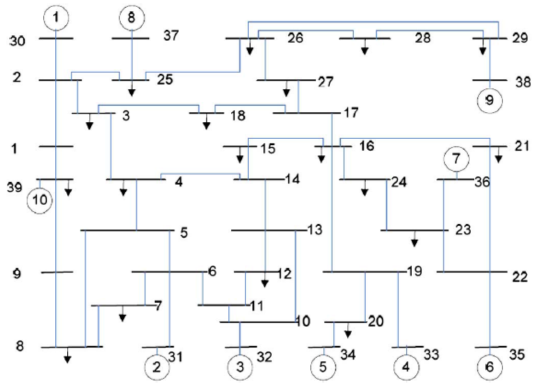

Figure 1. Single line diagram of 10-machine 39-bus power system

Modeling of three-phase short-circuit fault in bus number 4

A symmetrical three-phase short-circuit fault occurs at t = 1s on bus number 4. This fault is cleared at t=1.25 by tripping the line 4-5. Tthe system is stable. The trajectory of generator angles is shown in Figure 2. All the 10 generators can be divided into six coherent generator groups. G2 and G3 belong to a group, G5 and G6 belongs to other group, the G4 and G7 and G9 also belong to a group and other generators belong to separate groups.

Figure 2 shows the approximation angle and angular velocity waveforms of synchronous generators using the proposed method and numerical solutions of the swing equations of the grid. It can be seen that the predictive trajectory is perfectly tracked with the trajectory of the real system, so we can predict the Transactionient stability of the system exactly.

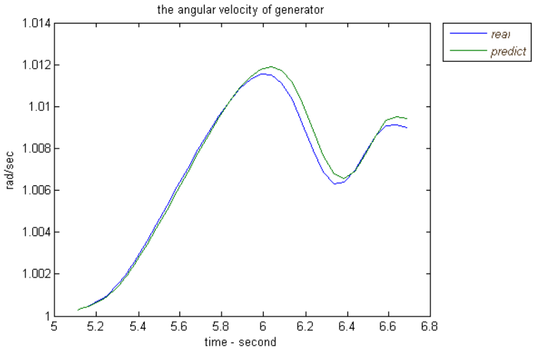

Figure 2. Swing curve for generator No. 5 and the fault clearing time 0.25 s

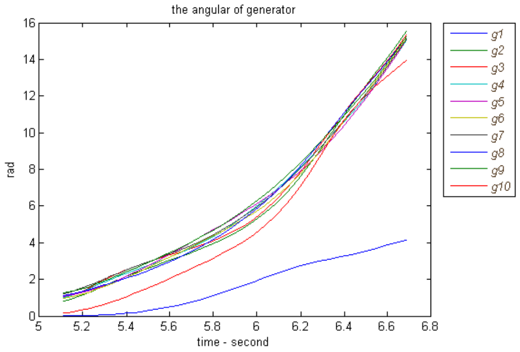

Figure 3. Groups of Generators for symmetrical three-phase short-circuit fault on bus number 4

Modeling of three-phase short-circuit fault in bus number 17

In the next example, three-phase short-circuit fault occurs on bus number 17 and is cleared after 0.2s by tripping line 17-18. All the 10 generators can be divided into six coherent generator groups. G4 and G6 and G7 belong to a group, G2 and G3 and G8 belongs to other group, and other generators belong to separate groups.

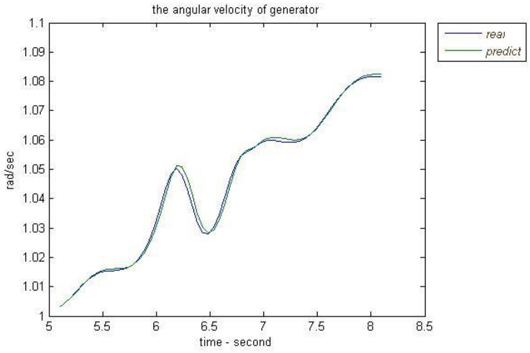

Figure 4. Swing curve for generator No. 17 and the fault clearing time 0.2 s

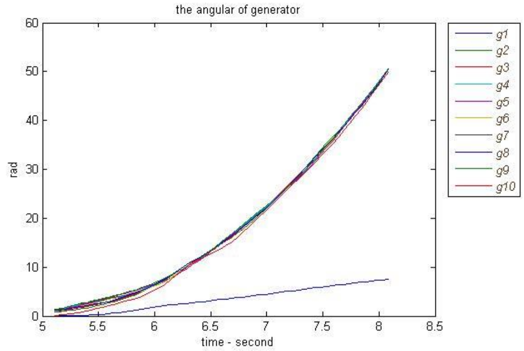

Figure 5. Groups of Generators for symmetrical three-phase short-circuit fault on bus number 4

Modeling of three-phase short-circuit fault in bus number 17

In this case, symmetrical three-phase short-circuit fault simulated on bus number 21 and cleared after 0.16 seconds, this fault can be resolved by tripping the line 21-22. The results of the waveform in the following:

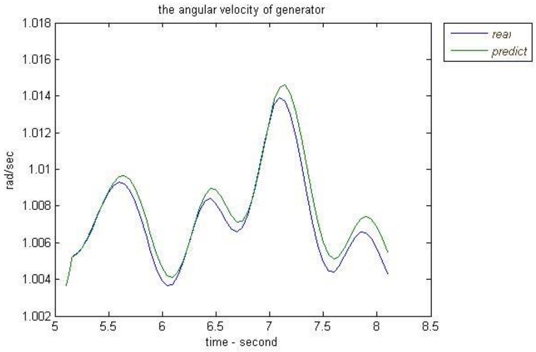

Figure 6. Swing curve for generator No. 21 and the fault clearing time 0.16 s

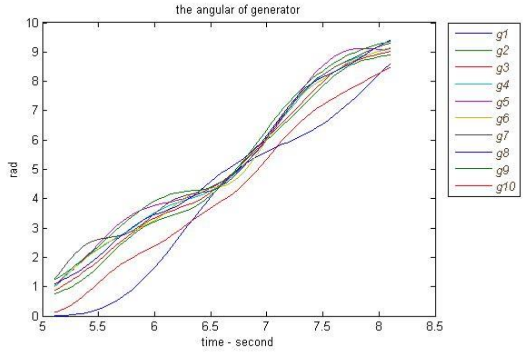

Figure 7. Groups of Generators for symmetrical three-phase short-circuit fault on bus number 21

6. Conclusion

In this paper, a measurement basis method was proposed to track the parameters of disturbed power system using Wide Area Measurement Systems. The proposed technique used an index to place the generators with similar characteristics in a coherent group. Then each group was replaced with an equivalent generator and so the order of system was reduced. The predicted trajectory can be done with real-time simulation. Simulation results show that the proposed method can track the parameters of disturbed system efficiently.

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