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Validation of Steady-State Stability Evaluation Exerting with Dimo's Approximation

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Abstract

Due to the increasing load requisition and the productiveness of the available transmission size. Therefore the present power systems are abundantly loaded as opposed to the olden days. Hence, these situations are leading the power system to be operated proximately towards the steady-state stability limit (SSSL). Thus, the intension of this paper is to contribute to the evaluation on SSSL in IEEE 9-bus test system based on REI-Dimo technique. REI network will be resulted from the REI-Dimo technique and the results manifested that the test system is implemented with the REI-Dimo technique to reduce the network size and to evaluate the SSSL index.

1 Introduction

Present-day, transmission networks in each country are designed to preserve dynamic power transfers that can be diverse from those for which they were scheduled by the power generation operators. This is due to the energy management throughout multi-area systems possibly resulted in parallel flows, superabundant network loadings and inadequate bus voltages. Subject to these circumstances, such deteriorate conditions literary lead to power system instability. Whenever instability took place in the power system, remedial action must be carried out or else blackout will be associated [1].

Standard transfer capability concepts such as Total Transfer Capability (TTC), Available Transfer Capability (ATC) and Transmission Reliability Margin (TRM) are being recognized by the power industries. However, real-time stability checks are not possible with these techniques due to the lengthy period of identifying the precondition of every particular state forecasting solution [2].

Corresponding to the summary stated by the North American Electric Reliability Corporation (NERC) [3], the TTC is stated in (1),

$$TTC = Min\ \{Thermal\ Limit,\ Voltage\ \mathrm{Limit},\ Stability\ Limit\} \qquad (1)$$

As specified by the NERC, the thermal limit and voltage limit can be determined offline. According to the policy of NERC, reliability coordinators are requested to determine the stability limits for present and the next following day operational activities. The policy is intended for forecasting the total loading in the transmission either below or beyond the operating reliability limit. For online identifying voltage and thermal interruption are very simple because stability limits must be specified, quantified and calculated in distinct proposition. Numerous advanced stability assessment programs are commonly accessible to resolve either provided the condition in the power system is stable or unstable. However, those assessment programs are yet have not been effective in instantly produce the capability to recognize, quantify and conceptualize the stability limits.

Complicated computational algorithms have been accelerated and clarified by the initiation of the Radial, Equivalent and Independent (REI) equivalent technique. For instant, exact clarification of steady-state stability issue is forecasted accordingly to the complete machine model and requires a secondary order of eigenvalues and load flow computation up until the instability takes place [4]. For worsen load flow cases, eigenvalues determination are computational rigorous and higher possible for the load flow may not intersect during the instability occurred [5]. An equivalent accompanied with suitable and simplified notion must be implemented in order to resolve those obstacles and therefore an equivalent named REI-Dimo has been introduced and being implemented in the smart grid system. Hence, real time load ability limits in the power system can be determined and the distance towards instability can be supervised as well [6, 7].

Numerous techniques have been introduced in the previous literatures related to steady-state stability. Despite that, these methods necessitated huge computational times and also not structured well for real time stability evaluation. In order to conduct real time stability evaluation by preserving the precision and accuracy for detecting the point of collapse in the system and also contribute guidance for the power system operators to perform remedial actions before voltage collapse taken part, there is a need for a technique to perform fast computational speed.

Hence, this paper is intended to conduct steady-state stability limit study in IEEE 9-b25test case by implementing the REI-Dimo's methodology. The maximum power18nsfer in the power system can be resolved by utilizing the steady-state stability limit-monitoring index.

The remaining of this paper is structured as following. Extensive background for this paper is outlined in section 2. While, the implemented methodology for this work will be presented in section 3. Section 4 will mainly consist of the achieved results and analysis as well. Last but not least, section 5 will include the conclusion for this paper.

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2 Extensive Background

2.1 Exploration of the Stability Limit

Due to the substitution for shunt reactors and static capacitors, therefore the stable states are reoriented. In addition, line outages, the transformer tap changes, generator trips and load variations, alter the distance towards instability. The occurrence of stability limits is not fixed quantities because the stability w21ubstitute accordingly to the utilization of the overall active power in the grid system, network and also the bus voltage profile.

On top of that, instability evolves rapidly and limited the reacting time. Therefore indices that quantify the range towards instability are particularly needed. Those techniques must be composed with the ability to continuously computing every single fundamental index for every latest system condition either for load flow or state estimation.

2.2 Transient and Voltage Stability Constrains

In the aforementioned past two decades, industries started strongly emphasized on voltage stability and transient stability. Conditions of transient stability are mainly detected by the transient stability indices [8]. However, transient stability indices have several drawbacks. In determining the stability condition in the system, transient stability indices required huge computational times. Moreover, large disturbance cases must be taken into account when performing transient stability indices and therefore this even caused additional computing burden [9].

The capability to transfer maximum active power into a particular load bus before the voltage collapse happened and therefore this term can be described as voltage stability [10]. In power system stability, the load stability's term also can be recognized as voltage stability. Moreover, stability for voltage also can be reflected in the power system's ability to ensure balanced voltages at every single bus after being exposed to a disruption as compared to the initial condition. In other words, the capability to preserve or reinstate balancing for the load requirement and load distribution in power system also can be manifested as voltage stability [11, 12]. The complete load buses in the system must be reiterated and this procedure is called bus oriented calculations. This procedure consumed burdensome calculation when dealing with the larger system to establish extensive power system.

2.3 Steady-State Stability Initiation (SSSL)

The steady-state power system working point is always located at steady-state balanced condition and hence this is known as the stability for steady state. However, when unpredictable minor modification in different orientation and operating quantities will lead the power system towards instability [13]. Steady-state instability can be originated from out of synchronism in units, self-amplifying small signal oscillations that resulted to instability and voltage collapse [14].

The SSSL offers a promising perspective. Firstly, SSSL index is quantifiable. Secondly, SSSL index does coincide with an operating boundary. Whenever any slight modification in the operating amounts and the occurrence of mismatched orientation. Therefore the operating states will immediately be under the SSSL. Another benefit for SSSL is the easiness. SSSL can be resolved based on the overall active power utilization in the transmission.

3 Implemented Methodology

The methods that will be imposed in this paper are being summarized according to the process sequence as illustrated in Figure 1.

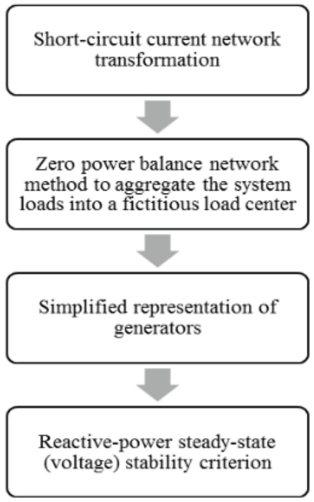


Figure 1: Process sequence based on Dimo's approach [15].

3.1 Short-Circuit Currents Transformation

Short-circuit currents transformation is implemented as part of the process in order to transform an extremely complicated power system network into a much simpler network which is a short-circuit admittances that linked series with a nodal point. REI network can be achieved when the short-circuit admittances is obtained. This transformation will allow the recognition of generators from the nodal point. ZPBN that illustrated in Figure 2 is utilized to connect the REI network with all the generators together with fictitious load center or short-circuit admittances [15].

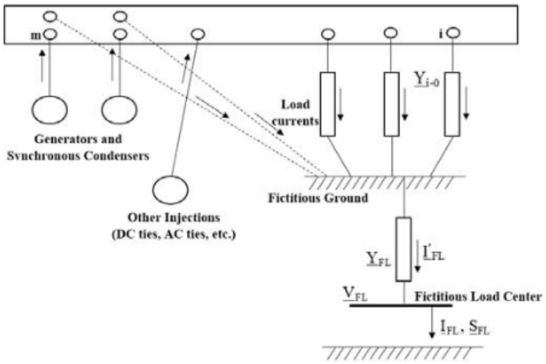


Figure 2: Zero power balance network (ZPBN).

3.2 Zero Power Balance Network (ZPBN)

ZPBN or known as REI-Dimo equivalence is introduced by Paul Dimo and illustration details for the ZPBN has been stated beforehand in Figure 2. Fictitious single-load center can be calculated by aggregating the entire loads in the system by implementing ZPBN. The advantage of utilizing ZPBN is that the characteristics and the stability of the base case are in a position to maintain [16].

3.3 Reactive Power Steady-State Stability Criterion

The radial characteristic of the REI network where the generators are attached to a central node has successfully converged the regulation of the reactive power steady-state stability foundation (voltage stability). Dimo constructed the equation based on a network that consists of fictitious or realistic load bus connected radially with $1....,i,....G$ generators, synchronous condensers and DC or AC ties through admittances $Y_1....,Y_i,....Y_G$ [15]. Hence, the equation is provided as in (2).

$$\frac{d\Delta Q}{dV} = \sum_m \frac{Y_m E_m}{\cos\delta_m} - 2\left(\sum_m Y_m + Y_{load}\right)V \qquad (2)$$

Where:

E_m is the internal voltage of the machine (assumed to remain constant, unaffected by small adjustments made under steady-state stability conditions)

δ_m is the internal angle of the machine with reference to the voltage, V on the load bus (either fictitious or actual)

V is the voltage in the load center

Y_{load} is the load center admittance

The steady-state stability criterion must always maintain according to the SSSL index, $\frac{dQ}{dV} < 0$. Therefore, the stability of the power system is qualified to sustain inside the stability limit region.

3.4 Power System Test Case

Test cases according to the IEEE standards have been widely implemented by the researchers. These test cases are based on the actual data according to the IEEE standard power system test system configuration. Hence, the test case that has been selected for this paper is known as IEEE 9-bus test case.

A total of 3-machines and 9-bus system has been represented by the IEEE 9-bus test case and this test case is actually a part of the Western System Coordinating Council (WSCC). In this test case, there are three generators, three loads and nine buses [17, 18]. The connection layout for the IEEE 9-bus test case has been encapsulated in Figure 3.

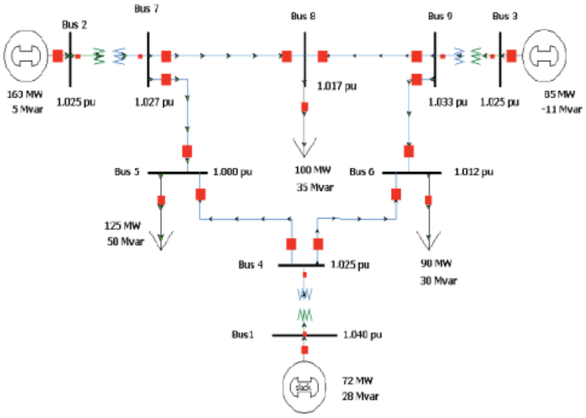


Figure 3: IEEE 9-bus test network [17, 18].

4 Results and Analysis

The particular details for the IEEE 9-bus test case such as generation, load and bus voltage information are provided in Table I. The details for these information are achieved by performing base case load flow analysis by utilizing the power flow solution based on Newton-Raphson method in Matlab 2015. The total generated active and reactive power is 319.64MW and 22.84MVAr subsequently. In the meanwhile, the total load consumption for active and reactive power is 315.00MW and 115.00MVAr.

Bus No.	Gen (MW)	Gen (MVAr)	Load (MW)	Load (MVAr)	V (p.u.)	Angle (degree)
1	71.641	28.000	0.000	0.000	1.040	0.000
2	163.000	5.000	0.000	0.000	1.025	9.280
3	85.000	-11.000	0.000	0.000	1.025	4.665
4	0.000	0.000	0.000	0.000	1.026	-2.217
5	0.000	0.000	125.000	50.000	0.996	-3.989
6	0.000	0.000	90.000	30.000	1.013	-3.687
7	0.000	0.000	0.000	0.000	1.026	3.720
8	0.000	0.000	100.000	35.000	1.016	0.728
9	0.000	0.000	0.000	0.000	1.032	1.967

Table 1: Base case generation, load and bus voltage data for IEEE 9-bus test case.

The initial 9-bus test network is being expanded with the internal nodes for each unit of the generator. The generators are located at Bus 1, Bus 2 and Bus 3. Besides that, the loads at Bus 5, Bus 6 and Bus 8 are being substituted with linearizing impedances. After that, Bus 5, Bus 6 and Bus 8 are being connected to the intermediate ground, 100031 as illustrated in Fig. 3. The impedances that linearize by Bus 5, Bus 6 and Bus 8 are converted to passive buses and then linked between buses 5-100031, 6-100031 and 8-100031. Finally, intermediate ground, 100031 is connected to the equivalent load center, 100011. At this end, the total loads at Bus 5, Bus 6 and Bus 8 are equivalences in order to achieve a single total system load.

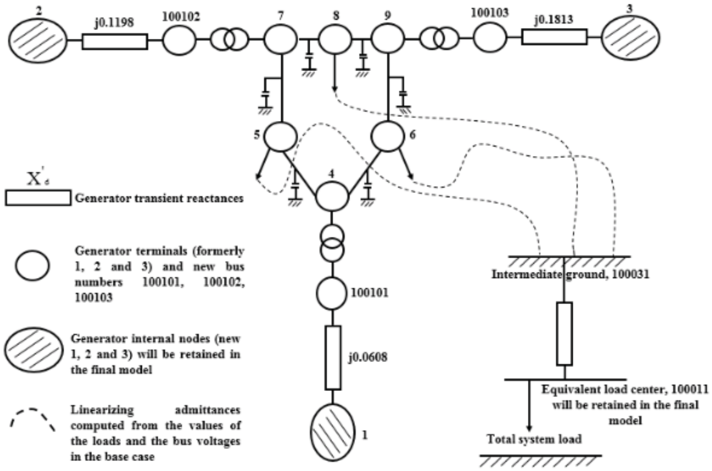


Figure 4: IEEE 9-bus network extended with the internal nodes of the generators and the zero power balance network.

Once after the IEEE 9-bus network is being transformed into zero power balance network (ZPBN). Hence this network is assumed to be a lossless network. This lossless network is formed by branches of 5-100031, 6-100031, 8-100031 and 100031-100011. Line data for the extended IEEE 9-bus test case network are encapsulated in Table 2.

From Bus	To Bus	R (p.u.)	X (p.u.)	$Y_{cap/2}$ (p.u.)
1	100101	0.0000	0.0608	0.0000
2	100102	0.0000	0.1198	0.0000
3	100103	0.0000	0.1813	0.0000

From Bus	To Bus	R (p.u.)	X (p.u.)	$Y_{cap/2}$ (p.u.)
4	5	0.0100	0.0850	0.0880
4	6	0.0170	0.0920	0.0790
5	7	0.0320	0.1610	0.1530
6	9	0.0390	0.1700	0.1790
7	8	0.0085	0.0720	0.0745
8	9	0.0119	0.1008	0.1045
4	100101	0.0000	0.0576	0.0000
7	100102	0.0000	0.0625	0.0000
9	100103	0.0000	0.0586	0.0000
5	100031	0.6836	0.2735	0.0000
6	100031	1.0255	0.3418	0.0000
8	100031	0.9194	0.3218	0.0000
100011	100031	-0.2841	-0.1037	0.0000

Table 2: Line data for the extended IEEE 9-bus test case network.

Posterior to the development of the extended 9-bus from the base case condition with 315MW and the calculated $\frac{dQ}{dV}$ stability criterion proven that the initial state of the system is in stable condition with the value of -28.2249. In order to evaluate the case weakening condition stressed the system with the load increment until the system becomes unstable. The case worsening strategy from the base case value of 315MW to the maximum load of 529.211MW before the system experienced instability condition and therefore the results are being plotted as a PV curve as encapsulated in Figure 5. The final value for the calculated $\frac{dQ}{dV}$ is -4.5615 and this showed that the $\frac{dQ}{dV}$ stability criterion is approaching 0. According to the stability criterion theory, whenever the condition is fulfilled with $\frac{dQ}{dV} < 0$ then the system is experiencing the maximum load ability and the occurrence of instability. SSSL indices for IEEE 9-bus test system from base case condition to stress condition are being represented in the graph as showed in Figure 6.

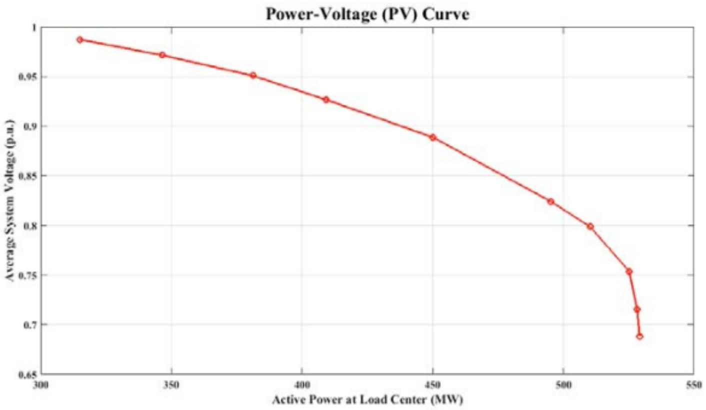


Figure 5: P-V curve for the base case condition towards stressed condition by using REI-Dimo approach.

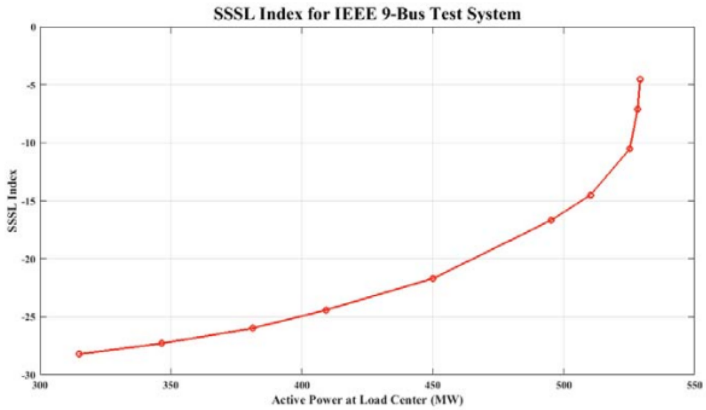
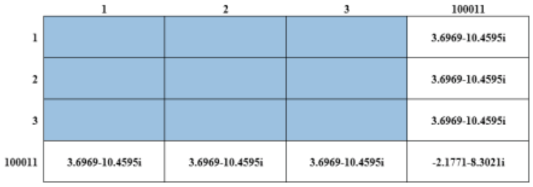


Figure 6: SSSL index for base case condition towards stressed condition for IEEE 9-bus test system.

The Y-matrix of nodal admittances after applie hort-circuit current transformation and the REI network are shown in Figure 7 and Figure 8 subsequently.



	1	2	3	100011
1				3.6969-10.4595i
2				3.6969-10.4595i
3				3.6969-10.4595i
100011	3.6969-10.4595i	3.6969-10.4595i	3.6969-10.4595i	-2.1771-8.3021i

Figure 7: Y-matrix after Gaussian elimination.

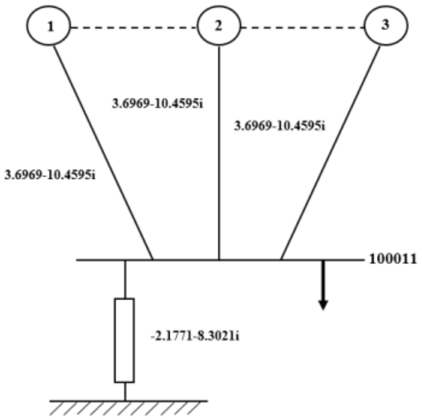


Figure 8: The resulting REI network for the IEEE 9-bus test case system.

5 Conclusion

In the nutshell, the steady-state stability assessment method motivated by Paul Dimo is able to resolve the stability index rapidly. Besides that, this method also being reviewed as very reliable in determining the distance of a transmission network from a condition where the voltage instability might happen first and soon accompanied by voltage collapse. Whenever voltage collapse happens, the units in the network may experience loss of synchronization. Numerous theoretical aspects in determining the SSSL index have been implemented and the results are being proven in details. A significant conclusion related to the $\frac{dQ}{dV}$ steady state stability criterion can be made. $\frac{dQ}{dV}$ stability criterion can be implemented as an indicator in order to determine the stability or instability condition in the power system network.

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