EVALUATION OF CATASTROPHIC INDICATORS FOR POWER SYSTEM STABILITY ASSESSMENT

by

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Contents

Objectives

- To use MAT-POWER toolbox along with MATTRANS software to perform Transient Stability Analysis.
- To prepare an algorithm and codes for Catastrophic Indicators for Power System Stability Assessment for Simulated PMU Data.
- To obtain the results of indicators for simple transient stability analysis on IEEE 10 Bus and 145 Bus System

1. Indicator Based on Coherency:

- Coherency is the measure of the closeness of all generator rotor angles after fault-clearing (or closeness to the center of inertia COI).
- For example if the angles of all generators in Case A are closer to the COI after fault-clearing than in Case B, Case A is more coherent than Case B.
- The Performance Index is calculated as the maximum difference of maximum and minimum angle for all generators in some short period (say, 0.5 second) after fault clearing.
- $Performance\ Index = max\big(\theta_i(t)\big) - min\big(\theta_i(t)\big)$

2. Indicator Based on Transient Energy Conversion:

- Transient energy includes kinetic energy and potential energy.
- The transient kinetic energy is mainly related to the speed of generators. The transient potential energy includes three parts: position energy of all rotors relative to the COI, magnetic energy, and dissipation energy.
- If the system has enough potential energy capability, then the excess kinetic energy injected into the system can be “absorbed”, and the system will not lose synchronism, and reach a new stable equilibrium point.
- $Performance\ Index = max\big(V_{ke}(t)\big) - min\big(V_{pe}(t)\big)$

3. Indicator Based on Dot Products- Contingency Severity Assessment (CSA):

- A dot product. is defined for detecting the exit point in the Transient Energy Function method.
- AThe exit point is characterized by the first maximum of rotor angle deviation from COI with respect to the post-fault network.
- It is computed by the dot product of the fault-on rotor angle mismatch vector and the fault-on speed vector.
- $CSA(t) = \sum_{i=1}^{N_{area}} V_i(t) = \sum_{i=1}^{N_{area}} \omega_i(t)[\delta_i(t) - \delta_i(0^+)]$
- $Performance\ Index = max\big(CSA(t)\big) - min\big(CSA(t)\big)$

Catastrophic Indicators (cont.)

4. Indicator Based on Wide Area Severity Index (WASI):

- In a largely interconnected network, the power-transfer level increases, so to capture the fault severity of the area WASI indicator is defined.
- The WASI is defined as the logarithm of power spectral density (PSD) of the CSA index.
- At high power transfers, the signal energy exhibits an exponential increase, which can be captured through a log-linear relationship with power transfer.
- Therefore, the indicator includes logarithmic aspect, which makes the indicator more sensitive when it needs.
- $WAST(T) = log(max_{t \in [0^+, T]}(max_i(PSD(V_i(t)))))$
- $Performance\ Index = max\big(WASI(t)\big) - min\big(WASI(t)\big)$

5. Indicator Based on Inter-area Stability Prediction Index (ISPI):

- It works on the basis of 2 components voltage-magnitude change (reduction) and the phase-angle movement (separation).
- This index can be an alternative to the aforementioned WASI, which is defined in the frequency domain.
- considerable feature of this index is its fast and easy calculation from synchronously measured voltage without system modelling and simulation and without dependency on network size.
- It calculates the percentage change in voltage magnitude and its rate of change and angle deviation from center of inertia (COI) and also its rate of change of each coherent area.

- When these parameters change below a pre-specified threshold during system swings, an alert is done to prevent the system operator or to activate a control action.
- The level of ISPI is obtained between 100%, where
  - Less than 33% - Normal State
  - 33% to 66% - Alert State
  - More than 66% - Alarm State
- $ISPI = 1 - (1 - P\Delta V).(1 - PV').(1 - P\Delta d\delta gc).(1 - Pd\delta gc')$

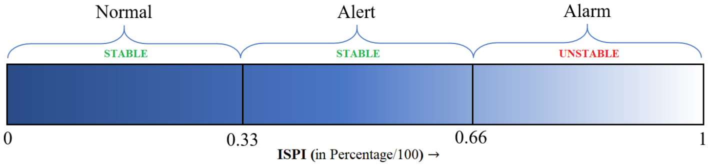
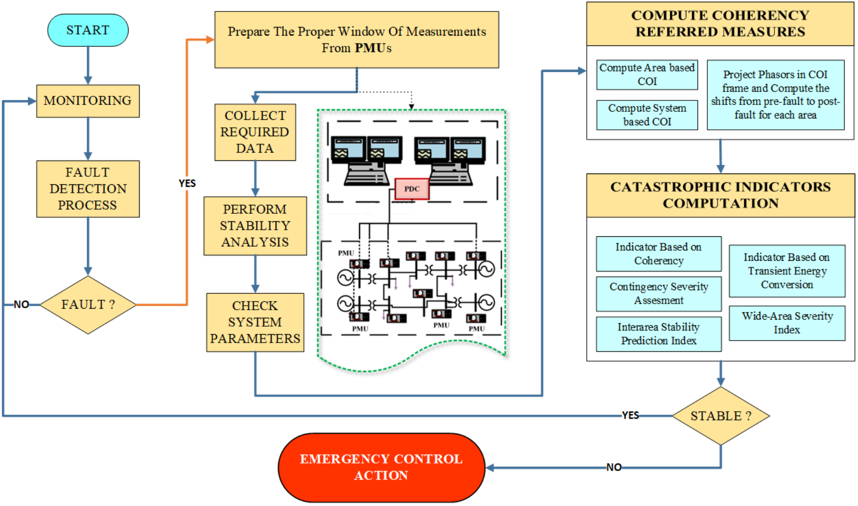


Figure: Stability Prediction Index Categories

Solution Methodology Flowchart

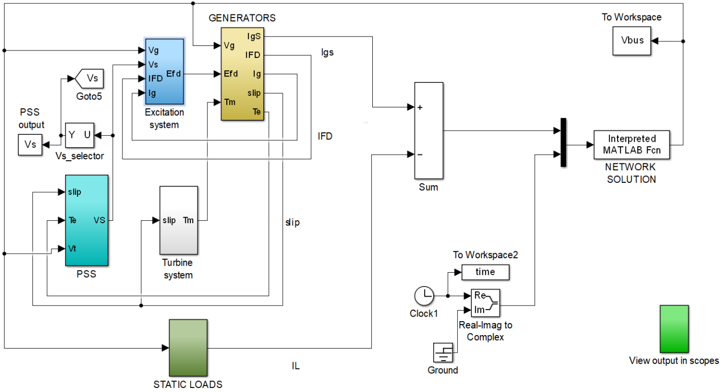


MATTRANS Tool Box

- MATTRANS is a free and open-source programme package of MATLAB(R)/Simulink (M-files and .mdl files) for performing transient fault analysis, developed in 2008 by G. Ravikumar.
- The MATTRANS syntax for using it is **runts(case# , case# dd);** which needs two input files in .m format: 1) network steady-state data and 2) network dynamic data. The network steady-state data is used from MATPOWER, whereas the network dynamic data includes generator machine parameters, exciter parameters, turbine parameters, and power system stabilizing parameters.
- All these dynamic data are taken from the execution of base simulation model **transientStability.mdl**, which includes various sub models such as Turbine System, Excitation system, Power System Stabilizer Model, Static Loads And there system parameter outputs.

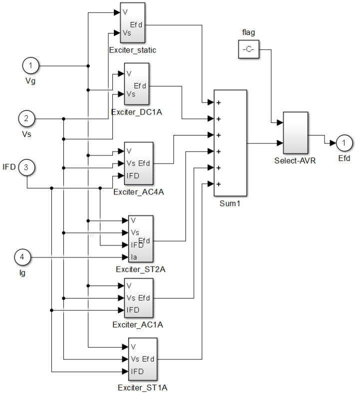
Transient Stability Model

- It is the base model which include various sub models to check for Transient Stability of a system, Main sub models includes Generators, Turbine System, Excitation system, Power System Stability Model, Static Loads and its outputs.

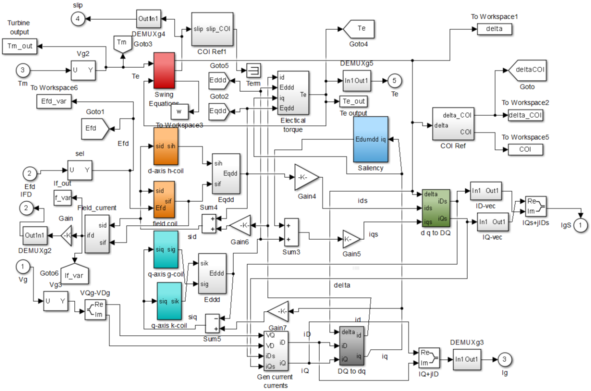


Excitation System Model

- This is an excitation system created to do the work of an generator exciter, it takes input of Vg, Vs, IFD and Ig and with the help of different exciter system it produces the Excitation voltage(EFD) and passes to the generator.

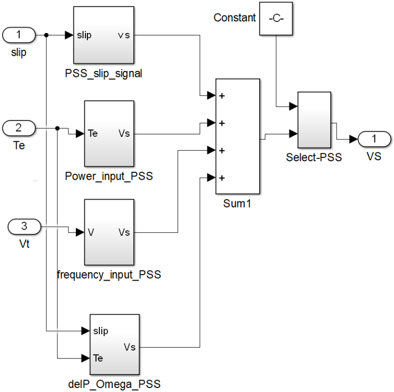


- It is the Generator Model created to do the work of a normal generator (Electric machine) and along with calculating its parameters like torque, angle deviation, field current, saliency etc..



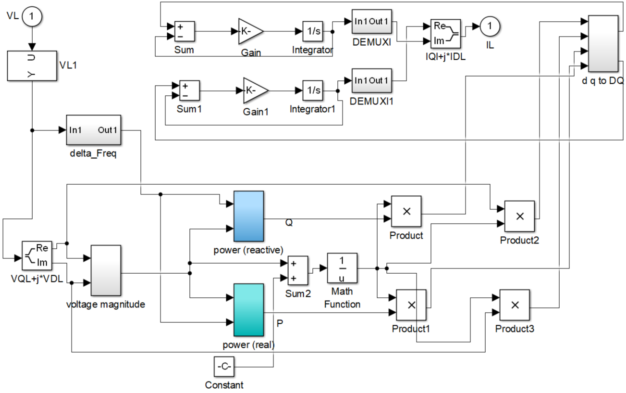
Power System Stabilizing Model

- It is created to give feedback to the excitation system according to the deviation of generator from the system parameters. It checks the generator slip and torque and bus voltage and by using four functions (Slip Signal, Power Input, Frequency Input and DelP_Omega) it gives the feedback voltage.



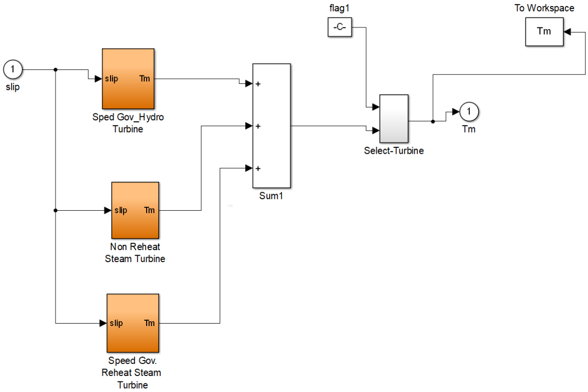
Static Loads Model

- This simulation model is prepared to create a load system which uses active and reactive part to calculate the consumption by the load with the help of various mathematical formulas and gives the current output to the system to calculate power consumption.



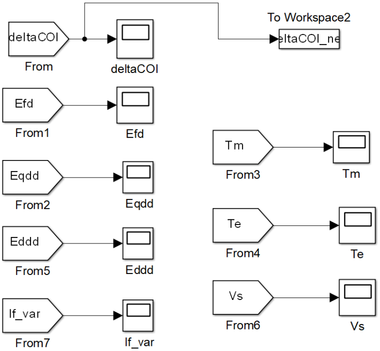
Turbine System Model

- Different Turbine Systems are included such as Speed Governor Hydro Turbine, Speed Governor Reheat Steam turbine and Non Reheat Steam turbine to add Turbine parameters to check system variance in case of real time use.



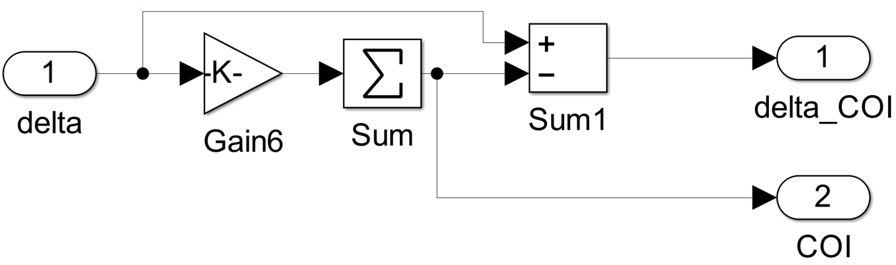
System Parameters Output in Scope

- 8 System parameters (Generator Angle Deviation, Field EMF, Quadrature Axis Parameter, Direct Axis Parameter, Field Current, Mechanical Torque, Electrical Torque and System Voltage) are loaded to observe the result of transient stability of the system in graphical form.



Generator sub-models modified for Indicator Evaluation

- Important part of the Indicator Evaluation is the calculation of rotor angle and and its deviation from center of Inertia (COI).
- Delta is the rotor angle of generator taken as input here to calculate COI and delta_COI.
- COI and delta_COI are the center of Inertia and Rotor angle deviation from Center of Inertia respectively.

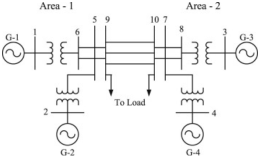


Solution Methodology Flowchart

- Choose the Test System
- Define the contingency to be analysed such as:
  - The line where fault occurred
  - Fault initiation time
  - Fault clearance time
- **for** (Fault clearance time = 0 sec to System unstable condition
  - **while** (an indicator is not processed) **do**
    - Collect the simulated PMUs for computing Performance Index of the respective indicator chosen.
    - Compute Performance Index of the respective Indicator using defined formula.
    - Output the Performance Index Curve.
    - **if** (Performance Index > Threshold value or sudden and maximum rise in PI)
      - Label the case as **Unstable**
    - **else**
      - Label the case as **Stable**
    - **end if**
  - **end while**
  - Increment the Fault clearance time by ΔTclear.
- **end for**
- Output the result data set for analysis and comparison of indicators.

Stability Analysis in 10 Bus 4 Generator System

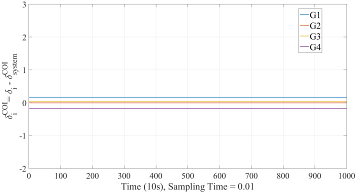
- To illustrate the application of mentioned catastrophic indicators, a practical 10 Bus 4 Generator network system (see fig.) is considered.



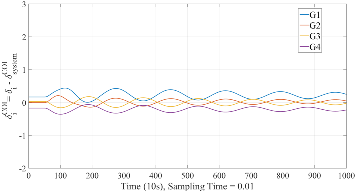
- One contingency is considered as follows
  - A base power flow is considered as a steady-state operating point
  - A three-phase short circuit fault at bus-9 is applied at 0.5 s (Tfault)
  - The fault is cleared in 0.1 s (Tclear) by opening the line between bus-9 and bus-10 (line contingency).
- So, assuming the fault initiated at 0.5 sec, for different fault clearing time, the faulted bus is provided for observing the transient stability result from performance of Indicators.

Results for Indicator based on Coherency

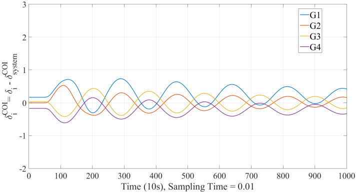
Speed Deviation Vs. Time Curve for:-



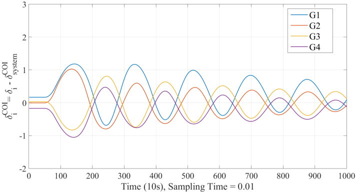
(a) No Fault



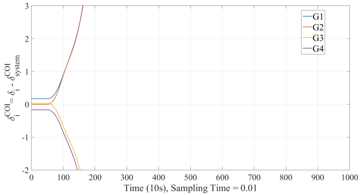
(b) Tclear = 0.1 sec



(c) Tclear = 0.2 sec



(d) Tclear = 0.3 sec



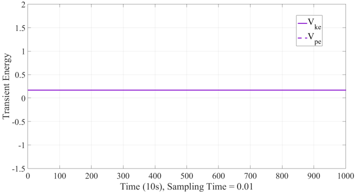
(e) Tclear = 0.4 sec

Table: Contingency Analysis using Indicator based on Coherency

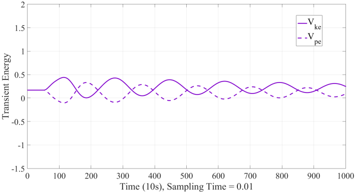
Fault Clearing Time	**Performance Index**	**Remarks**
No Fault	1.7262e-10	Stable
0.1 sec	0.4349	Stable
0.2 sec	1.0385	Stable
0.3 sec	1.8697	Stable
0.4 sec	66.9471	Unstable

Results for Indicator based on TEC (Transient Energy Conversion)

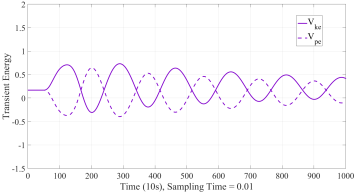
Transient Energy Vs. Time Curve for:-



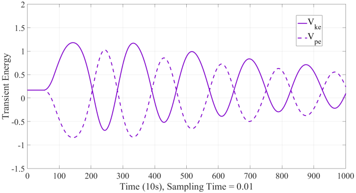
(a) No Fault



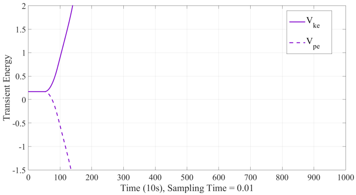
(b) Tclear = 0.1 sec



(c) Tclear = 0.2 sec



(d) Tclear = 0.3 sec



(e) Tclear = 0.4 sec

Table: Contingency Analysis using Indicator based on Transient Energy Conversion

Fault Clearing Time	**Performance Index**	**Remarks**
No Fault	3.3922e-10	Stable
0.1 sec	0.5432	Stable
0.2 sec	1.1266	Stable
0.3 sec	2.0253	Stable
0.4 sec	133.8941	Unstable

Results for Indicator based on Dot Products: Contingency Severity Assessment (CSA)

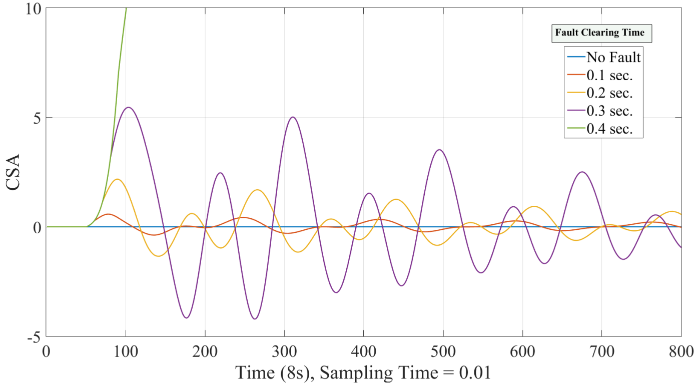


Figure: Contingency Severity Assessment Vs. Time Curve for different Tclear

Table: Contingency Analysis using Indicator based on Dot Products: Contingency Severity Assessment (CSA)

Fault Clearing Time	**Performance Index**	**Remarks**
No Fault	1.5902e-10	Stable
0.1 sec	0.9557	Stable
0.2 sec	3.5214	Stable
0.3 sec	9.6711	Stable
0.4 sec	2.4770e+03	Unstable

Results for Indicator based on Wide Area Severity Index (WASI)

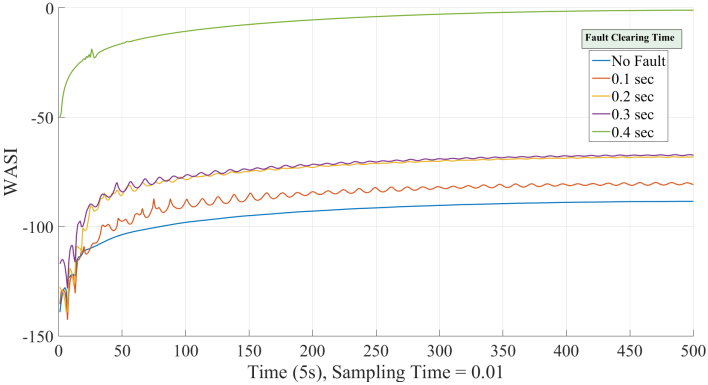


Figure: Wide Area Severity Index Vs. Time Curve for different Tclear

Table: Contingency Analysis using Indicator based on Wide Area Severity Index (WASI)

Fault Clearing Time	Performance Index	Remarks
No Fault	-88.4891	Stable
0.1 sec	-80.7781	Stable
0.2 sec	-68.1678	Stable
0.3 sec	-67.3590	Stable
0.4 sec	-1.0775	Unstable

Results for Indicator based on Inter-area Stability Prediction Index

Table: Contingency Analysis using Indicator based on Inter-area Stability Prediction Index (ISPI)

Fault Clearing Time	ISPI	Remarks
No Fault	0.0000	Stable
0.1 sec	3.1537	Stable
0.2 sec	11.6207	Stable
0.3 sec	31.9145	Stable
0.4 sec	82.5676	Unstable
0.5 sec	92.5350	Unstable

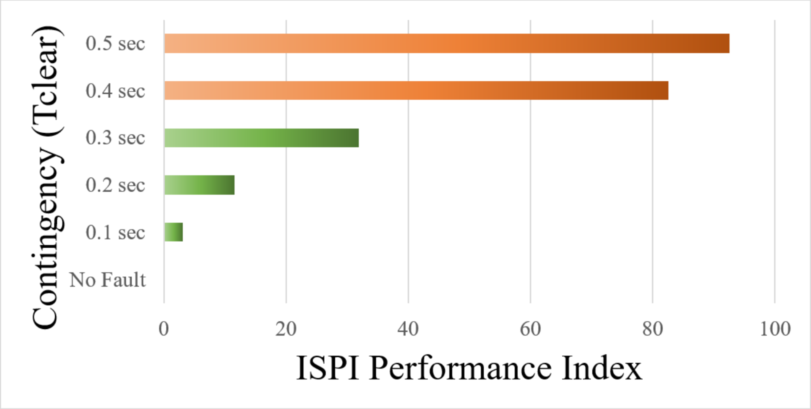


Figure: Graphical Representation of Inter-area Stability Prediction Index (ISPI)

Stability Analysis in Different Contingencies

Tclear	Coherency Based Indicator	TEC Based Indicator	CSA Indicator	WASI Indicator	ISPI Indicator	Remarks
Contingency 1: 145-Bus, 50-Machine System || Fault on Bus-100 || Line Tripped between Bus-100 and Bus-103						
0.1 sec	0.7925	1.1139	6.0352	-132.6903	19.9160	Stable
0.2 sec	1.9300	2.3566	17.9379	-81.9617	33.3588	Stable
0.3 sec	1.3248e+03	2.6497e+03	3.7071e+05	-9.2605	100	Unstable
0.4 sec	1.3913e+03	2.7826e+03	3.9845e+05	-6.9247	100	Unstable
Contingency 2: 10-Bus, 4-Machine System || Fault on Bus-8 || Line Tripped between Bus-7 and Bus-8						
0.1 sec	0.3341	0.6311	0.4248	-78.2523	1.4020	Stable
0.2 sec	0.5372	0.8180	0.7497	-77.2143	2.4740	Stable
0.3 sec	0.8436	1.1307	1.7686	-75.2880	5.8365	Stable
0.4 sec	1.2719	1.2682	3.8308	-63.7517	12.6416	Stable
0.5 sec	1.8062	2.1298	8.9612	-62.0844	29.5719	Stable
0.6 sec	28.7068	46.7095	317.4158	-4.7632	66.0481	Unstable
0.7 sec	38.9884	66.7956	382.7585	-1.3148	66.0580	Unstable

Results Discussion

- As sudden and large deviation in the curve are considered for analyzing the system behavior, i.e. Stable or Unstable, so the clear margin decides the strength of Indicator.
- Indicator based on coherency is very much simple and depends only on one parameter i.e. Rotor angle coherency, which is both advantage and disadvantage to the system. Its PI changes from 1.8697 to 66.9471 in $\Delta Tclear = 0.1$ sec.
- Indicator based on Transient energy conversion performance index changed from 2.0253 to 133.8941 in $\Delta Tclear = 0.1$ sec., the margin quite large from indicator based on coherency.
- Indicator base on dot products gives a fast, coarse and conservative ranking of the contingencies. Looking at its performance index the margin is quite large compared to both the above indicators, as its PI changes from 9.6711 to 2477 for $\Delta Tclear = 0.1$ sec.

Results Discussion (cont.)

- WASI don't show large margin in comparison to other but it can cover the exponentially rising high power signal energy.
- ISPI standardizes the system performance in the range 100%, by which the large system values converted to ISPI clearly differentiate between stable and unstable along with Normal, Alert and Alarming situation.

Conclusion

- After disturbance has been addressed, these indicators are focused on coherency, transient energy conversion between kinetic and potential energy, dot products, and generator coupling parameters.
- These indices are quick to calculate because they don't require a lengthy simulation to determine if a situation is stable or unstable as well as precise because they have a high probability of capturing all unstable circumstances.
- These indices have been examined on a variety of test systems in the background while developing project including the discussed contingencies, and the findings indicate that the result provided by each of the indicator is correct and match to the original data.
- The possibility of mis-detection is zero till now, so this could be useful in future contingency screening.
- And it is well known that some indices work better than others for particular power systems and that combinations of indices usually work better than a single index.

Future Scope

- The catastrophic indicators have been analyzed through a single method i.e. observing sudden and large deviation in the curve to analyze the system behavior in my paper.
- But there is need to define Threshold values for each indicator to observe the system behavior after fault. So, finding threshold values through any type of optimization method or any other makes this Indicator Evaluation a complete process.
- Execution of these indicators in parallel with a better computational performance can be achieved by developing an online implementation framework. The framework can be developed either by a high-performance computing (HPC) or by a parallel processing architecture.

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