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Dynamics of Momentary Reserves under Contingency: Observations from Numerical Experiments

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Brief

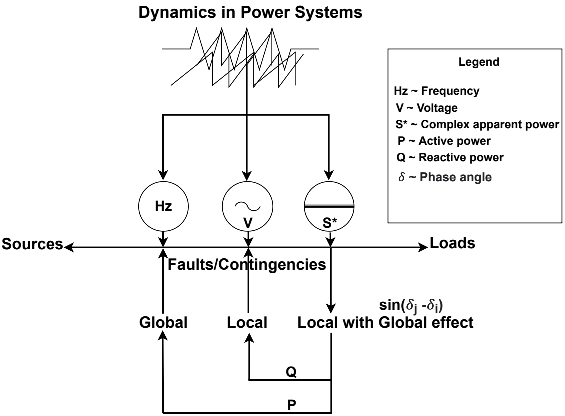
- B.Eng. in Electronic and Computer Engineering from Nnamdi Azikiwe University, Awka, Nigeria.
- M.Sc. in Electrical Engineering (Power) from Universität Rostock, Germany.
- Ph.D. in view from Jacobs University Bremen under the supervision of *Prof. Dr. Stefan Kettemann*
- Licensed Professional Engineer with COREN Nigeria.
- Worked with Redington Gulf, PHCN, MTN Nigeria, IHS Africa, MP-Infrastructure Limited, as Field Engineer.

Research Focus :

- Frequency and voltage dynamics in high voltage power transmission and distribution networks.
- Control devices for power system oscillations.
  –> `http://condynet.de/veroeffentlichungen.html`

Introduction

Power Systems Dynamics



Introduction

Power Systems Dynamics

This means that

the primary, secondary and tertiary control schemes of a grid frequency depend on the active power control of the controller.

But two questions arise due to disturbed operations :

- How much of P are the generators willing to momentarily supply or absorb through their droop functions for rapid frequency control response ?
- How does these few nodal injected chunks of active power (P) ensure a balanced synchronous frequency ?

–> to answer these questions, Let us observe how signals move across the network through the equation of motion.

Swing equation of motion

which describes the torque balance between the turbine's mechanical torque T_t and the electromagnetic torque T_e given as [1, 2, 3]

$$J_i \frac{d\omega_i^{\Theta}}{dt} + D_{r_i}\omega_i^{\Theta} = T_t - T_e - D_{r_i}\omega_0, \tag{1}$$

where $J_i = \frac{2H_i}{\omega_0^2} S_i$, D_{r_i} is the rotational loss due to generator rotor windings, and ω_i^{Θ} is the angular velocity of the rotor. With rotor's angular position δ, the swing equation can then be re-written in many forms as [4]

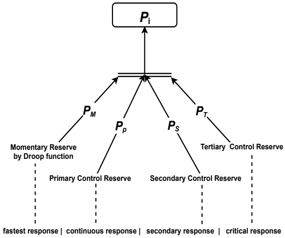
$$M_i \frac{d^2\delta_i}{dt^2} + D_i\left(\frac{d\delta_i}{dt}\right) = P_m - P_e, \tag{2}$$

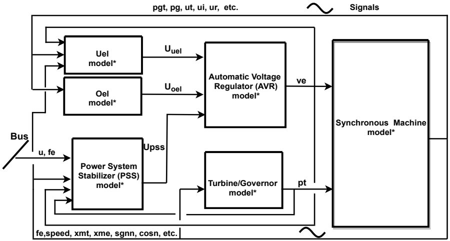
$$\frac{2H_i}{\omega_o} S_i \frac{d^2\delta_i}{dt^2} + D_i \frac{d\delta_i}{dt} = P_i + \sum_{j=1}^{N_S} W_{ij} \sin(\delta_j - \delta_i) \tag{3}$$

where rotor's $M_i = J_i\omega_0 = \frac{2H_i}{\omega_0} S_i$, $D_i = D_{r_i}\omega_0$ and W_{ij} is the power capacity.

1. Kundur, *Power System Stability and Control*, 1994
2. Machowski, Bialek et Bumby, *Power System Dynamics : Stability and Control*, 2008
3. Sallam et Malik, *Power System Stability : Modelling, Analysis and Control*, 2015
4. Manik et al., "Network Susceptibilities : Theory and Applications", 2017

Reserves and Introduction to PowerFactory





–> What happened to generator transient dynamic controllers (i.e., machine's AVR, TGOV, PSS, Uel, Oel), voltage equations, transient, subtransient and stationary reactances of the rotor windings, etc. ?

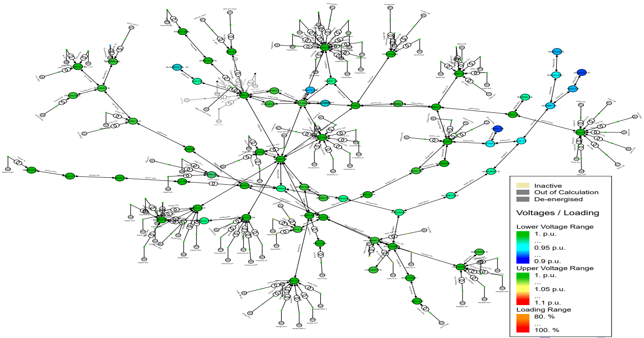
DigSILENT PowerFactory

–> A power simulation and application software
–> Modelling with higher (5^{th}) order machine equations.
–> Considers higher order voltage equations, transient reactance, etc.
–> Modelling machine's controllers according to IEEE Guides
–> Considers inhomogeneous distribution of inertia, etc.

Nigerian 330 kV Transmission Power Network

Summary of the grid

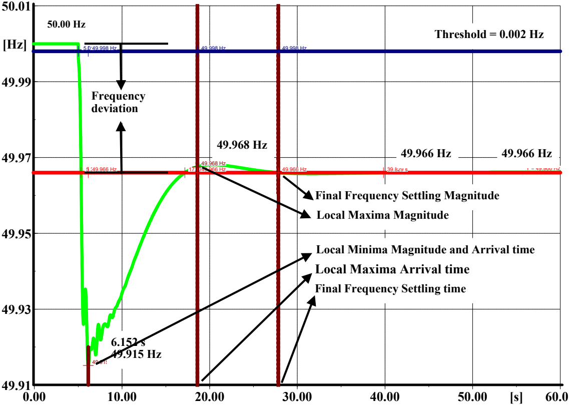
–> 107 less decommissioned power units of generators.
–> 71 overhead transmission lines with 1.32 kA limiting current and $13,208MW$ power capacity as of 2020.



Numerical Experiments in PowerFactory

Dynamics of Momentary Reserves

Frequency as a function of time at contingency. Frequency Time of Arrival (ToA) is defined as the time when the frequency deviation first reaches a small threshhold of $\delta\nu = 0.002$ Hz.



Numerical Experiments in PowerFactory

Dynamics of Momentary Reserves

Here, we choose 11 buses for the investigation ;
–> The fault location is bus 24 with H_{agg} as the aggregated inertia constant.
–> Two buses at the same geodesic distance, $r = 2$ from fault location with no inertia (i.e., buses 8 and 10) and three buses with inertia (i.e., buses 22, 55, and 57).
–> four buses at the same $r = 7$ (i.e., buses 7 and 30 with no inertia) and with inertia (i.e., buses 3, 28, and 69) [5].

Case studies

Case 1 : Large disturbance, no reserve at fault location given $H_{agg} = 2s$.
Case 2 : Large disturbance, large reserve at fault location given $H_{agg} = 2s$.
Case 3 : Large disturbance, large reserve at fault location given $H_{agg} = 6s$.
Case 4 : Large disturbance, large reserve at fault location and an increased reserve at bus 22 given $H_{agg} = 2s$.
Case 5 : Large disturbance, large reserve at fault location with a newly installed reserve at bus 7 given $H_{agg} = 2s$.

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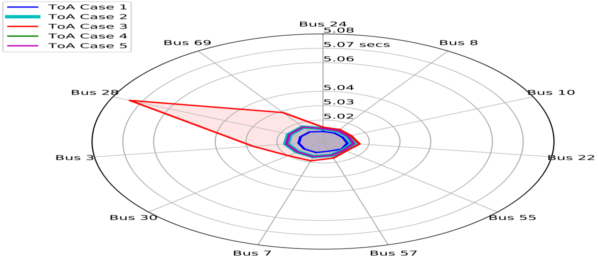
5. K.P. Nnoli and S. Kettemann,“Spreading of Disturbances in Realistic Models of Transmission Grids : Dependence on Topology, Inertia and Heterogeneity”, 2021

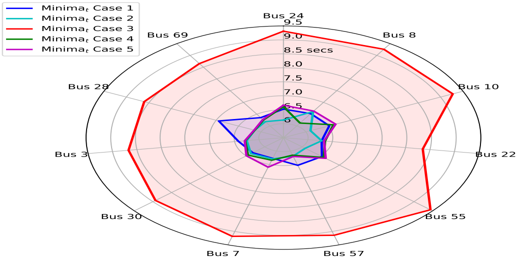
ToA Observations



Findings :

–> Disturbance arrived at Fault Location (FL, i.e., bus 24) first, delayed for buses at $r = 2$ and with further delays for buses farther away.
–> Frequency ToA increased in Case 2 due to Momentary Reserve (MR) at FL.
–> Means that MR delays the disturbance as it propagates.
–> Increasing the grid inertia causes further delay in ToA (i.e., more damping).
–> Further improvement of MR at other nodes did not improve the ToA from Case 2.

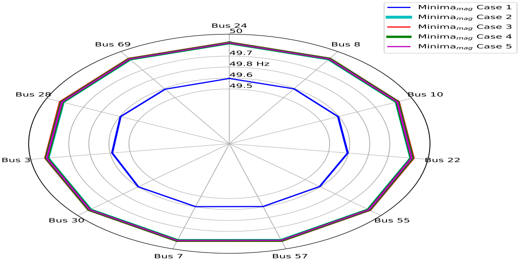
Minima time (Minima$_t$) Observations



Findings :

–> Minima$_t$ decreased in Case 2 from Case 1. This indicates oscillations damping.
–> MR at FL decreases the time of frequency dip (Minima$_t$) than at any other bus
–> Increasing the grid inertia causes further delay in the Minima$_t$
–> Further increment in the MR at other locations improved the delay in Minima$_t$.

Minima Magnitude ($\text{Minima}_{\text{mag}}$) Observations



Findings :

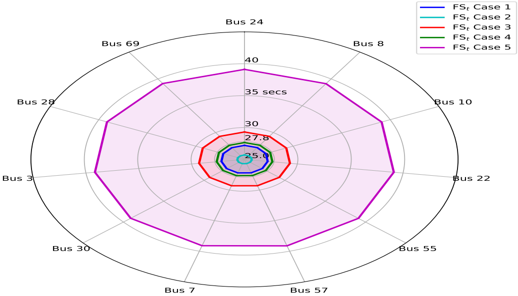
–> Without MR at fault location, the average $\text{Minima}_{\text{mag}}$ is greatly impacted in Case 1.

–> Introduction of inertia and MR at FL improved the frequency dip from Case 1 to Case 2.

–> Increasing the grid inertia alone does not have any improved impact on the magnitde of the frequency dip.

–> Further increment in the MR at other locations did not indicate further improvement in $\text{Minima}_{\text{mag}}$.

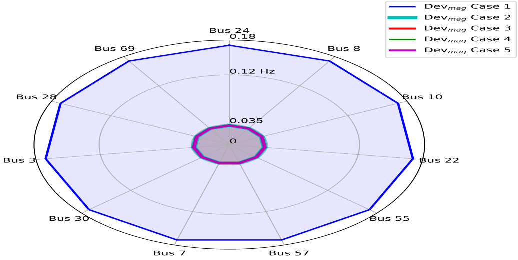
Final Settling time (FS_t) Observations



Findings :

–>Increasing the nodal MR at the FL decreases the frequency FS_t at the nodes.
–> Increment of MR at other location other than the FL further causes an increased FS_t.
–> Increasing the grid inertia causes further delay in the frequency FS_t.
–> Increasing MR at a location with a bus degree of 7 farther away from the FL decreases the FS_t.

Deviation Magnitude (Dev_{mag}) Observations



Findings :

–> Increasing the MR at the fault location greatly decreases the Dev_{mag}.
–> Further increment in MR at other locations does not show improvement.

Summary of Findings

–>increase in nodal MR delays the travel and arrival of disturbances.
–> MR improves frequency dip and reduces its FS_t.
–> Optimal placement of momentary reserve is at the point of contingency.
–> Increase in H_{agg} without increase in reserve does not improve Dev_{mag}.
–> Increasing MR reduces the need for primary and secondary control power.

THANK YOU FOR LISTENING!!!

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