A Plug and Play, Approximation-Based, Selective Load Shedding Mechanism for the Future Electrical Grid

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Outline

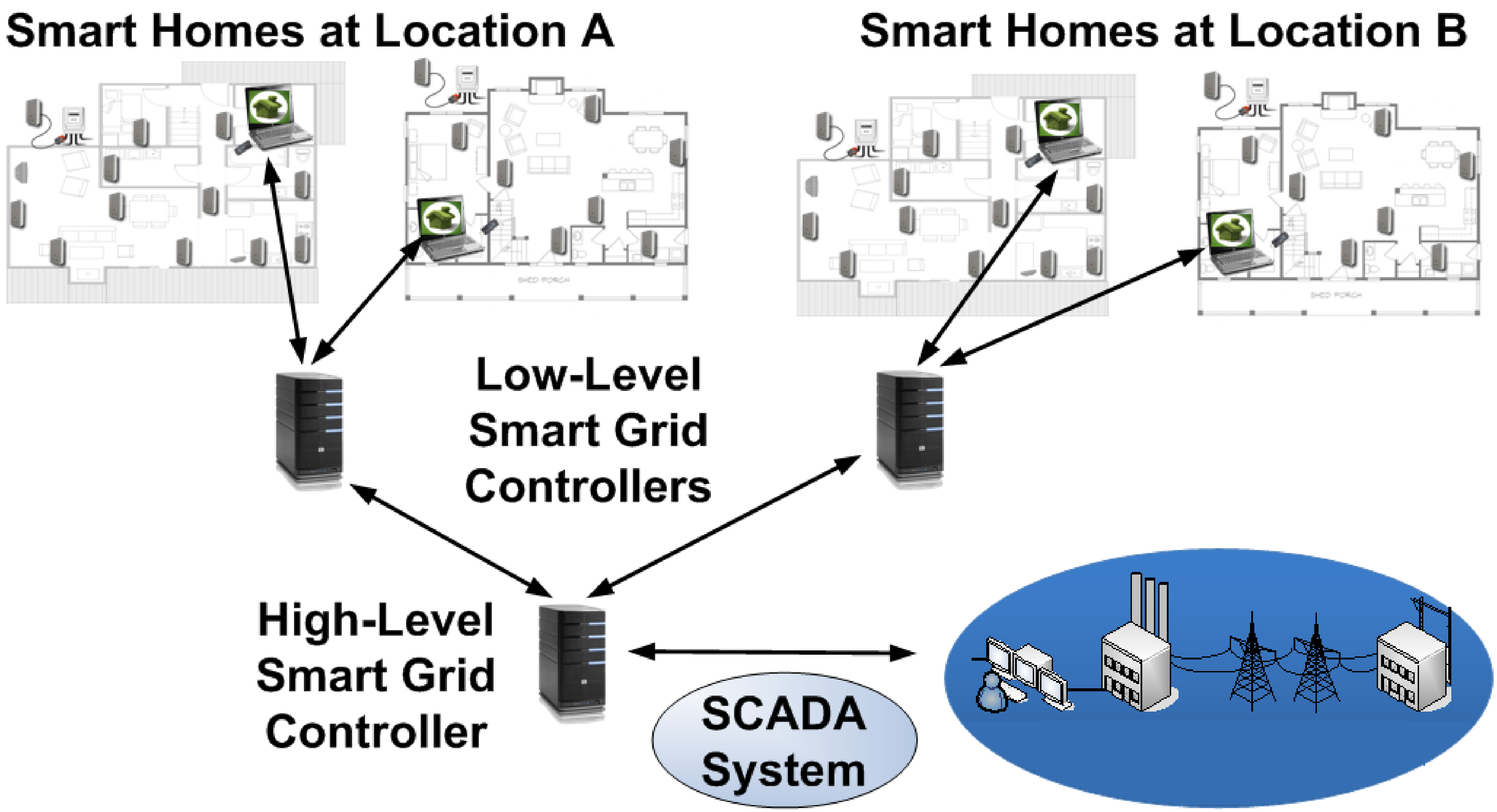
- The role of electric frequency and the Big Picture
- Conventional load shedding scheme
- The Proposed Scheme for Load Management
  - Methodology
  - Results
- Current and Next Steps
- Summary

Frequency as an accurate indicator of power balance

- Frequency as a ubiquitous indicator
- It is essential to be kept constant at 50/60 Hz (Why?)
- If not, drastic measures are taken:
  - Brutal load shedding == total blackout
  - Based on under-frequency relays –> over-shedding
  - Their operation is based on a rule of thump: the connected load magnitude should be decreased linearly in relation to the frequency decline.
  - Causes major inconvenience to consumers and businesses and costs a lot…

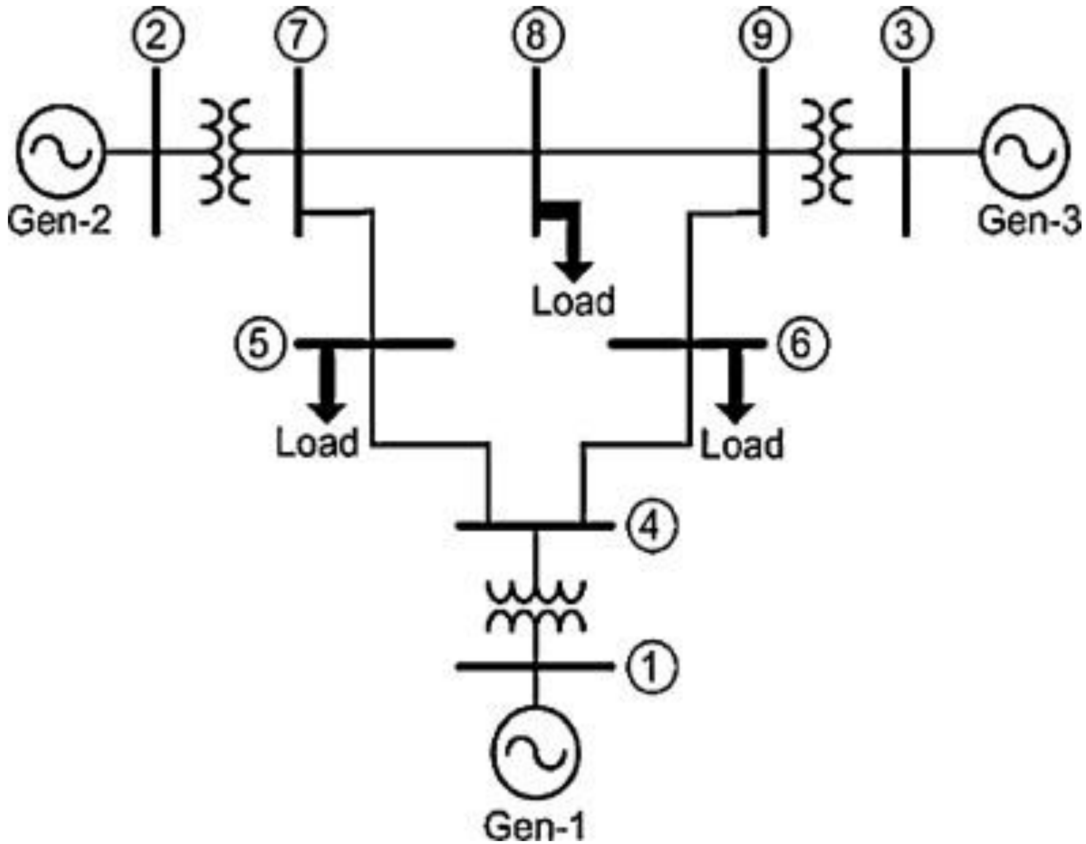
Solution: an automatic and more flexible scheme…

The Big Picture…



The Scenario…

- Nine-bus, Three-Machines, Three-Load, P. M. Anderson Test System



Methodology

- The swing equation of a power system is given by:

$$\frac{2H}{f_{syn}^{2}} f(t)\frac{df(t)}{dt} = p_{mp.u.}(t) - p_{ep.u.}(t) - \frac{Df(t)}{f_{syn}} \Rightarrow$$

$$\frac{df(t)}{dt} = \frac{f_{syn}^{2}}{2H}\left(\frac{p_{mp.u.}(t)}{f(t)} - \frac{p'_{ep.u.}(t) + \Delta p'_{ep.u.}(t)}{f(t)} - \frac{D}{f_{syn}}\right)$$

$$= \underbrace{\frac{f_{syn}^{2}}{2H}\left(\frac{p_{mp.u.}(t) - p'_{ep.u.}(t)}{f(t)} - \frac{D}{f_{syn}}\right)}_{g_1^{*}(f)} + \underbrace{\frac{f_{syn}^{2}}{2Hf(t)}}_{g_2^{*}(f)}\underbrace{\Delta p'_{ep.u.}(t)}_{u(t)}$$

Unknown functions

Methodology

- The two unknown functions are approximated with Linearly Parameterized approximators:

$$g_1^*(f) = \hat{g}_1\left(f, \theta_{g_1}^*\right) + \delta_{g_1}(f)$$

$$g_2^*(f) = \hat{g}_2\left(f, \theta_{g_2}^*\right) + \delta_{g_2}(f)$$

Minimum functional approximation error

where:

$$\hat{g}_1\left(f, \theta_{g_1}^*\right) = \Phi_{g_1}(f)^T \theta_{g_1}^* = \sum_{i=1}^{12} \theta_{g_{1i}}^* \varphi_{g_1}(\| f - c_i \|)$$

$$\hat{g}_2\left(x, \theta_{g_2}^*\right) = \Phi_{g_2}(f)^T \theta_{g_2}^* = \sum_{i=1}^{12} \theta_{g_{2i}}^* \varphi_{g_2}(\| f - c_i \|)$$

Methodology

- The control law is chosen as follows:

$$u = \frac{-a_m(f-1) - \Phi_{g_1}(f)^T \hat{\theta}_{g_1} - v_g}{\Phi_{g_2}(f)^T \hat{\theta}_{g_2}}$$

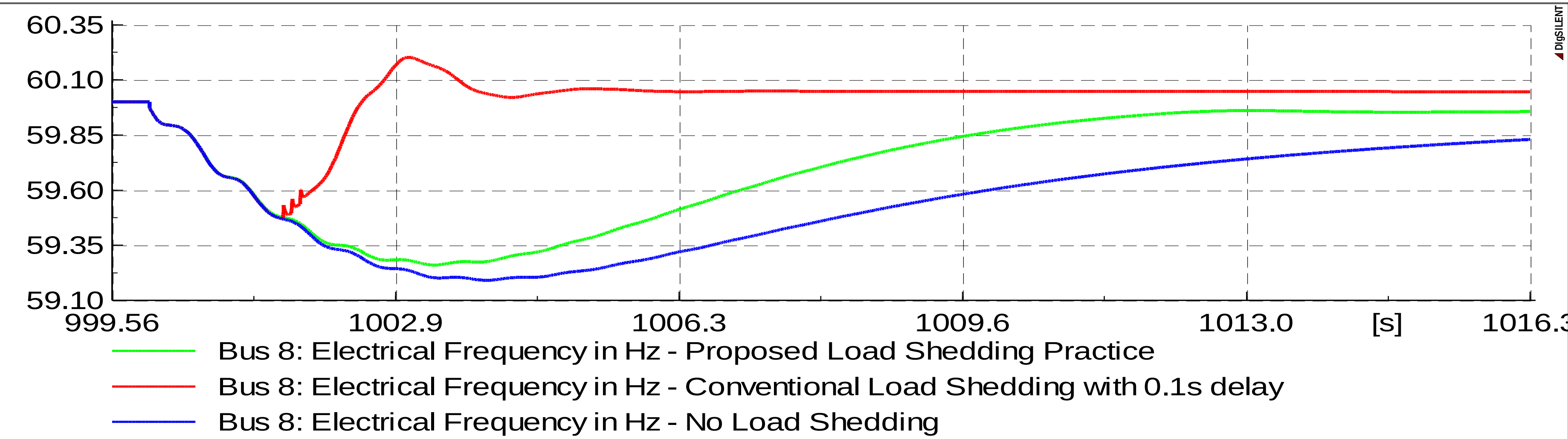
$$\dot{\hat{\theta}}_{g_1} = \Gamma_{g_1}\Phi_{g_1}(f)(f-1),\ \ \dot{\hat{\theta}}_{g_2} = \Gamma_{g_2}\Phi_{g_2}(f)(f-1)u,\ \ \alpha_L\delta_L(f) \le \delta(f,u,t) \le \alpha_U\delta_U(f)$$

$$v_g = \begin{cases} \hat{a}_U\delta_U(f) & \text{if } f > 1 \\ \hat{a}_L\delta_L(f) & \text{if } f < 1 \end{cases}$$

$$\dot{\hat{a}}_U = \begin{cases} \gamma_U(f-1)\delta_U(f) & \text{if } f > 1 \\ 0 & \text{if } f < 1 \end{cases}$$

$$\dot{\hat{a}}_L = \begin{cases} 0 & \text{if } f > 1 \\ \gamma_L(f-1)\delta_L(f) & \text{if } f < 1 \end{cases}$$

Results



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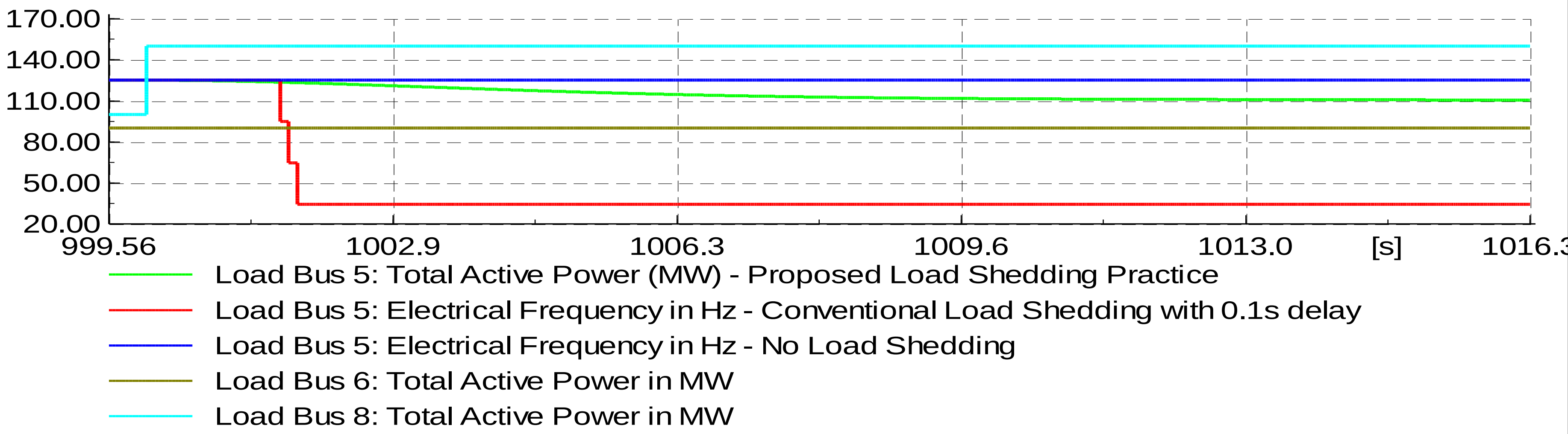
Bus 8: Electrical Frequency in Hz - Proposed Load Shedding Practice
Bus 8: Electrical Frequency in Hz - Conventional Load Shedding with 0.1s delay
Bus 8: Electrical Frequency in Hz - No Load Shedding



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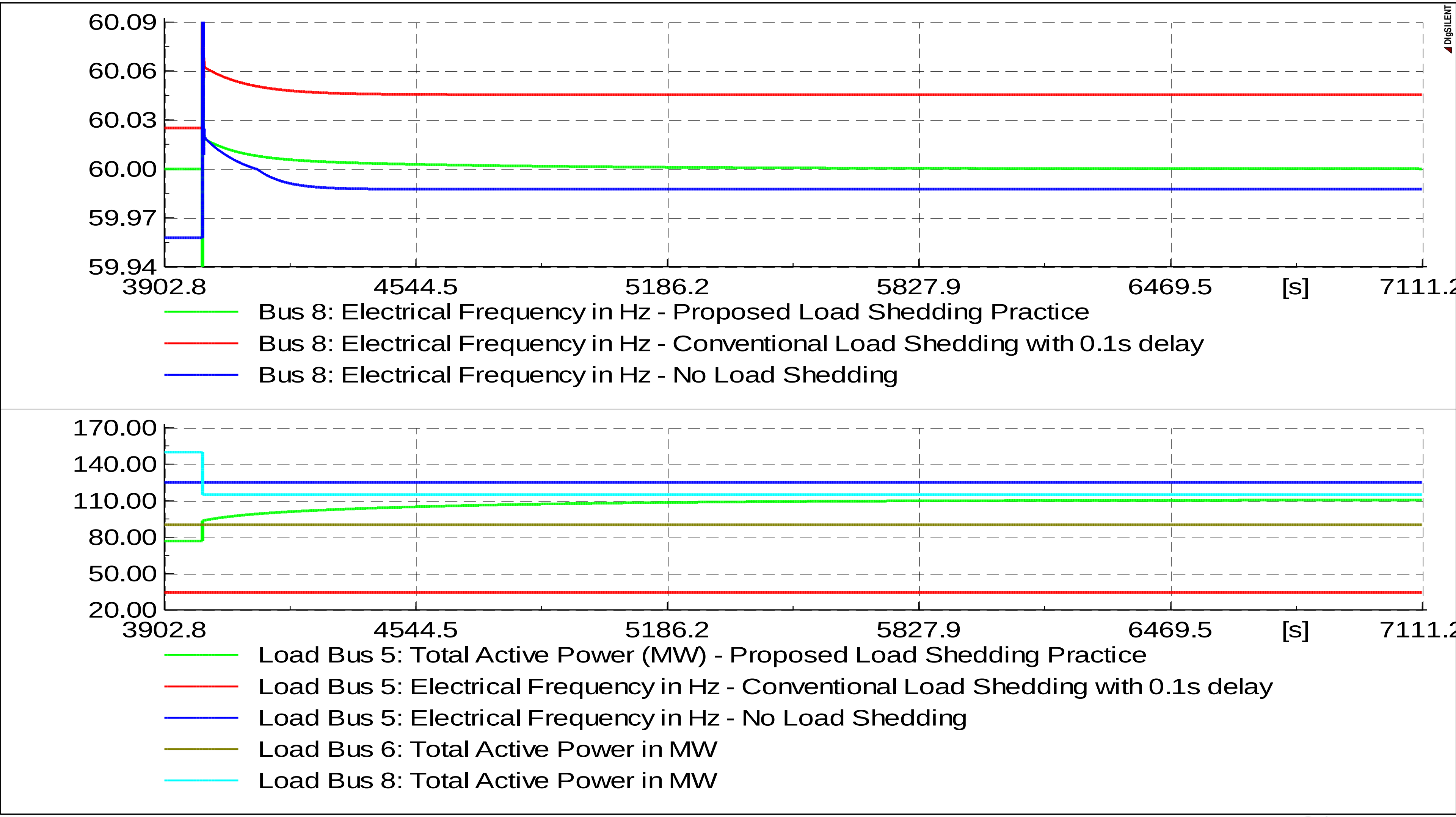
Load Bus 5: Total Active Power (MW) - Proposed Load Shedding Practice
Load Bus 5: Electrical Frequency in Hz - Conventional Load Shedding with 0.1s delay
Load Bus 5: Electrical Frequency in Hz - No Load Shedding
Load Bus 6: Total Active Power in MW
Load Bus 8: Total Active Power in MW

Results



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Conclusions

- Proposed Load Shedding Scheme outperforms the conventional practices, minimizing the load to be shed and maintaining the frequency in acceptable levels.

- It prevents over-shedding and extended under/over-frequency operation.

- It enables seamless load restoration preventing oscillations between shedding and restoration.

Questions

Thank you ☺

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