Energy Management of a Microgrid using Virtual Inertia and Energy Storage

Santa Clara University School of Engineering

Ahmed Saad Karsani (ahsaad@scu.edu), Saleh Dinkhah, Sofia Brumbaugh, Nathan Kehl, Advisor: Dr. Maryam Khanbaghi

Latimer Lab – Santa Clara University

ABSTRACT

- In this work, a microgrid (MG) is modeled in Simscape Electrical to propose an enhanced Energy Management Strategy (EMS) and implement virtual inertia for the inverter control scheme, following the addition of energy storage to the MG along with commercial loads, consisting of a synchronous machine (SM), a fuel cell and a photovoltaic (PV) system. Results illustrate the effectiveness of the proposed contributions.

1 PROBLEM STATEMENT

- Today's power grid experiences increasingly frequent outages mainly due to climate change, affecting its reliability. Renewable Energy (RE) sources are a solution for constant supply during grid outages (Fig. 1). However, there are some complexities faced with implementing microgrids (MGs) as they operate in a different manner than conventional generation, i.e. Synchronous Machines (SMs).
- All grid SMs are synchronized in terms of voltage and **frequency** (60 Hz or cycles/sec). However, RE (inverter-based) resources lack physical rotational inertia and are more likely to lose synchronism during a disturbance (Fig. 2 and Fig. 3).
- For efficient operation, MGs need hierarchical control consisting of **primary level stabilization**, secondary level regulation and **tertiary level Energy Management Strategy (EMS) optimization** (Fig. 3).
- At the **primary level**, there is a need to compensate for the lack of inertia with inverters control schemes introducing virtual inertia. At the **tertiary level**, there is a need to compensate for the economic capital of purchasing energy storage by introducing cheaper EMS techniques.

2 RESEARCH OBJECTIVES

- This study proposes the addition of energy storage for Santa Clara University (SCU)'s Sobrato Campus for Discovery and Innovation (SCDI) building for reliable energy supply during emergency scenarios, which is modeled as a grid-connected MG for our study.
- The study implements an enhanced hierarchical control scheme (as shown in Fig. 4) with two contributions: introducing energy storage and comparing the **EMS** advantages in terms of a base scheme without storage for tertiary level optimization, as well as introducing **virtual inertia** for better primary level stabilization.

REFERENCES

[1] Unisonenergy.com, "*Unison Energy Overview,*" [Online] Available at: https://unisonenergy.com/resources/blog/unison-energy-overview/, [Last Accessed: April 7th 2023].

[2] U. Tamrakar, D. Shrestha, M. Maharjan, B. P. Bhattarai, T. M. Hansen, and R. Tonkoski. 2017. "Virtual Inertia: Current Trends and Future Directions" Applied Sciences 7, no. 7: 654.

[3] L. Meng et al., "Flexible System Integration and Advanced Hierarchical Control Architectures in the Microgrid Research Laboratory of Aalborg University," in IEEE Transactions on Industry Applications, vol. 52, no. 2, pp. 1736-1749, March-April 2016.

[4] R. Ofir, U. Markovic, P. Aristidou and G. Hug, "Droop vs. virtual inertia: Comparison from the perspective of converter operation mode," 2018 IEEE International Energy Conference (ENERGYCON), Limassol, Cyprus, 2018, pp. 1-6

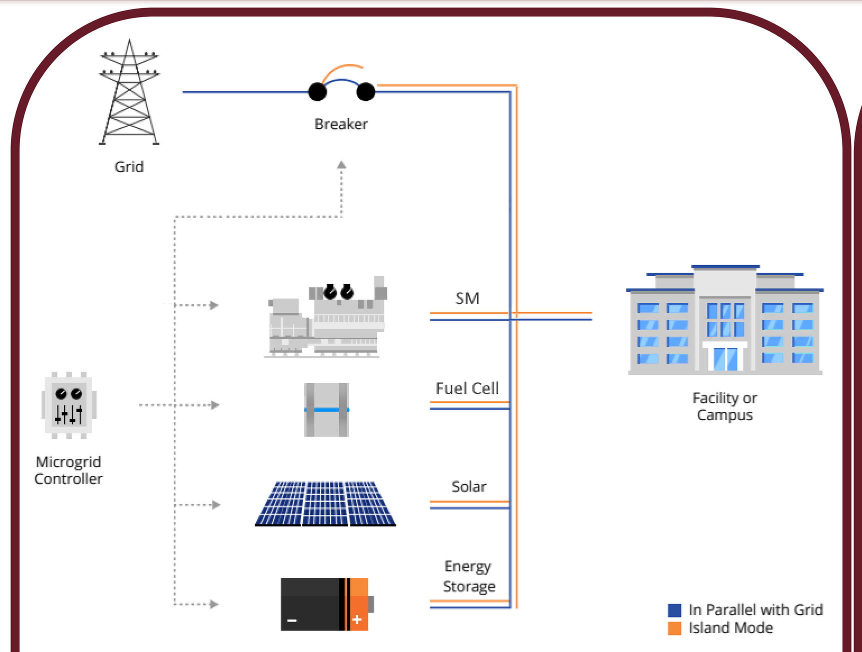

Figure 1: A microgrid (MG) model resembling Sobrato Campus for Discovery and Innovation (SCDI) building. A MG controller coordinates supply and demand across RE sources [1].

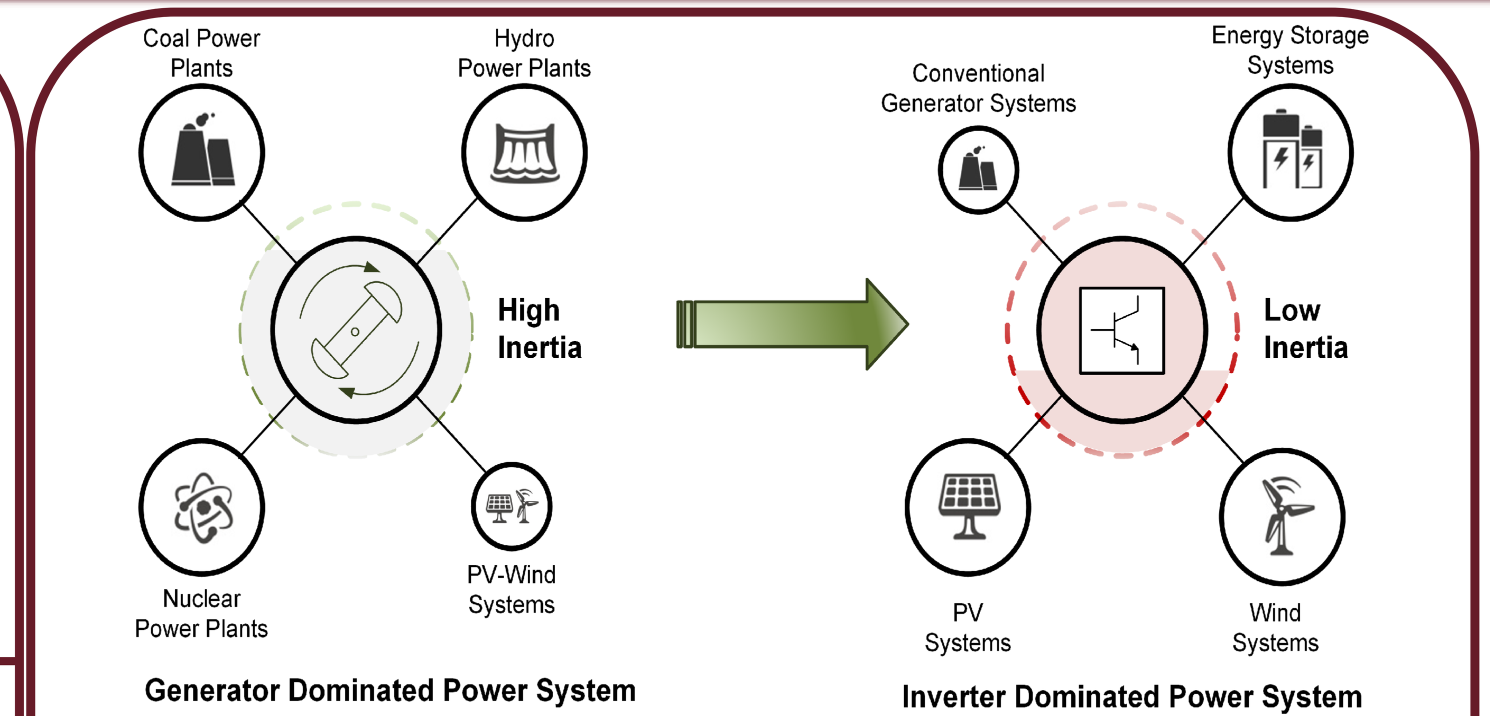

Figure 2: Power grids are transforming from synchronous machine (SM) dominated to inverter dominated with the integration of renewable energy (RE), reducing the overall grid inertia and its effectiveness in frequency stabilization and regulation [2].

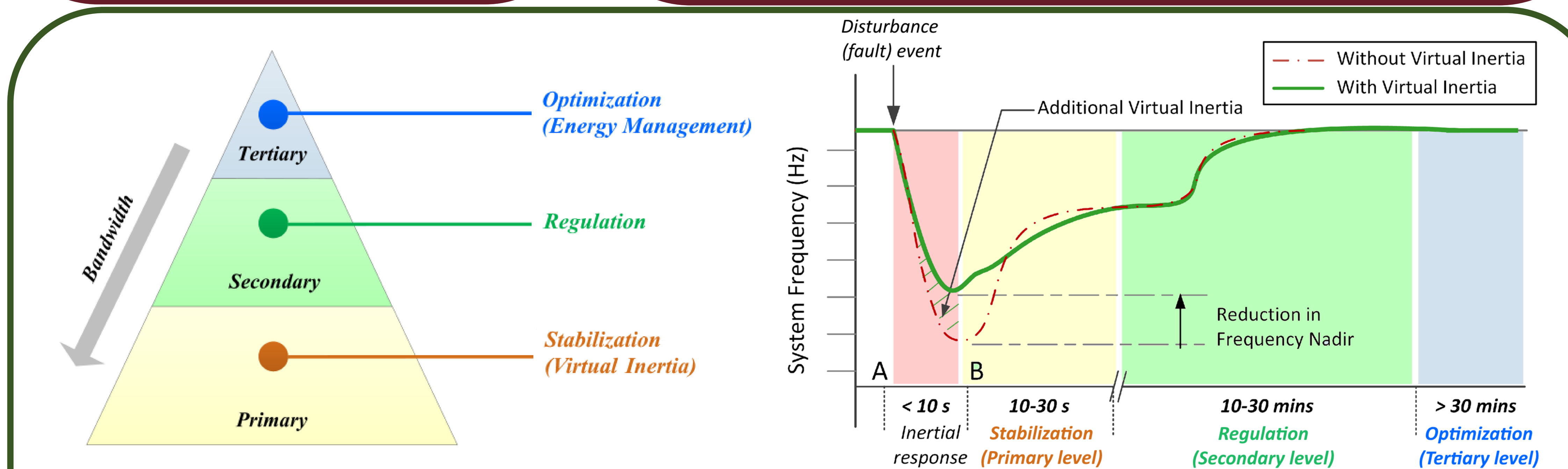

***Figure 3: Left:** A typical MG hierarchical control scheme [3]. **Right:** Rate of change of grid frequency with (green) and without (red) Virtual Inertia. Frequency oscillations are less, and sources are less likely to lose synchronism and disconnect from the grid [2].*

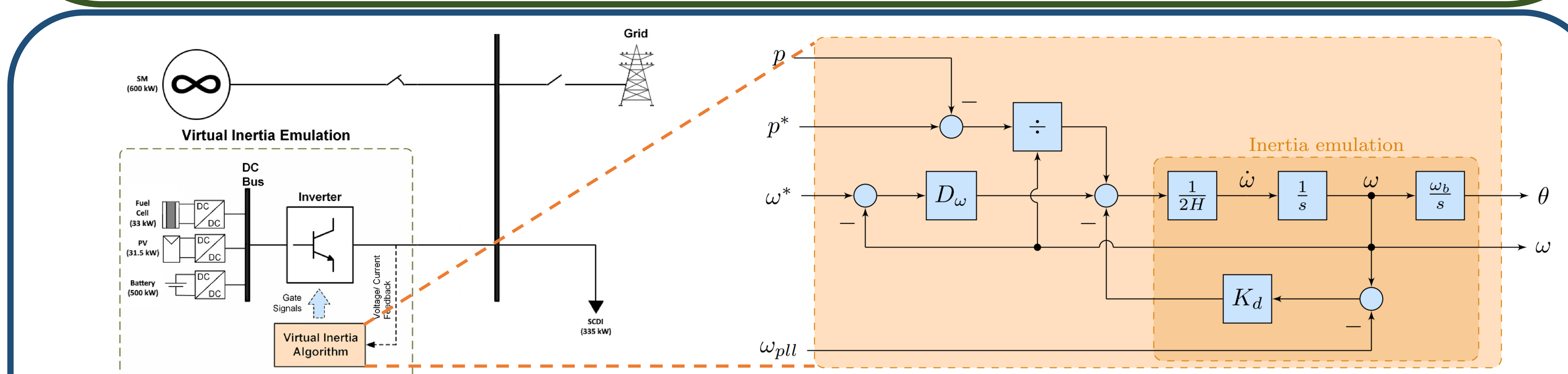

***Figure 4: Left:** The MG single line diagram of SCDI building. **Right:**. The virtual inertia control scheme added to further stabilize the microgrid frequency and dampen its oscillations, i.e. apply virtual inertia [2], [4].*

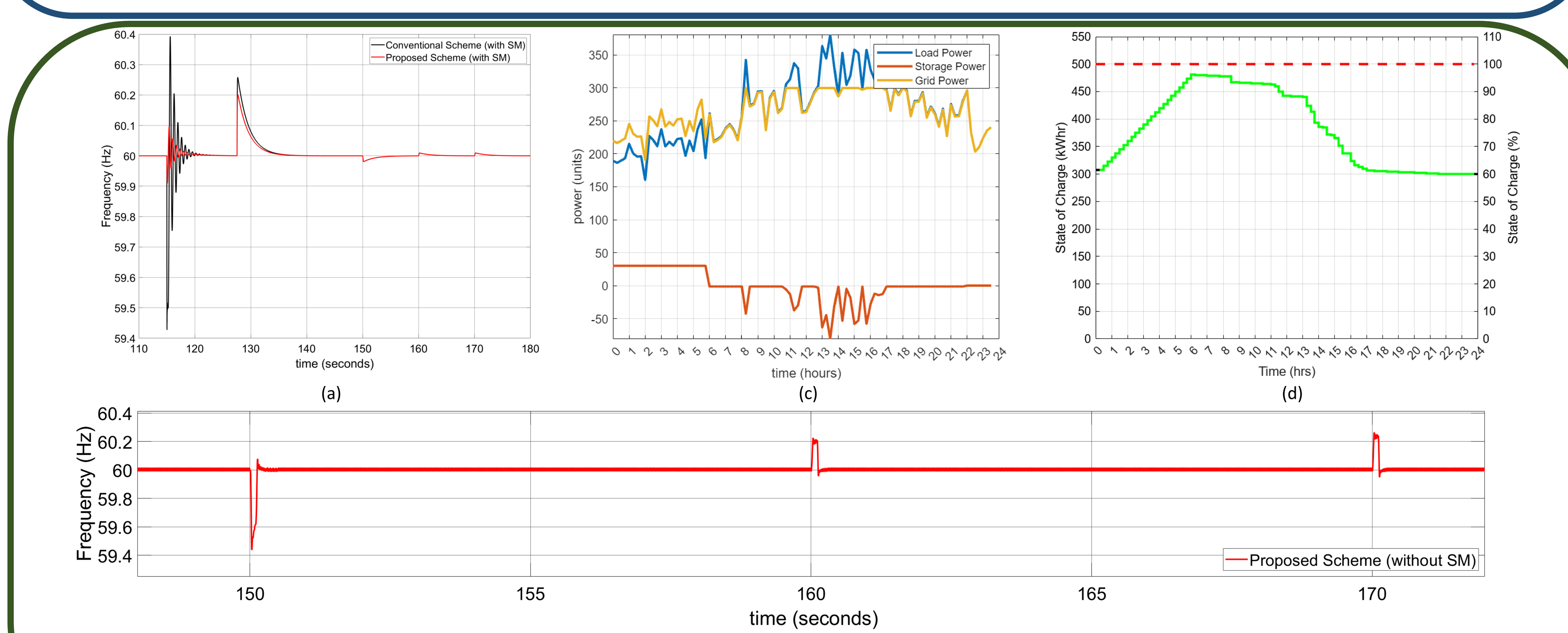

***Figure 5:** MG Frequency: (a) with SM using conventional droop control (black) and proposed control (red) and (b) without SM (blue). Results show lesser frequency oscillations. Energy Management Strategy Analysis: (c) Optimized Charging Profile for Peak Lopping and (d) Storage Unit State-Of-Charge (SOC).*

3 CONTROL DESIGN

- **Primary Level:** A conventional generator's rotational (inertial) dynamics (or changes in frequency) can be represented by the swing equation:

$$M\dot{\omega} = \underbrace{P_m}_{P_{in}} - \underbrace{P_e}_{P_{out}}$$

- Based on above, the proposed inverter virtual inertia primary level control scheme (Fig. 4) with droop (i.e. linear relation between active power P and angular frequency ω, and damping (to lessen frequency oscillations) [2]:

$$M\dot{\omega} = \frac{P^* - P}{\omega} - \underbrace{D_\omega(\omega - \omega^*)}_{Droop} - \underbrace{K_d(\omega - \omega_{pll})}_{Damping}$$

- where P^* and P are the reference and actual active power, ω_s, ω_{pll} and ω are the base, grid and calculated angular frequency, H is the inertia constant and D_ω and K_d are the droop and damping gain coefficients.
- **Tertiary level:** In terms of EMS, constrained cost optimization has been performed on MATLAB following the addition of energy storage into SCDI, considering peak lopping (capped grid supply), peak and off-peak grid energy cost, and State of Charge (SOC) limits. The constrained optimization utilizes quadratic programming (interior point method):

$$J = min_x \frac{1}{2} x^T G x + f^T x$$

- where x is the storage power, G is its variation and f is the grid cost.

4 SIMULATION RESULTS

- **Primary Level:** The proposed scheme is compared with conventional droop-only control scheme. In Fig. 5 (a), the MG has an operating SM. The frequency fluctuations are lesser when the MG goes from islanded to grid-connected mode at 115 secs.
- After 127 secs, the islanding detection scheme detects an increase in grid frequency to 60.5 Hz which results in the MG going back to islanded mode. At 150, 160 and 170 secs, the load changes but both conventional and proposed schemes produce similar frequency oscillations. In Fig. 5 (b), without the SM, no feasible results were obtainable for the conventional control scheme.
- **Tertiary Level:** Fig. 5 (c), (d) shows the optimized charging profile for peak lopping and storage unit SOC, using a 24 hour SCDI load profile. The grid supply peak is 300 kW, and the utility's Time-of-use (TOU) peak hours are between 6 AM and 10 PM. Therefore, The storage SOC is 100% at off-peak hours (0.104 \$/kWh) and discharges during peak hours (0.136 \$/kWh), resulting in a 0.71% reduction in energy cost. It is also assumed there is an SOC lower limit of 50% as 'operating reserve' in case of emergencies.

5 CONCLUSION

- In this work, an SCU-based MG is modeled with added energy storage, and tertiary level Energy Management Strategy (EMS) along with a primary level virtual inertia schemes have been successfully implemented as demonstrated by simulation results on MATLAB/Simscape.