SAND2021-0357C

Smart Inverter Functions and Features for Power System Parameter Estimation

ISGT 2021 Panel Session On:

Technological Advancements for Large Scale Adoption of Smart-Inverters

Ujjwol Tamrakar, Ph.D.
Postdoctoral Appointee
Sandia National Laboratories

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

IEEE PES Power & Energy Society®

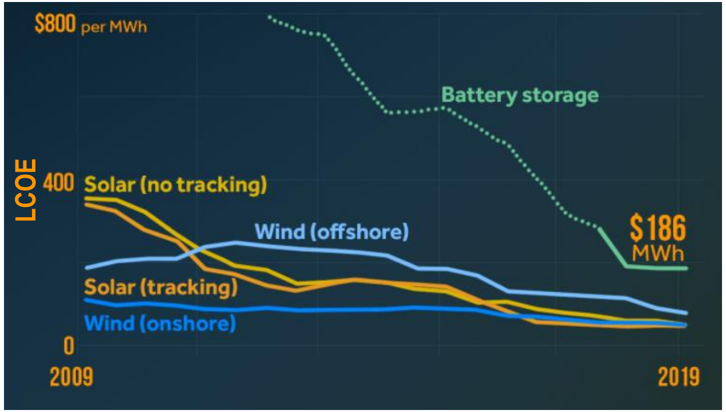
IEEE

Outline

- Introduction
- Smart inverters – Building Block of Smart Grids
- What are “smart” inverters?
- Functions of smart inverters
- IEEE 1547 and smart inverters
- Outlook beyond IEEE 1547
- Application: Inertia estimation in low inertia microgrids
- Conclusions

Renewables and Smart Grids

- Cost of renewables declining
- High penetration results in:
  - Overvoltages, frequency excursions (low-inertia)
  - Compromises reliability and stability



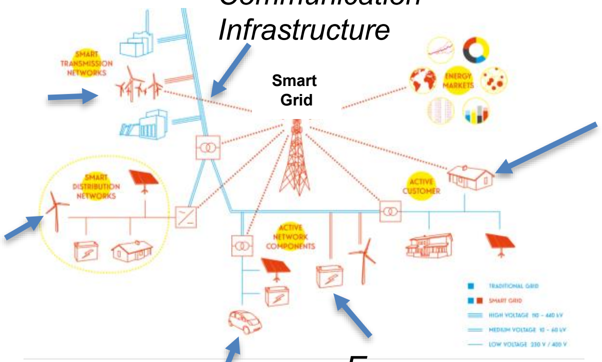
***Source**: Climate Central. https://www.climatecentral.org/*

Renewables are HIGHLY INTERMITTENT!

How do we integrate renewable energy sources without compromising reliability and stability?

IEEE PES Power & Energy Society® IEEE

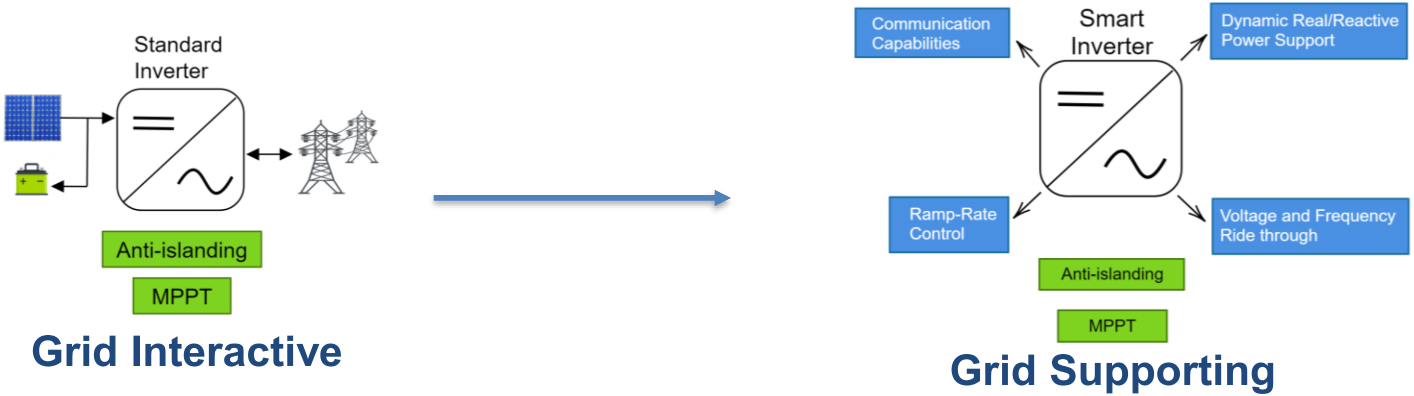
Smart Inverters: The Building Block of Smart Grids



***Source**: Smart Grids and Energy Markets. Available: http://sgemfinalreport.fi/list*

- Components of a smart grid are interfaced using smart inverters
- Smart features: Ensure reliable and stable integration
- Building blocks of smart grids

What are "smart" inverters?



"An inverter that performs functions that, when activated, can autonomously contribute to grid support during excursions from normal operating voltage and frequency by providing:"

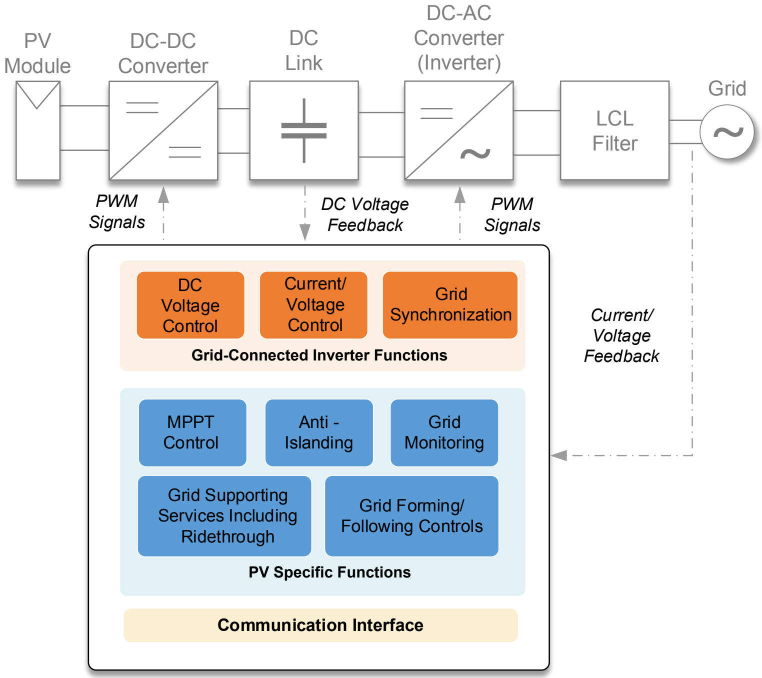
- Voltage and frequency ride-through
- Dynamic reactive/real power support
- Ramp-rate Control
- Communication Capabilities

__Enabling Smart Inverters for Distribution Grid Services__. Tech Report. October 2018. Available [Online]:https://www.pge.com/pge_global/common/pdfs/about-pge/environment/what-we-are-doing/electric-program-investment-charge/Joint-IOU-SI-White-Paper.pdf

Functions of Smart Inverters

- For PV specific functionalities include:
  - MPPT, Anti-islanding
  - Voltage and frequency ride through
  - Grid support services
  - Grid forming controls

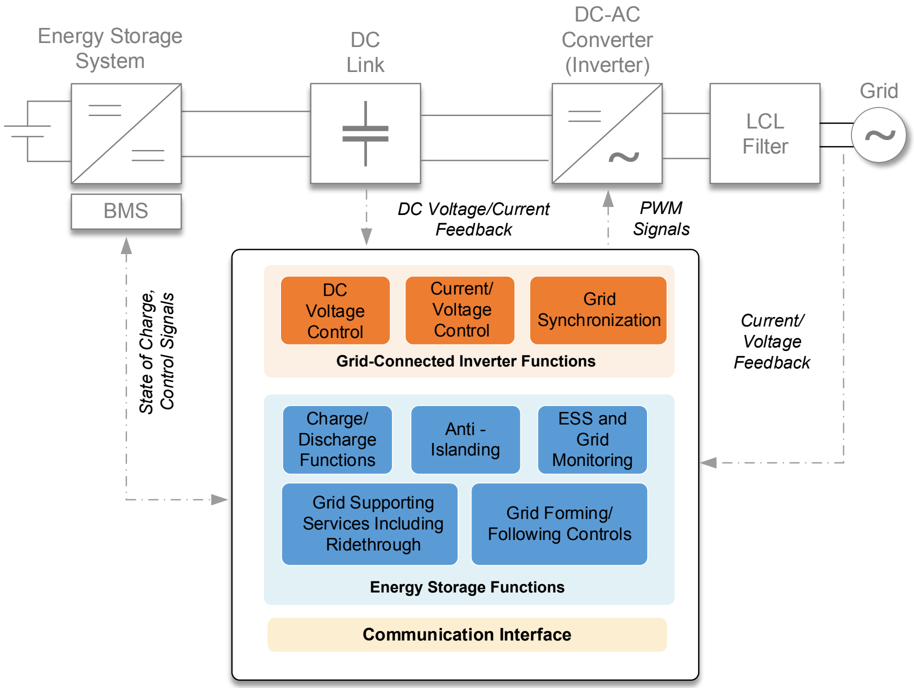
- Cyber-physical systems
  - Communication key for optimal operation, economic dispatch of units



Functions of Smart Inverters

- Functions specific to energy storage include:
  - Ideal for grid forming functions
  - Energy storage charge/discharge
  - ESS and grid monitoring

- Enables ESS to participate in behind the meter (BTM) and utility-scale applications



IEEE 1547 and Smart Inverters

IEEE 1547-2003

- Shall NOT actively regulate voltage
- Shall trip on abnormal voltage/frequency

↓

IEEE 1547a-2014 (Amendment 1)

- **May** actively regulate voltage
- **May** ride through abnormal voltage/frequency
- **May** provide frequency response[1] (frequency-droop)

↓

IEEE 1547-2018

- **Shall be capable of** actively regulating voltage
- **Shall** ride through abnormal voltage/frequency
- **Shall be capable of** frequency response[2]
- **May** provide inertial response[3]

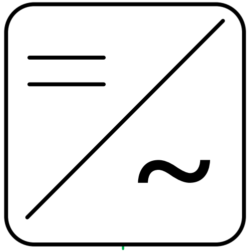
***Source**: IEEE 1547 Standard for Interconnecting Distributed Energy Resources with Electric Power Systems. Available : https://energyworkshops.sandia.gov/wp-content/uploads/2018/08/6_Vartanian_2018_PE_Workshop.pdf*

- Defines functional requirements of a smart inverter
- Progression from grid interactive to grid supporting inverters can be seen in IEEE Std. 1547 standard as well
- For transmission and sub-transmission level IEEE P2800 standard is under development

Outlook Beyond IEEE 1547

Current Status

- MPPT, Charge/Discharge, Anti-islanding
- Grid Support Functions
  - Voltage/Frequency Ride Through
  - Ramp-rate control
  - Dynamic reactive/real power support
  - Advanced protection schems
- Communication Capabilities

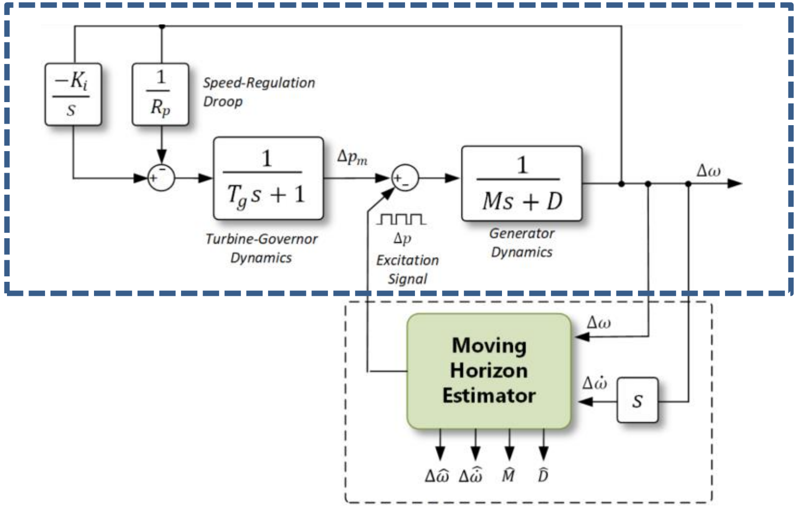


Future Outlook

- Inertial Support (Grid Support Function)
- Analytics
  - Forecasting
  - Parameter Estimation
  - Diagnostics
- Storage/Demand Response
- Cybersecurity
- Adaptability/ Situational Awareness
- Communication leveraged optimal operation

Inertia Estimation Using Smart Inverters

Power System Representation

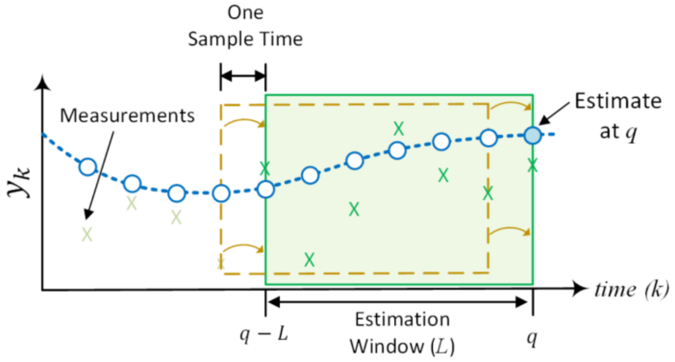


ESS with Inertia Estimation Algorithm

- Energy storage systems (smart inverters) can be used to excite the frequency dynamics
- Estimate inertia of the power system online
  - Improved control and resource allocation

Formulation of MHE for Inertia Estimation

Concept of MHE



Predictive Model

$$\begin{bmatrix}\Delta\dot{\delta}\\ \Delta\dot{\omega}\\ \Delta\ddot{\omega}\end{bmatrix} = \begin{bmatrix}0 & 1 & 0\\ 0 & 0 & 1\\ -\frac{K_i}{MT_g} & -\left(\frac{D}{MT_g}+\frac{1}{R_pMT_g}\right) & -\left(\frac{D}{M}+\frac{1}{T_g}\right)\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta\omega\\ \Delta\dot{\omega}\end{bmatrix} + \begin{bmatrix}0\\ 0\\ \frac{-1}{MT_g}\end{bmatrix}(\Delta P)$$

MHE Formulation

$$\underset{\hat{x},\Delta\hat{p},\hat{M},\hat{D}}{\text{minimize}}\ J_L := \sum_{k=q-L}^{q}(C_d\hat{x}_k-y_k)^\top V\,(C_d\hat{x}_k-y_k) + \sum_{k=q-L}^{q-1}(\Delta\hat{p}_k-\Delta p_k)^\top W\,(\Delta\hat{p}_k-\Delta p_k)$$

*Penalize difference between predicted and measured outputs by **V***

*Penalize difference between applied and measured control input by **W***

subject to

$$\hat{x}_{k+1} = A_d\hat{x}_k + B_d\Delta\hat{p}_k \quad \forall k\in\{q-L,\ldots,q-1\}$$

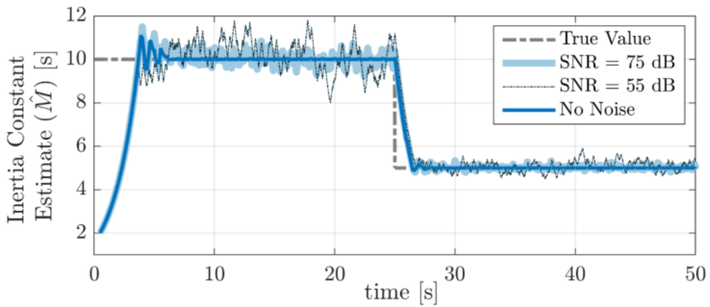
$$M^{min}\le\hat{M}\le M^{max} \qquad D^{min}\le\hat{D}\le D^{max}$$

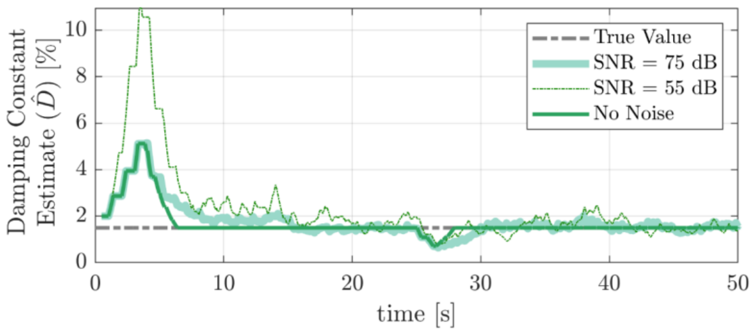
Optimal Estimates

$\hat{x},\Delta\hat{p},\hat{M},\hat{D}$

Next sampling instant

Inertia Estimates for a Linearized Power System Model

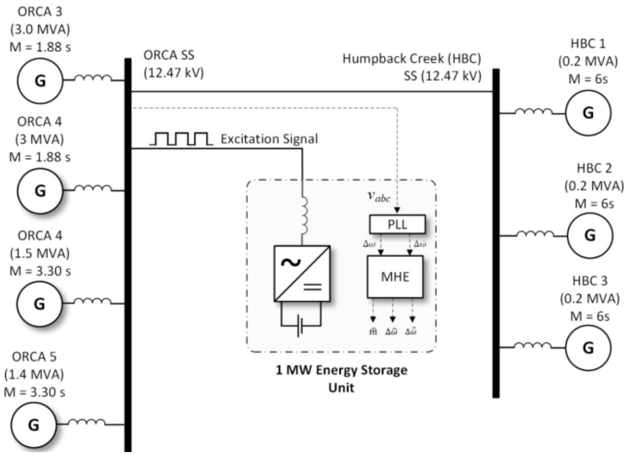




- Simulation for different noise levels, Gaussian distribution with zero mean
- MHE can estimate change in inertia and damping constant
- Higher error with higher noise (still acceptable errors)

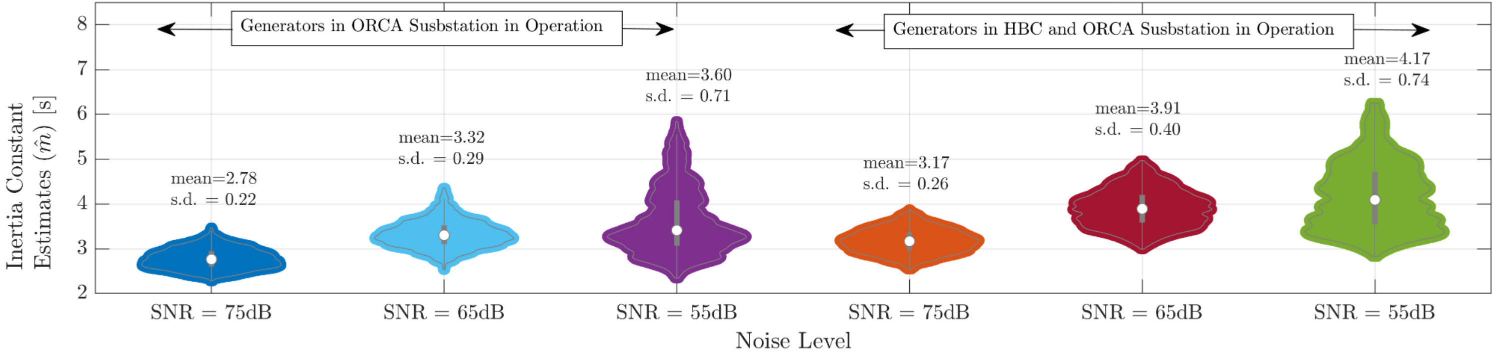
U.Tamrakar, D.Copp, T. Nguyen, T.M. Hansen, and R. Tonkoski, "**Online Moving Horizon Estimation of Inertia Constant of Microgrids**", to be submitted to IEEE Access.

Inertia Estimation for Modified Cordova, Alaska Microgrid Benchmark



- 1 MW energy storage unit installed at the ORCA substation
- ESS used to inject excitation signal, a PLL then measures the change in frequency
- MHE implemented within the ESS’s control system

Inertia Estimates for Modified Cordova, Alaska Benchmark



- Estimates close to the calculated inertia constant of
  - 2.34 s with ORCA substation and 2.57 with both ORCA and HBC substations online
- Increase in estimation error higher noise in the measurements
- Able to detect change in system inertia when both substations are interconnected

Conclusions

- Smart inverters are capable of providing number grid supporting services
  - Helps in reliable integration of renewables
- Future applications can go beyond grid supporting services
- Inertia estimation for microgrid system demonstrated
  - Can be expanded to interconnected power system utilizing distributed smart inverters
- Advanced applications like forecasting, optimal control, cybersecurity, etc. are generating interest

Acknowledgements

Dr. David A. Copp, *University of California-Irvine*

Dr. Tu Nguyen, *Sandia National Laboratories*

Dr. Timothy M. Hansen, *South Dakota State University*

Dr. Reinaldo Tonkoski, *South Dakota State University*

Funding provided by US DOE Energy Storage Program managed by **Dr. Imre Gyuk** of the DOE Office of Electricity.