Smart Grid in a Room Simulator (SGRS):

Toward Plug-and-Play Design and Operation of Microgrids

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http://www.masscec.com/events/microgrid-der-controller-symposium;

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- ***Use of NW AC OPF*** software for demonstrating potential of advanced microgrid controllers

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Outline

- **Challenges and opportunities with microgrids**
- **Technical challenge problems** (Sheriff and Banshee)
- **Systems approach to overcoming technical challenges**
  - *Enhancing hierarchical modeling, analysis and control*
  - *Novel distributed plug-and-play interactive operations*
- **All illustrated using Smart Grid in a Room Simul**ator
- **SGRS showcase with many details**
- **Conclusions and recommendations**

Challenges and opportunities

- ***Technical challenges:*** Design and control to enable stable operation for wide ranges of input variations and topological changes.
- ***Business challenges***: Maximize DER deployment, while minimizing load shed, and need for expensive fast storage.
- ***Technical opportunities*****:** Major innovation at value.
- ***Business opportunities:*** ***a) for utilities*** *(high tech business of electricity services at value);* ***b) for vendors*** *(massive development and deployment of smart hardware and system cyber software);* ***c) for electric energy users*** *(choice at value).*
- ***Societal opportunities:*** *Clean, secure electricity service at choice and value.*

Overall technical challenge

- **Need systematic tools to assess operating problems**

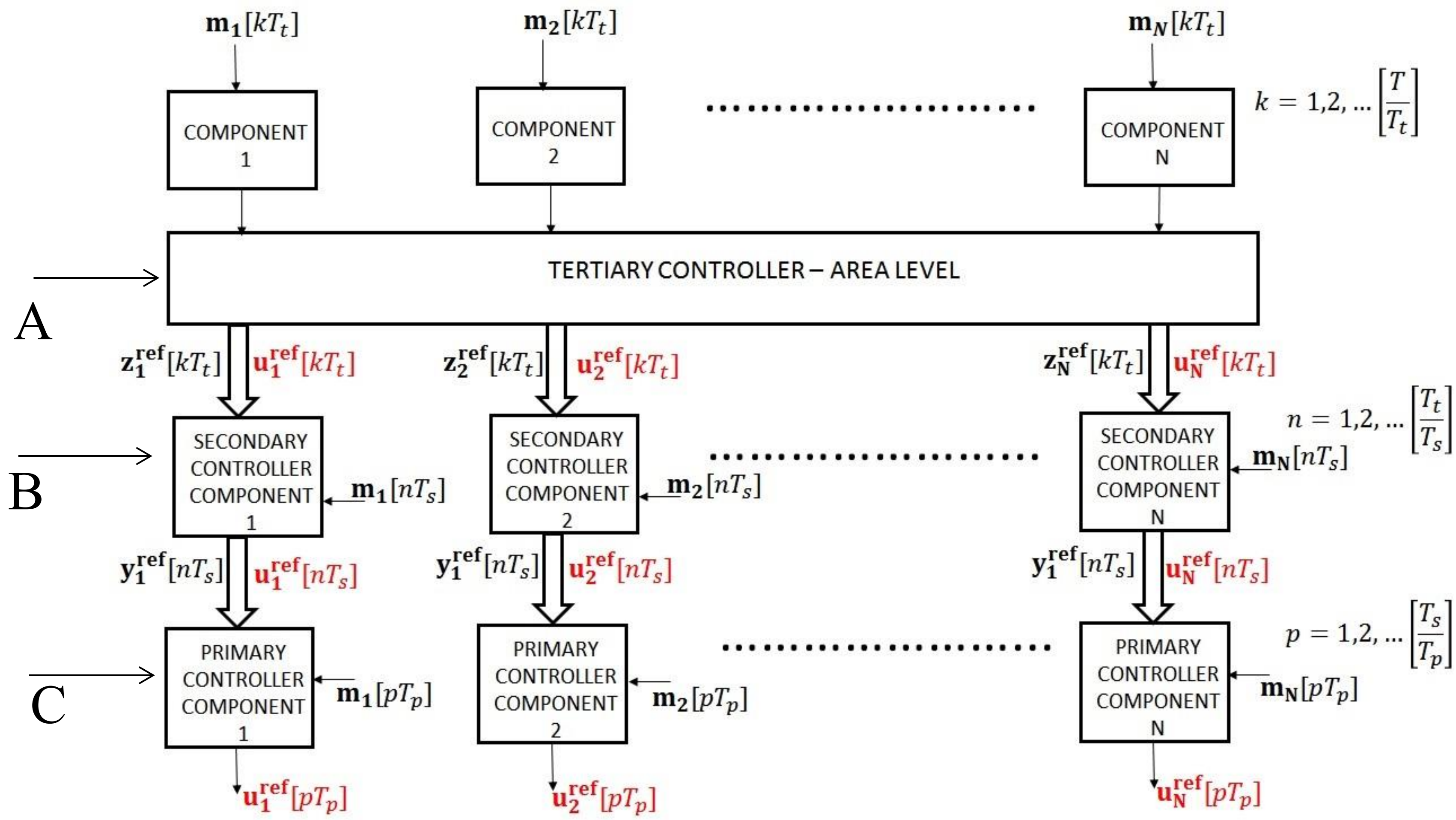
--when and why the grid may not work—could trigger protection and cascading failures (power cannot be delivered within given constraints; conditions sensitive/unstable w/r to input disturbances and model uncertainties)

- **Must design control to manage technical problems**
  - enhanced hierarchical control; fail/safe distributed coordination; protocols for coordination
  - primary control capable of meeting specifications

Systems Approach to Solutions

- ***Rapid automated modular modeling, simulations and stability analysis*** *(models in standard state space form key to stability analysis and control design for provable performance) (CAMPS, DAMPS)*
- ***Enhanced hierarchical control***
  - *Advanced microgrid controller; performance metrics (maximize DERs, minimize load shedding,minimize battery needs)*
  - *Primary control for provable performance required by the microgrid controller*
- ***Distributed control when communications with microgrid control are not available (no DMS, failures)***

Hiearchical control in microgrids*



*Foundations and Trends in Electric Energy Systems, Vol. 1, No. 1 (2016) 1–141,c 2016 Marija D. Ilic´ DOI: 10.1561/3100000002

Enhancements needed—hidden traps

- ***A (microgrid controller*)**: should have adaptive performance metrics and optimize over all controllable equipment *(not currently the case)*
- ***B (secondary control-droops):*** *modeling assumptions often hard to justify*
- ***C (primary control)*:** A combination of primary and secondary control should guarantee that commands given by microgrid controller are implemented. *Huge issue—hard to control power/rate of change of power while maintaining voltage within the operating limits!*

Potential of advanced microgrid controllers*

Challenge problem: MICROGRID CONTROL	Actions required – based on typical ED microgrid controller	Actions required –based on advanced microgrid controller	QUANTIFABLE DIFFERENCES
Case S1 (Sheriff, high load, low PV power)	No steady state solution within limits	PV must produce reactive power Need to add shunts at critical buses	Can operate without load shedding
Case B1 (Banshee, interconenced, all NoS)	No steady state solution within limits	Battery serve in grid forming mode; optimized taps on critical transformers	Can operate without load shedding
Case B2 (Banshee, islanded all NcS)	No steady state solution within limits	Both PV and battery serve in grid forming mode; key transformer taps optimized	Can operate without load shedding

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**Ilic, Marija, Potential of Advanced Microgrid Control: Cases of Sheriff and Banshee, LL white paper WP-2017-1.*

Potential of plug-and-play primary/secondary controllers*

Challenge problem	State-of-the-art control primary control	Energy-based Plug-and-Play primary control (with microgrid control)
Case S1 (Sheriff, high load, low PV power)	Stable; does not settle to the right voltage w/o retuning; Induction motors when simulated result in poor voltage profile	Stable; voltage profile around 1 p.u. is ensured by generators re-adjusting their power output
Case S2.1 (Sheriff, islanded feeder1)	Stable; settles to right voltage if tertiary control set points are accurate. Dynamic loads when used result in poor voltage profile	Stable; voltage profile is good irrespective of the load model used.
Case S2.2 (Sheriff, islanded feeder 2)	Stable; Grid forming mode requires either lot of tuning or requires proper selection of filter parameters to ensure current evolves much faster than voltage. Switches might hit saturation for large disturbances.	Stable; Doesn't require any island detection loop for different modes of operation. Same control can be used in all the modes
Case S2.3 (Sheriff, islanded feeder3)	Stable; Short line model when used can result in over-voltage; Large in-rush current produced by Induction motors results in poor voltage profile	Stable; Regulates voltage irrespective of the line/load model
Case S3 (Sheriff, reconnecting)	Stable; but the load is not served; might also damage loads because of sudden drop in voltage; sensitive to control gains on generators and solar PV	Stable; desired load is always served as the generators reschedule themselves during sudden islanding and ensure good voltage profile with overshoots being within the protection limits

*Marija Ilic, Xia Miao, Rupamathi Jaddivada, Aidan Dowdle, " Distributed Multi-Layer Energy-based Control for Stabilizing Microgrids", MIT-EESG Working Paper, February 5, 2017, 2017-2

*Marija Ilic, Xia Miao, Rupamathi Jaddivada, Aidan Dowdle, "Nonlinear Control Design for Plug-and-Play Integration and Operation in Electric Energy Systems", MIT-EESG Working Paper, February 5, 2017, 2017-3

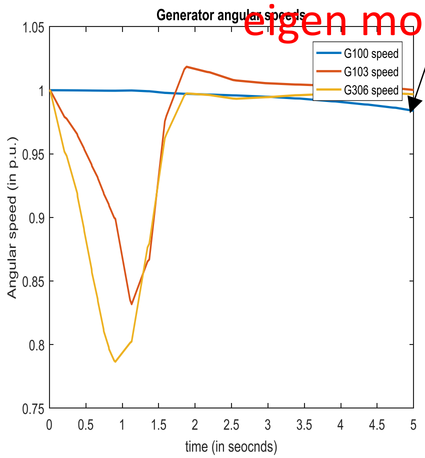
Banshee grid-utility connected

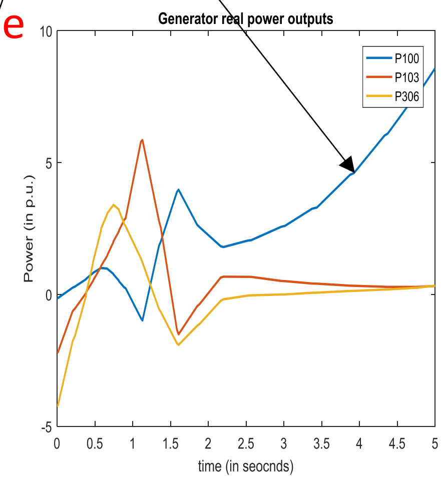
Controller implemented: 1. PV in grid following mode 2. Battery in grid forming mode

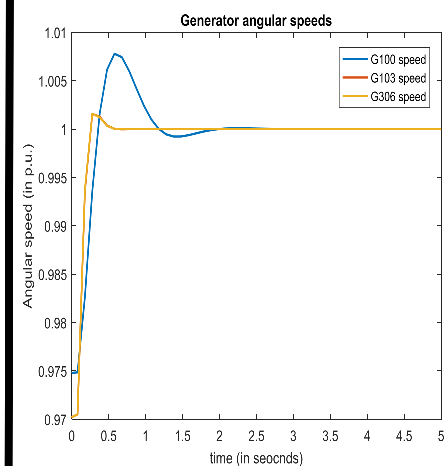
Constant gain control

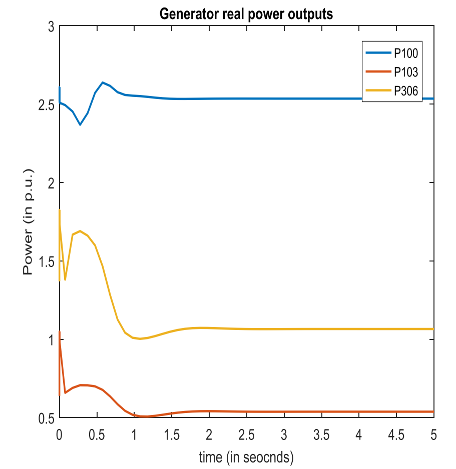
Energy based control

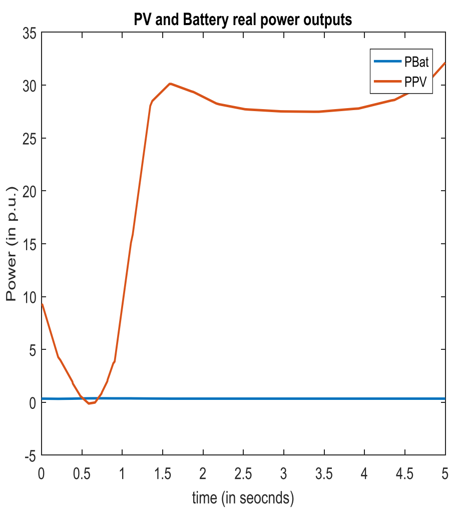
One positive unstable eigen mode

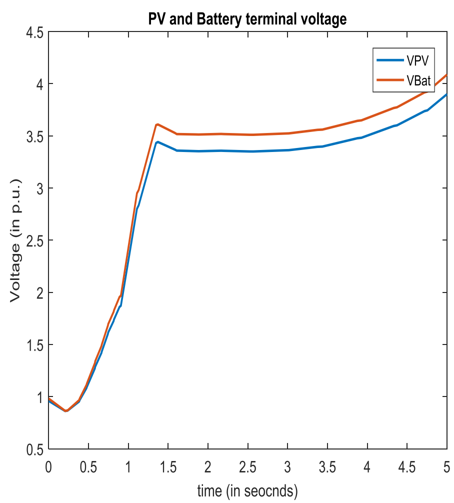


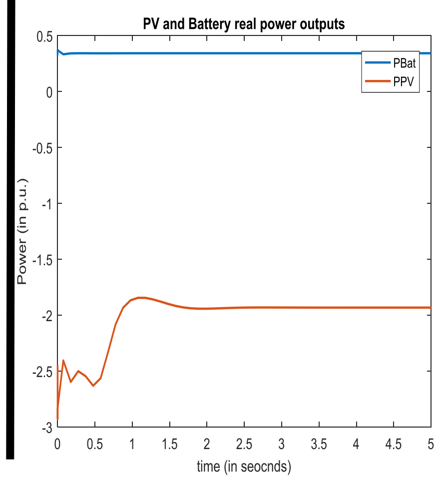


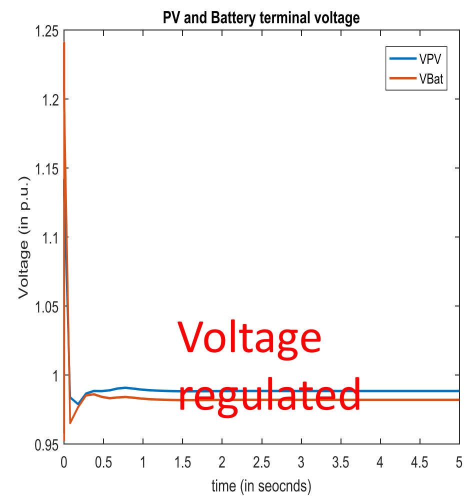








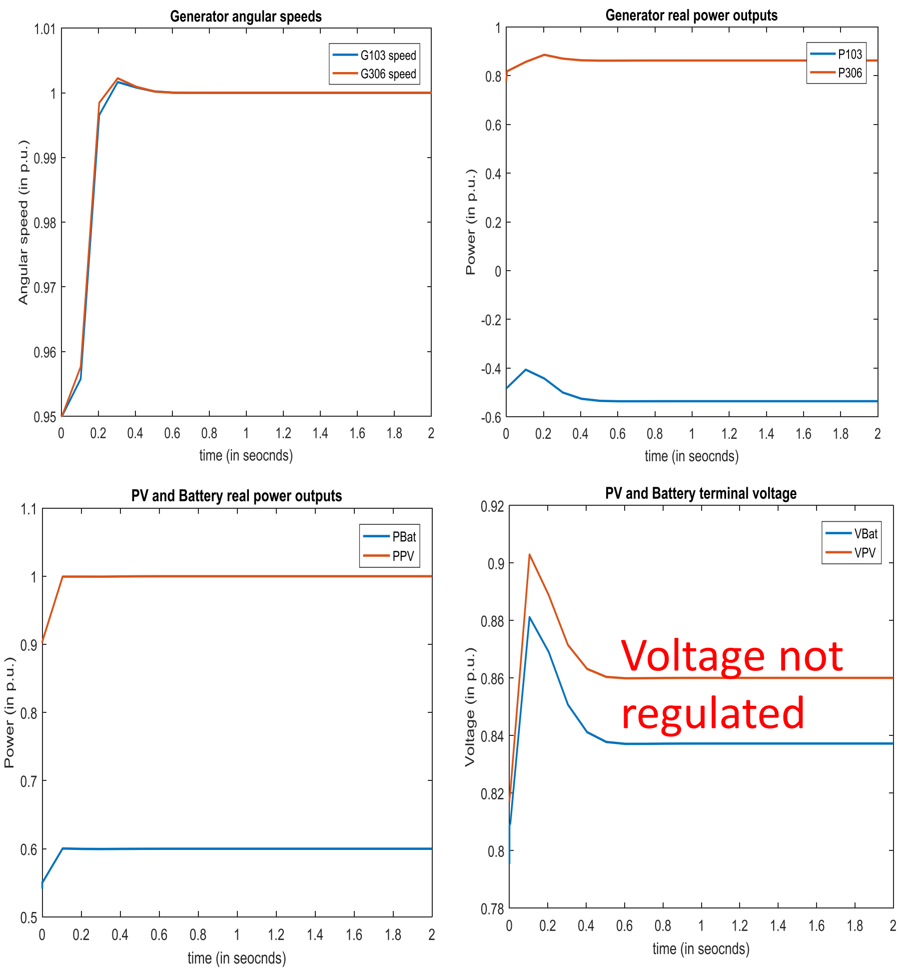




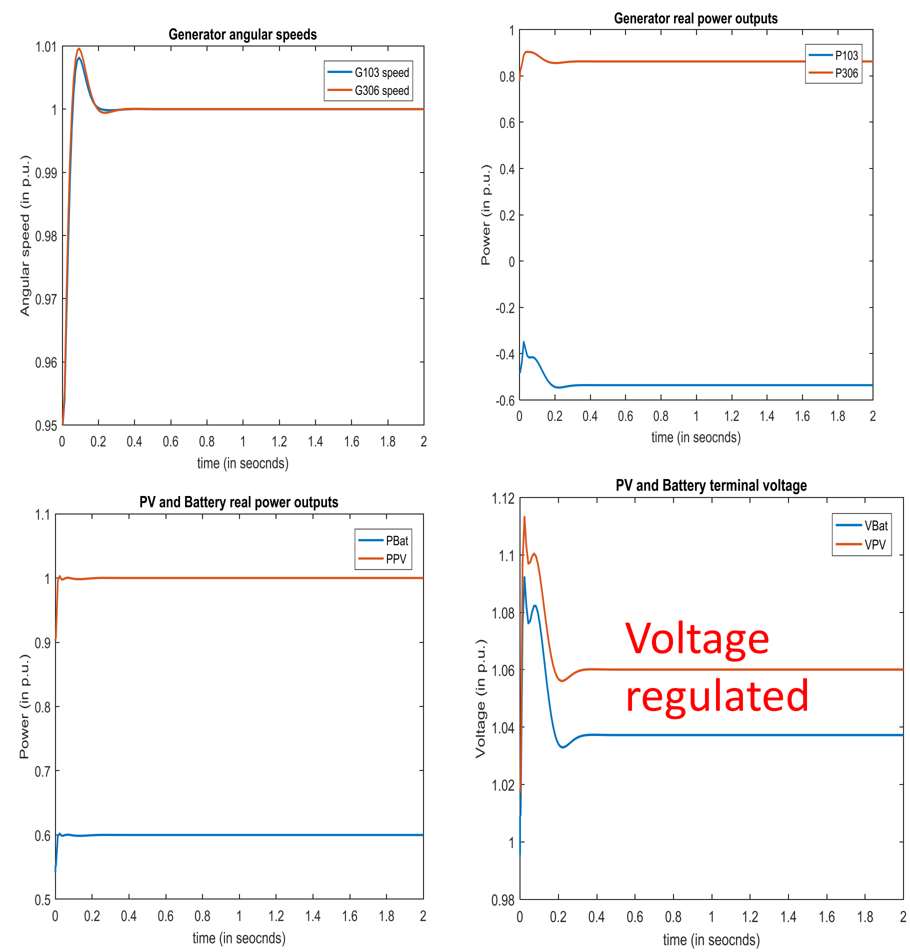
Banshee grid—islanded, closed switches

Controller implemented: 1. PV in grid following mode 2. Battery in grid following mode

Constant gain control



Energy based control



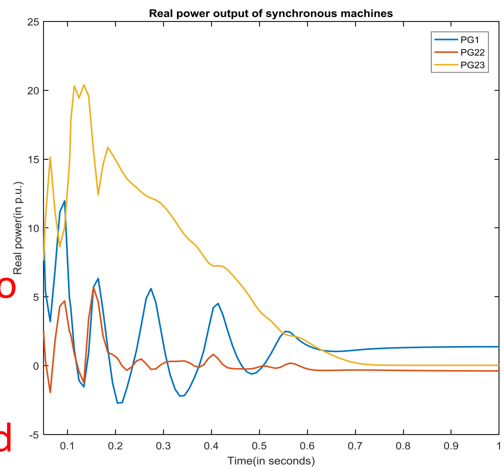
Primary control performance in systems with induction motors

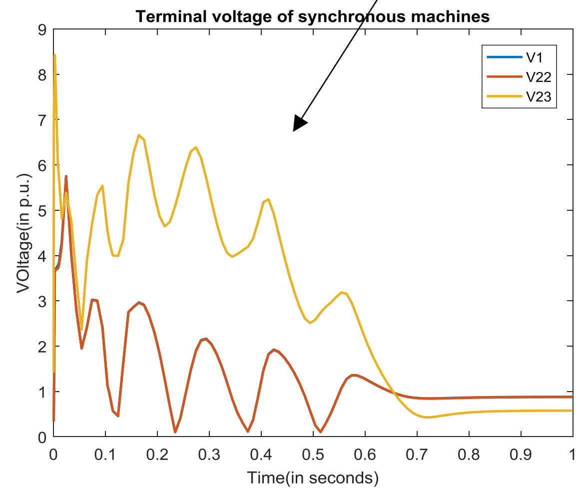
System simulated: Utility connected Sheriff with two large industry scale induction motors

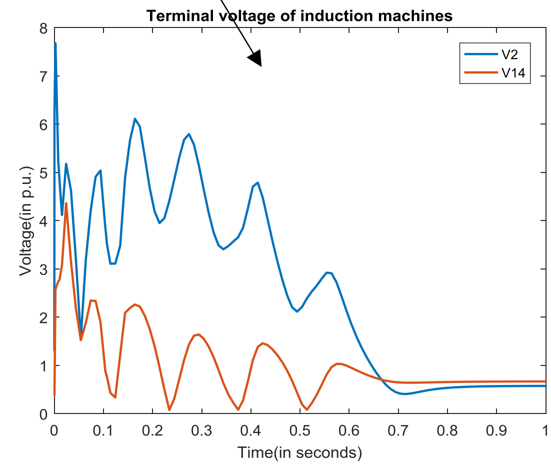
Would have damaged the machines if protection does not exist

Constant gain control

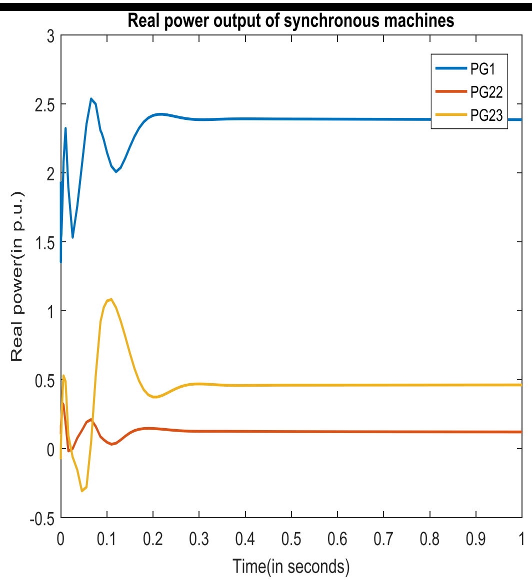
Concept of quasi-static droops used to calculate control gains might not hold here

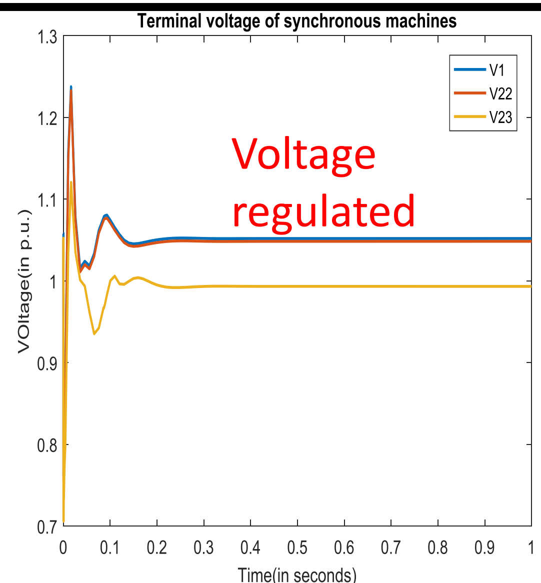




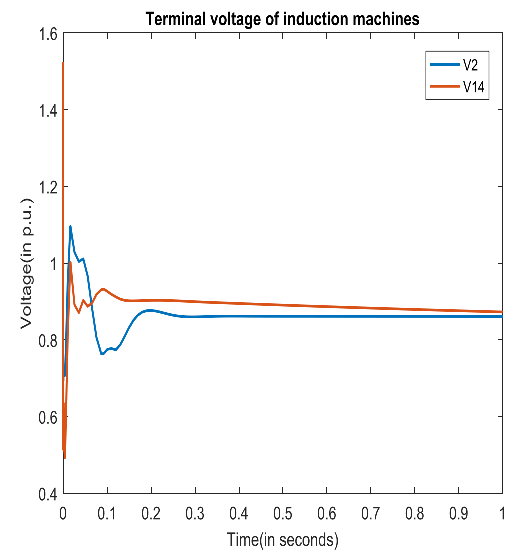


Energy based Control



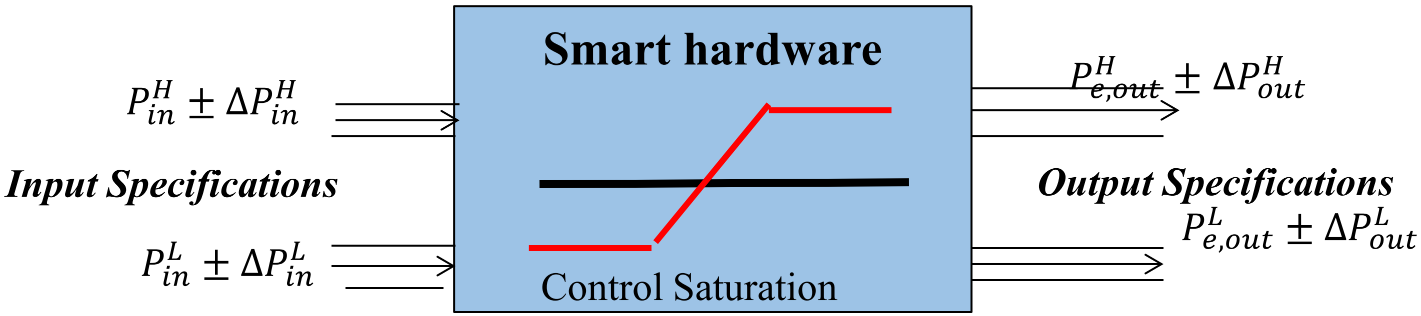


Voltage regulated



Toward plug-and-play microgrid control

- ***Primary level specifications:*** All (groups of components) must specify input output ranges of ***power, rate of change of power and expected deviations.***



- ***System-level protocols***
  - enhanced hierarchical control to define exact set points given the specifications of smart hardware;
  - distributed interactive protocols for exchanging specifications among (groups of) components

Conclusions and recommendations

- Use systematic modelling and analysis to identify potential operating problems (locations, types)
- Enhanced primary control required for unit testing so that microgrid control commands are implemented (power, rate of change of power, voltage ranges)
- Could be used for simple standardization (similar to digital electronics standardization) and protocols for ensuring system level performance metrics
- Could go a very long way toward overcoming today's technical challenges
- Major recommendation—extend to include economic incentives