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Electric Springs – A Smart Grid Technology for Taming the Intermittent Nature of Wind and Solar Power

2016 IERE – CLP-RI Hong Kong Workshop

by

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Outline

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- Background & The Grand Challenge
- Electric Springs & Hardware Tests
- Simulation Studies in Power Systems
- Remarks

Problems of Intermittent renewable added to the electric grid

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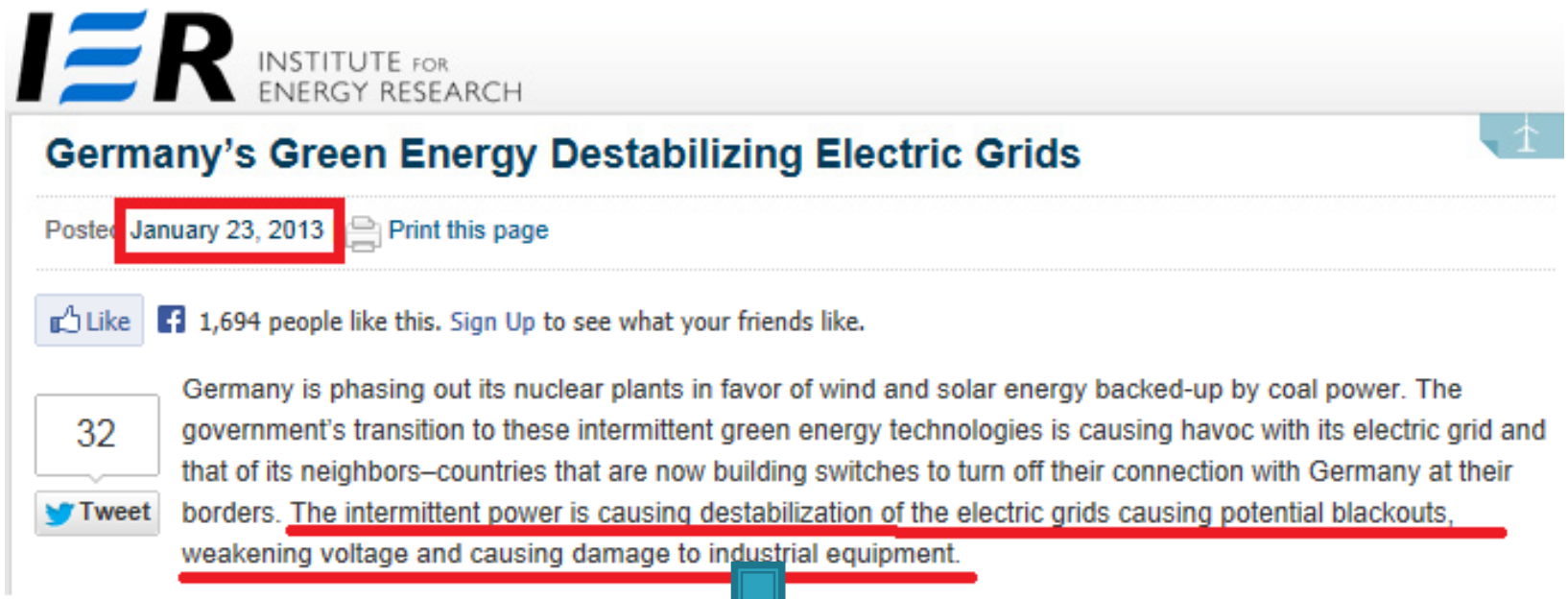

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Germany's Green Energy Destabilizing Electric Grids

Posted January 23, 2013 Print this page

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Germany is phasing out its nuclear plants in favor of wind and solar energy backed-up by coal power. The government's transition to these intermittent green energy technologies is causing havoc with its electric grid and that of its neighbors–countries that are now building switches to turn off their connection with Germany at their borders. The intermittent power is causing destabilization of the electric grids causing potential blackouts, weakening voltage and causing damage to industrial equipment.

The intermittent power is causing destabilization of the electric grids, causing potential blackouts, weakening voltage and causing damage to industrial equipment.

- **The Oahu-Hawaii power system *collapsed in April 2013* when the wind power reached 17 % ! [EPRI]**

Problem of intermittent renewable added to the electric grid

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BloombergBusiness | News | Markets | Insights | Video

German Green Power Forces Neighbors to Bolster Blackout Defenses

by Weixin Zha and Marek Strzelecki

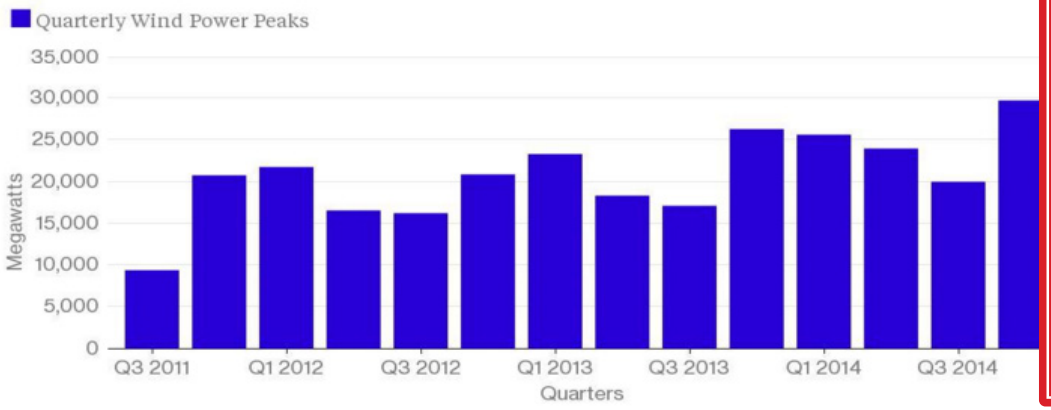
July 8, 2015 – 7:01 AM HKT *Updated on* July 9, 2015 – 5:27 AM HKT

Germany's drive to harness wind and solar power is producing so much electricity that it's spilling over into neighbors' grids and increasing the threat of blackouts.

Poland and the Czech Republic are spending $180 million on equipment to protect their systems from German power surges, while Austria is curbing some trading to prevent regional networks from collapsing. On a windy day, the overflow east can exceed the output from four atomic reactors.

Something in the Wind

German wind power output has more than doubled in four years



Source: EEX

Bloomberg

Important points:
1.Wind and solar power is the best way to cut CO_2 emission.
2.Rapid increase of Wind and Solar Power is possible, but….
3.there is a urgent need to cope with stability issues.

Effect from wind

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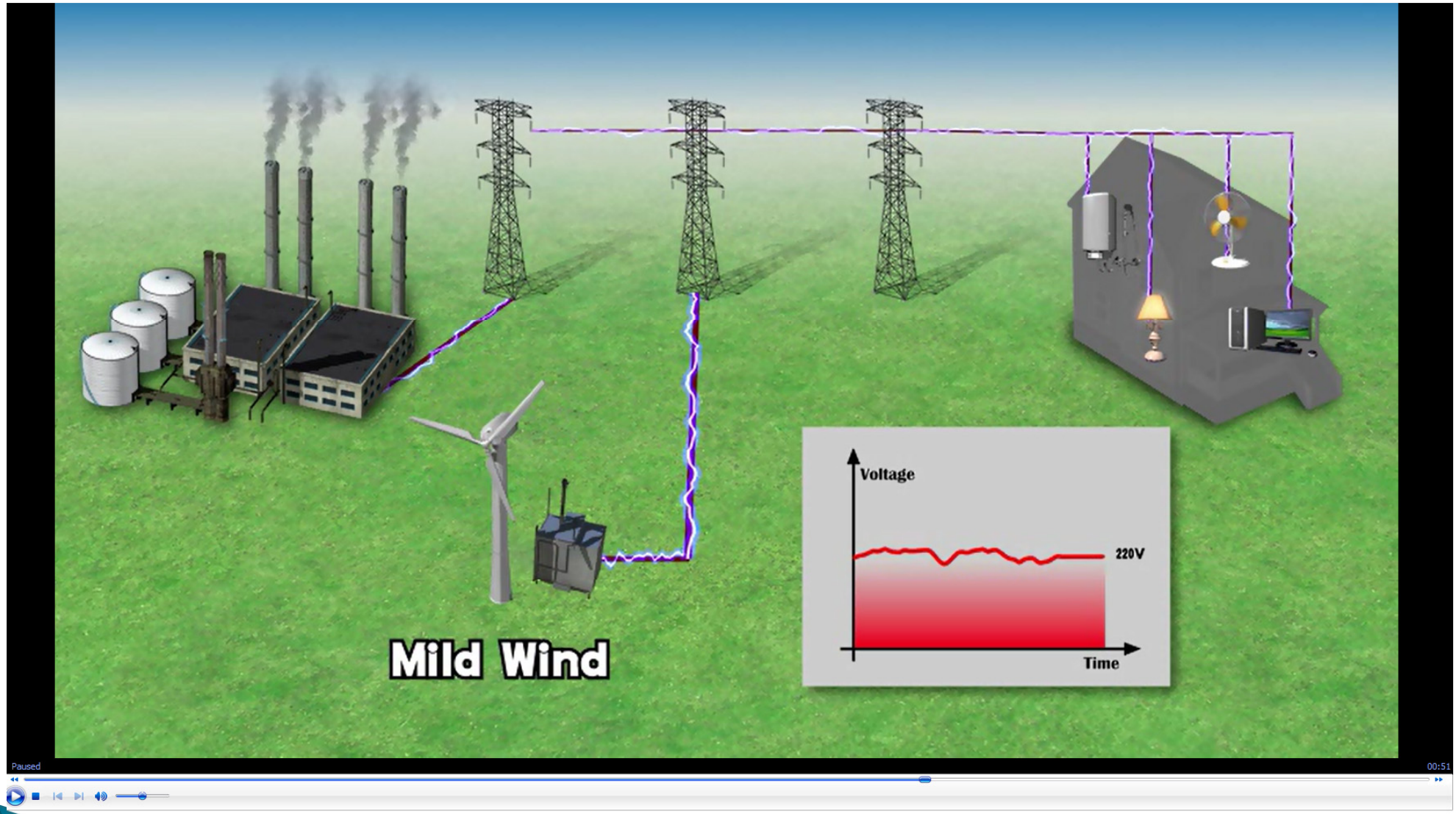

New Control Paradigm

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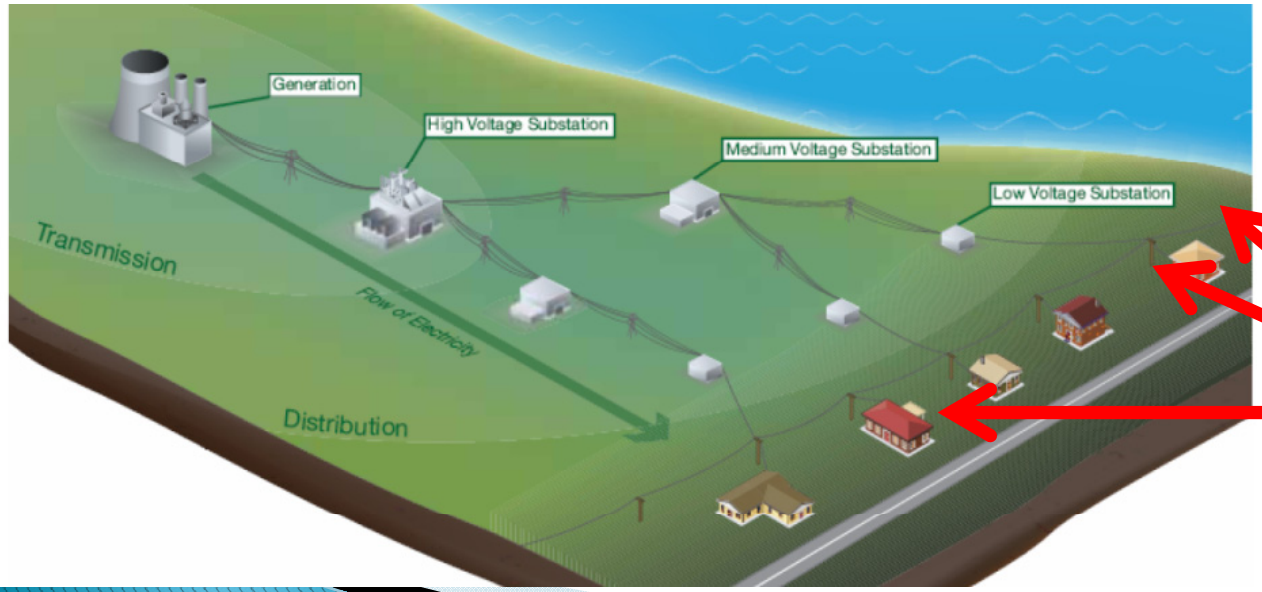
Existing Power Generation	Future Power Generation
Centralized	Distributed
One-way power flow	Bi-directional power flow
Existing Control Paradigm	**Future Control Paradigm**
Power Generation follows Load Demand	Load Demand follows Power Generation



Electric Springs (2010)

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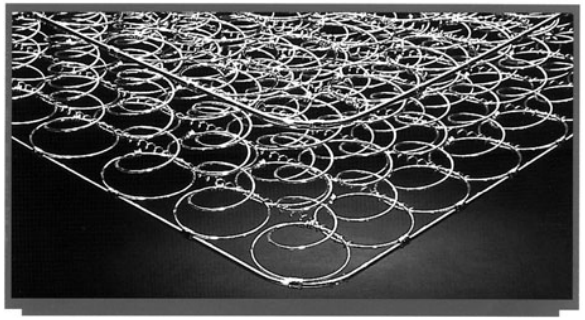
- A power electronics device adaptive to
  - fluctuating mains voltage and/or frequency

- It is low cost and autonomous
  - No need for centralized control systems
- It can therefore be 'distributed" over the power grid
  - eg. Households and industrial sites to stabilize the mains voltage and/or frequency in real-time.
- Although they are all small power devices,
  - many "small" but distributed electric springs should provide a collectively robust stabilizing effect.

Hooke's Law (1660)



Follows the Intermittent Power Generation

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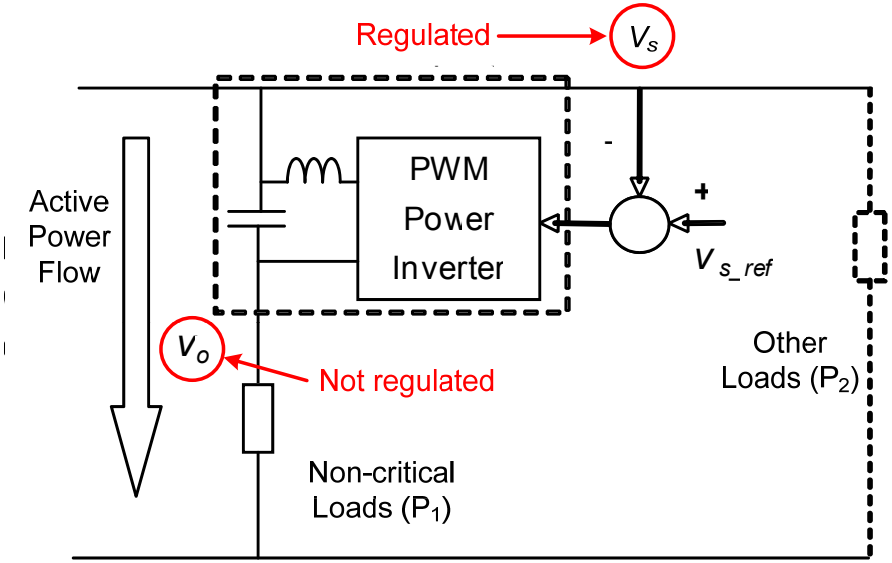
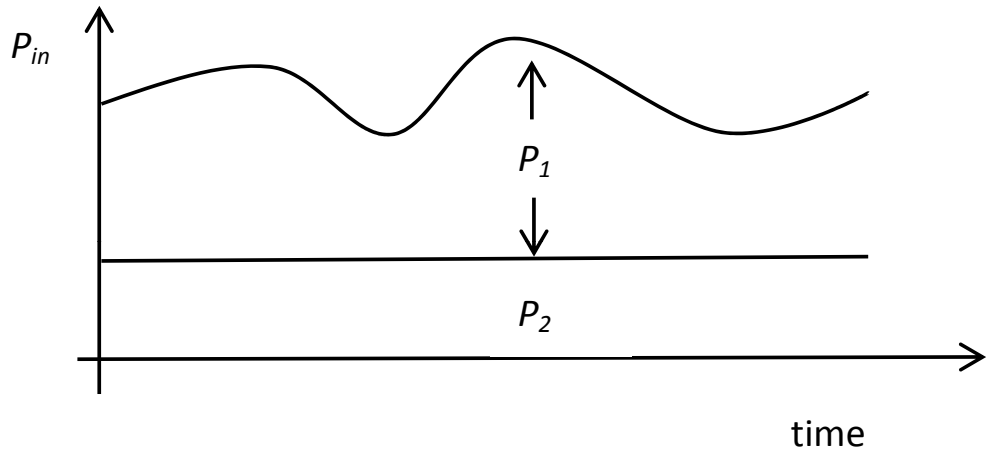
- Non-critical load power P_1 follows the intermittent power generation
- Mains voltage V_S is regulated to its nominal value





$$P_{in} = \left(\frac{v_o}{Z_1}\right)^2 \mathrm{Re}(Z_1) + \left(\frac{v_s}{Z_2}\right)^2 \mathrm{Re}(Z_2)$$

$$P_{in} = P_1 + P_2$$

$$P_{in} = \frac{v_s^2 - v_a^2}{R_1} + \frac{v_s^2}{R_2}$$

$$P_{in} = P_1 + P_2$$

Controller for Electric Springs

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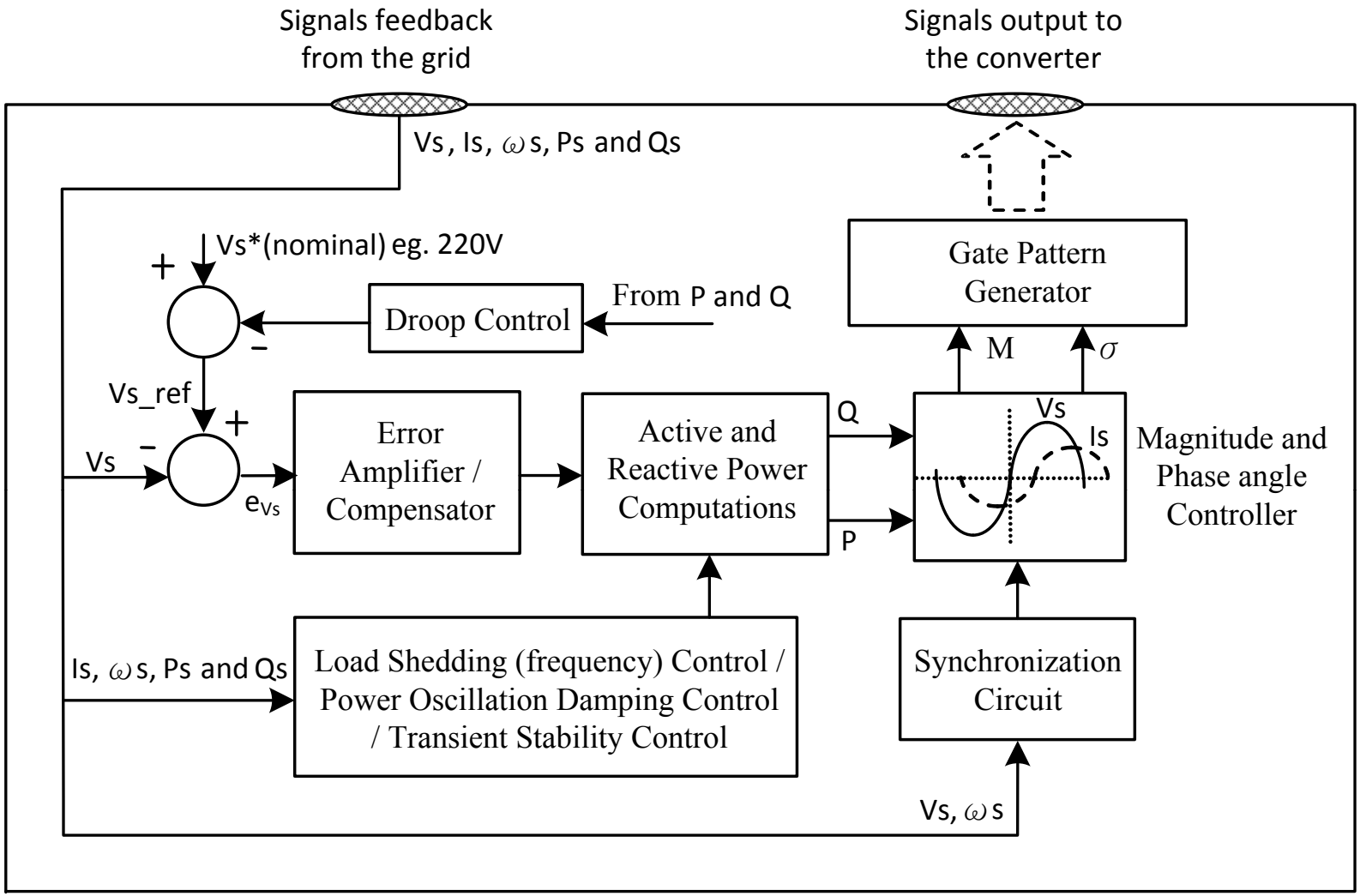

ES P&Q Controller

Non-critical Loads

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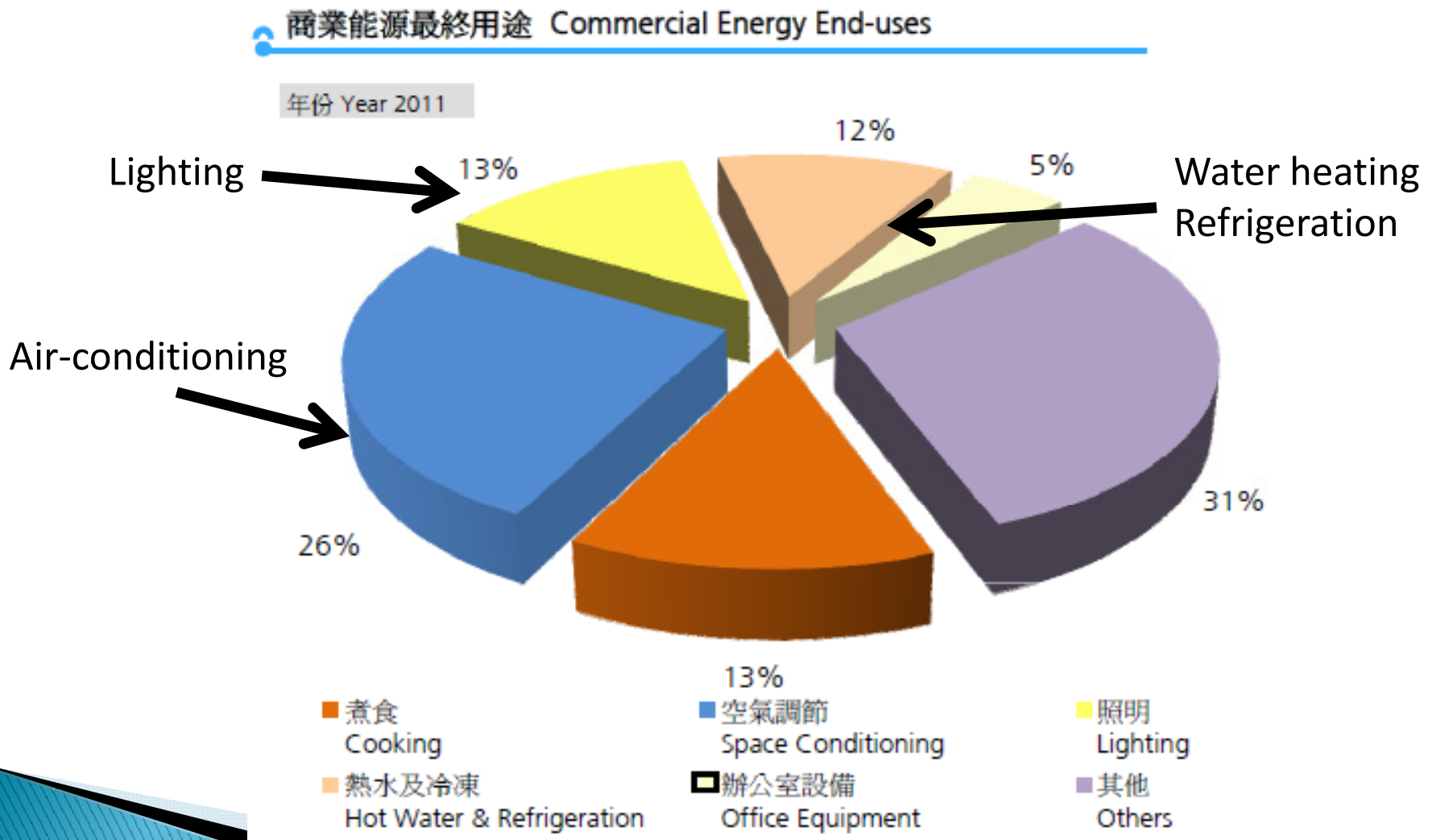
- Thermal loads + Lighting systems = 40% ~ 50%



Functions of Electric Springs

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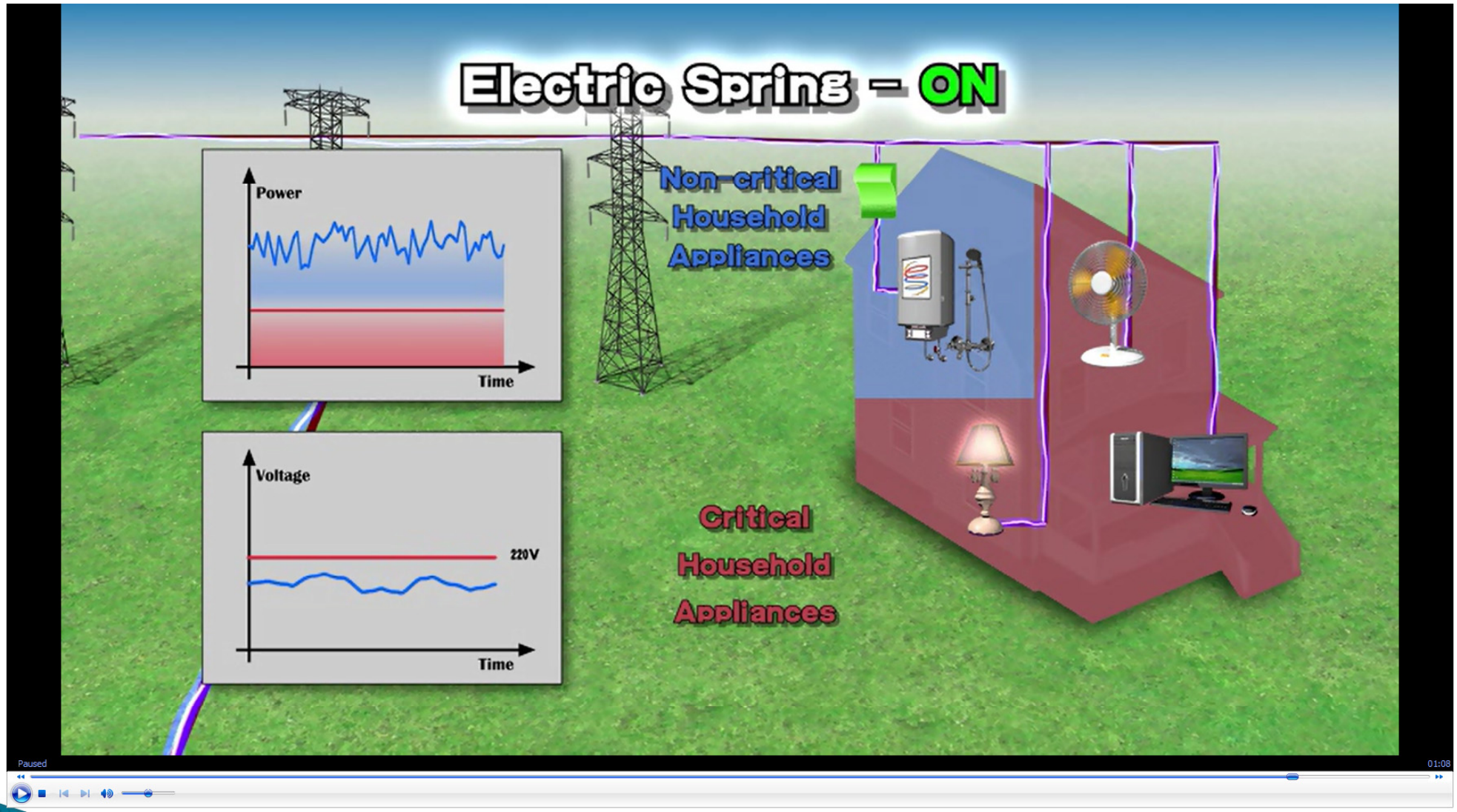

Embedded in Appliances / in Power Supply Infrastructure

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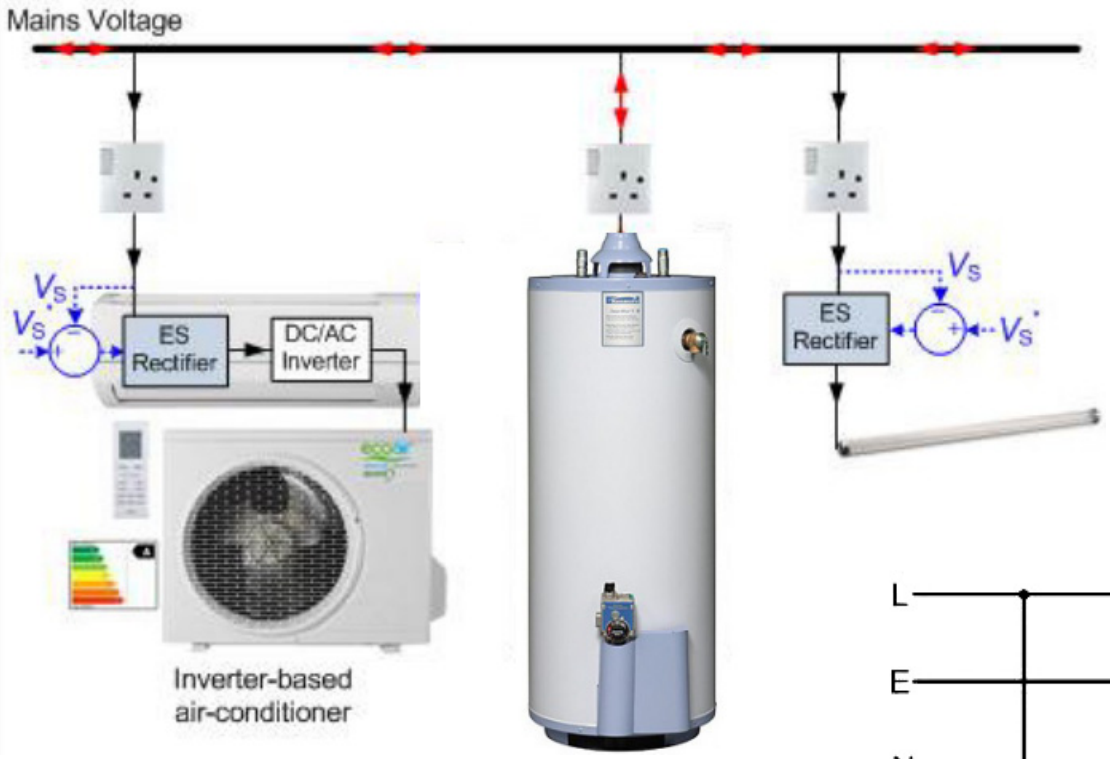

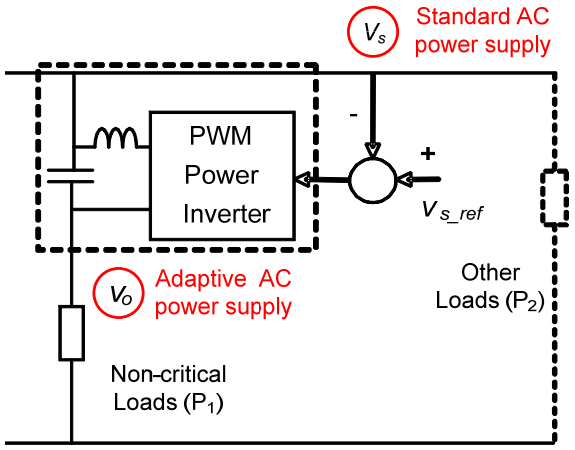

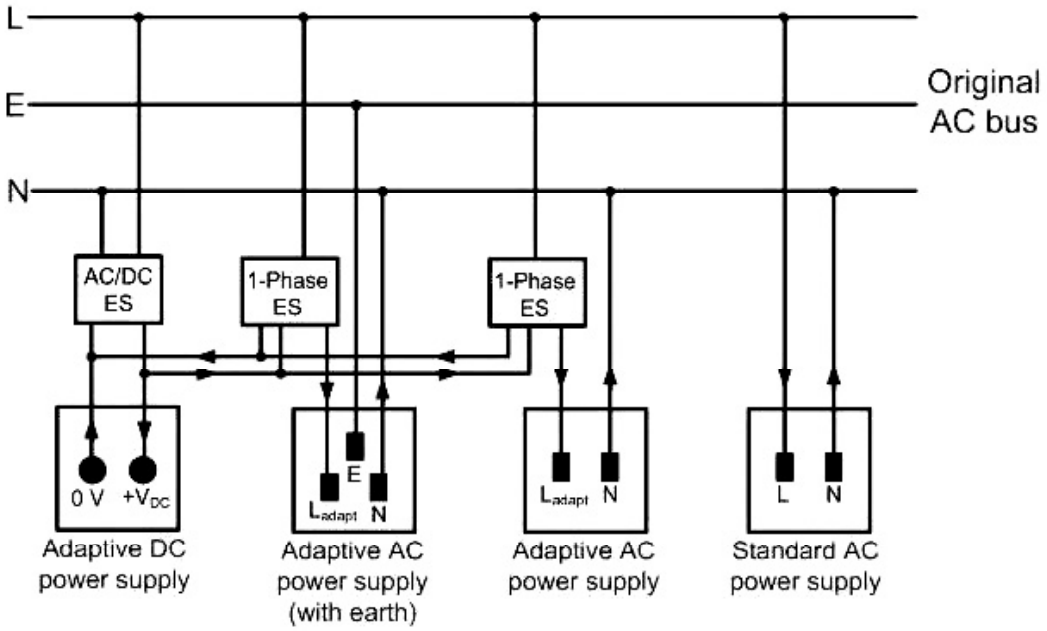

Electric-Spring-embedded power supplies

100KVA Lab Scale Microgrid

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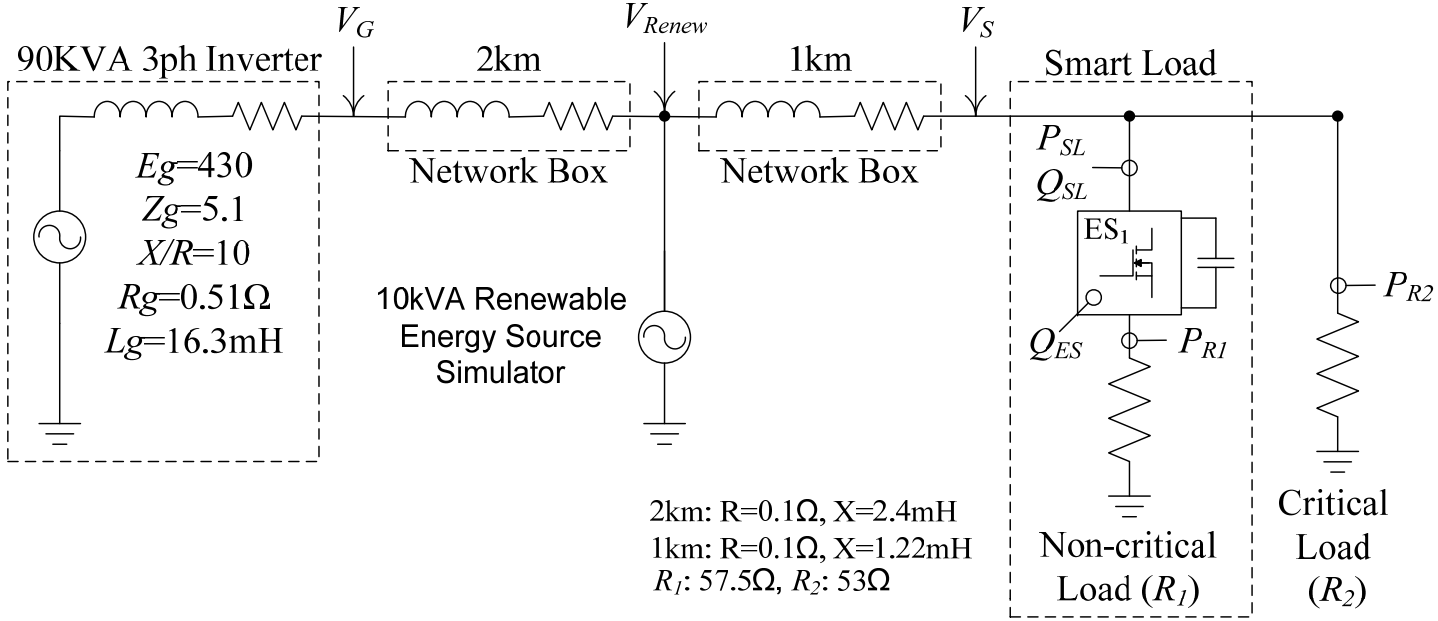

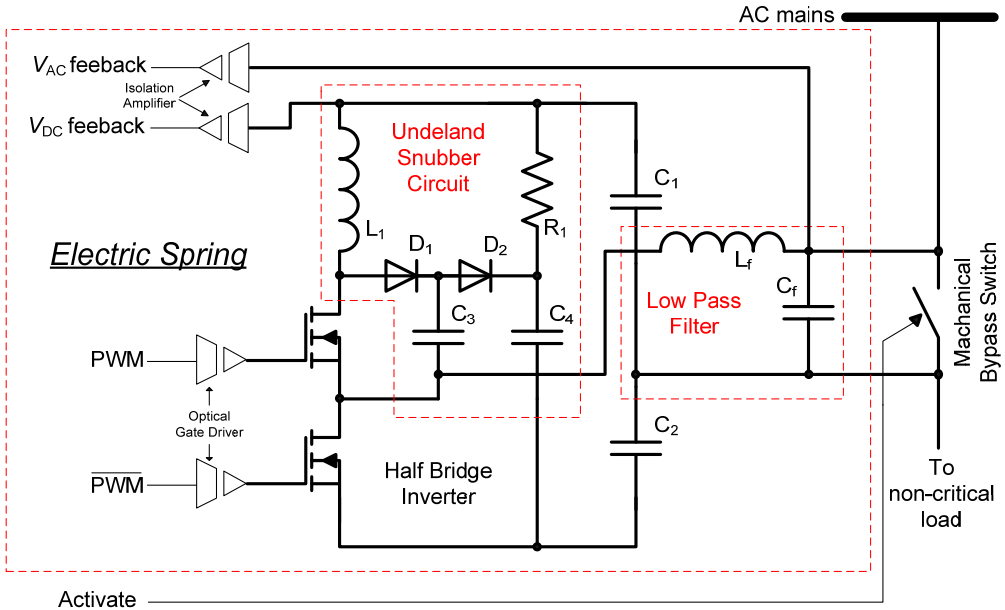

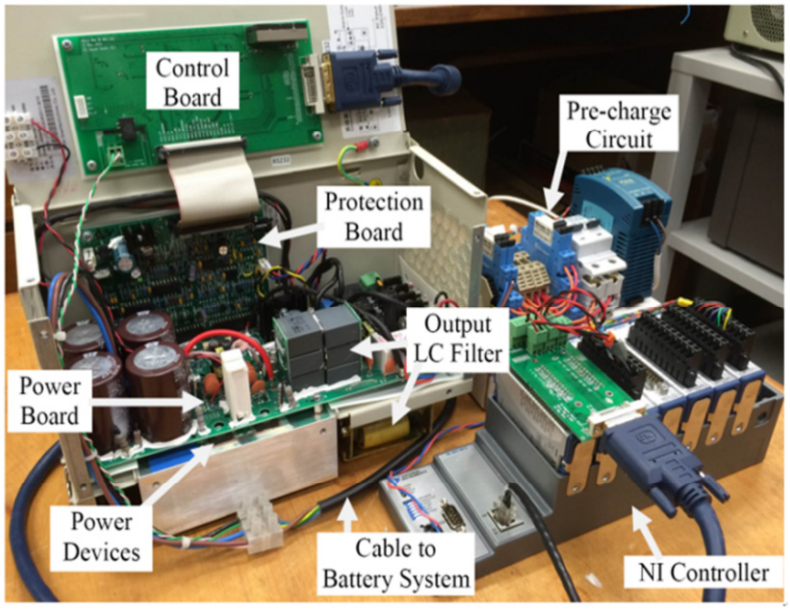

Demonstration 1:
Voltage Regulation

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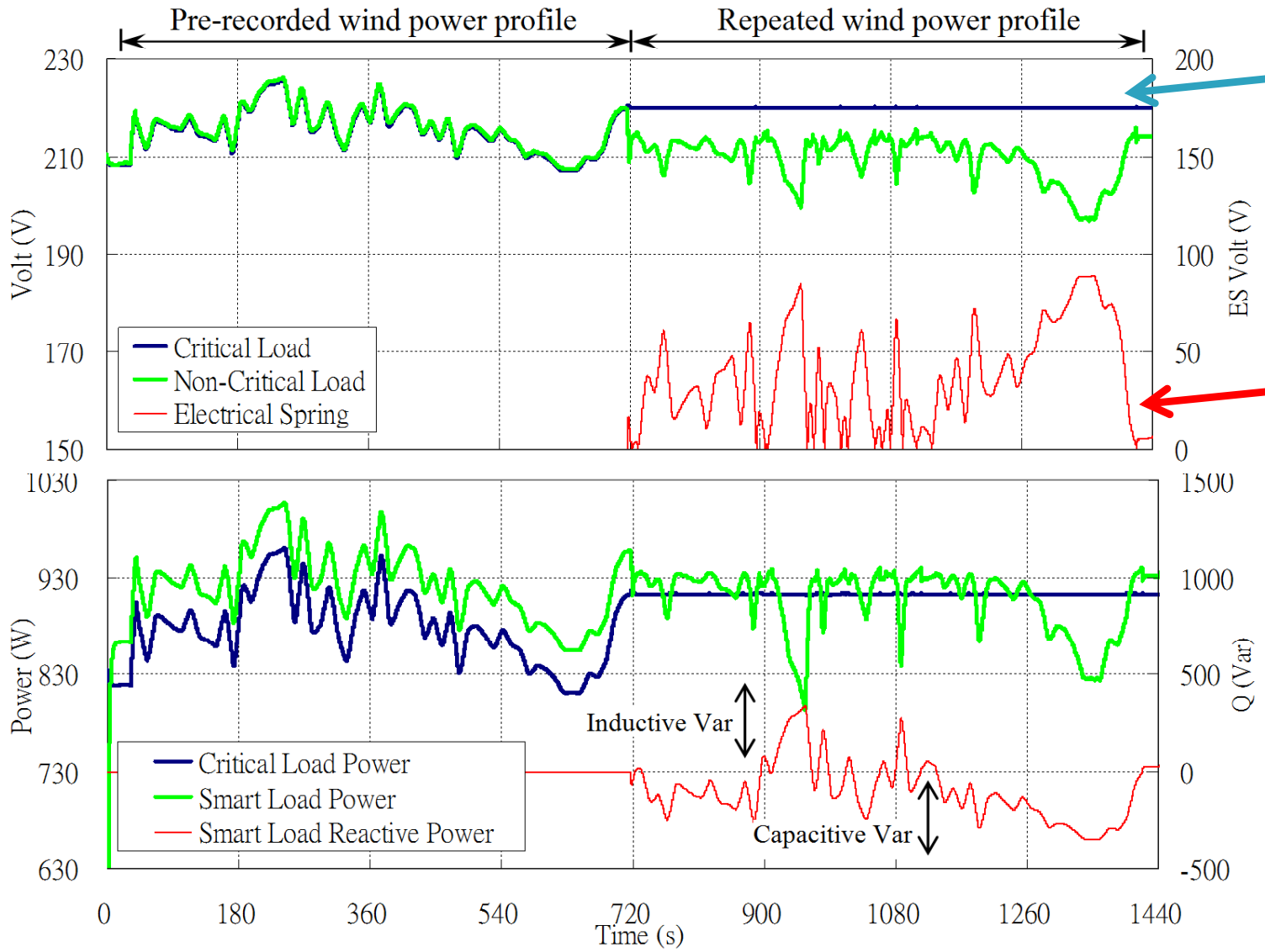

Demonstration 1: Voltage Regulation

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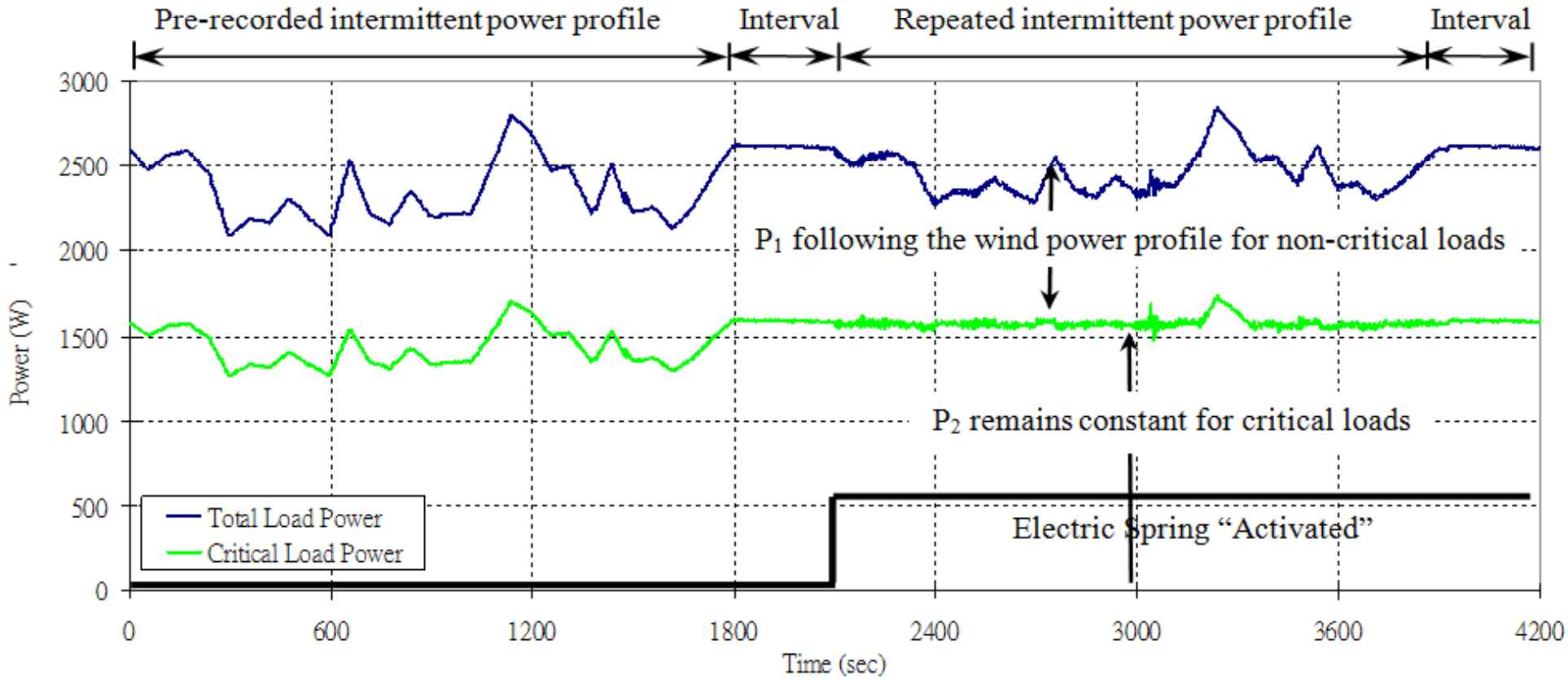

Load demand following power generation

Hui S.Y.R., Lee C.K. and Wu F.F., "Electric Springs: A New Smart Grid Technology", ***IEEE Transactions on Smart Grid, 2012***

Demonstration 2:
Reduction of Energy Storage

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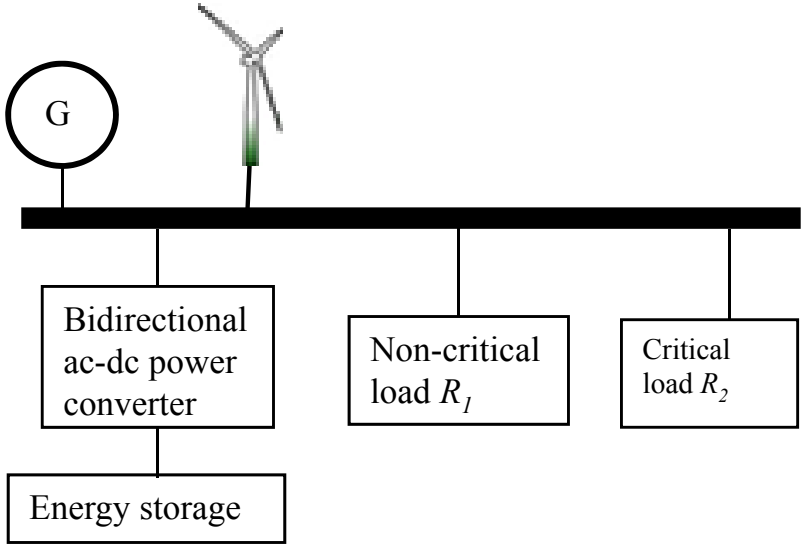
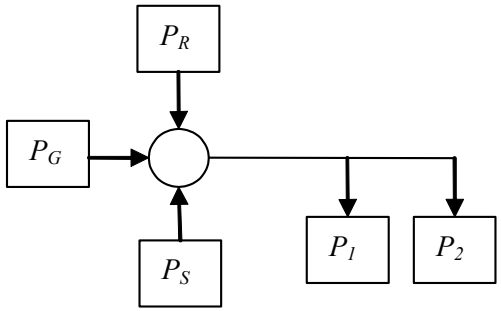
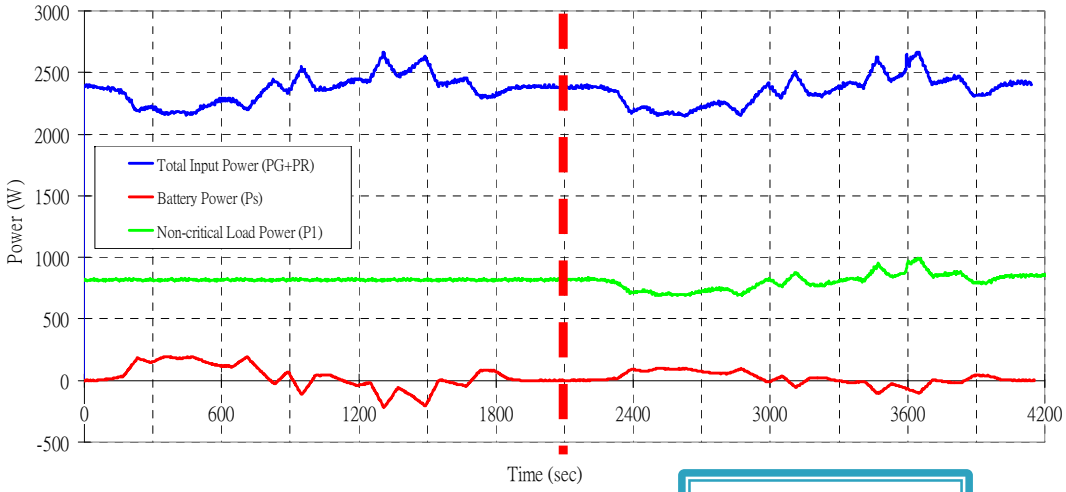
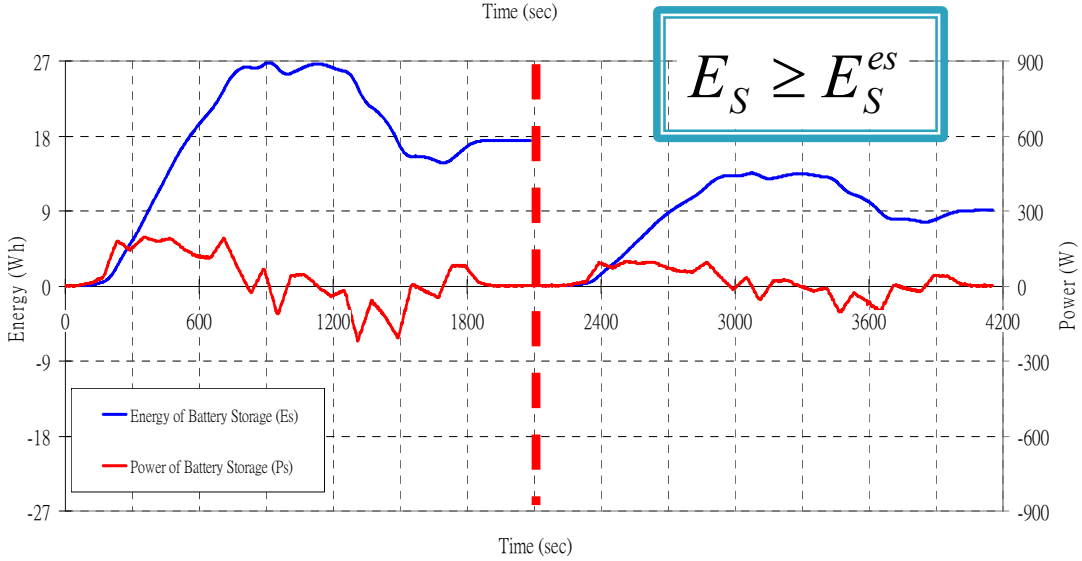


$$P_S = -P_G - P_R + P_1 + P_2$$







$$P_{gen} + P_{renewable} = P_{critical} + P_{non\text{-}critical} + P_{storage} + P_{ES}$$ ← Distributed Storage

Lee C.K. and Hui S.Y.R., "Reduction of energy storage requirements for smart grid using electric springs", ***IEEE Transactions on Smart Grid***, **2013**

Demonstration 3:

Reduction of power imbalance in 3-phase system

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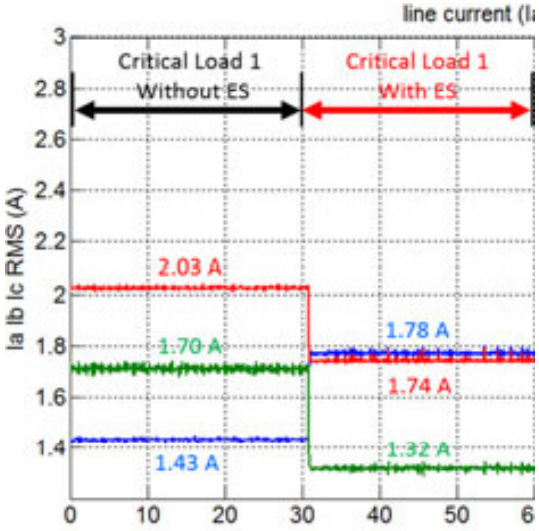
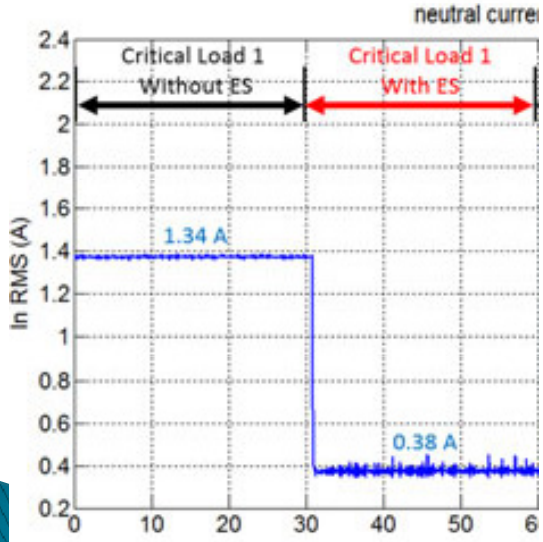
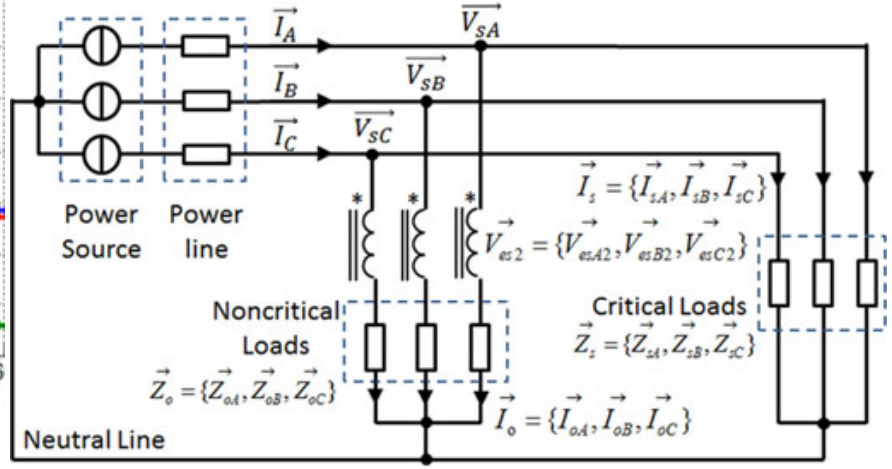
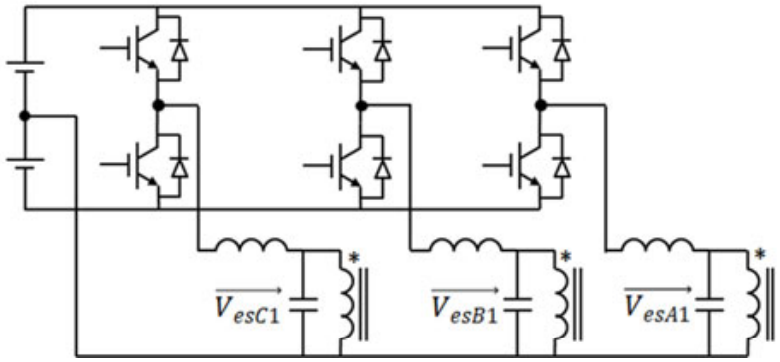
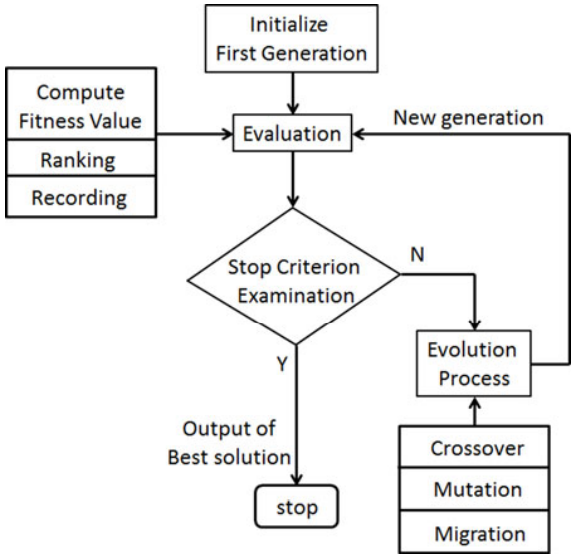




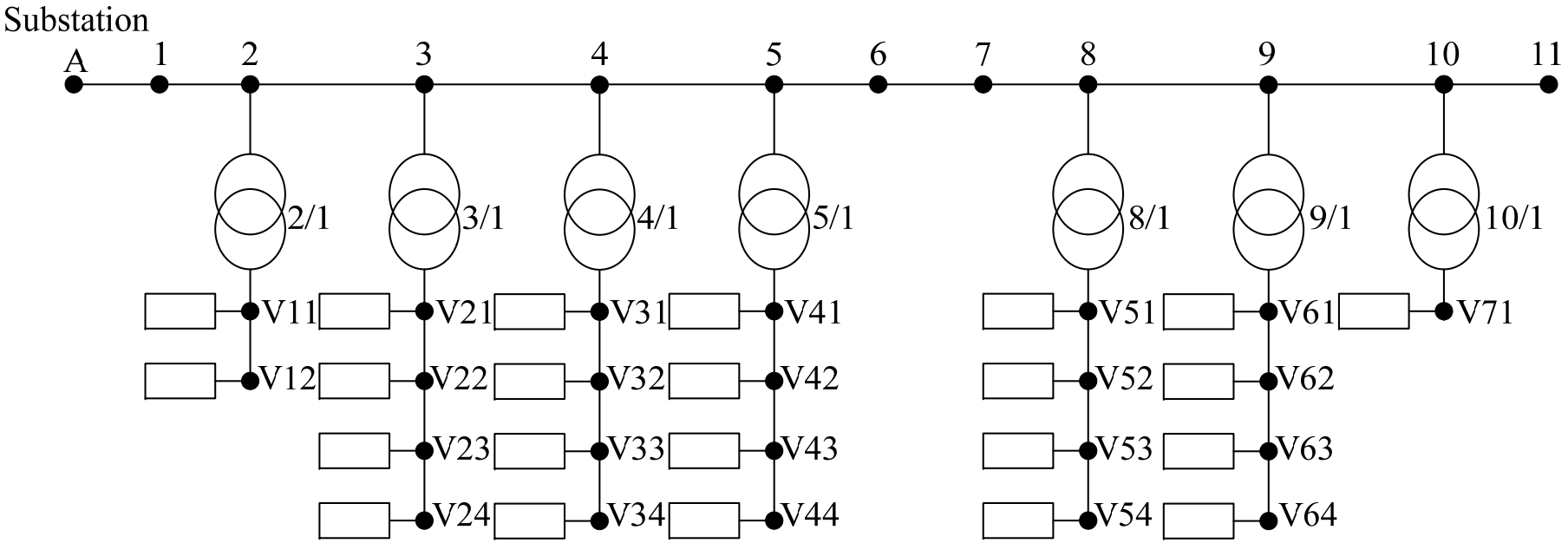






Yan S., Tan S.C., et al. "Electric springs for reducing power imbalance in three-phase power systems", ***IEEE Transactions on Power Electronics***, **2015**

Case study 2:
Sa-Lo Bay, Lantau Island, Hong Kong (11kV -> 220V)



Performance Evaluation : Centralized or Decentralized ?

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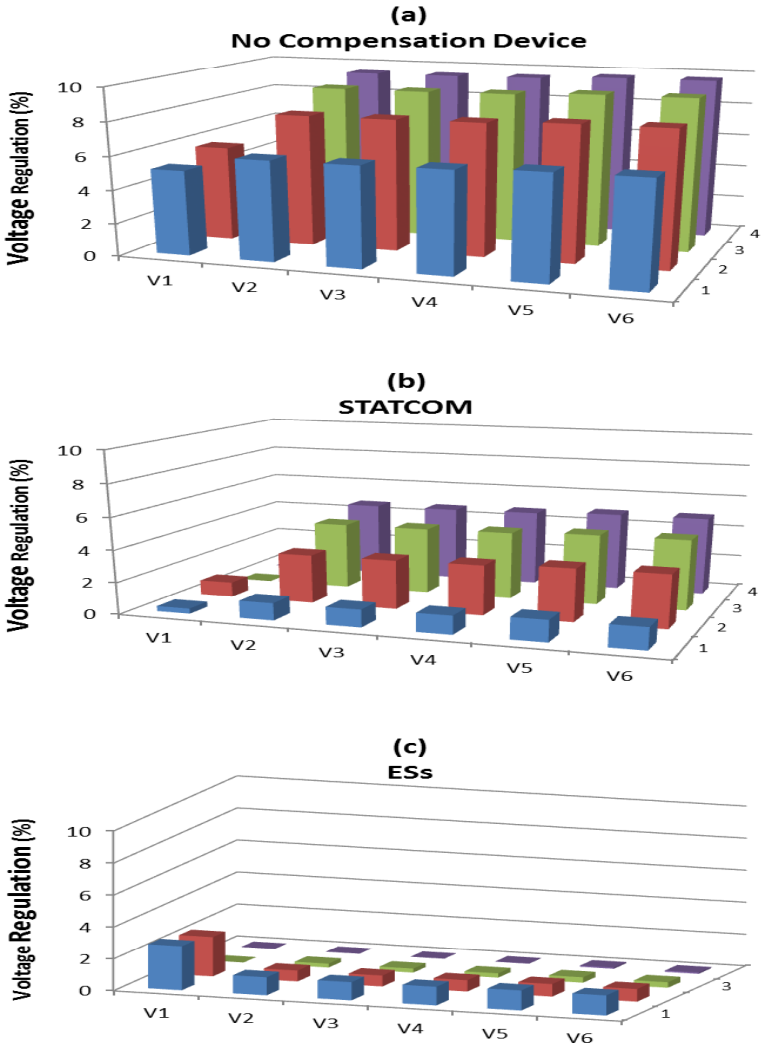

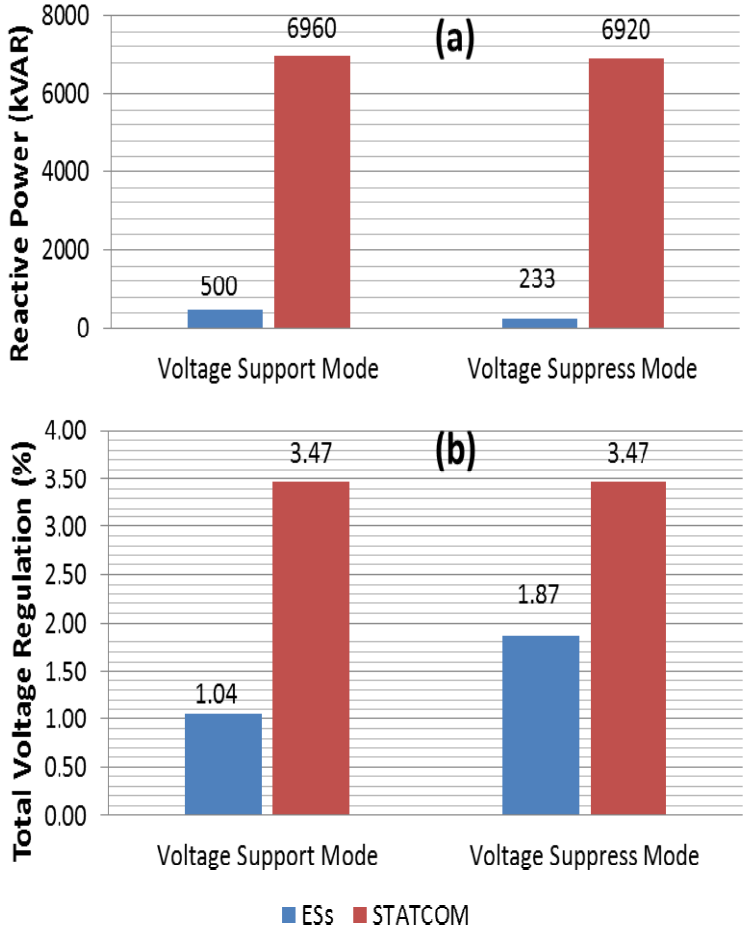

The total reactive capacity required for the ESs is about 14 times less for under-voltage condition and 30 times less for over-voltage condition than that required by the STATCOM.

Remarks

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- Without considering the stability of the power systems, existing grid-connected power inverters could be '***destabilizing***" the power systems.
- With the stability of power system in mind, our patent-pending technologies make grid-connected power inverters a "***stabilizing force***".

Electric Springs – a New Technology to:

–***tame*** the ***intermittent nature*** of wind/solar power

–***achieve*** the ***new control paradigm*** of having the ***load demand to follow the power generation***

–potentially push the intermittent renewable power generation ***well above 20%.***

With fast P and Q control, the Electric Springs is a technology with huge potential for *both voltage and frequency stabilities* of power systems.

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