"Distributed Renewable Energy Systems: System of Systems Based Intelligent Management of Micro-Grids"

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UTSA

OUTLINE

1. **Brief Introduction to System of systems (Cyber-Physical Systems - CPS)**
2. SoS (CPS) Engineering – *Challenges*
3. SoS (CPS) Engineering – *Innovations* in Energy, Earth, Defense, Security, Space exploration, etc. -
4. Intelligent control of PV penetration and storage in grid
5. Intelligent control of PV penetration, storage with Air Quality Constraints
6. ***i*-EMS:** : An intelligent energy management of a smart home
7. Research at ACE Laboratory and UTSA
8. Conclusions & More Movie Clips

Preliminary Comments

- Internet has connected people of the world since ~ 1995
- System of Systems (or Cyber-physical systems) is a generalization of connectivity of systems or systems and people – or a crossing of cyberspace and physical space!
- SoS or CPS is getting into new application cases in a very persisting pace – from IT to defense, energy, space, environment, healthcare, services, earth studies, etc.

A Definition of SoS

One out of many definitions …

SoS is a system consisting of an integration of other independent *non-homogeneous* systems with a unified goal --- improve performance measures, e.g.: cost, robustness, reliability, etc.

Applications: Environment, Energy, Defense, Automation, etc..

(Jamshidi, 2005)

What is a system of systems

Retail businesses

Freeways

Transportation SoS:
Roads +GPS+
ONSTAR

***i*POD**

Unanticipated benefits of SoS extension beyond MP3 player (Blogs, PODCAST) or Internet purchases

Others: ***i*PAD**

Aircraft

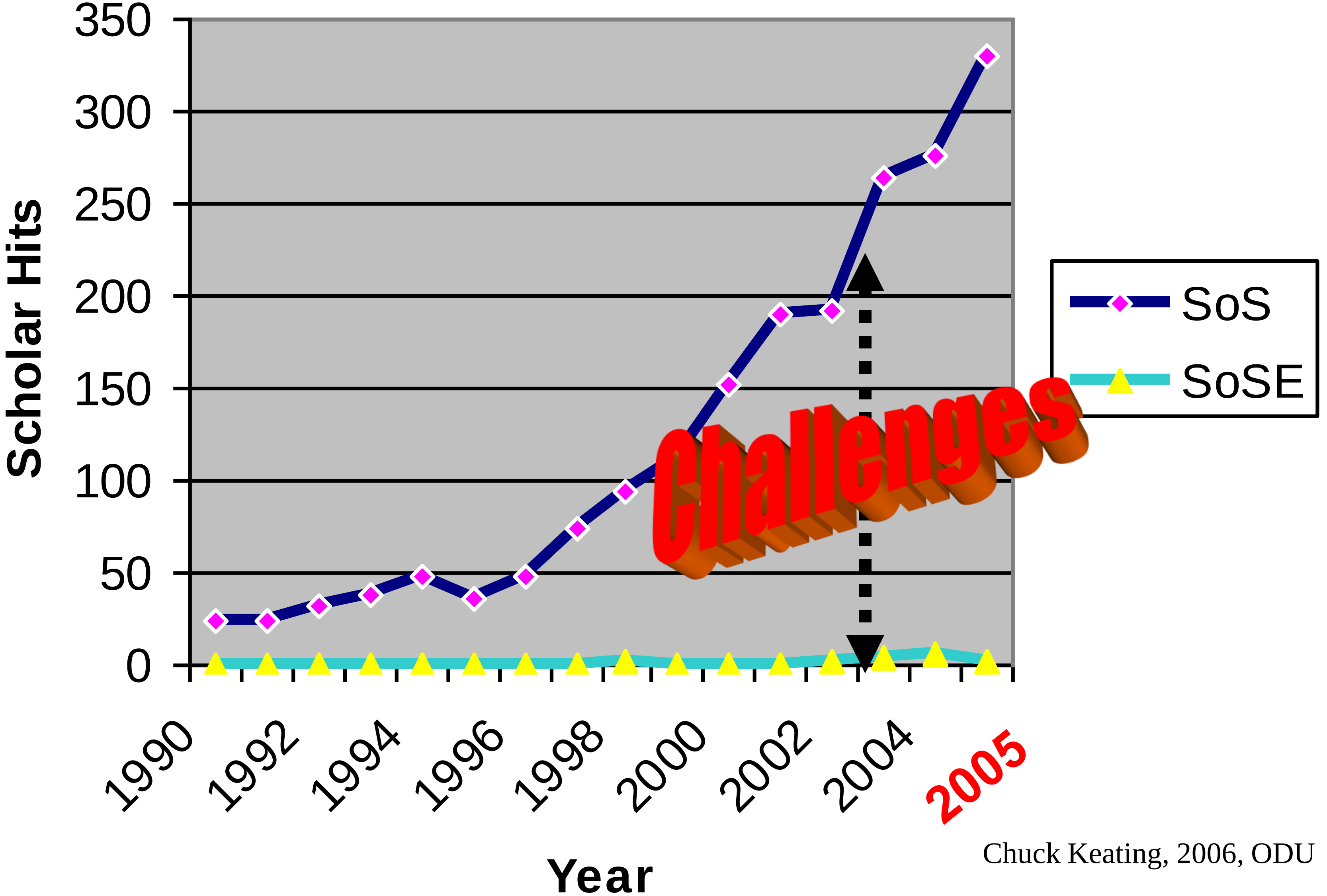
System of Systems

- **SoS**: A meta system consisting of multiple autonomous embedded complex systems that can be diverse in:
  - ✓ **Technology**
  - ✓ **Context**
  - ✓ **Operation**
  - ✓ **Geography**
  - ✓ **Conceptual frame**
- An airplane is not SoS, an airport is a SoS.
- **A robot is not a SoS, but a robotic colony (a swarm) is a SoS**
- Significant challenges:
  - **Determining the appropriate mix of independent systems**
  - **The operation of a SoS occurs in an uncertain environment**
  - **Interoperability**

Application Domains
of System of Systems

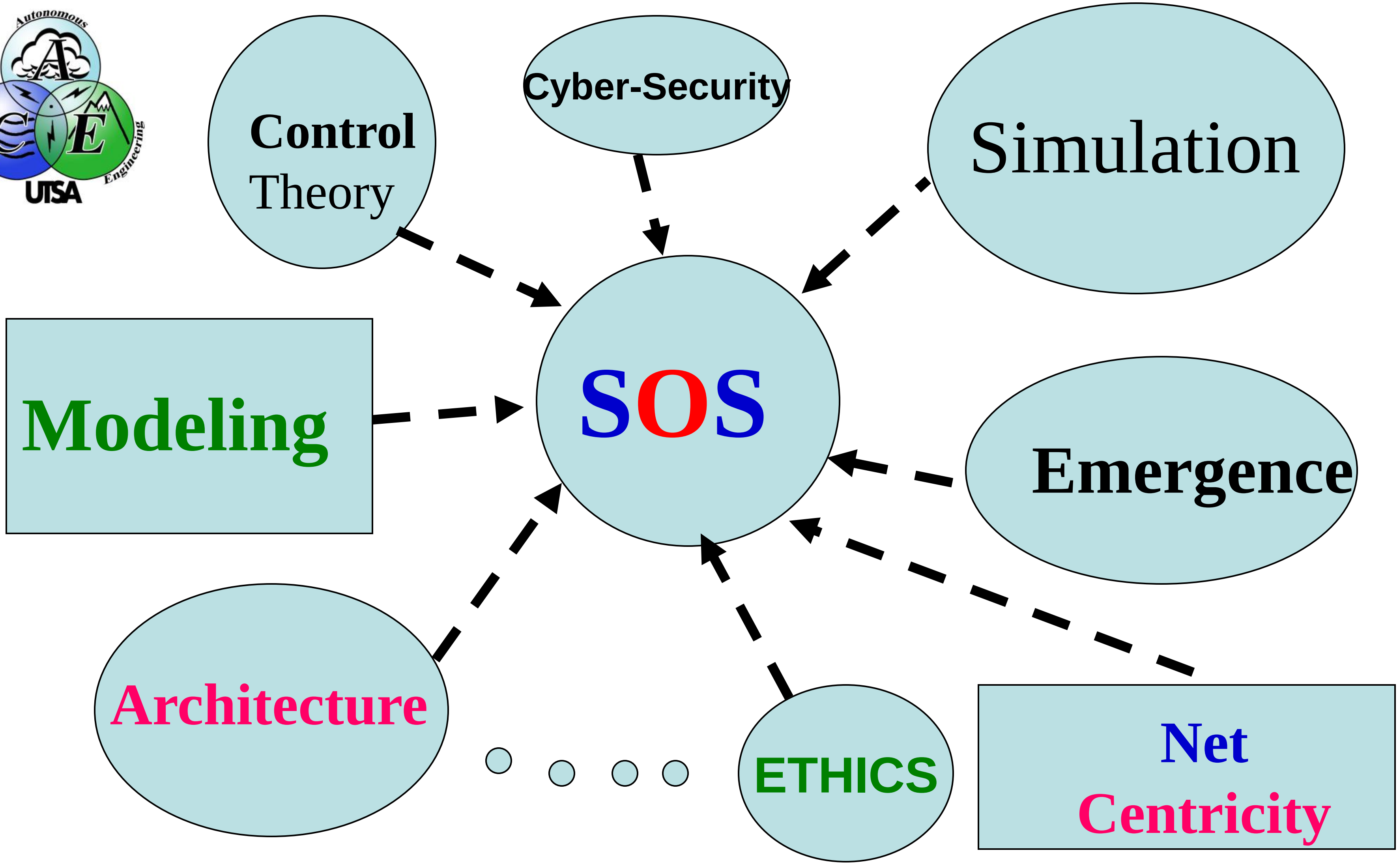
-
  1. Homeland Security – from borders and ports to natural disasters
  2. Planet Earth - Global Earth Observation SoS
  3. Defense and Military – future combat missions
  4. SPACE – robot colonies, formation flying objects
  5. Energy, fossil fuels to renewable
  6. Environment
  7. Healthcare
  8. Transportation
  9. Etc.

SoS (CPS) vs. SoSE (CPSE)



Chuck Keating, 2006, ODU

Challenges … SOS → SoSE



System Engineering
vs.
SoS (CPS) Engineering

System Engineering is a discipline (at least 5 decades old)

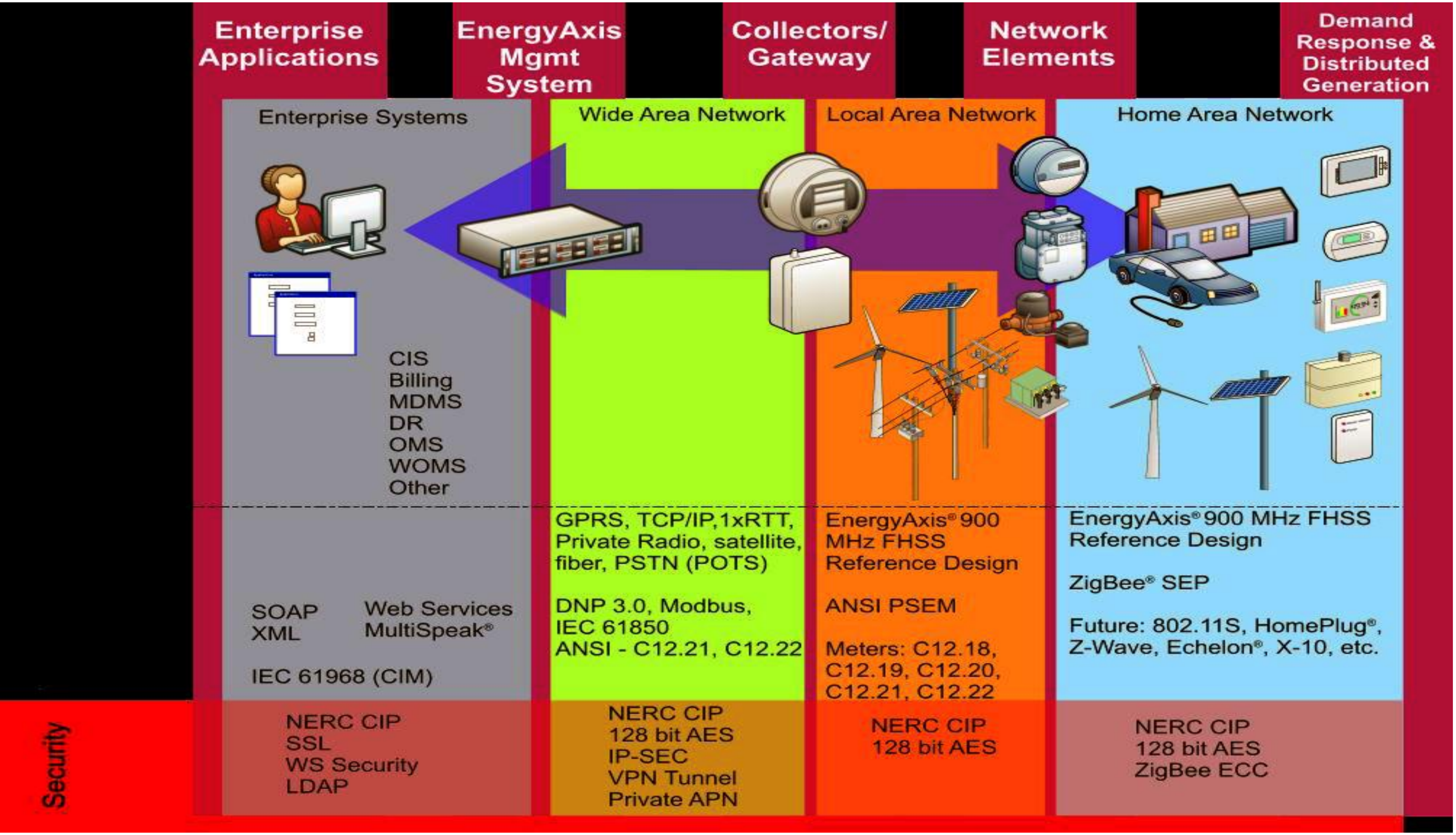
BUT

SoS (CPS) Engineering (at the present time) **is only an opportunity**

Energy

Smart-Grid Energy SoS

Smart Grids



Fuzzy Control of Electricity Storage Unit for Energy Management of Micro-Grids

(WAC 2012, Manjili, et al., 2012)

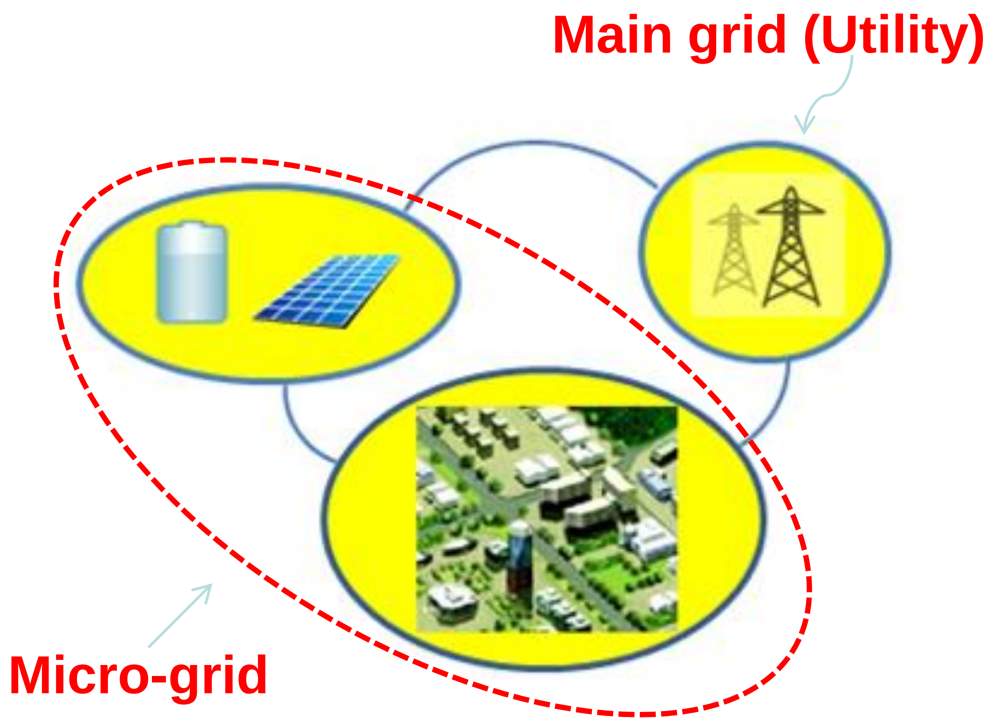
MICRO-GRID NETWORK: DEFINITION

- Micro-Grid can be considered as a small-scale grid that is designed to provide electrical and/or thermal energy for local loads and communities:
  - distributed generators (DGs)
    - Renewable energy sources (solar, wind, hydro, bio-fuels, etc.)
    - Conventional generators (coal, gas, nuclear, etc.)
  - energy storage units
    - Battery storage (Lithium-ion, Vanadium-redox, etc.)
  - local loads and communities
    - Conventional Residential buildings
    - Smart homes
    - Industrial plants, factories, malls, recreational parks, etc.

MICRO-GRID NETWORK: OPERATION

- Synchronous mode, in parallel with the main grid
- Islanded mode, disconnected from the main grid

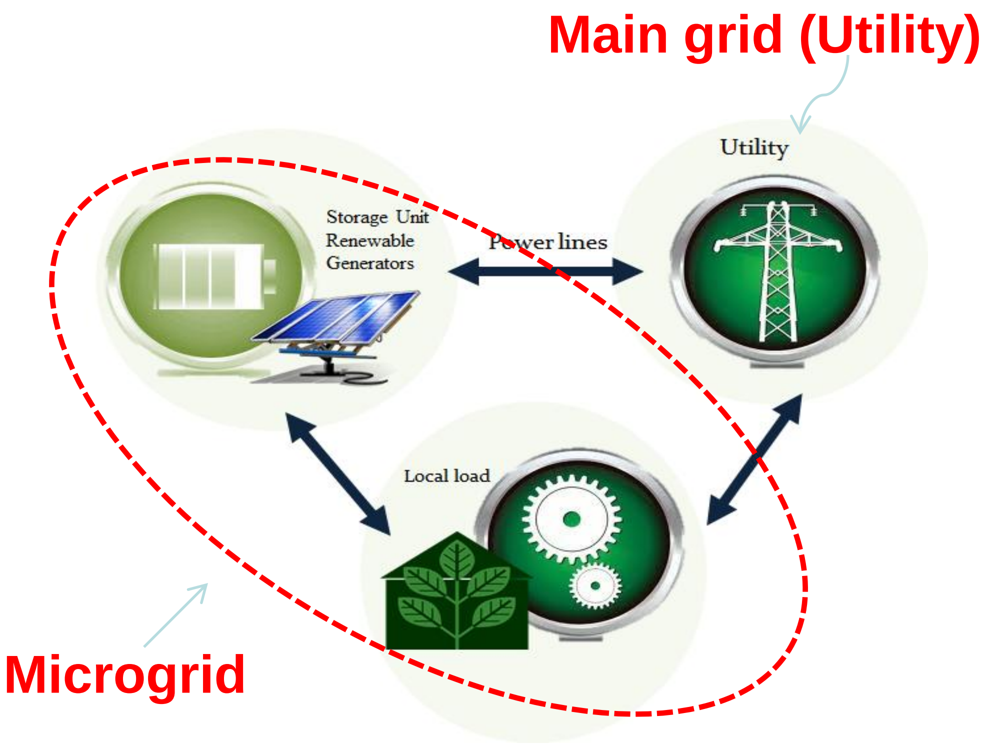
In synchronous mode complementary power can be drawn from the main grid or the excess power can be delivered to it.



MICROGRID NETWORK; OPERATION

- Synchronous mode, in parallel with the main grid
- Islanded mode, disconnected from the main grid

In synchronous mode complementary power can be drawn from the main grid to help micro-grid provide the local loads with their demand. Also, the excess power can be delivered to the main grid from microgrid's side.



MICRO-GRID NETWORK: COST FUNCTION

- The following formula takes into account the effect of distribution loss, and the payment or profit of purchasing/ selling electricity from/to the main grid:

$$Cost = \sum_{t=1}^{T}\left(\Pr(t)\,.\,S_U(t)\right)$$

T : Total number of 15-minute time intervals **($1 =< t =< T=96$)**

Pr(t): Electricity Price (per kWh) during time interval t

$S_U(t)$: Apparent power purchased from/sold to the main grid during time interval t ($S_U(t)>0$ if purchased, $S_U(t)<0$ if sold)

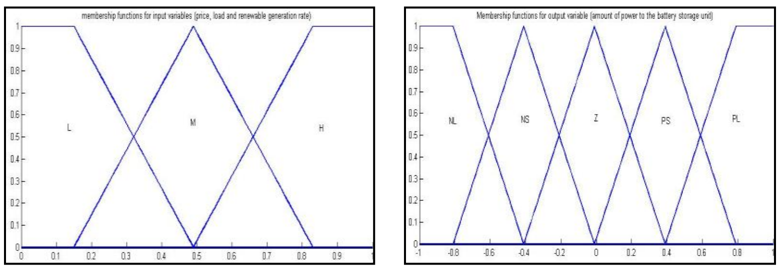
Cost : Payment/revenue (Cost>0 means net purchase; Cost<0 is net revenue)

FUZZY CONTROL

Variables:

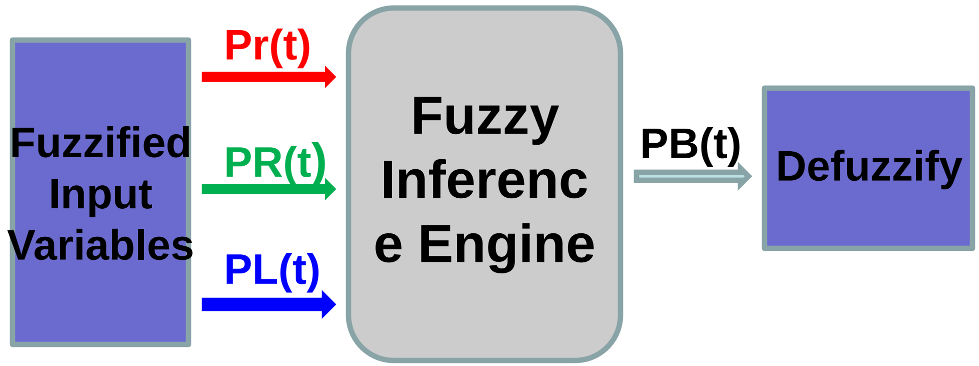
- Inputs: Electricity price (**Pr(t)**), Renewable electricity generation rate (**PR(t)**), Local load (**PL(t)**)
- Output: Rate at which energy should be delivered to/taken from storage unit (**PB(t)**)

Membership functions:



(a) (b)

Membership functions for input and output variables; (a) inputs (b) output



Schematic of the Fuzzy controller with inputs and output

Rule-base:

"Goal is to improve the cost function so that the value of cost is reduced"

Rules are determined based on human reasoning, e.g.:

IF *Price* is *Low*, AND *Gen_Rate* is *High*, AND *Load* is *Medium*, THEN *Output* must be *Positive-Large*

Defuzzification:

Center of Gravity, i.e. Centroid, method:

$$y_{crisp} = \frac{\sum_{i=1}^{n} (max_j\ (\mu_i) \times y_i)}{\sum_{i=1}^{n} max_j\ (\mu_i)}$$

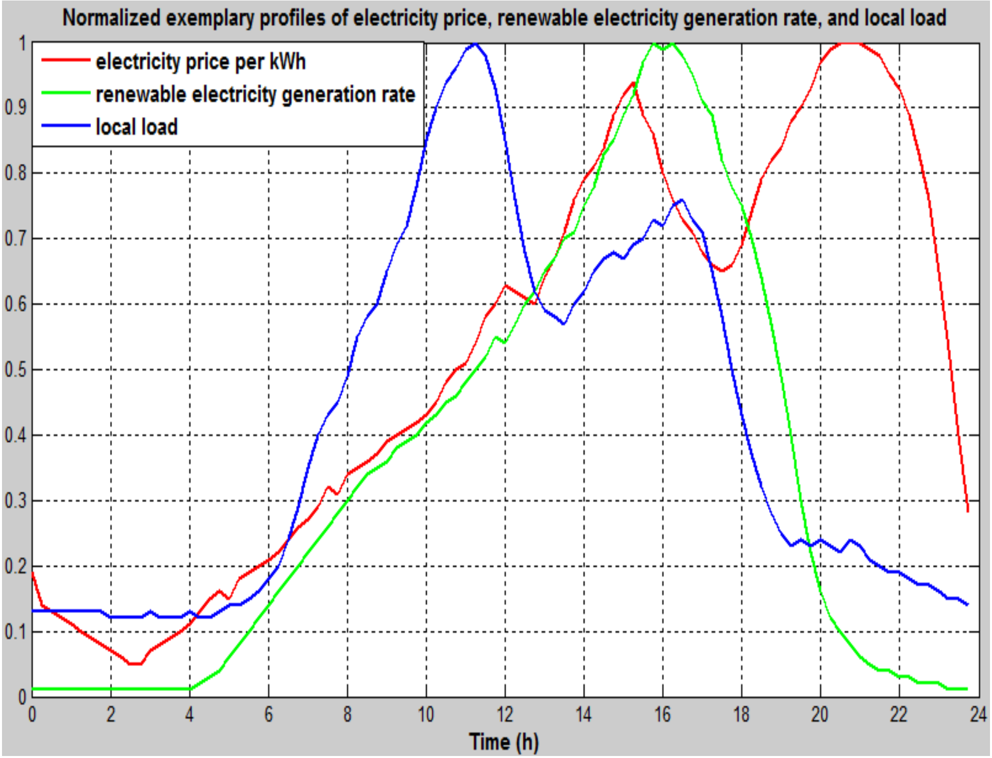
SIMULATION: SCENARIOS

Power flow is calculated using Gauss-Seidel algorithm
Profits/Payments is computed based on cost function

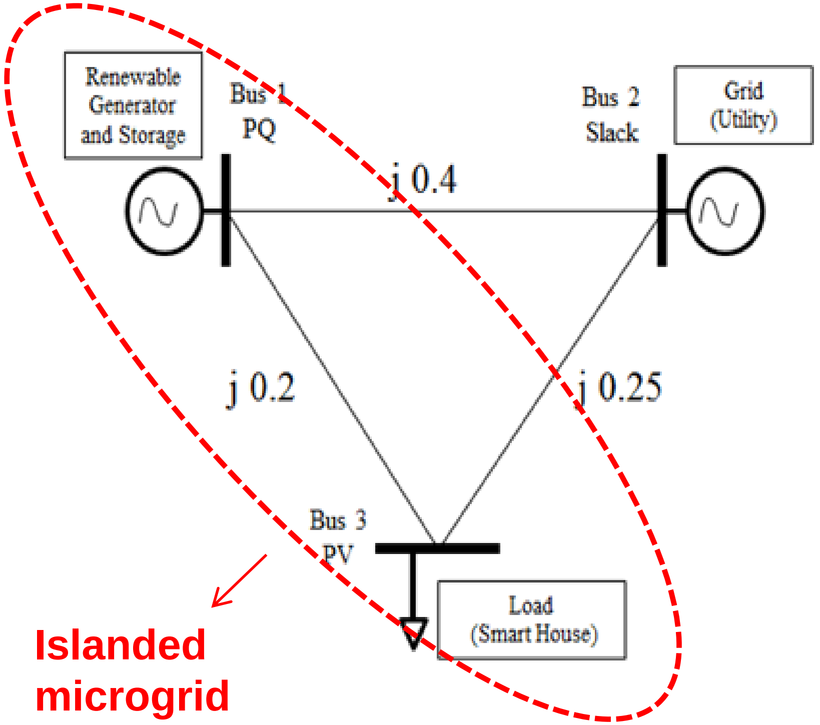
- **Scenario 1**
  Micro-Grid includes the renewable energy electricity generators and local load. No battery storage units. No Fuzzy controller.
- **Scenario 2**
  Micro-Grid includes the renewable energy electricity generators associated with ideal, infinite capacity battery storage unit, and local load. Fuzzy controller is deployed.
- **Scenario 3**
  Micro-Grid includes the renewable energy electricity generators associated with ideal, finite capacity battery storage unit, and local load. Fuzzy controller is deployed.

SIMULATION: DATA & MODEL

15-minute time interval is assumed for electricity price update

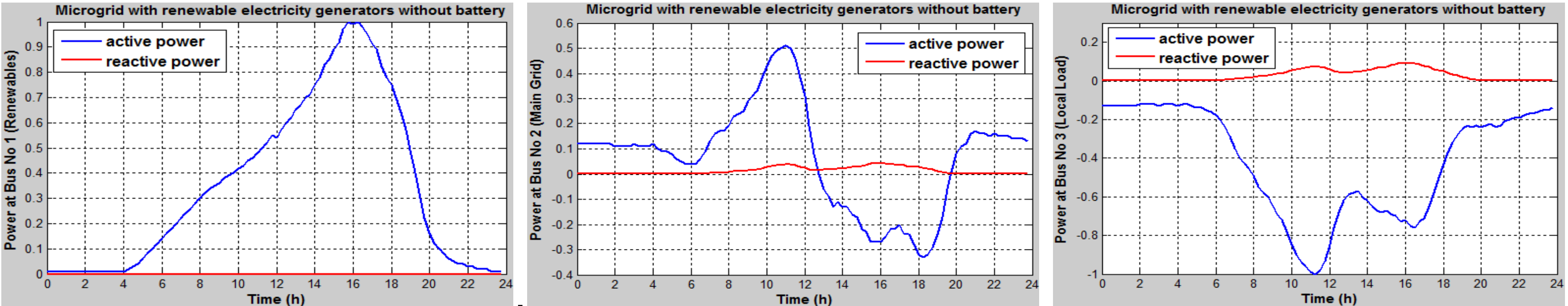


Normalized exemplary data for input variables to the Fuzzy controller: electricity price, renewable electricity generation rate, and local load

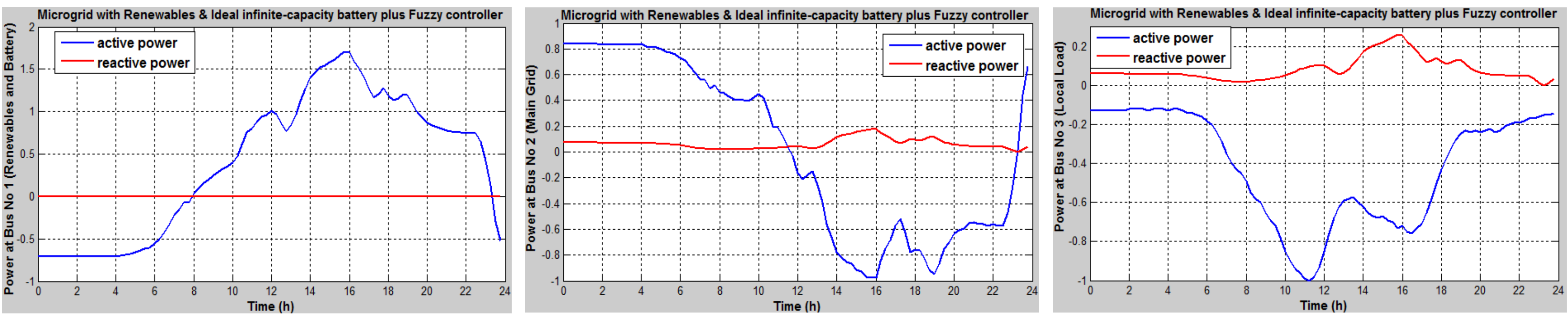


Three-bus model of microgrid used for power flow analysis

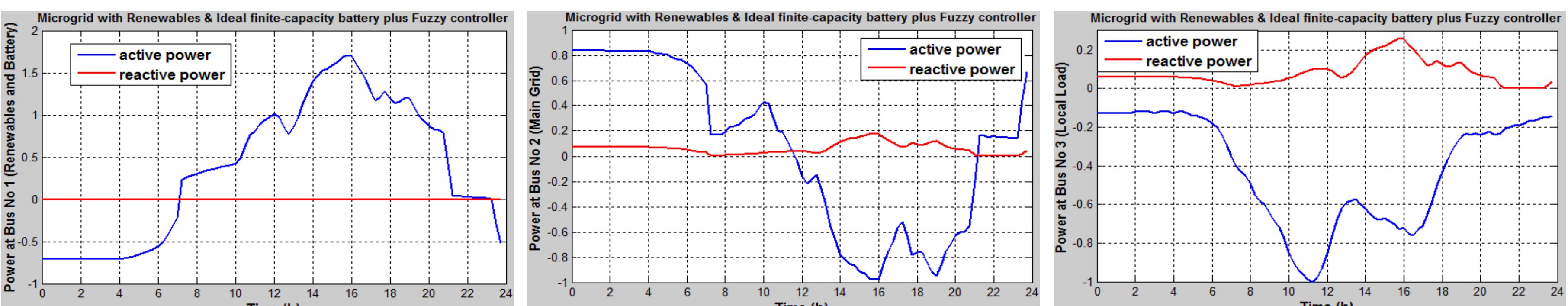
SIMULATION RESULTS: BUS PROFILES



Active and reactive power on each bus for 24-hour period; Scenario 1



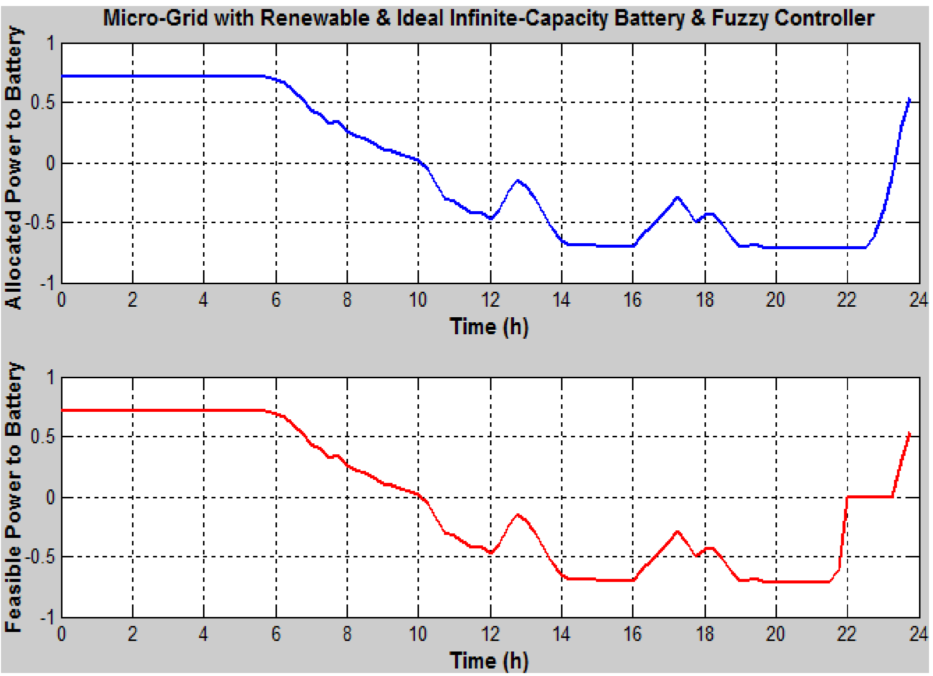
Active and reactive power on each bus for 24-hour period; Scenario 2



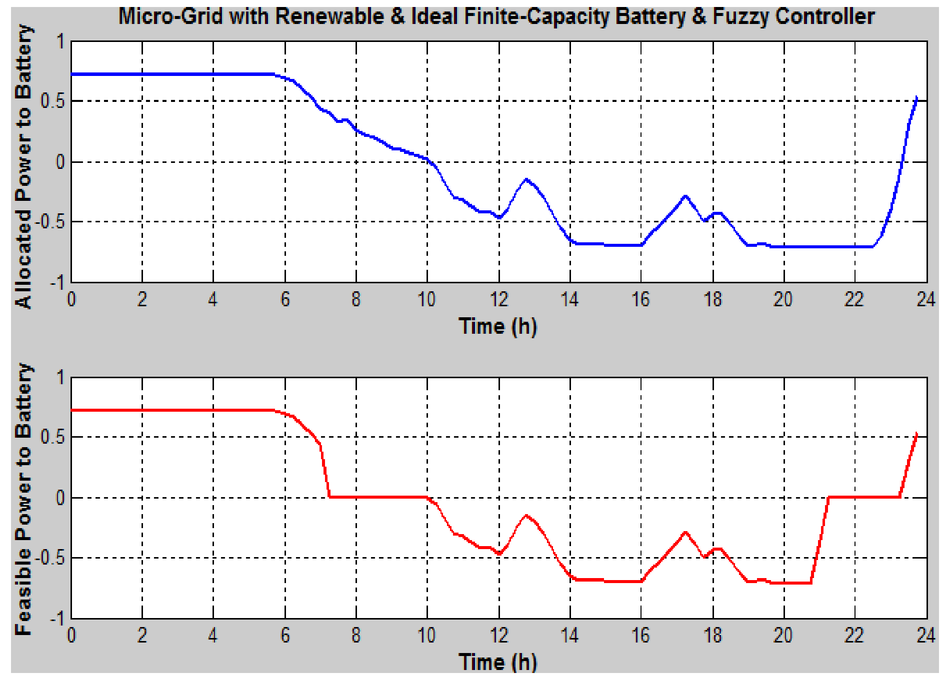
Active and reactive power on each bus for 24-hour period; Scenario 3

SIMULATION RESULTS: STORAGE UNIT

Output of the Fuzzy controller is the rate at which energy should be exchanged between the storage unit and the rest of the network.

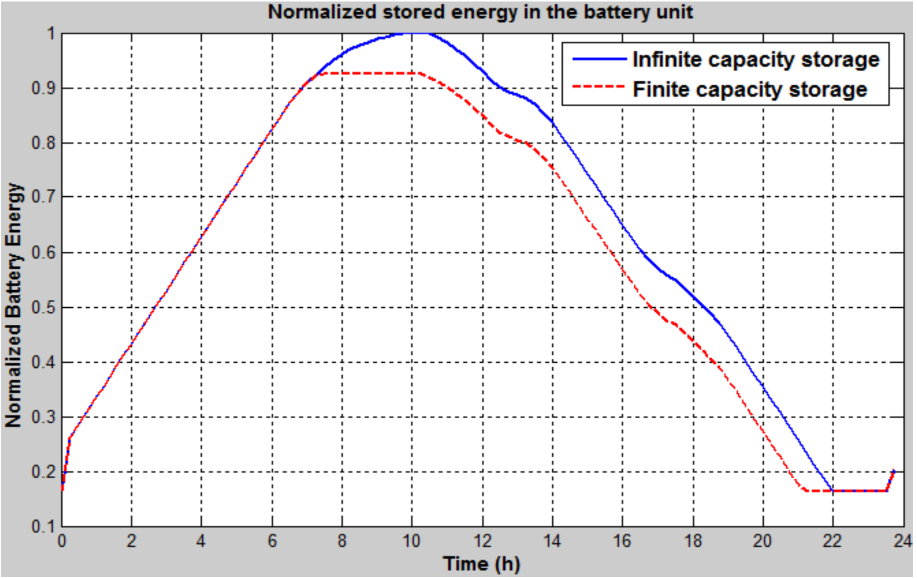


Curves of power exchange with battery for scenario 2

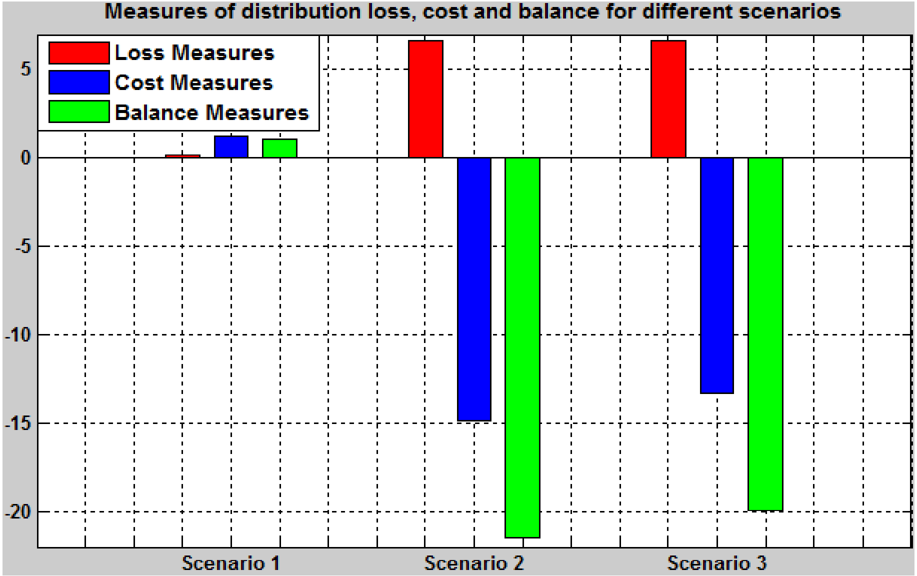


Curves of power exchange with battery for scenario 3

SIMULATION RESULTS: MEASURES



Normalized Battery State of Charge (SOC) for scenarios 2 and 3



Measures of Loss, Cost and Balance for different scenarios

	Loss	Cost	Balance
Scenario 1	0.1339	1.2294	1.0955
Scenario 2	6.6039	-14.8711	-21.4750
Scenario 3	6.6039	-13.3021	-19.9059

$$Balance = Cost - Loss$$

$$Loss = \sum_{t=1}^{T} (\Pr(t) \, . \, S_L(t))$$

Table 1. Summary of the simulation results; Loss, Cost, and Balance

**Scenarios 2 and 3 deploy the Fuzzy control approach of storage unit in order to maintain energy management in the microgrid network*

Intelligent Decision Making for Energy Management in Microgrids with Air Pollution Reduction Policy

(SoSE 2012)

DECISION MAKING; AIR POLLUTION

According to the Environmental Protection Agency (EPA)

$$p = \psi E$$

p : Amount of CO_2 added to the environment in pounds (*lb*)

Ψ : Restricting coefficient, must be 1000 (lb/MW) or less

E : energy generated by the power plant during a specific time in MegaWatts (MW), i.e. $E = \int P(t) dt$, where P(t) is the power profile

"Pollution Update"

$$C(k+1) = C(k) + \Delta C$$ al.

$$\Delta C = \Delta p(k) - \Delta r(k)$$

$\Delta r(k)$: Removal term of pollution associated with chemical reactions and pollution's atmospheric dispersion

$$\Delta p(k) = p(k+1) - p(k) = \psi \int_{k\Delta t}^{(k+1)\Delta t} \left(\sqrt{P_U^2(t) + Q_U^2(t)}\right) dt$$

MODIFYING THE RULE-BASE

Original

IF the *Price* is ***Medium***, **AND** the *Renewable Generation Rate* is ***Low***, **AND** the *Load* is ***Medium***, **THEN** the *Battery* should be ***Lightly Discharged***.

Modified

IF the *Price* is ***Medium***, **AND** the *Renewable Generation Rate* is ***Low***, **AND** the *Load* is ***Medium***, **AND** the *Air Pollution* is ***High***, **THEN** the *Battery* should be ***Heavily Discharged***.

$P_B(t)$

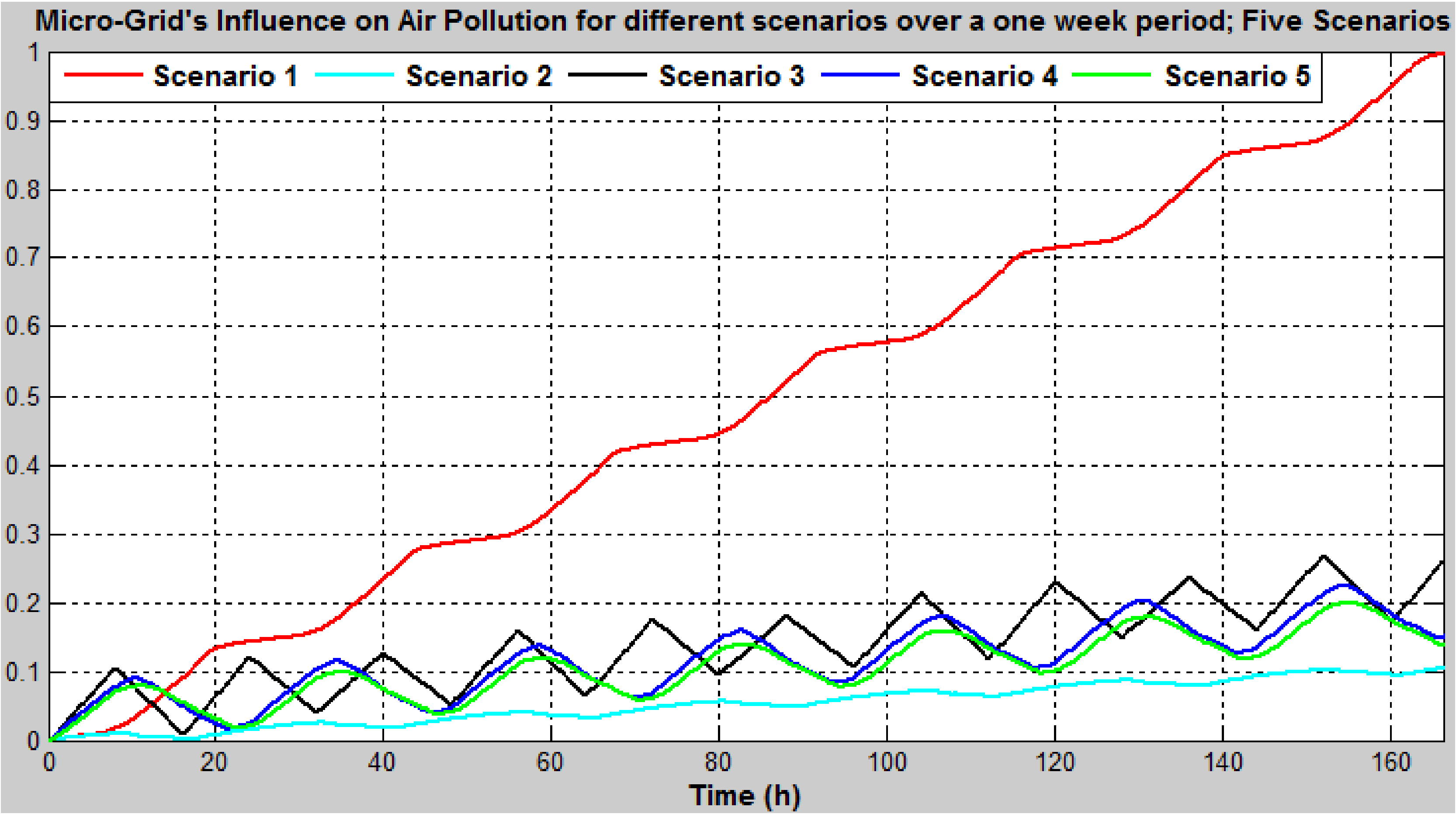
SIMULATION; SCENARIOS

Power flow is calculated using Gauss-Seidel algorithm

Profits/Payments is computed based on cost function

	Microgrid Model Elements	Fuzzy Inputs	Fuzzy Output
Scenario 1	Main grid Local Load	---	---
Scenario 2	Main grid Local Load Renewables	---	---
Scenario 3	Main grid Local Load Renewables Battery Storage	---	---
Scenario 4	Main grid Local Load Renewables Battery Storage Fuzzy Control	Pr(t) $P_R(t)$ $P_L(t)$	$P_B(t)$
Scenario 5	Main grid Local Load Renewables Battery Storage Fuzzy + Pollution Control	Pr(t) $P_R(t)$ $P_L(t)$ C(t)	$P_B(t)$

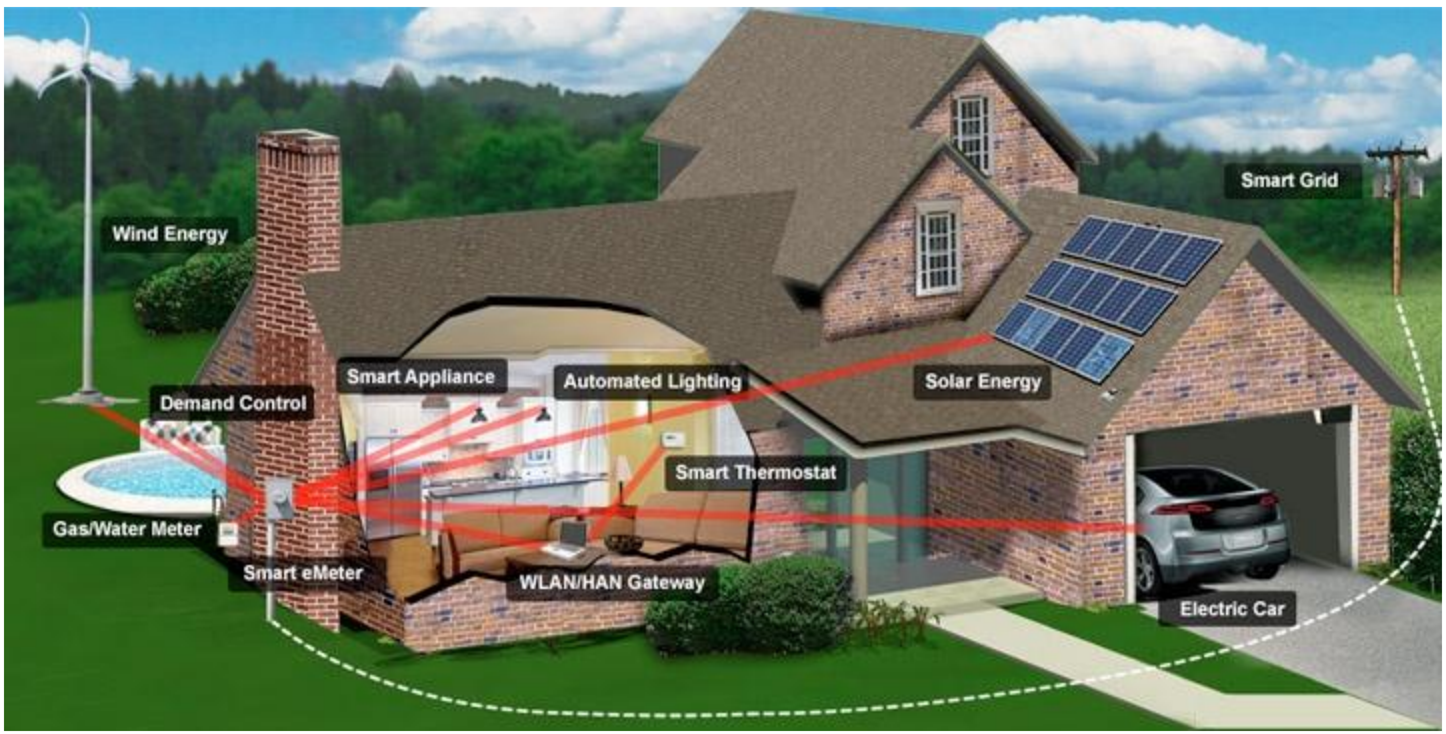
SIMULATION RESULTS: AIR POLLUTION



Normalized Effect of Micro-grid on Air Pollution for five scenarios during a week period

Energy Smart Homes

Home Area Network (HAN) and Wide Area Network (WAN)



i-EMS: Intelligent Energy Management System in a Smart House

(WAC 2012, Shahgoshtasbi and Jamshidi, 2012**)**

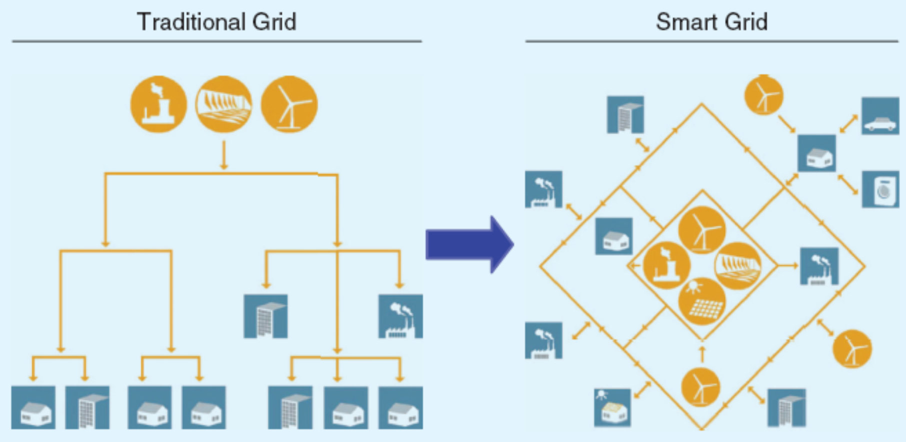
Objective & Contributions

- Objective
  - Design an automated energy management system which is intelligent and very reliable.
  - It should be intelligent and act like a human being in critical situations.
  - The system should be designed in a way that a customer spends the minimum time to adjust the system. (a few hours in a year).
- Contributions
  - A new Architecture for intelligent management of home energy consumption.
    - The main part of the system is an intelligent lookup table. It can stabilize the system during peak hours and do the best based on what it has been trained before. Also system should be able to learn new scenarios if necessary in off-peak hours. (i.e. a robust and reliable system).
    - The core of the intelligent lookup table is a new topology of neural network. It acts as an associative memory and has a crystal type structure, which can be expanded easily.

The automated energy management systems are able to find the best energy efficiency scenario in different conditions.

Introduction-Smart Grid

- The electric industry is poised to make the transformation from a centralized, producer-controlled network to one that is less centralized and more consumer-interactive.
- Smart Grid is a novel initiative which its aim is to deliver energy to the users and also to achieve consumption efficiency by means of bidirectional communication.



Traditional Grid	Smart Grid
Centralized Generation	Generation Everywhere
Power Flows Downhill	Power Flows from Everywhere
Utility Controls Connections	Anyone May Participate
Behavior: Predictable	Behavior: Chaotic

Introduction-Demand Response

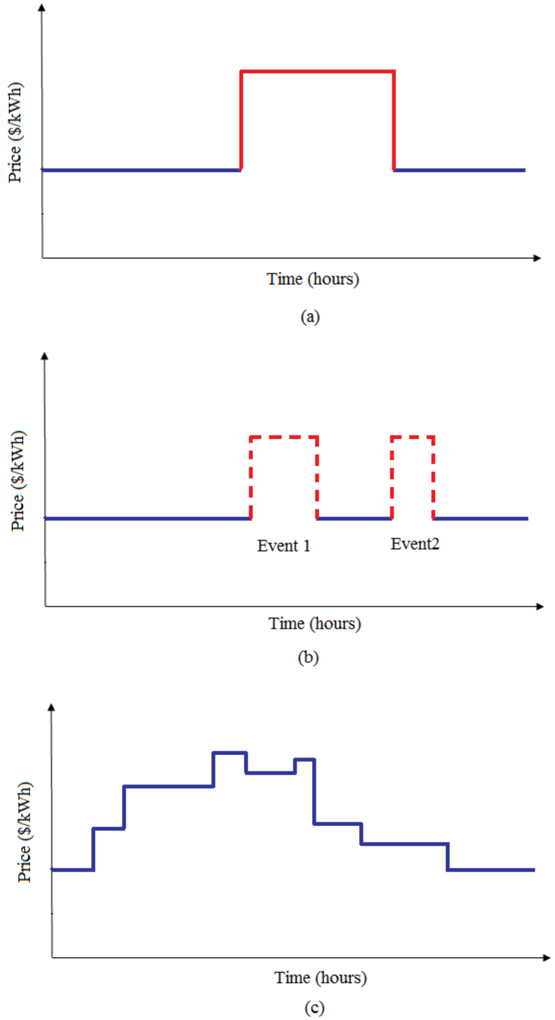
- Demand Response is the action voluntarily taken by a consumer to adjust amount or timing of its energy consumption.

- It can be discussed on
  - Generation
  - Transmission
  - Residential levels

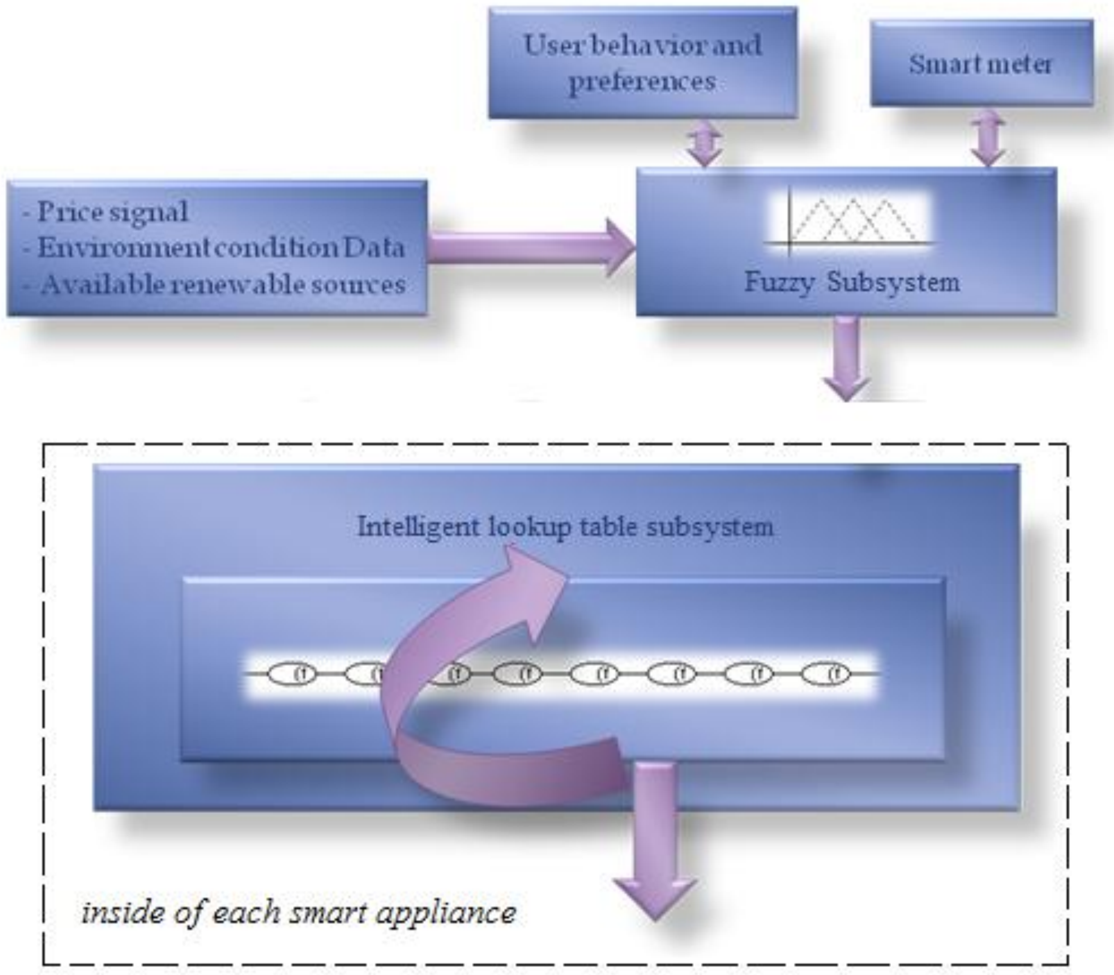
Introduction-Demand Response

Time varying demand response programs are:

- Time-of-use-pricing (TOU): rates charges different prices for electricity used within defined time periods.
- Critical-peak-pricing (CPP): is similar to the TOU rates except that the times and the rates are not fixed
- Real-time-pricing (RTP): rates vary continuously based on wholesale price or regional demand. Unlike the critical-peak-pricing and time-of-use pricing, real-time-pricing rates provide different prices for the electricity consumer at each hour of the day.



Suggested Automated Energy Management System



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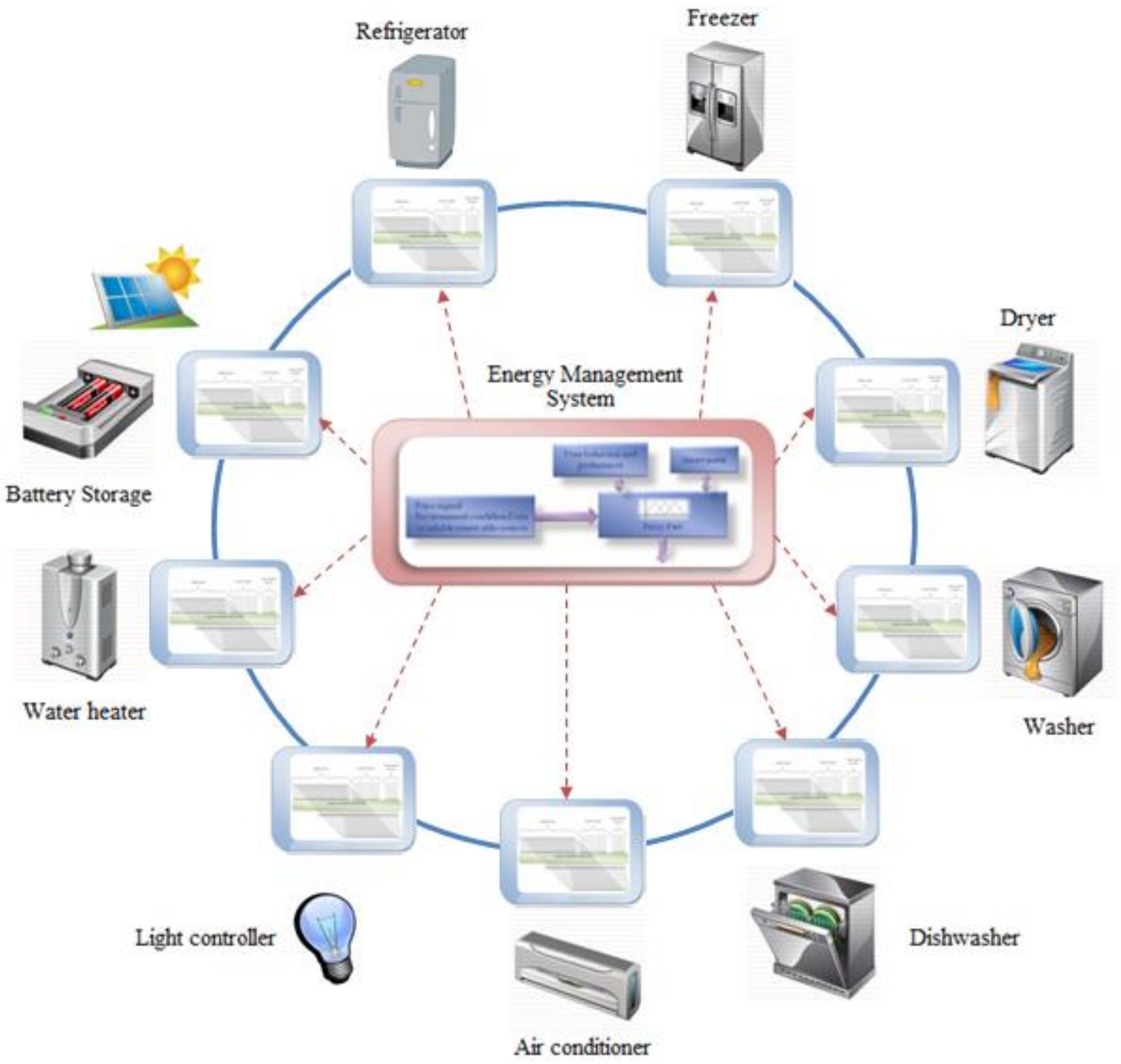


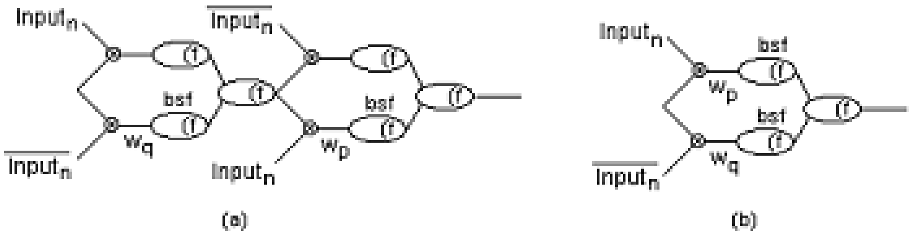
Fuzzy inference system implementation

Algorithm for Energy Management System

1: **If** (cost is low) then output ← neutral_minus
2: **If** (cost is meduim and battery is high and solar is high) **then** output ← neutral_plus
3: **If**(cost is meduim and battery is high and solar is meduim) **then** output ← neutral_plus
4: **If**(cost is meduim and battery is high and solar is low) **then** output ← normal
5: **If**(cost is meduim and battery is meduim and solar is high) **then** output ← normal
6: **If**(cost is meduim and battery is meduim and solar is meduim) **then** output ← normal
7: **If**(cost is meduim and battery is meduim and solar is low) **then** output ← high_minus
8: **If**(cost is meduim and battery is low and solar is high) **then** output ← high_minus
9: **If**(cost is meduim and battery is low and solar is meduim) **then** output ← high_plus
10: **If**(cost is meduim and battery is low and solar is low) **then** output ← high_plus
11: **If**(cost is high and battery is high) **then** output ← peak_minus
12: **If**(cost is high and battery is meduim and solar is high) **then** output ← peak_minus
13: **If**(cost is high and battery is meduim and solar is meduim) **then** output ← peak_minus
14: **If**(cost is high and battery is meduim and solar is low) **then** output ← peak_plus
15: **If**(cost is high and battery is low) **then** output ← peak_plus

Intelligent lookup table

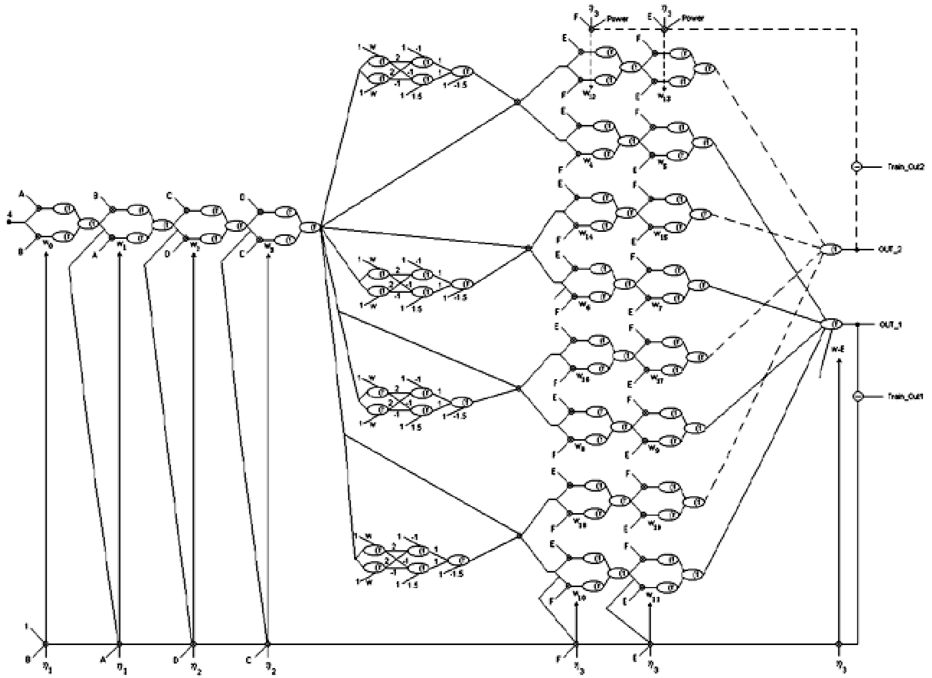
- Structure:
  - Each cell is constructed of two middle neurons and four side neurons such that the two upper ones have fixed weights and the two lower ones have trainable weights.
  - Cells would be connected as a chain up to the $(n\text{-}1)$th input. The only remaining input is n where the output of the chained string is connected to $\frac{2^n}{2}$ of this input cell.



One cell of the network, (a): Original Shape , (b): The summary of part a

Intelligent lookup table

- Only active neurons are trained. The characteristic of the lower neurons is that the increasing and decreasing rate of the weight changes are not equivalent during the training step.



The structure of the associative memory layer with 3 inputs and 2 outputs.

Intelligent lookup table

Functionality: Continue …

- All the appliances should send their control bits to each other.
- It is Considered priority for the appliances.
- The highest priority appliance sends its control bit information to the second one. The second one adds its control bit information to it and sends them to the third one. This process continues to reach the last one. The last one adds its control bit information and sends all the control bit information to the first one.
- Then, the intelligent lookup tables are waiting for inputs from Fuzzy component. When they receive it, each intelligent lookup table tries to find the best scenario for its appliances based on the inputs and whatever they have been trained.

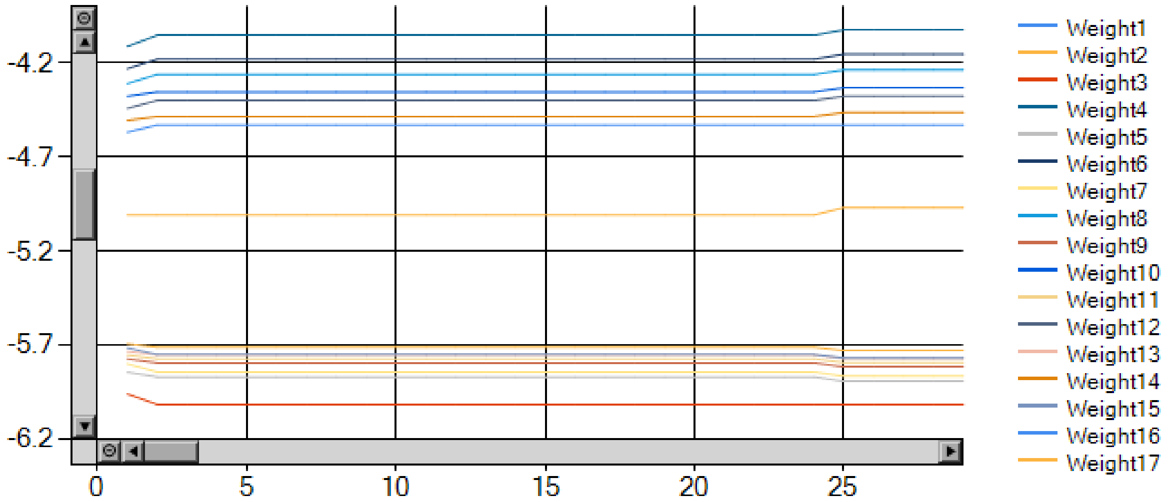
Simulation

- It is Considered a smart house with water heater, air conditioner, light, solar panel, battery storage, refrigerator, freezer, dishwasher, washer and dryer.
- 15 fuzzy rules in the first category which make proper inputs for the intelligent lookup table.
- Associative memory with 38 inputs and 18 outputs. Totally 4096 cells are considered for its parallel layer.
- The outputs of the fuzzy system implementation enter the first six inputs of the network and the rest inputs come from output feedback.
- 12 control bits which enter the network as next inputs. These control bits are for solar, battery storage and home appliances situation.
- The rest inputs come from feedback outputs.
- Seventeen different scenarios are defined.

Simulation, Cont'd.

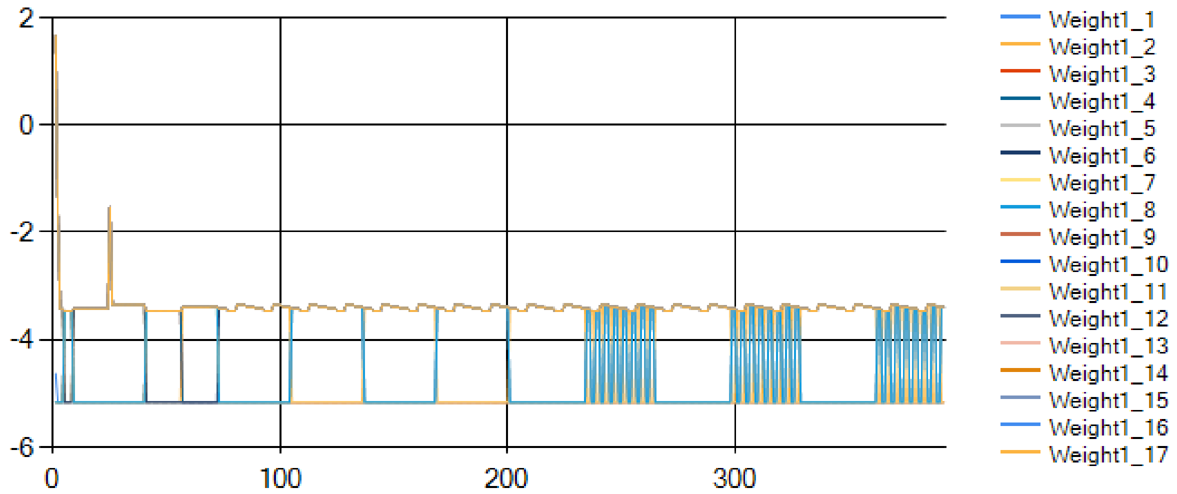
No.	Scenario
1	Charge battery by grid
2	Charge battery by solar
3	Turn on water heater
4	Turn on air conditioner
5	Turn on dishwasher if programmed on
6	Turn on washer if programmed on
7	Turn on dryer if programmed on
8	Give portion of energy to dishwasher if programmed on
9	Give portion of energy to washer if programmed on
10	Give portion of energy to dyer if programmed on
11	Give portion of energy to refrigerator if needed (on)
12	Give portion of energy to freezer if needed (on)
13	Turn off dishwasher
14	Turn off washer
15	Turn off dryer
16	Get energy from battery storage
17	Turn on light controller

Simulation



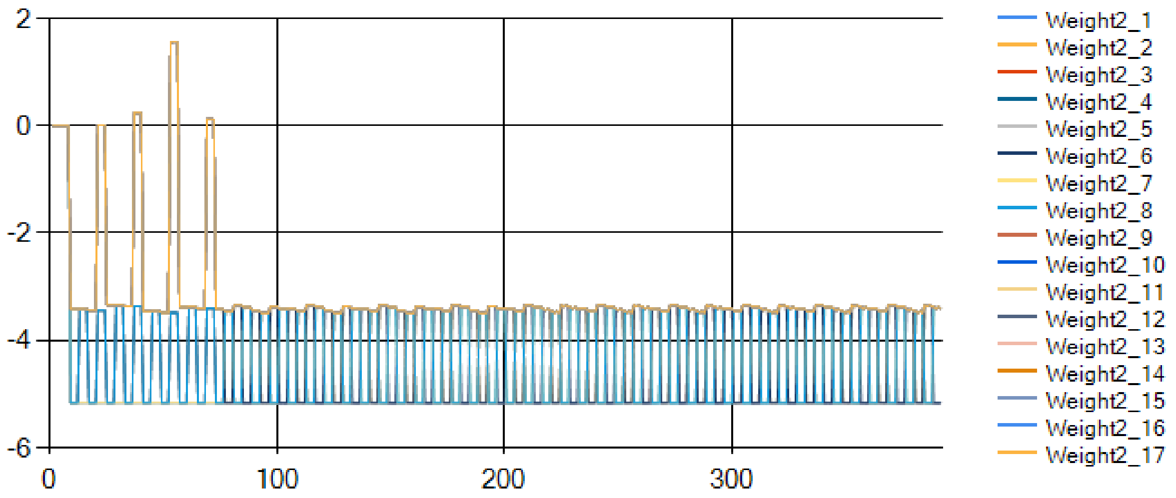
The value of weight changes for simulation of system with 38 inputs and 18 outputs

Simulation



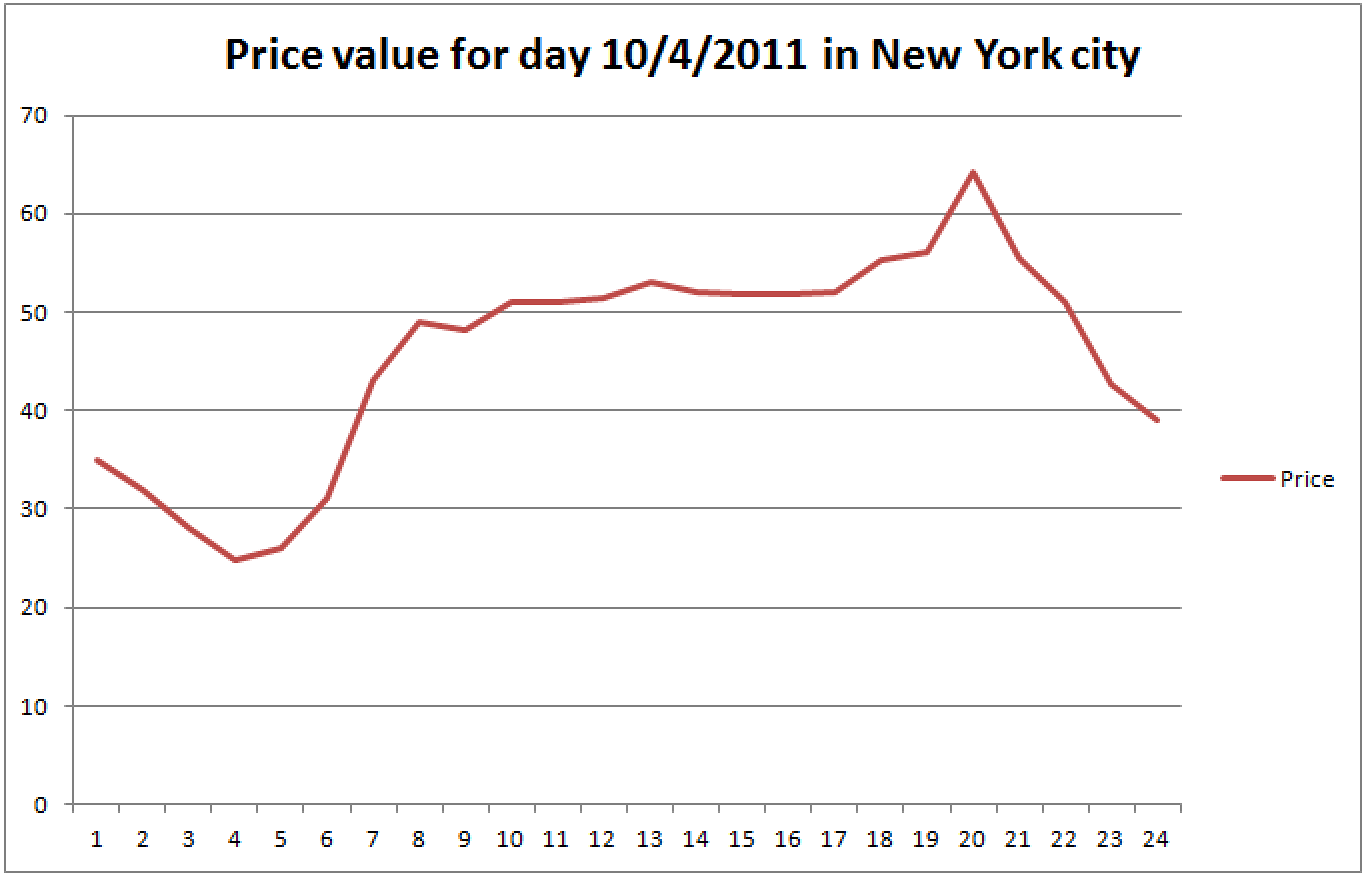
Weight changes for the first lower trainable weight in parallel layer for all of the training situations

Simulation



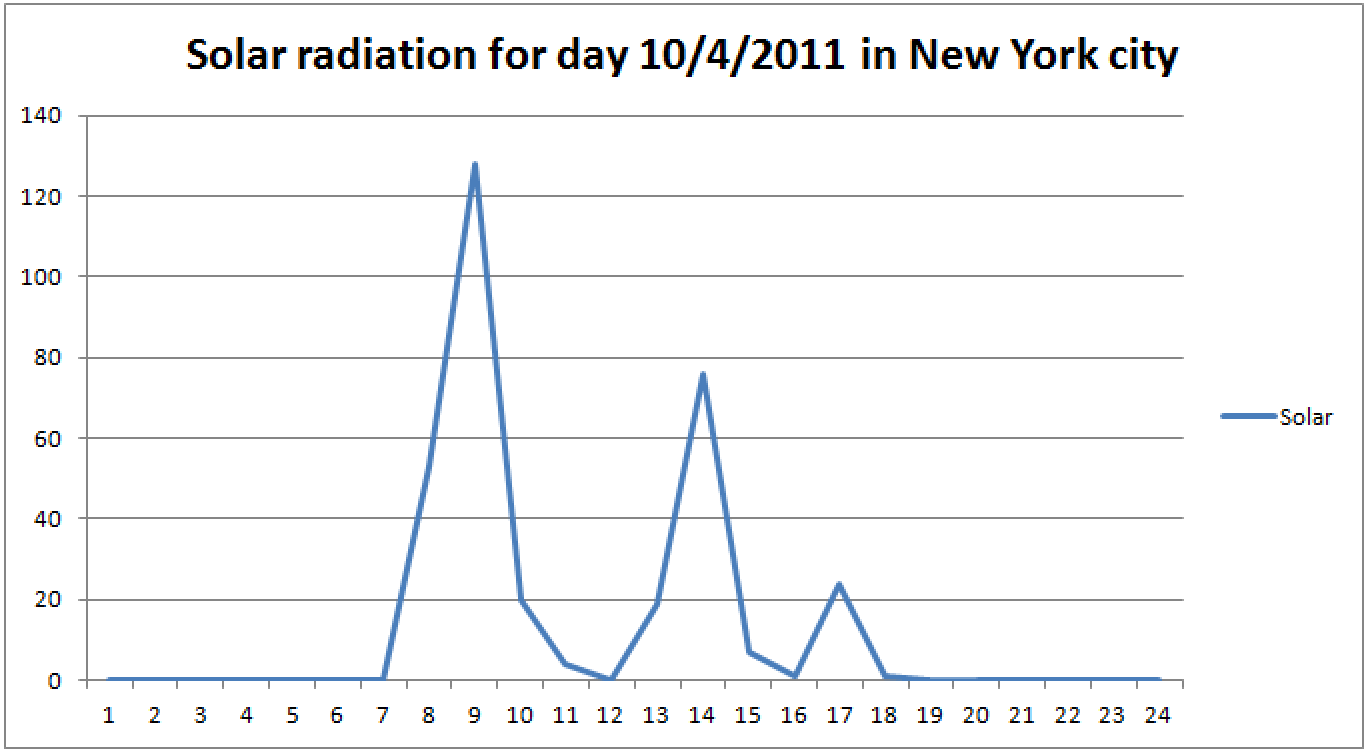
Weight changes for the second lower trainable weight in parallel layer for all of the training situations

Simulation



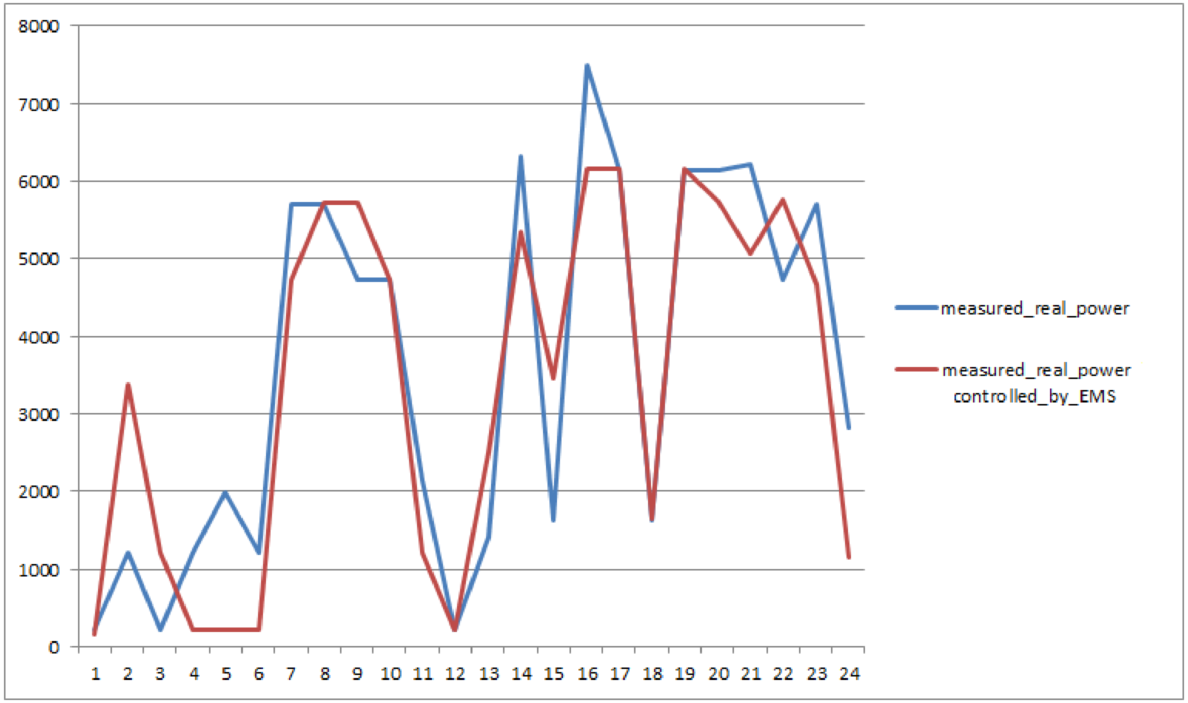
Price value for day 10/4/2011 in New York city
70
60
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Price

Simulation



Solar radiation for day 10/4/2011 in New York city
140
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Solar

Simulation



Comparing measured power with and without applying the intelligent EMS to the system during one day (24 hours)

SoSE Research at ACE Laboratory - UTSA

Research Areas

Air-Land-Sea Rovers

Green energy

Green energy infrastructure

Cloud Computing as an SoS

Texas Sustainable Energy Institute ... **TSERI**

http://texasenergy.utsa.edu/

Les Shephard, Director

(Est. 2009)

Carbon Capture, Management and Reutilization

Electrification of the Transportation Sector

Energy Efficiency and Conservation

Energy/Water Nexus

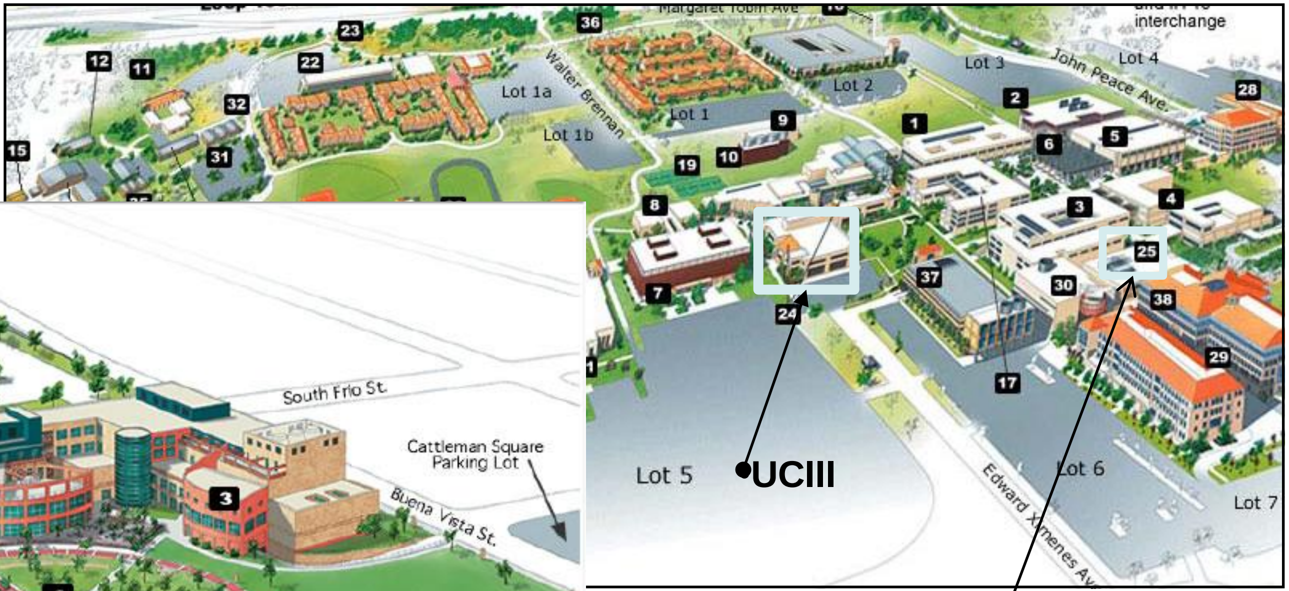
Renewable Energy Technology and Storage

SMART Secure Distributed Grid

Institute Comprised of Several Elements

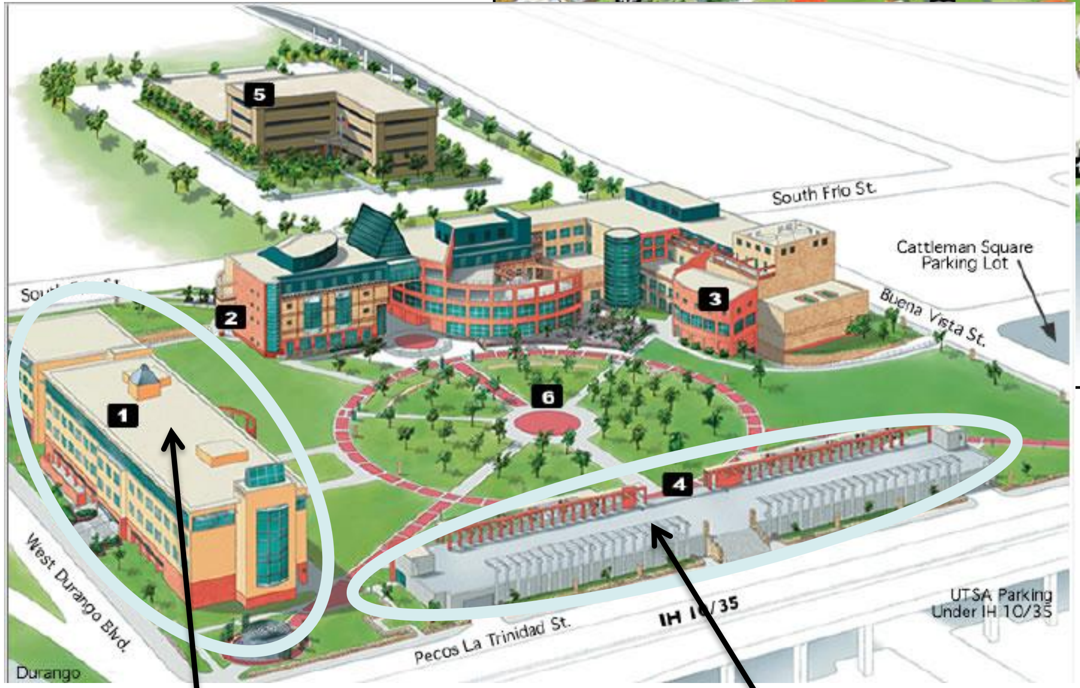
UTSA Smart Grid Project Distribute UTSA Sites - $ 2.4 ML

North Campus



EB Building

Downtown Campus



•Durango Building

•Durango Parking Garage


TXSPC

1604 Campus Micro-Grid Interactive PV System

ENERGY RESEARCH AT UTSA

- **Electric vehicles … Shuo Wang**
- **Inverters & PV Penetration … Hari Krishnaswamy**
- **Energy Smart Homes … Mo Jamshidi**
- **DG Integration, management, and cloud data centers … Brian Kelley and Mo Jamshidi**
- **Cyber-Security of Smart Grids … Ram Krishnan**

MASTER OF ENGINEERING IN SUSTAINABLE EENRGY SYSTEMS

COURSE WORK === ROJECT

(36 credits + Exam) === (30 credits + 6 credit project)

E L E C T I V E S

(12-18 credits)

ECE TRACK CORE

(9 credits)

ME TRACK CORE

(9 credits)

COMMON CORE

(6 Engineering credits and 3 credits out of 9 others)

MASTER OF SUSTAINABLE ENRGY SYSTEMS DEGREE STRUCTURE

Degree involves: COE, COS, COB, COA and COPP

Megawatt Electric Vehicle Super Fast Charging Stations with Enhanced Grid Support Functionality

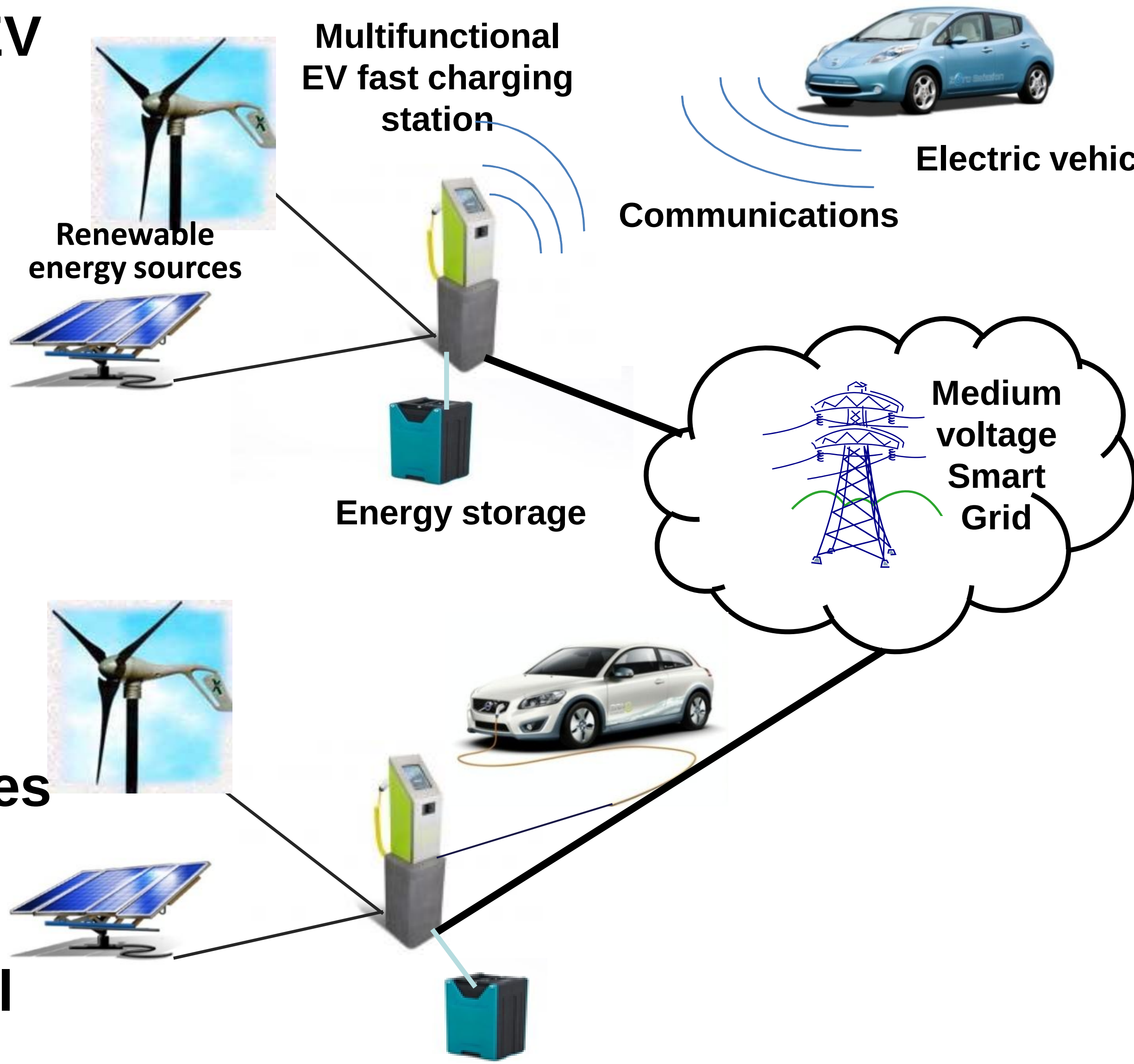
2011 NSF CAREER AWARD: Dr. Shuo Wang

Objective: Development of MW superfast (3 minutes) EV charging stations as an energy hub to have the energy exchanges among grid, EV's.

Supports EV and most of grid support functionalities so as to reduce grid infrastructure expenses and stabilize the grid.

Megawatt Electric Vehicle Super Fast Charging Stations with Enhanced Grid Support Functionality

1. Megawatt 3-minute EV charging station
2. Integrated with grid energy storage
3. Integrated with renewable energy sources
4. Offer most of grid support functionalities
5. Low energy loss w/ medium voltage level grid



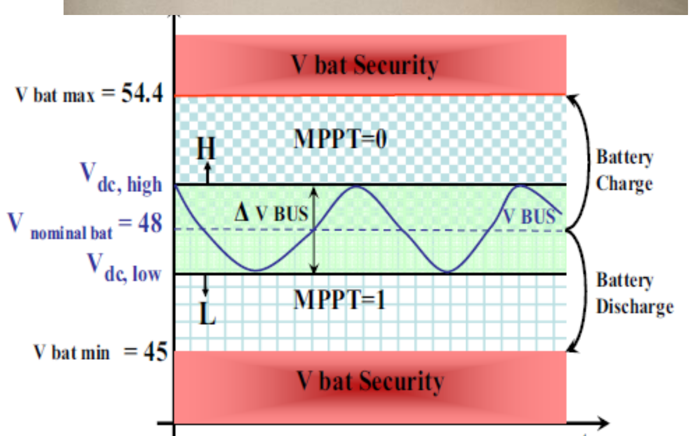
Collaborations in Energy R & D

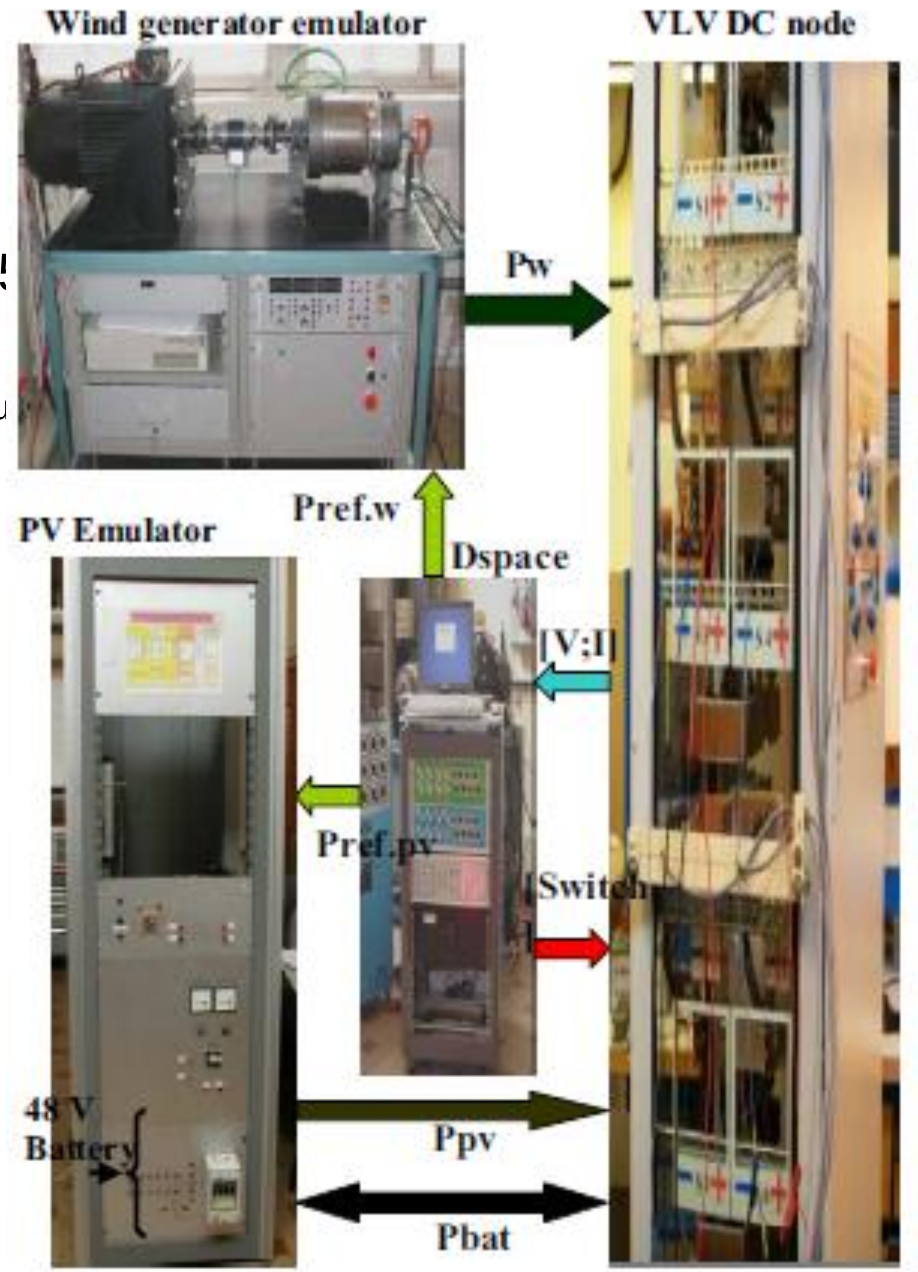
1) MIT, CalTech, U Penn (systemic Risk in complex systems – Energy, Financial Markets and Transportation)
2) Purdue and Power Analytics
3) SwRI, SunEdison, Ideal Power
4) NREL
5) EC/EU funded grant with Univ. Loughbrough and Univ. Bournemouth (UK) and Purdue
6) CPS Energy ($ 50 ML- 10 year grant) …TSERI
7) UTSA-TTU Energy Alliance (PV + Wind)
8) UT-Austin UTSA Energy Forum (March 7th 12)

Note: UTSA is 2nd Largest Hispanic Institution in USA.

- The utility of energy management supervisor is
to control the battery SOC by keeping
voltage , between two imposed limits(5

around the rated battery voltage V_{bat_nu}





June 2nd – June 6, 2013
Makena Beach and Golf Resort
Maui, Hawaii, USA

IEEE

SMC

Conference Theme:

SoSE in Cloud Computing and Health Care Information Technology

ReliabilitySociety

CALL FOR PAPERS

IEEE System, Man, and Cybernetics Society and IEEE Reliability Society announce the 8th International Conference on System of Systems Engineering (SoSE) with its vast ramifications in numerous engineering fields such as control, computing, communication, information technology and in applications such manufacturing, defense, national security, aerospace, aeronautics, energy, environment, healthcare, and transportation. The conference theme is "SoSE in Cloud Computing and Health Care Information Technology", two areas of significant investment within the public and private sectors as well as being significant initiatives areas of IEEE. Papers on theories, methodologies, model-based systems engineering and applications of system of systems Engineering in science, technology, industry, and education are welcome.

Contributed Papers:

Papers should be five to six pages in length, in standard two-column IEEE Conference Proceedings format. We will also accept three-page poster papers (in two-column format). Detailed instructions for paper/poster submission and format can be found on the conference web site (http://www.sose2013.org). Invitations will be made to the authors of the best papers to submit an extended version of papers to the following journals or book chapters for the CRC Taylor-Francis SOSE Book Series:

1. **IEEE Systems Journal** (ieeesystemsjournal.org)
2. **Journal of Enterprise Transformation** (http://www.tandf.co.uk/journals/UJET)
3. **AutoSoft Journal** (http://wacong.org/autosoft/auto/

R·I·T

UTSA

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Deadline for all papers:

- Papers submission (online): **15th March, 2013**
- Notification of accepted papers: **12th April, 2013**
- Final Camera Ready Manuscript due: **12th May, 2013**

For general and technical program inquiries about the conference, please contact the conference General co-Chairs, Ferat Sahin (feseee@rit.edu) and Ricardo Valerdi (rvalerdi@arizona.edu) and the Program Co-Chairs (aly.elosery@gmail.com) or matthew.joordens@deakin.edu.au) respectively.

Additional information on the SoSE 2013 can be found at:
http://www.sose2013.org

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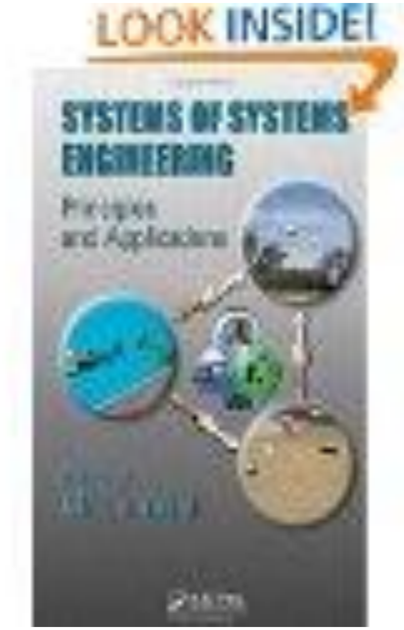

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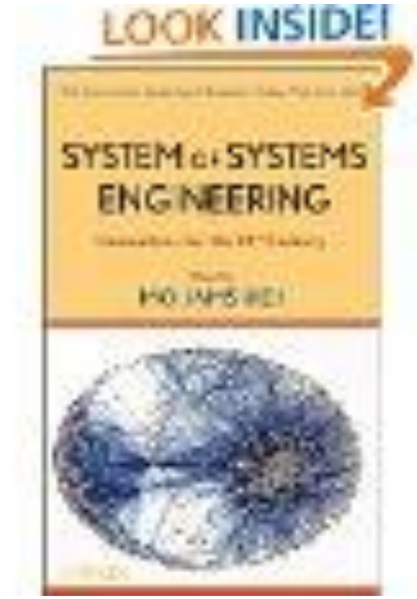

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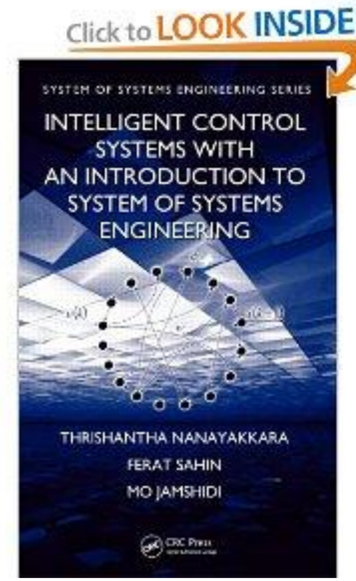

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http://www.wacong.org/freepublicationsbymojamshidi/,

Contact for ID and PW

体系工程

二十一世纪的创新

Mo Jamshidi 博士（编著）

倪军博士（译），2012年

Translator: Jin Ni, University of Iowa, USA

CONCLUSIONS

SoS has been with us for some time

Soon … System integration will be a matter of necessity and not Choice

Energy generation of the future is best managed by a SoS.

Application potentials are too numerous to be ignored by any scientist/engineer. While … Theoretical challenges are numerous as well.

These challenges will bring about numerous IP's and patents Resulting from IP's in energy and many other fields.

All societies need to be getting ready for an inter-Connected scenarios, and future smart grids is a Visid example of that.

Once again, Systems Engineering is a discipline

QUESTIONS

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