Smart Grid and Customer Transactions:

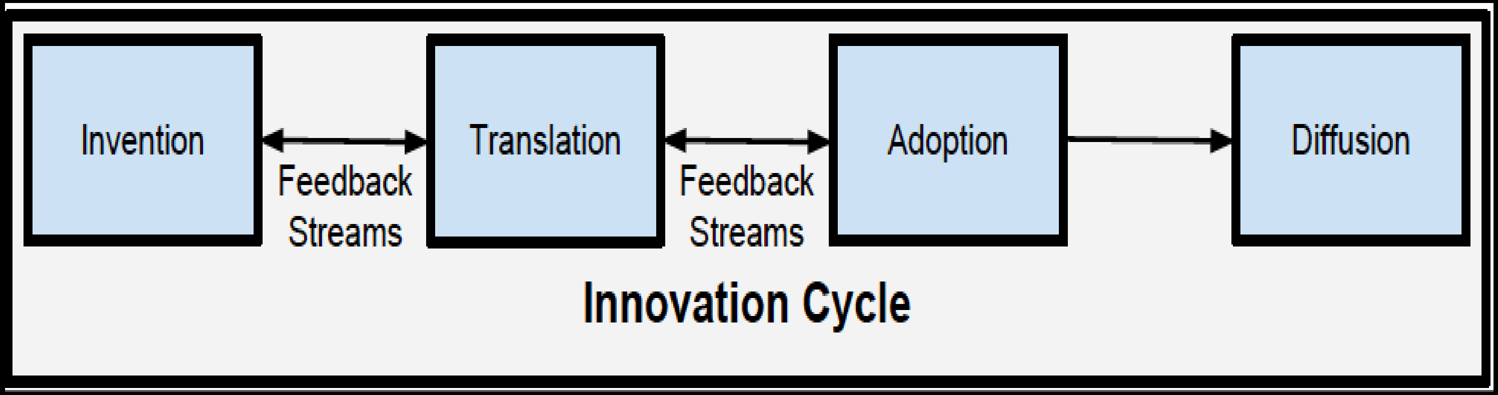
The unrealized Benefits of Conformance

Authors

- Girish Ghatikar – LBNL
- Ed Koch – Honeywell Building Solutions
- Rolf Bienert – OpenADR Alliance
- Jim Zuber – QualityLogic

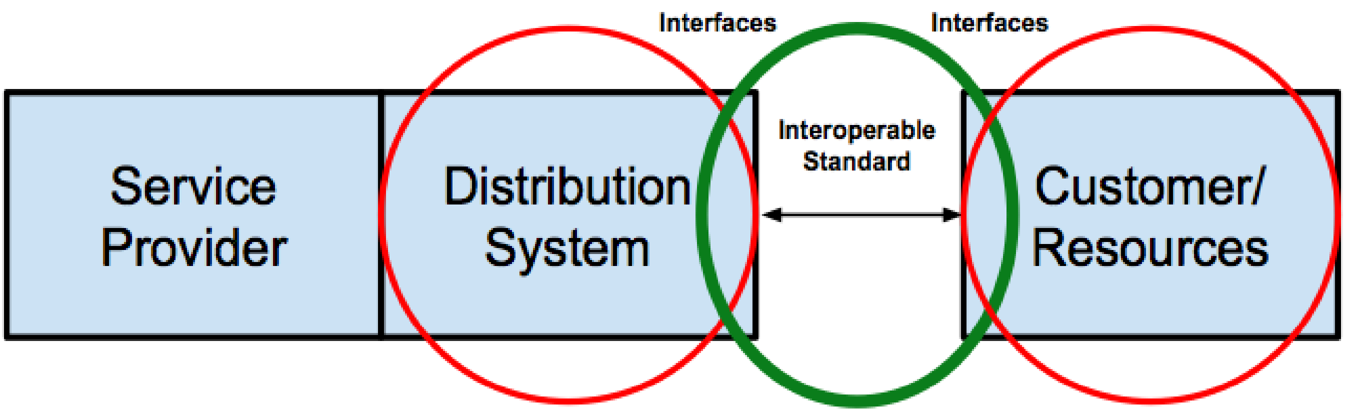
Premise

- Conformance is important for the adoption and diffusion of Smart Grid technologies



Focus

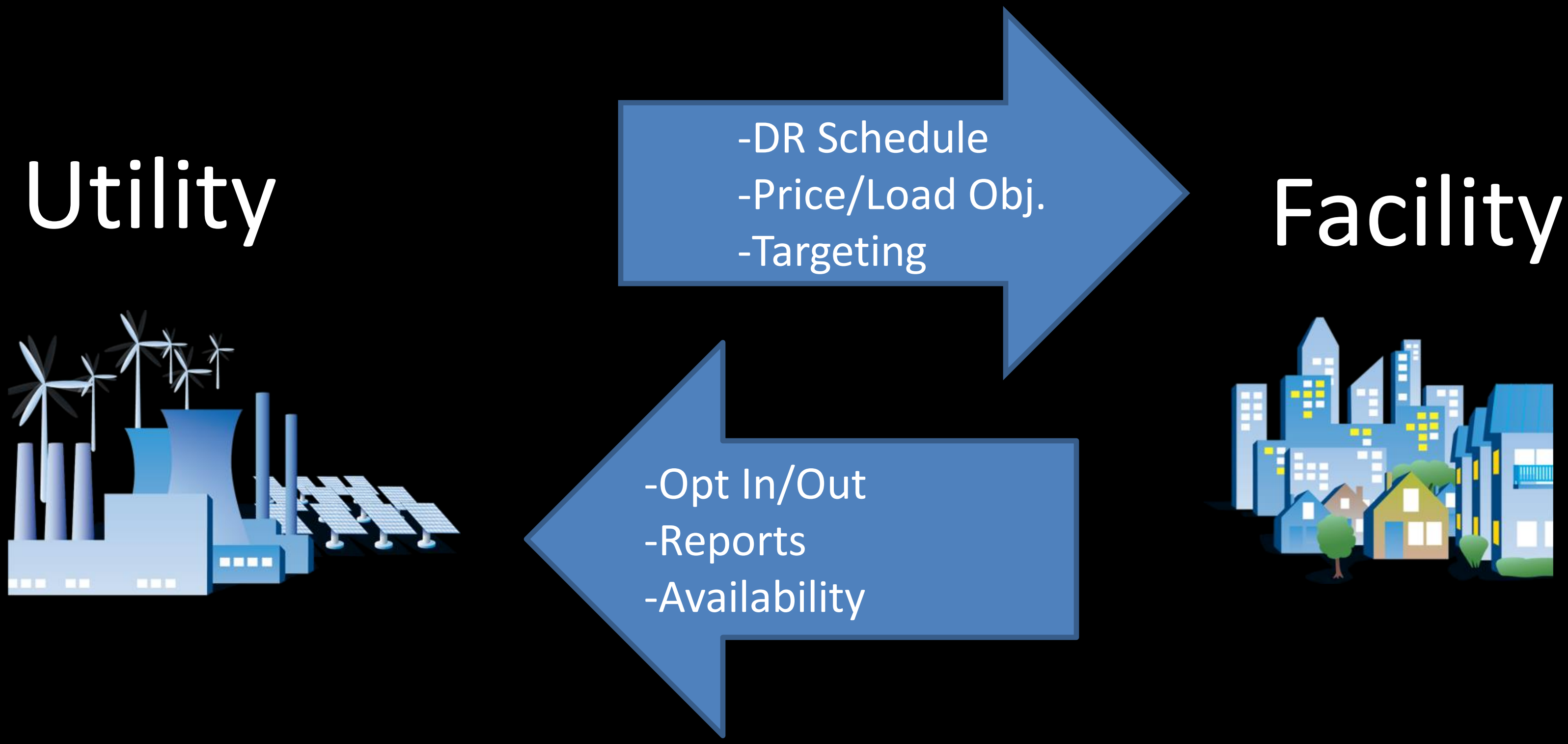
- Automated Demand Response (OpenADR)
- Enables changes to demand side load profiles in response to signaling from electricity service providers



Topics

- OpenADR Origins
- Technology Primer
- Conformance Requirements
- Testing
- Conclusions

Demand Response Information Exchanged



Utility

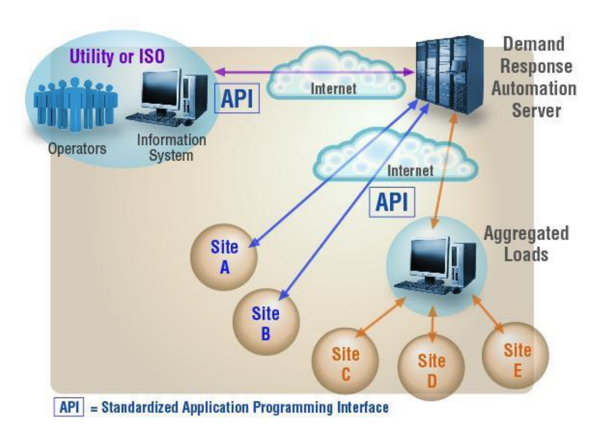
-DR Schedule
-Price/Load Obj.
-Targeting

Facility

-Opt In/Out
-Reports
-Availability

OpenADR 1.0

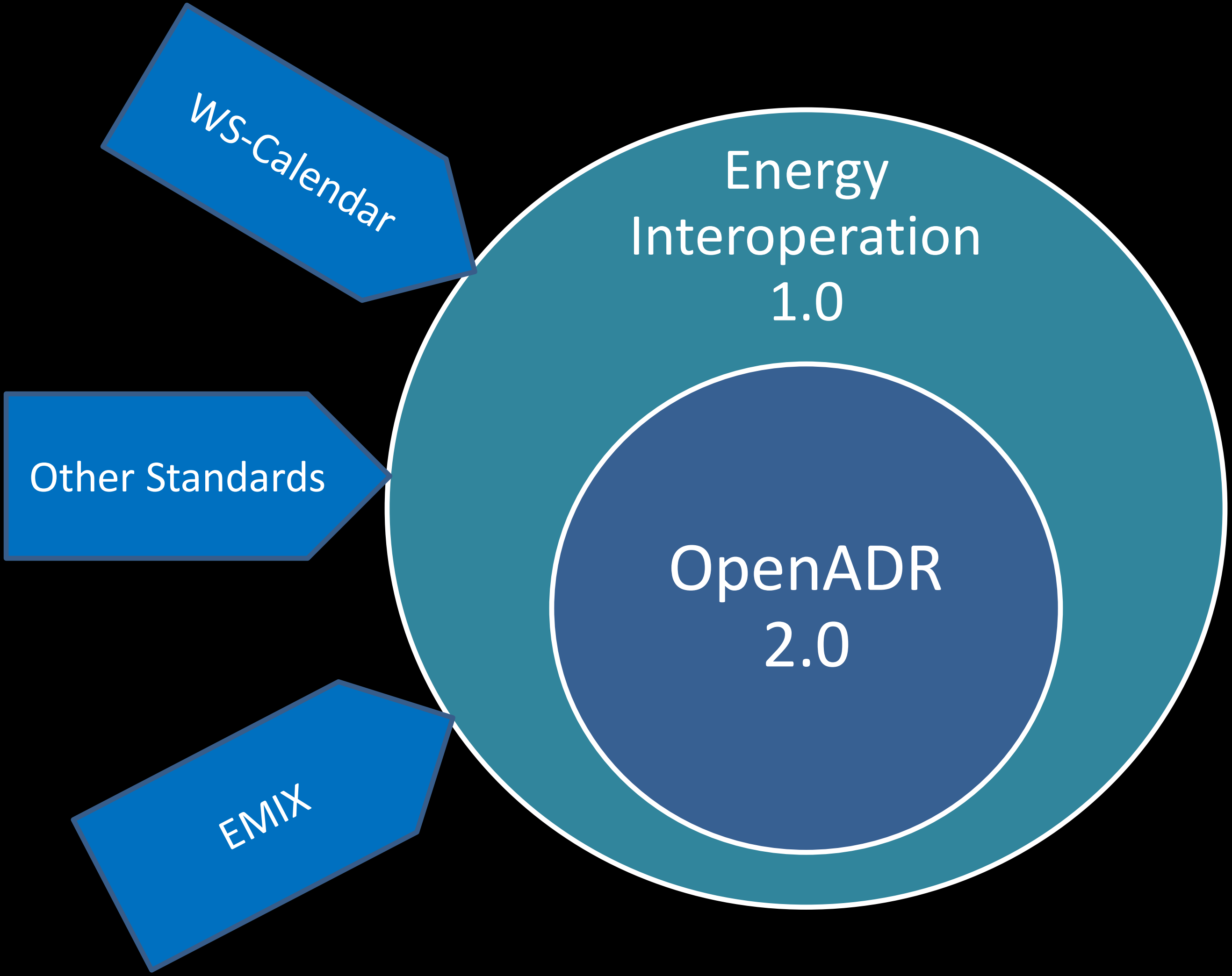
- Developed by Lawrence Berkeley National Labs, DR Research Center
- California state funded effort
- PG&E, SCE, and SDG&E collaboration
- Specification released April 2009
- Many successful deployments
    - 1300 facilities
    - 250 megawatts of DR Load



OpenADR 2.0

- NIST Smart Grid harmonization project initiated in 2009
- Priority Action Plans (PAPs) to work on common standards for price models, schedule representation, and standard DR Signals
- OpenADR Alliance formed in 2010 to evolve work done on OpenADR 1.0 into an recognized standard and to implement a formal certification process

OpenADR Origins



WS-Calendar

Other Standards

EMIX

Energy Interoperation 1.0

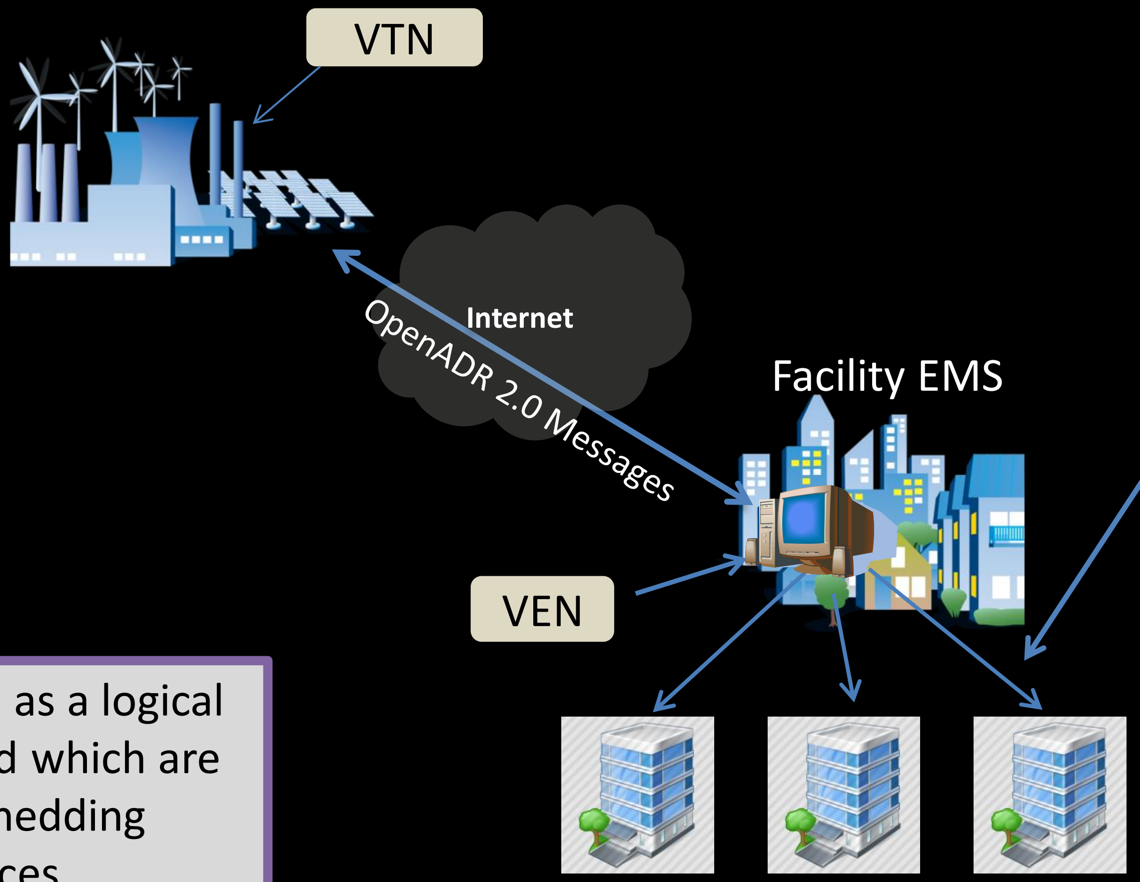
OpenADR 2.0

VENs and VTNs

QualityLogic
Putting Technology to the Test

- Two actors in OpenADR communication exchanges
  - Virtual Top Nodes (VTN)
    - Transmit events other nodes
  - Virtual End Nodes (VEN)
    - Receive events and respond to them
    - Control demand side resources

VENs and VTNs



VTN

Internet

OpenADR 2.0 Messages

Facility EMS

VEN

BACnet
OpenADR
LonMark
SEP 2.0
etc.

Think of a VEN as a logical interfac behind which are the load shedding resources.

Services

- Event Service
  - Send and Acknowledge DR Events
- Opt Service
  - Define temporary availability schedules
- Report Service
  - Request and deliver reports
- Registration Service
  - VEN Registration, device information exchange

Profiles

- A Profile
  - Simple devices, limited event service only
- B Profile
  - More robust devices, all services supported

Transports, Data Models

- IP based HTTP and XMPP transports
- XML Payloads
- Push and Pull exchange patterns
- Robust open source libraries available for implementation

Security

- Exchange of Client and Server x.509v3 certificates
- TLS 1.2
- SHA256 ECC or RSA ciphers
- Optional XML payload signatures
- Robust out of the box security

A and B Profiles

- Interoperability
  - VTNs must support all features and functions
  - VENs have some limited optionality
- Backwards Compatibility
  - VTNs must concurrently communicate with both A and B profile VENs
  - VTNs must upgrade to latest profile version to maintain certification

Optional Feature Support

		B VTN	B VEN	B VEN Report	A VEN
Services	EiEvent - Simple	M	M	NA	M
	EiEvent – Full	M	M	NA	NA
	EiOpt	M	M	NA	NA
	EiRegistraton	M	M	M	NA
	EiReport	M	M	M	NA
Security	RSA and ECC Ciphers	M	One(1)	One(1)	One(1)
	XML Signatures	O	O	O	NA
Transport	SimpleHTTP Only	NA	NA	NA	M
	XMPP and SimpleHTTP	M	One(1)	One(1)	NA
Exchange Model	Pull - SimpleHTTP	M	M	M	M
	Push - SimpleHTTP	M	O	O	O
Profile	B support for A profile	M	NA	NA	NA

(1) Must support at least one , but can support both.

O=Optional M=Mandatory

OpenADR Schema & Spec

- XML Schema
  - Specifies payload structure, data types, enumerated values, etc.
- Profile Specifications
  - Narrative description of protocol behavior
  - Formal conformance rules that specify..
    - Conformance (business) Rules
    - Security
    - Transport requirements

PICS Document

- Protocol Implementation Conformance Statement (PICS)
- Listing of all testable requirements
- Manufacturer declares conformance prior to certification
- Indication of supported features directs test cases run during certification

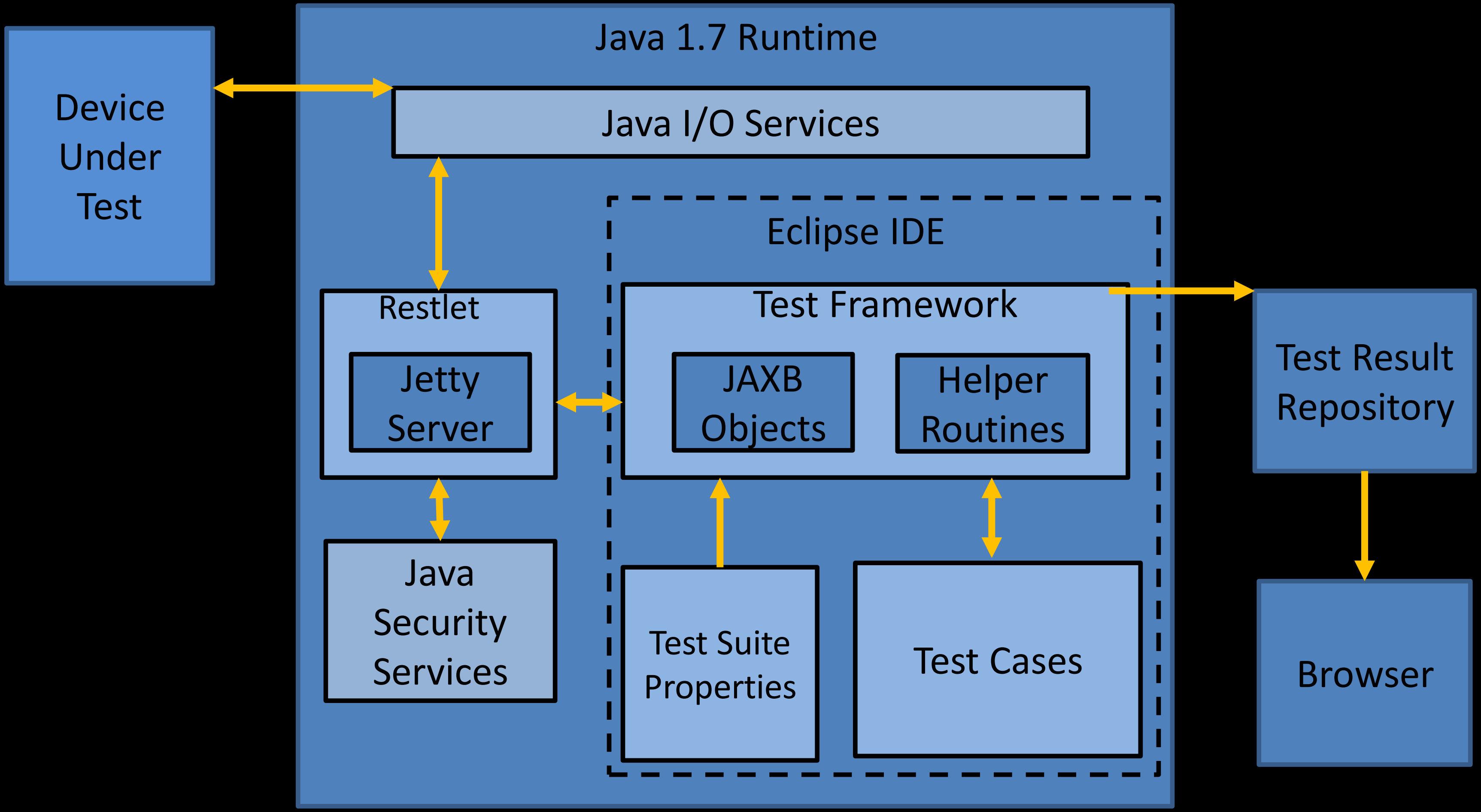
Certification Test Specification

- A set of tests that validate all of the testable requirements defined in the PICS
- Each test case validates the following
  - Payloads contain well-formed XML
  - Payloads validate against the OpenADR Schema
  - Correct message interaction pattern. Expected request or response root element.
  - OpenADR Conformance rules are followed
  - The intent of the test case is achieved

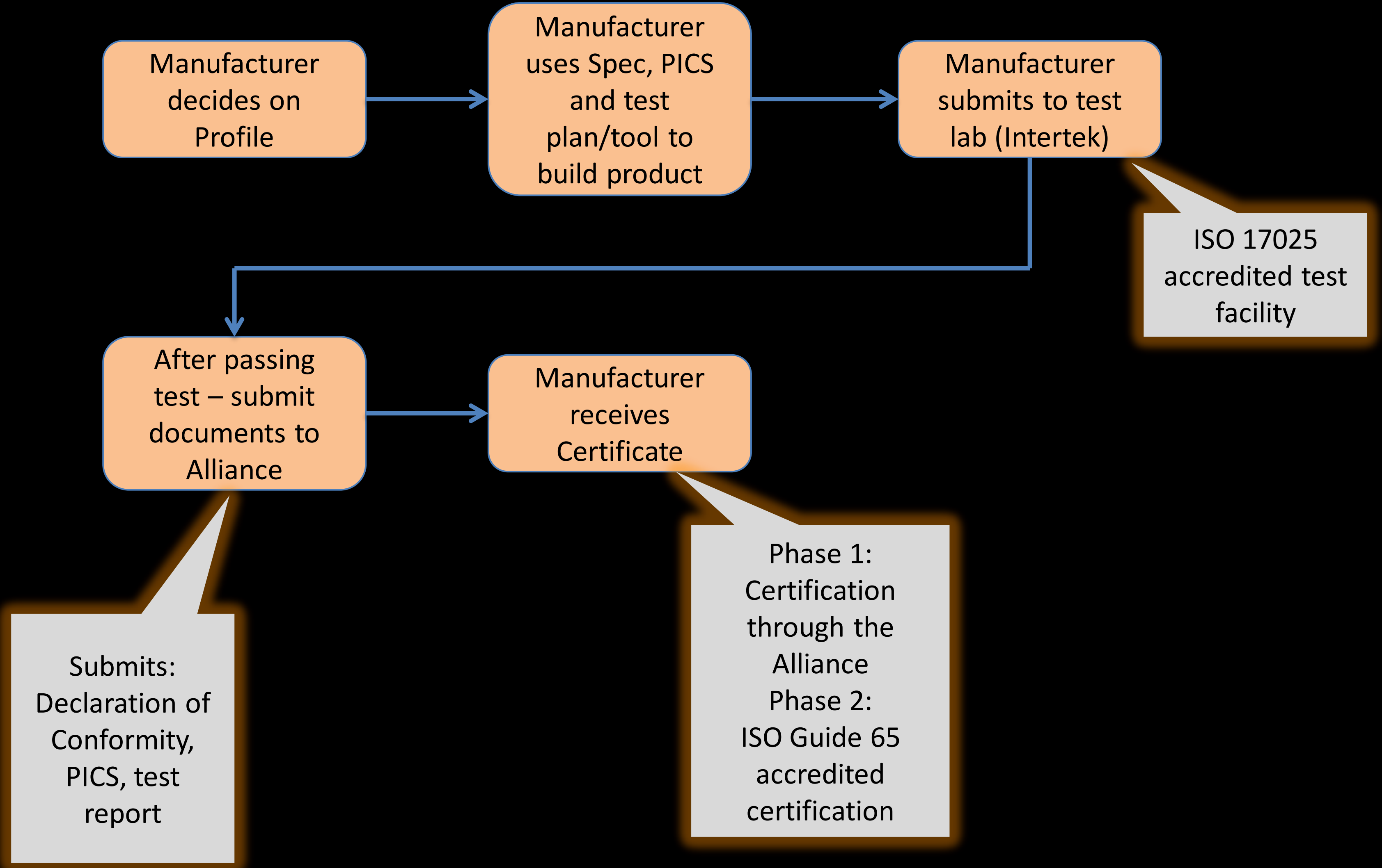
Test Harness

- Implements all test cases
- Plays one side (VEN or VTN) in the OpenADR message exchange
- Available to adopters prior to certification
- Self test mechanism provide reference implementation

Leverage of Open Source



Certification Process



Manufacturer decides on Profile

Manufacturer uses Spec, PICS and test plan/tool to build product

Manufacturer submits to test lab (Intertek)

ISO 17025 accredited test facility

After passing test – submit documents to Alliance

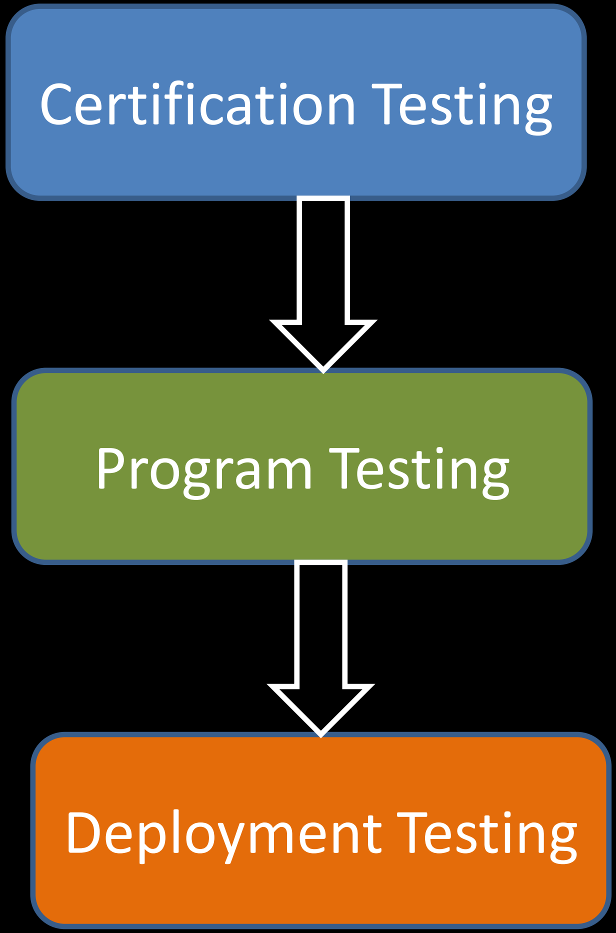
Submits: Declaration of Conformity, PICS, test report

Manufacturer receives Certificate

Phase 1: Certification through the Alliance
Phase 2: ISO Guide 65 accredited certification

Testing

- Certification Testing..
  - Baseline interoperability
- Program Testing
  - Programs specific event signals, reports, targeting, etc.
  - Pairwise device testing
- Deployment Testing
  - End-to-end configurations



Certification Testing

Program Testing

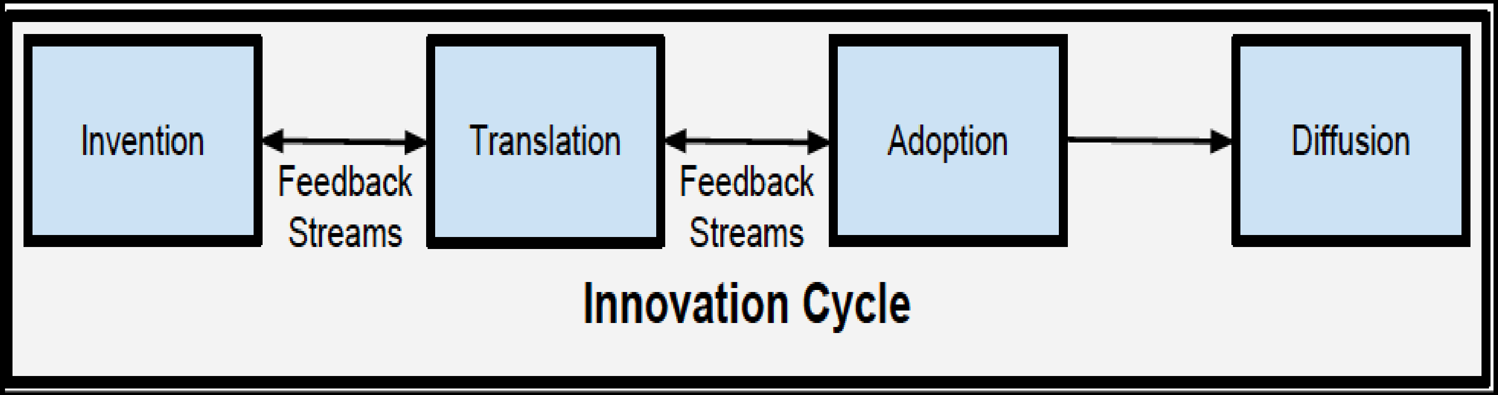
Deployment Testing

OpenADR Success

- Well defined requirements and robust requirements result in…
  - 120 OpenADR Alliance Member companies
  - Over 60 certified devices available
  - Strong national and international interest
  - Many trail deployments in progress
  - OpenADR being written into regulations
  - Broad perception that OpenADR VENs and VTNs are interoperable

Conclusions

- The transition of OpenADR from the Adoption to the Diffusion stage will be accelerated by robust conformance
- Other standardization efforts could benefit by following OpenADR's conformance model



Questions?

Simulation and Experimental Performance Analysis of Micro-grid Based Distributed Energy Resources

Never Stand Still Engineering **Electrical Engineering & Telecommunications**

Yunqi Wang

24 November 2014

Outline

- 1. Introduction
- 2. Model of simulation system
- 3. Impact of micro-grid operation modes
- 4. Impact of battery storage capacity
- 5.Impact of DG penetration level
- 6. Experimental study
- 7.Conclusion

Background

1.Definition of the Micro-grid

-- a cluster of loads and micro-sources operation as a single controllable system providing both power and heat to its local area.

2.Operation mode of the micro-grid

--islanded mode and grid-connected mode

3.Transient stability of micro-grid

--voltage and frequency should always be maintained within a permissible limit

--distributed generator need to be operated during these periods

Research Reason

-- Analysis of behaviors of distribution systems during transients is especially difficult.

-- The DGs output power is affected by many factors and could be changed rapidly and irregularly.

-- The DG output change may lead the undesirable impact on the component in the main network.

Research Objective

- To compare the dynamic response of a micro-grid when system load demand suddenly decreases.
- --Simulation: The simulations are carried out to study the micro-grid transients with different operation modes, different sizes of energy storage and different DG penetration levels.
- --Experiment: The results are validated using a laboratory setup of a micro-grid, having a mix of PV, wind turbine and battery storage.

Model of Simulation System

1.Micro-grid configuration

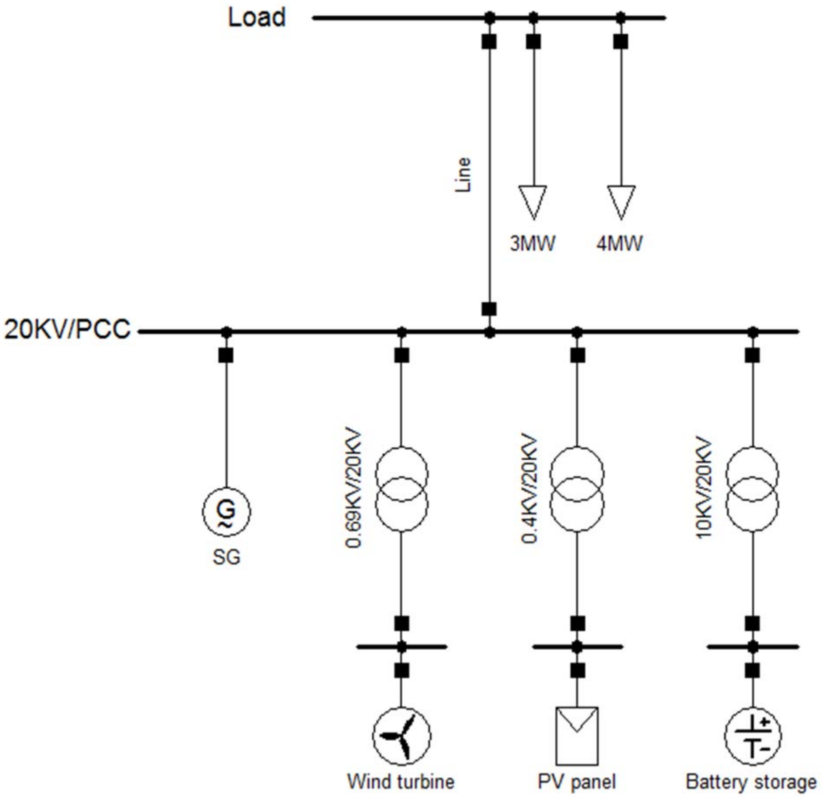


Fig.1 Micro-grid idagram

Model of Simulation System

2.High voltage ride-through requirement

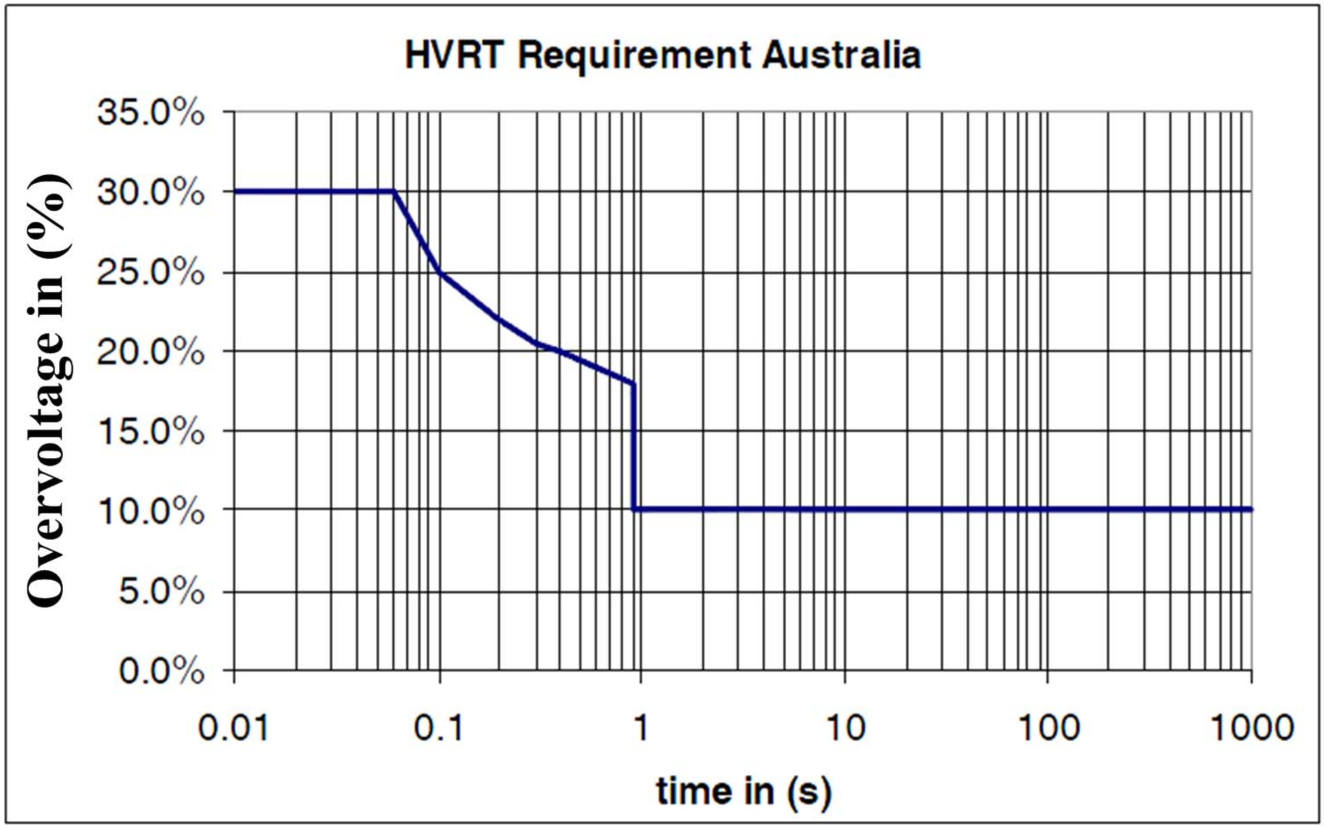


Fig.2: HV ride-through requirement in Australian grid code

Impact of micro-grid operation mode

- Scenario 1: In the grid-connected mode

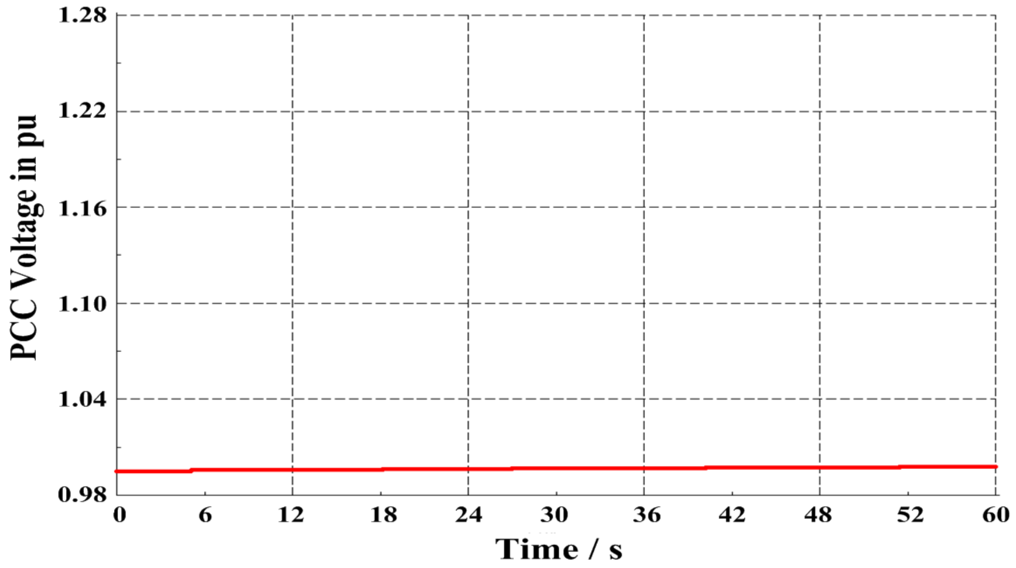


Fig.3 PCC voltage, grid-connected mode

Impact of micro-grid operation mode

- Scenario 2: In islanding mode

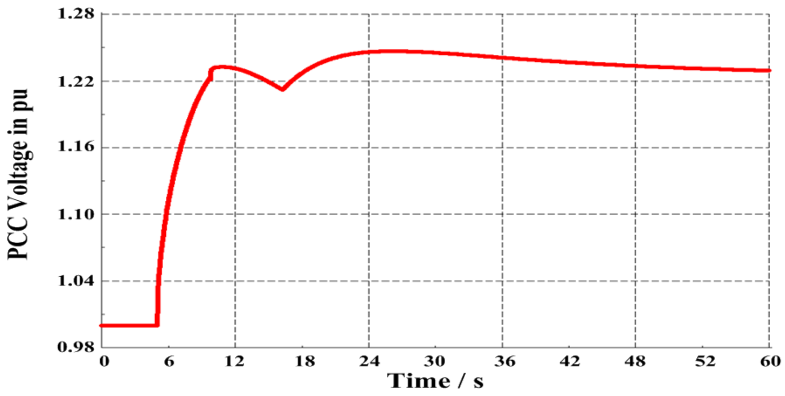


Fig.4 (a) PCC voltage, islanding mode

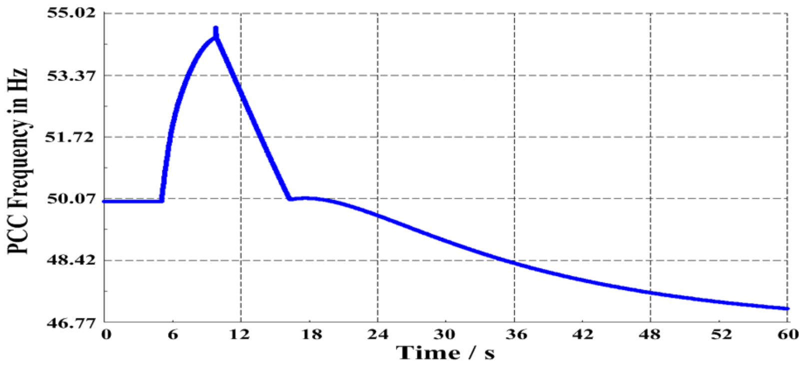


Fig.4 (b) PCC frequency, islanding mode

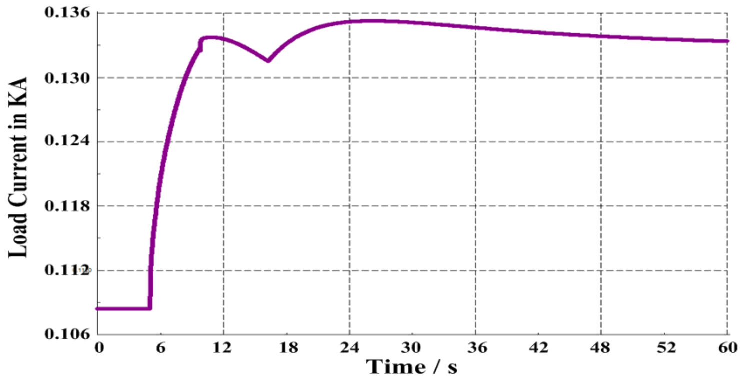


Fig.4 (c) 3MW load current, islanding mode

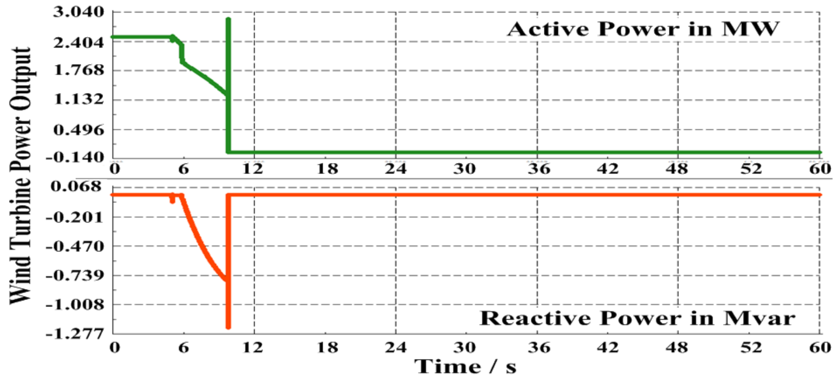


Fig.4 (d) wind turbine power output, islanding mode

Impact of the Battery Storage Size

- Battery capacity chosen

$$P_{load\ lost} = 4\text{MW, 0.8pf lagging}$$

Assuming the battery efficiency is about 70%. Note that some power losses also incur in the transmission lines.

Therefore, 10MVA is chosen as the battery power rating in the simulation .

Furthermore, the generator transient may also lead to some power unbalance. Thus, a second simulation with 30MVA battery is also considered

Impact of the Battery Storage Size

- Scenario 1: Impact of 10 MVA battery storage

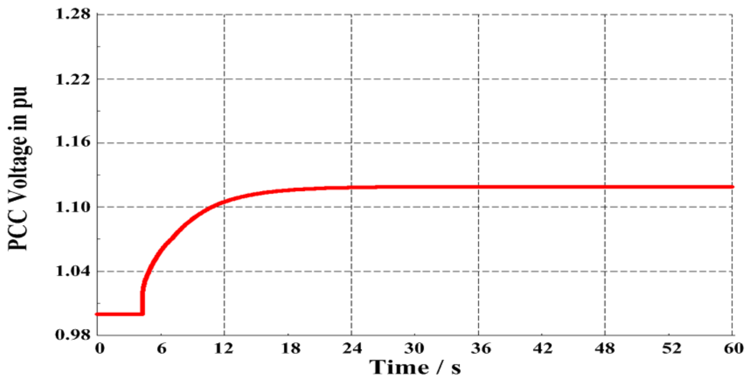


Fig.5 (a) PCC voltage with 10MVA battery

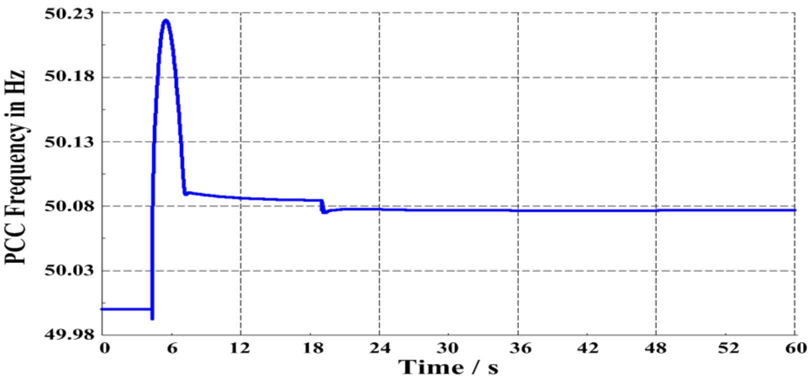


Fig.5 (b) PCC frequency with 10MVA battery

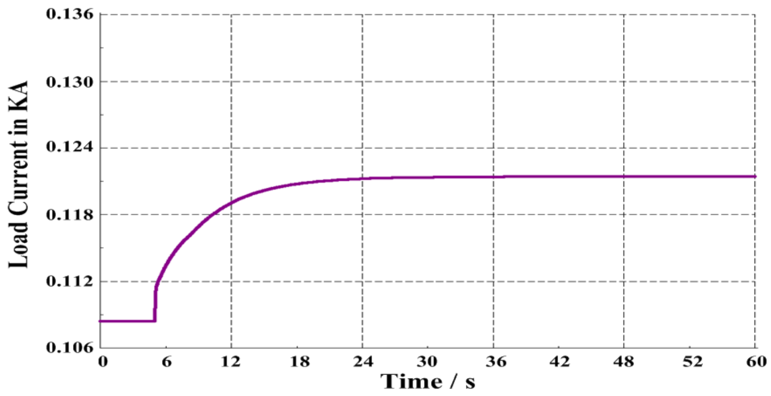


Fig.5 (c) 3MW load current with 10MVA battery

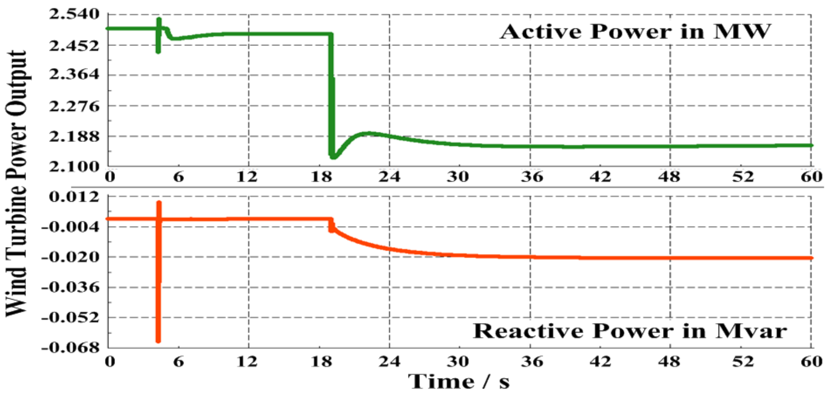


Fig.5 (d) Wind turbine power output with 10MVA battery

Impact of the Battery Storage Size

- Scenario 2: Impact of 30 MVA battery storage

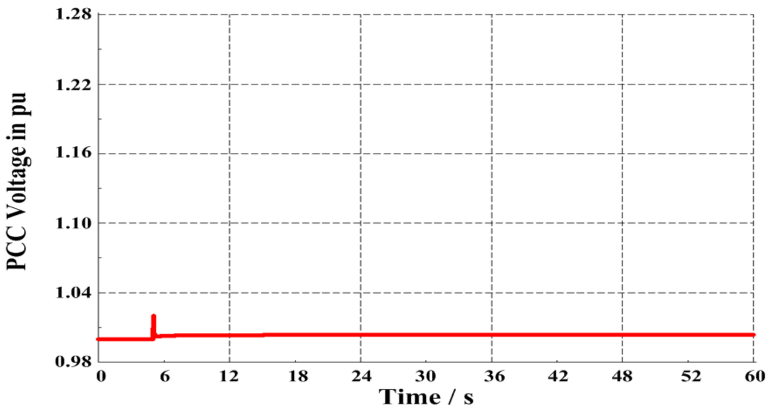


Fig.6 (a) PCC voltage with 30MVA battery

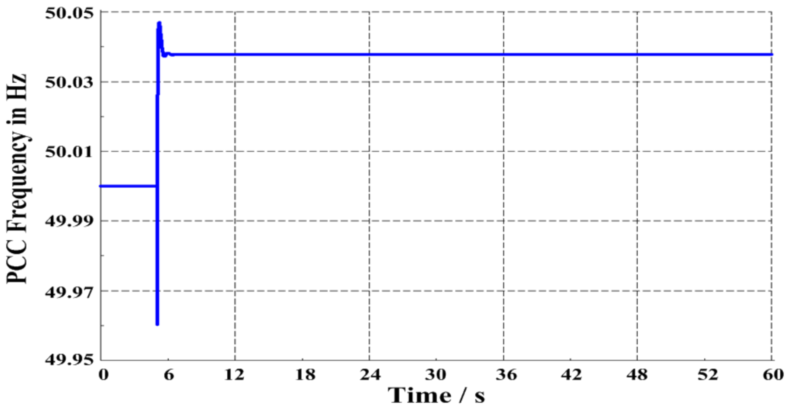


Fig.6 (b) PCC frequency with 30MVA battery

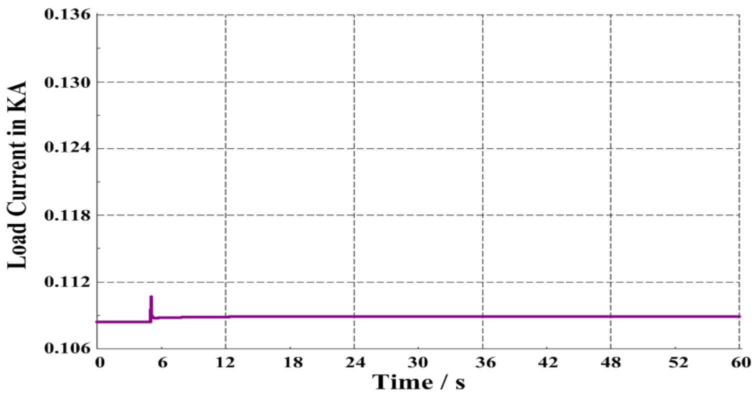


Fig.6 (c) 3MW load current with 30MVA battery

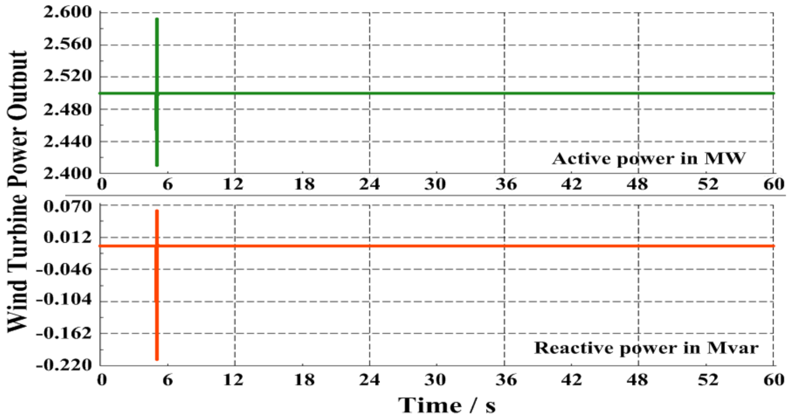


Fig.6 (d) Wind turbine power output with 30MVA battery

Impact of the DG penetration level

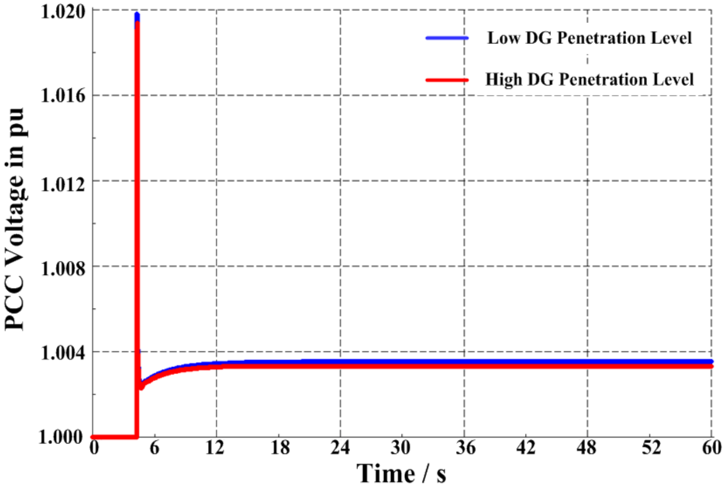


Fig.7 (a) PCC voltage

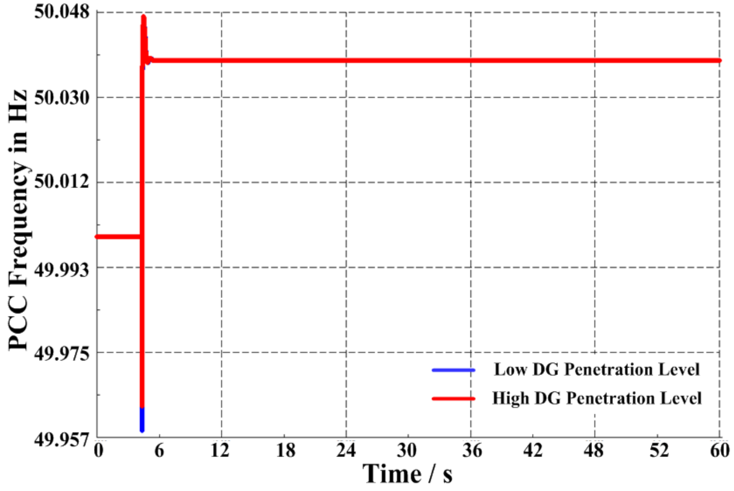


Fig.7 (b) PCC frequency

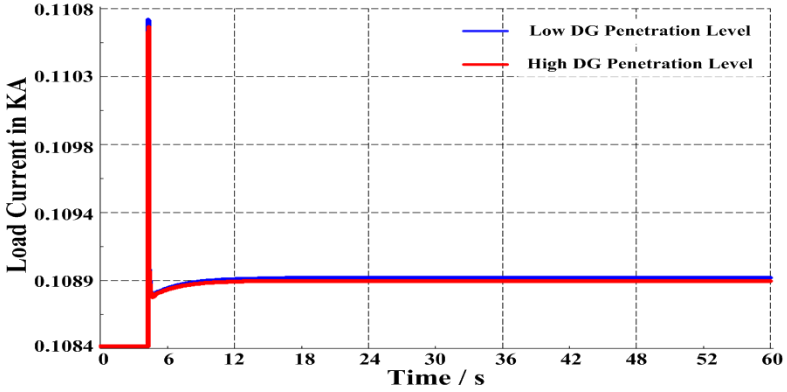
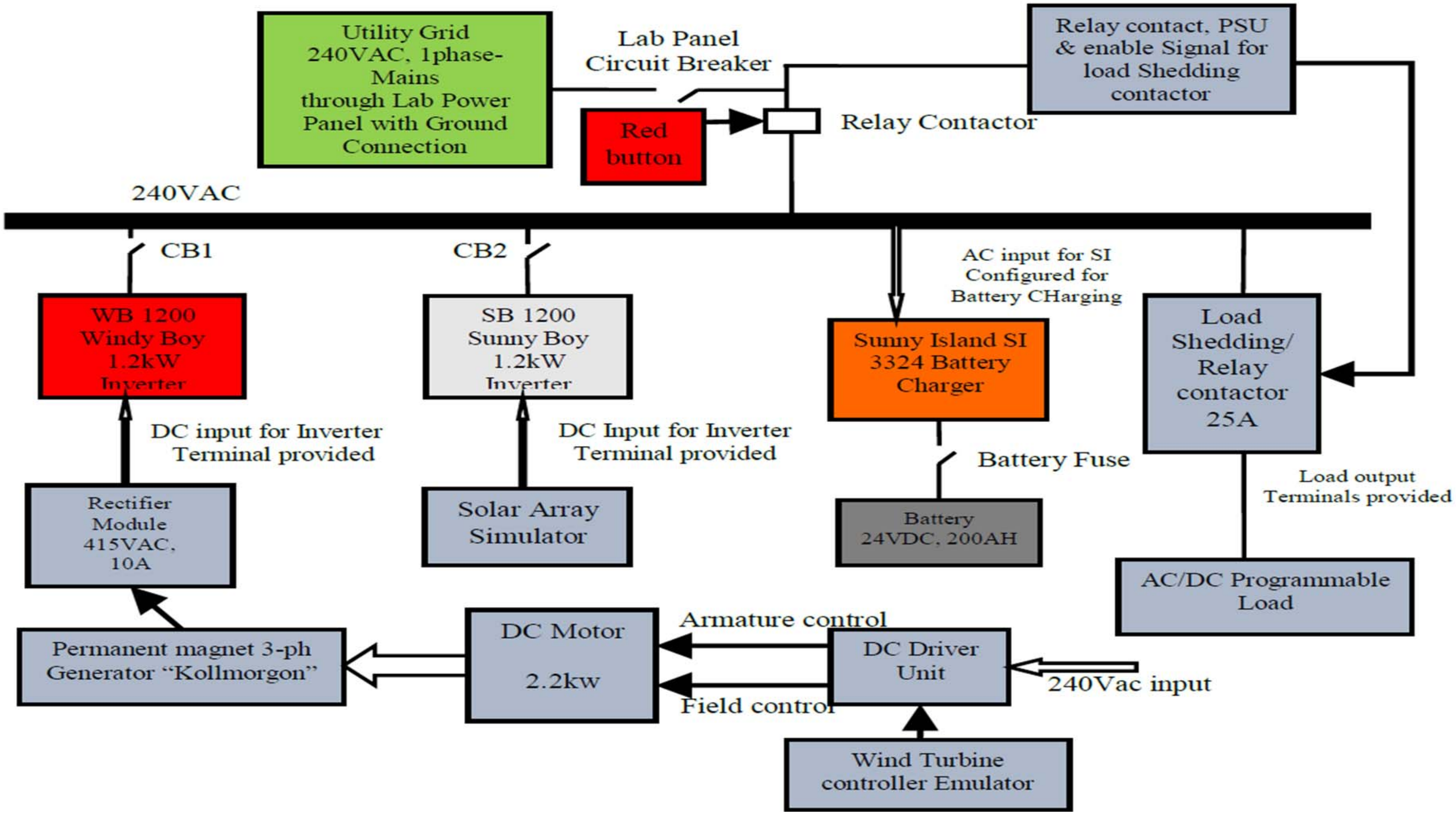


Fig.7 (c) 3MW load current

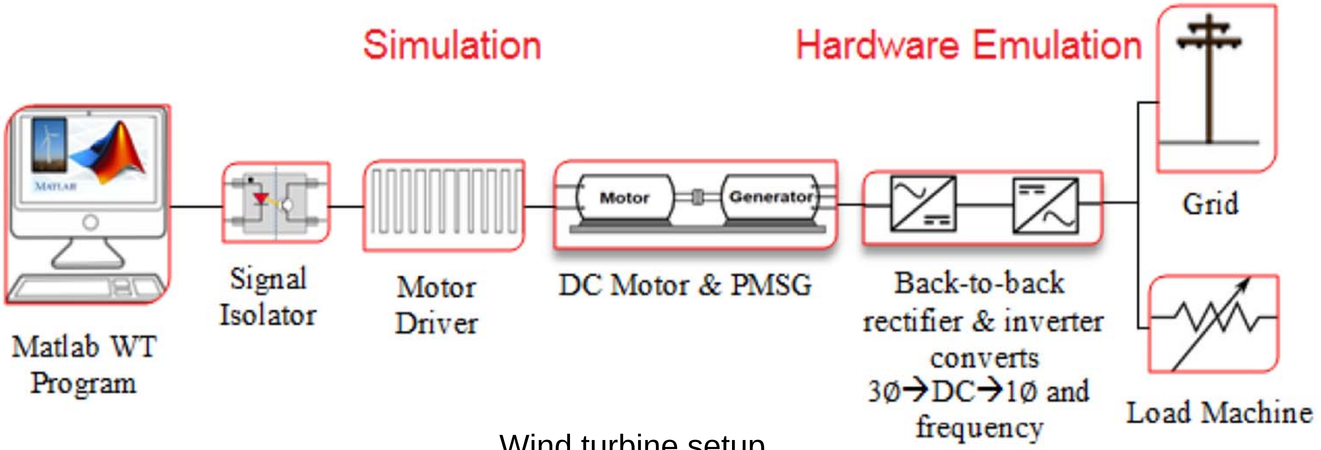
Experimental Result

- Laboratory setup

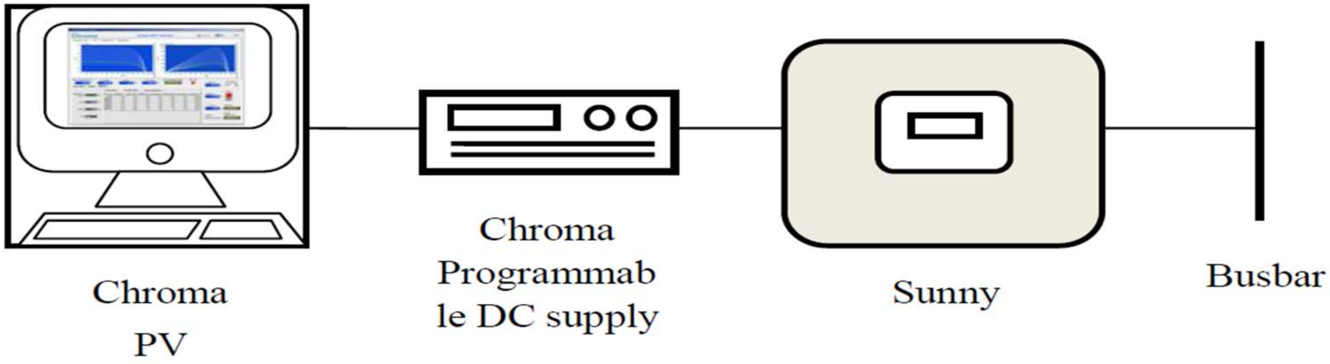


Experimental Result

- Laboratory setup



Wind turbine setup



PV penal setup

Experimental Result: Impact of battery storage

- Result 1: PCC Voltage

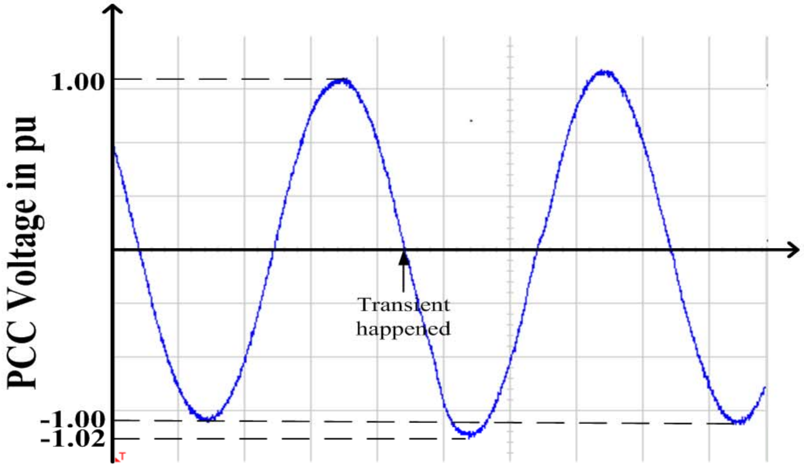


Figure 8(a): with 80% charged battery

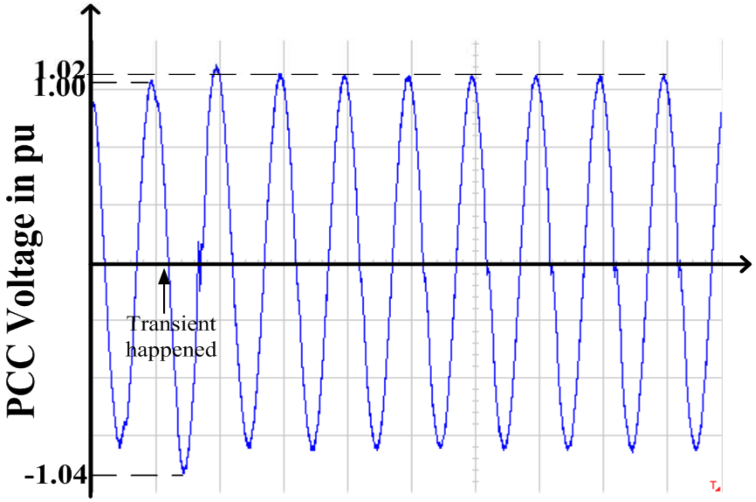


Figure 8(b): with 20% charged battery

Experimental Result: Impact of battery storage

- Result 2: Wind turbine current output

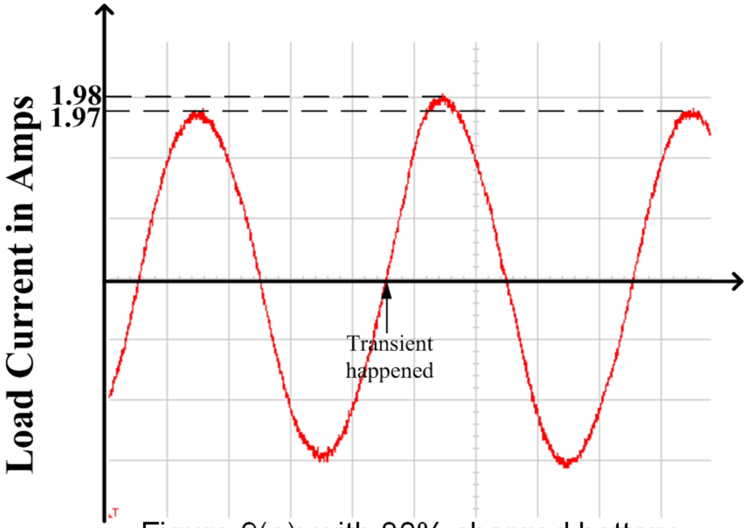


Figure 9(a): with 80% charged battery

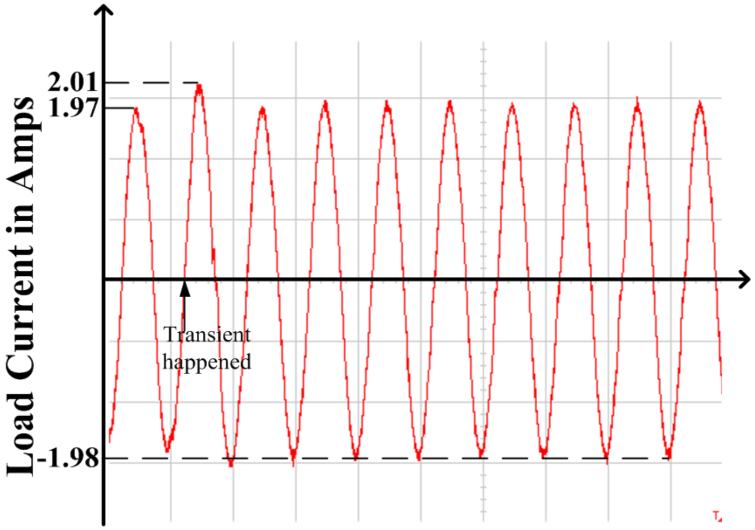


Figure 9(b): with 20% charged battery

Experimental Result: Impact of battery storage

- Result 3: Battery current output

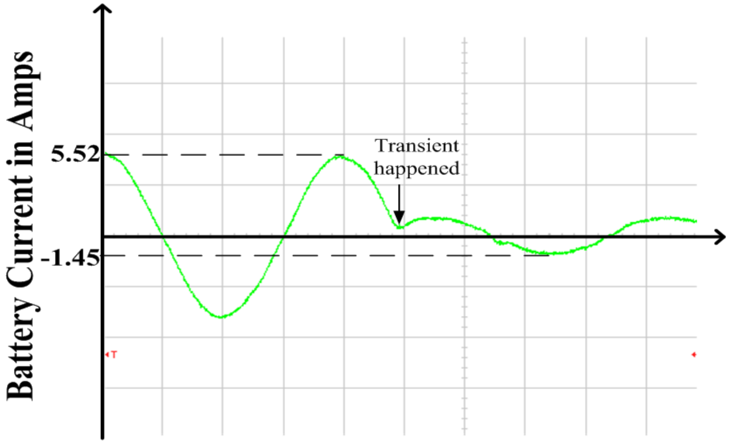


Figure 10(a): with 80% charged battery

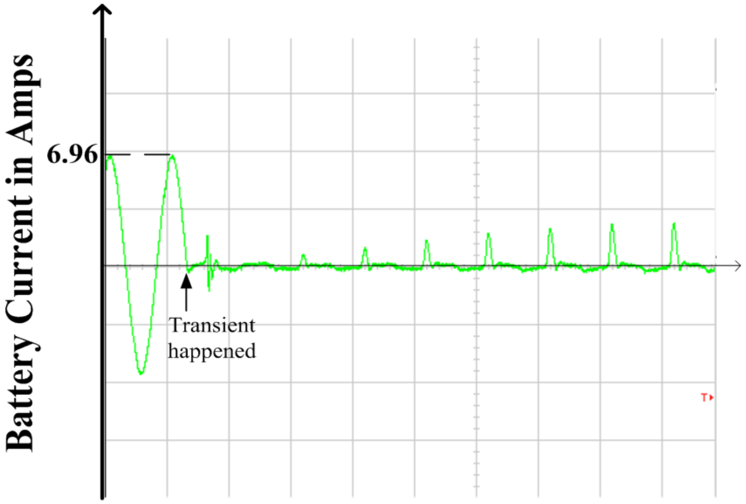


Figure 10(b): with 20% charged battery

Experimental Result: Impact of DG penetration

- Result 1:PCC voltage

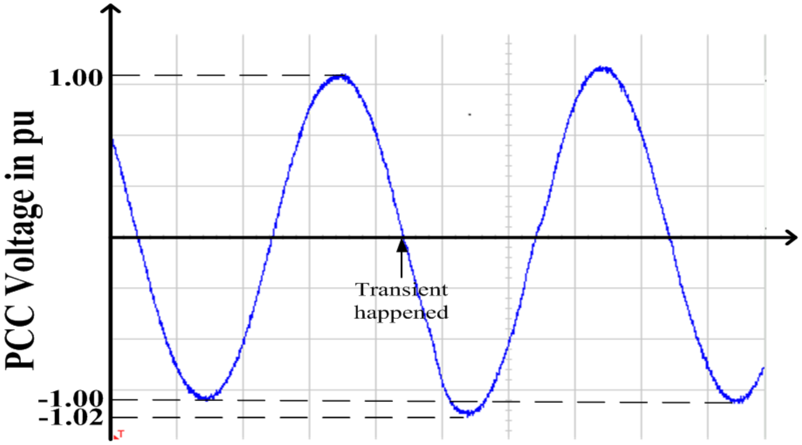


Figure 11(a): with high DG penetration

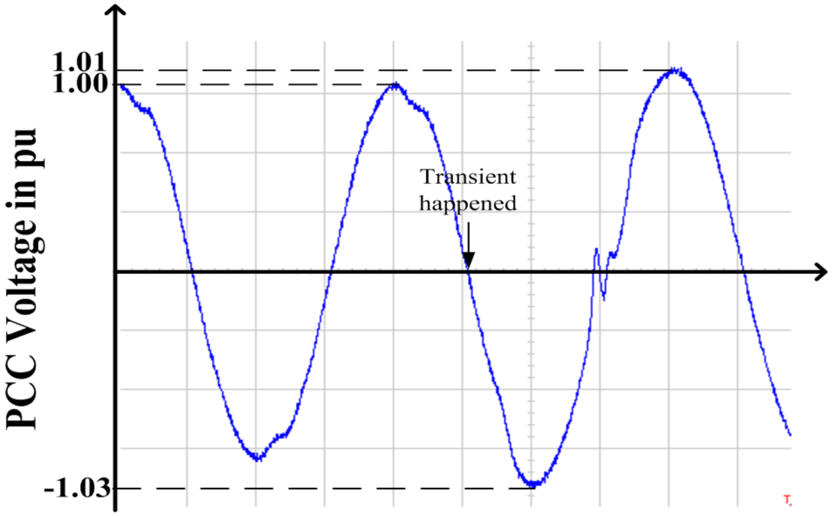


Figure 11(b): with low DG penetration

Experimental Result: Impact of DG penetration

- Result 2:wind turbine current output

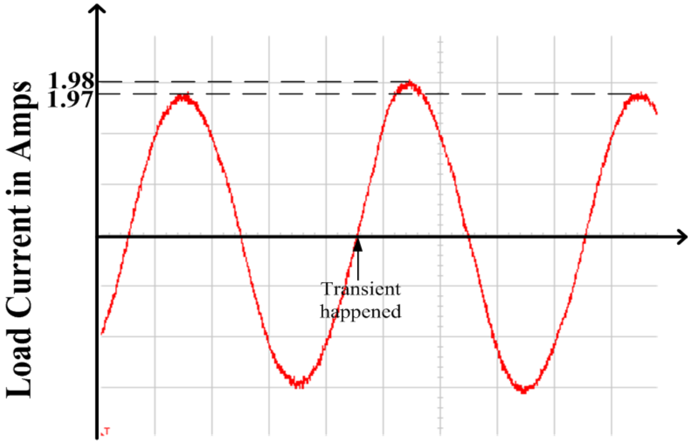


Figure 12(a): with high DG penetration

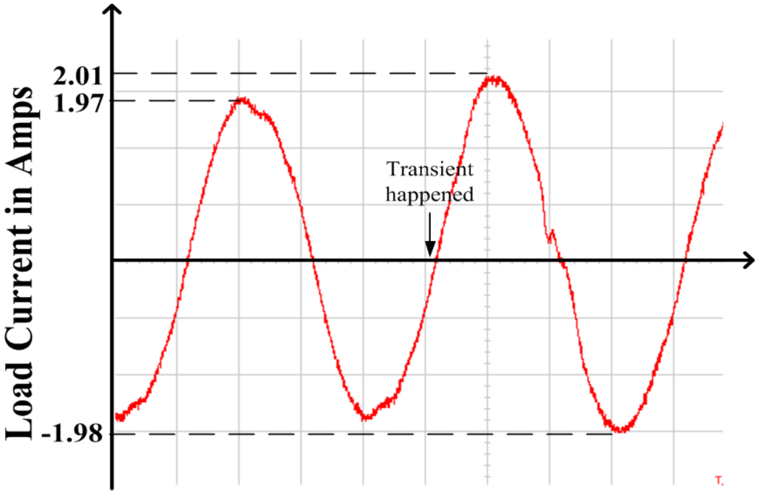


Figure 12(b): with low DG penetration

Experimental Result: Impact of DG penetration

- Result 3:battery current output

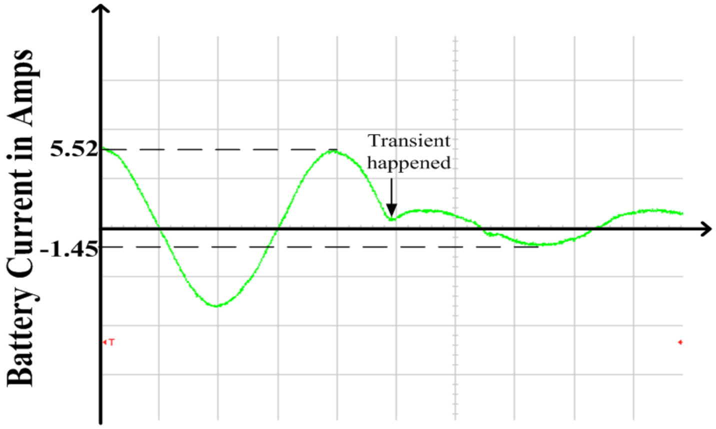


Figure 13(a): with high DG penetration

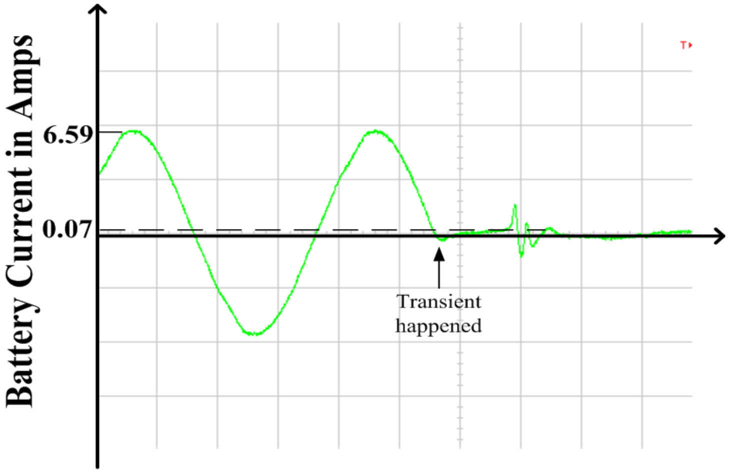


Figure 12(b): with low DG penetration

Conclusion

- When the micro-grid operates in islanding mode, the load demand changes affect the system stability significantly as they can cause a power rush during the disturbance;

- This problem can be solved by installation of storage unit. The power rush can be absorbed by this device and the micro-grid dynamic response is substantially improved. Nevertheless, the transient caused by the rotating machine should also be considered when determining the capacity of the battery. Otherwise, the micro-grid will face the high voltage situation;

- The DG penetration level also has impact on the micro-grid transient. Increasing the DG penetration level can reduce the overshooting during the transient and enhance the system transient performance as more power rush can be absorbed by both SG and DG.

Thank you

Advanced Metering Infrastructure's Measurement of Working, Reflected, and Detrimental Active Power in Microgrids

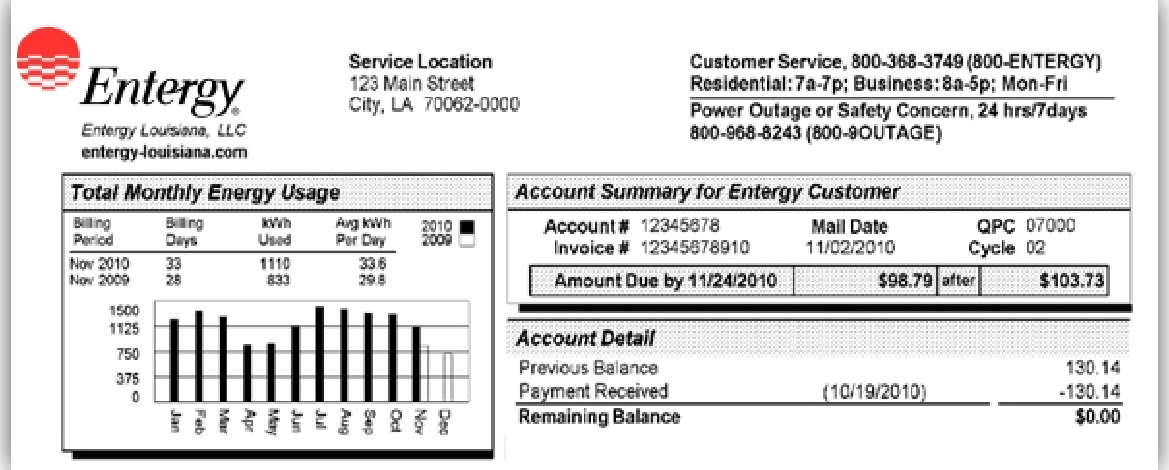
By: Tracy N. Toups,
Leszek S. Czarnecki

Louisiana State University
Nov. 23rd , 2014

IGESC 2014
IEEE Green Energy
and Systems Conference

Introduction

- Power system economics is very important.
- Current billing standards are 100 years old.
- Can these standard still be used for today's society?



Entergy
Entergy Louisiana, LLC
entergy-louisiana.com

Service Location
123 Main Street
City, LA 70062-0000

Customer Service, 800-368-3749 (800-ENTERGY)
Residential: 7a-7p; Business: 8a-5p; Mon-Fri
Power Outage or Safety Concern, 24 hrs/7days
800-968-8243 (800-9OUTAGE)

Total Monthly Energy Usage

Billing Period	Billing Days	kWh Used	Avg kWh Per Day
Nov 2010	33	1110	33.6
Nov 2009	28	833	29.8

Account Summary for Entergy Customer

Account # 12345678
Invoice # 12345678910
Mail Date 11/02/2010
QPC 07000
Cycle 02

Amount Due by 11/24/2010	$98.79	after	$103.73

Account Detail

Previous Balance		130.14
Payment Received	(10/19/2010)	-130.14
Remaining Balance		**$0.00**

Traditional Active Power

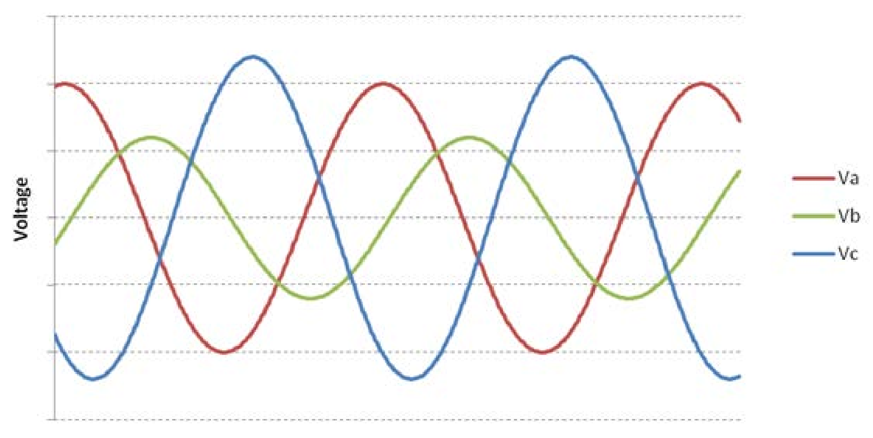
- Main component of energy bills is the cost of energy delivered to the customer in a month.

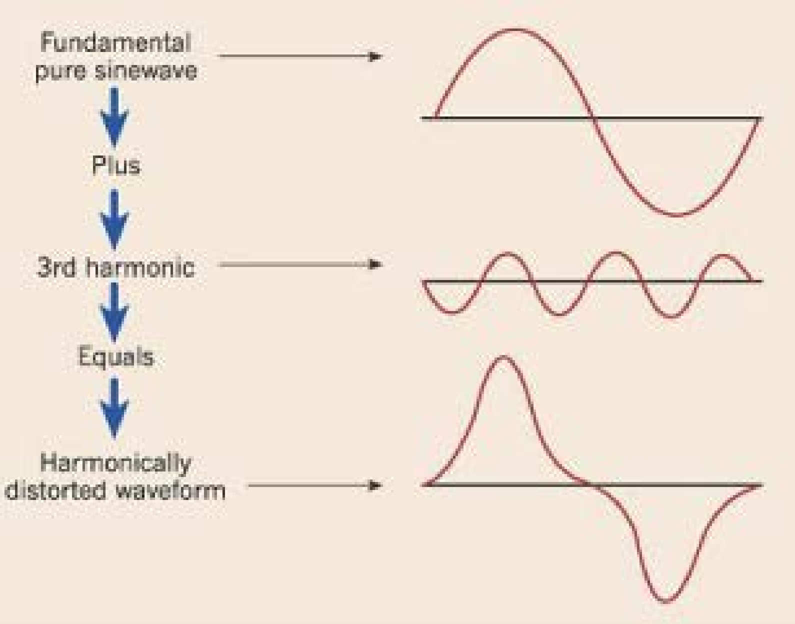
$$W_a = \int_0^{month} P dt$$

- Where W_a is the active energy and P is the active power.
- Analog meters are based upon this principle.

Power System Degradation

- Analog meter cannot pinpoint the degradation source.
- What if the source of degradation is not the utility even though he pays for it?
- Is it really the utility's fault?





Active Power Decomposition

- Active power consist of several quantities

$$P = P_w - P_r + P_d$$

Power needed for load operations

Load harmonics & unbalance

Supply harmonics & asymmetry

- Reflected Power, P_r refers to revenue loss of utility.
- Detrimental Power, P_d refers to customer overpayment.

Microgrids and Advanced Metering Infrastructure

- Due to the small size of microgrids, they tend to be low MVA systems which makes them especially susceptible to distortion and asymmetry.

- Additionally, most microgrids tend to integrate renewable sources of energy which uses power converters that are major sources of distortion.

- A new concept of ***working active power*** can easily be integrated with the use of the advanced metering infrastructure’s (AMI) microprocessor based meters.

Main Points of the Research

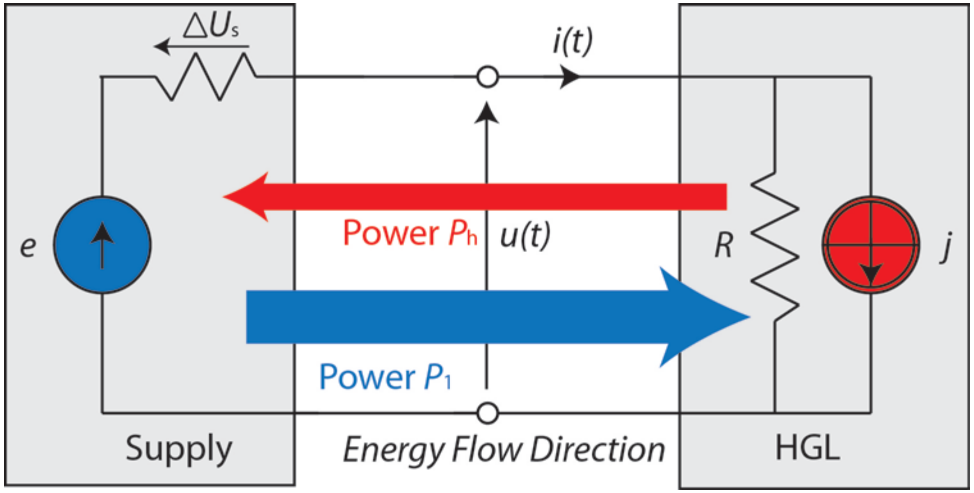
- Active power is a composite concept that needs further decomposition.
- One party (utility or customer) is not being accurately compensated financially by the other party.
- A new concept of ***working active power*** can reveal the disparity and pinpoint degradation source.
- Can be easily integrated into microgrid systems.

Reflected Active Power for 1Φ System

- 1Φ, sinusoidal voltage supply with purely resistive HGL.
- Waveform distortion caused by non-linearity of the load can be modeled as a current source in the load.

$$i(t)=\sum_{0}^{\infty} i_n(t)=i_1(t)+i_h(t)$$

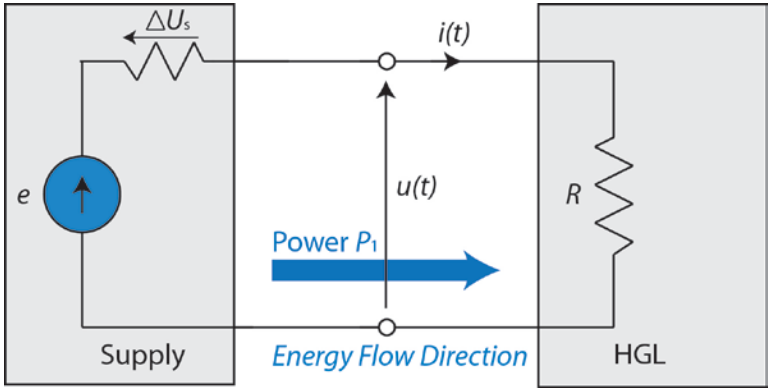
$$u(t)=\sum_{0}^{\infty} u_n(t)=u_1(t)+u_h(t)$$

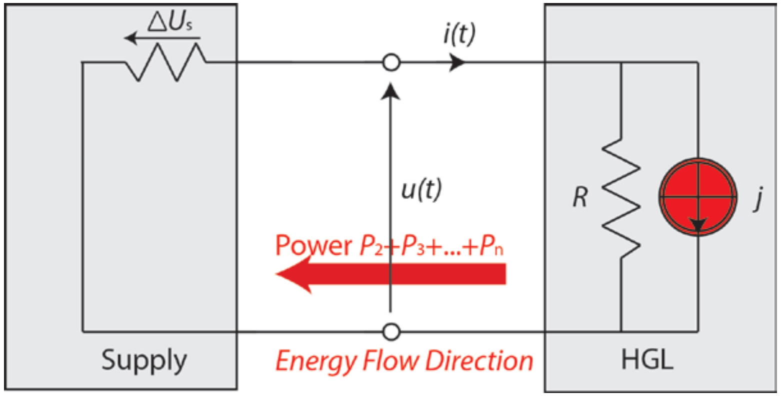


Fundamental & higher harmonics

Reflected Active Power for 1Φ System

- Since different order harmonics are orthogonal to each other, the circuit can be redrawn per harmonic order.
- Fundamental harmonics & higher harmonics





Supply e is sinusoidal.

HGL, $j = j_2 + j_3 + ... + j_n$

Reflected Active Power for 1Φ System

- Because of the orientation of the energy flow, the harmonic components are considered negative.

$$P_2, P_3, P_4, \ldots, P_n < 0$$

- The active power at the load terminals is equal to,

$$P = \underbrace{P_1}_{\text{Fundamental Power}} + \underbrace{P_2 + P_3 + \ldots + P_n}_{\text{HGL sends back energy}}$$

Reflected Active Power for 1Φ System

- Harmonic powers are referred as ***reflected active power***

$$P_r = -\underbrace{(P_2 + P_3 + P_4 + \ldots + P_n)}_{\text{These powers are negative}} > 0$$

- Fundamental power is referred as ***working active power***

$$P_w = P_1$$

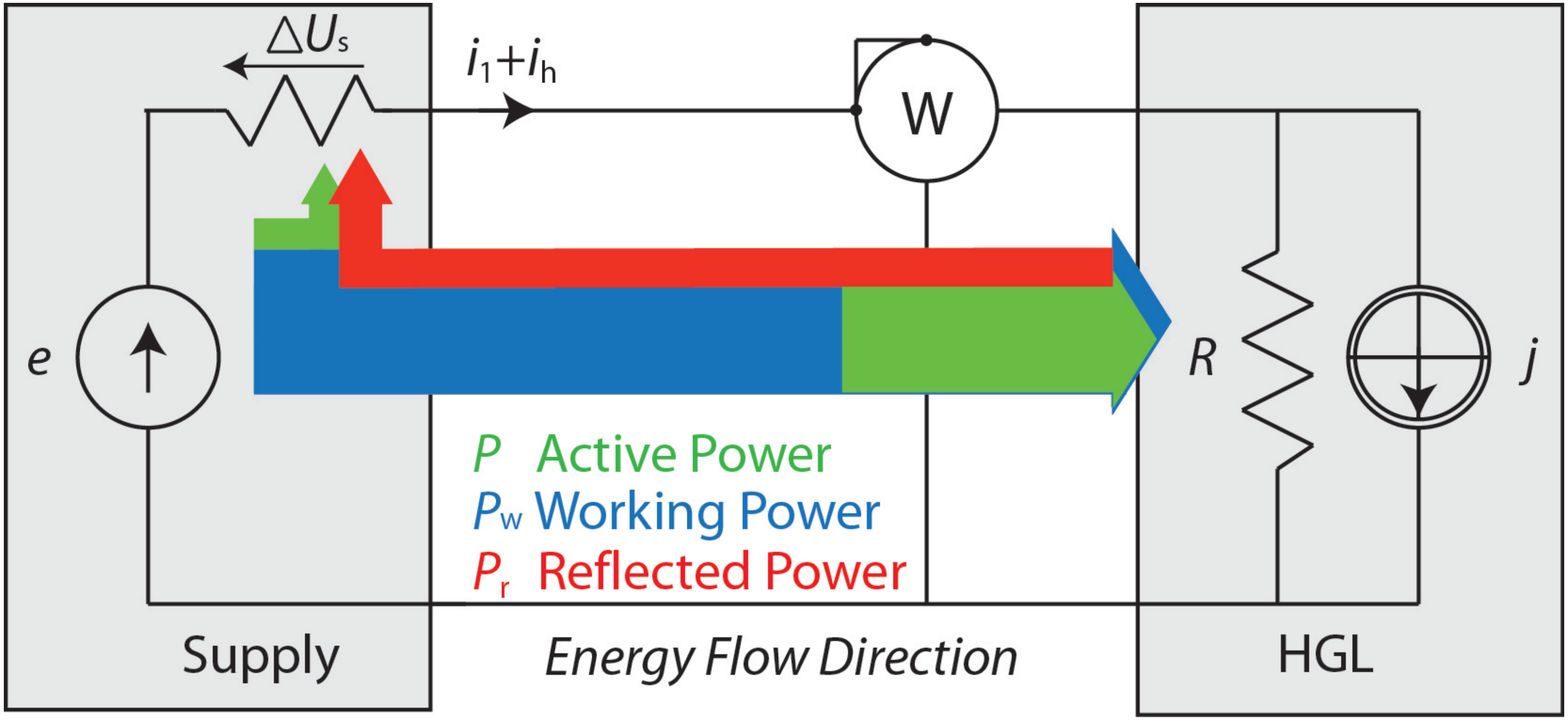
Reflected Active Power for 1Φ System

- Active power is composed of a ***working active power*** component and a ***reflected active power*** component.

$$P = P_w - P_r$$

Metered Power *Working Power* *Reflected Power*

Reflected Active Power for 1Φ System



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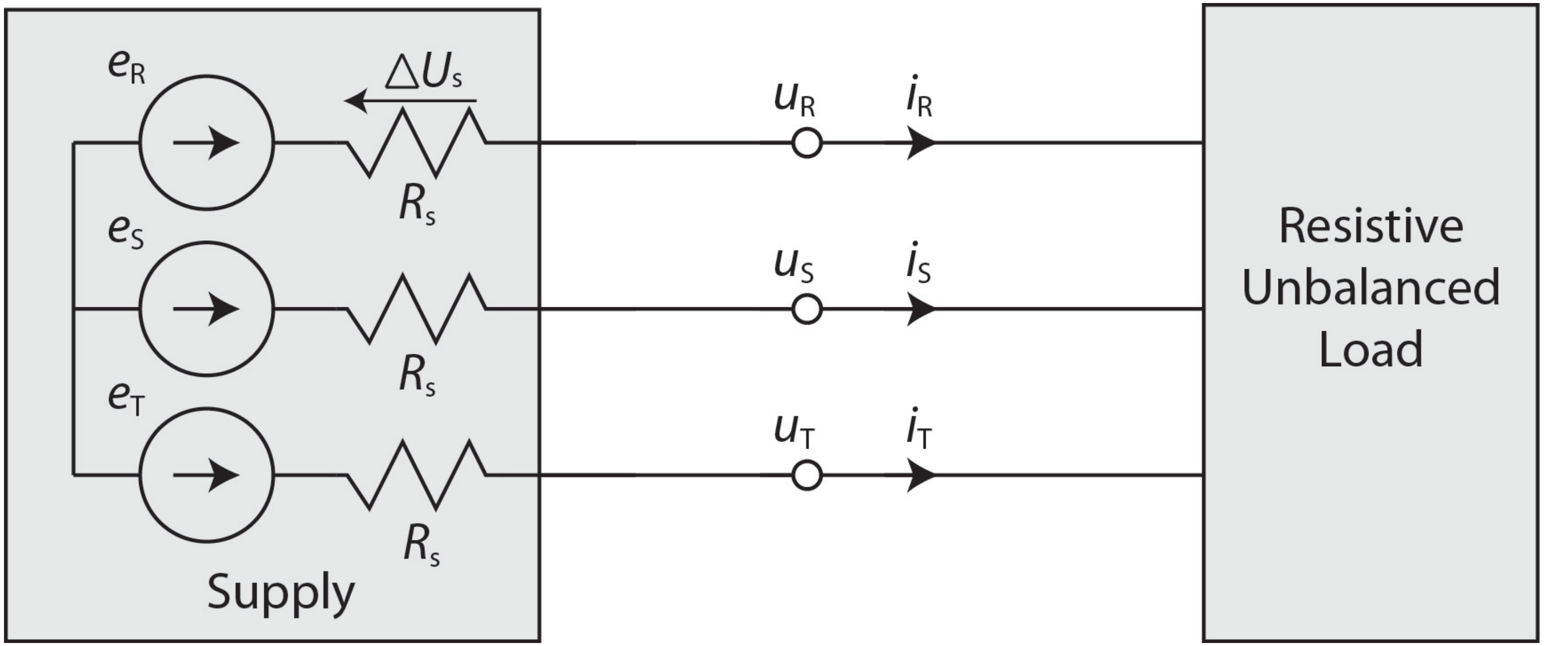
Reflected Power in Unbalanced Loads

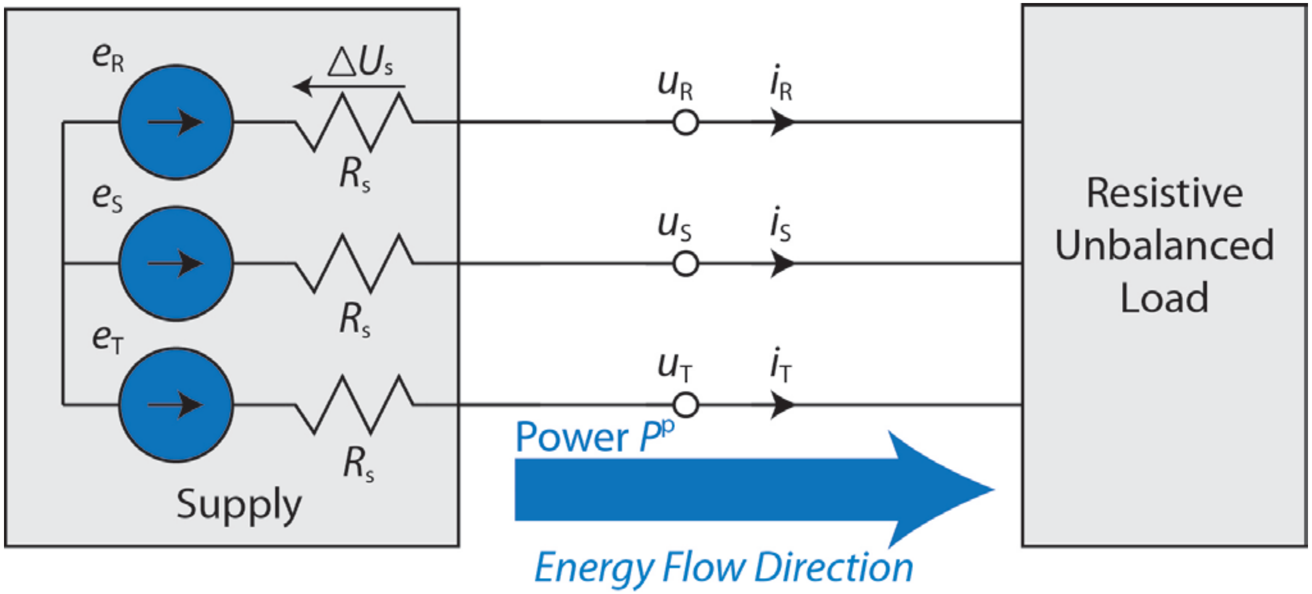
- Three phase, three wire system. Sinusoidal, symmetrical voltage supply, but unbalanced resistive load.



Reflected Power in Unbalanced Loads

- Positive sequence components produce the positive sequence power.

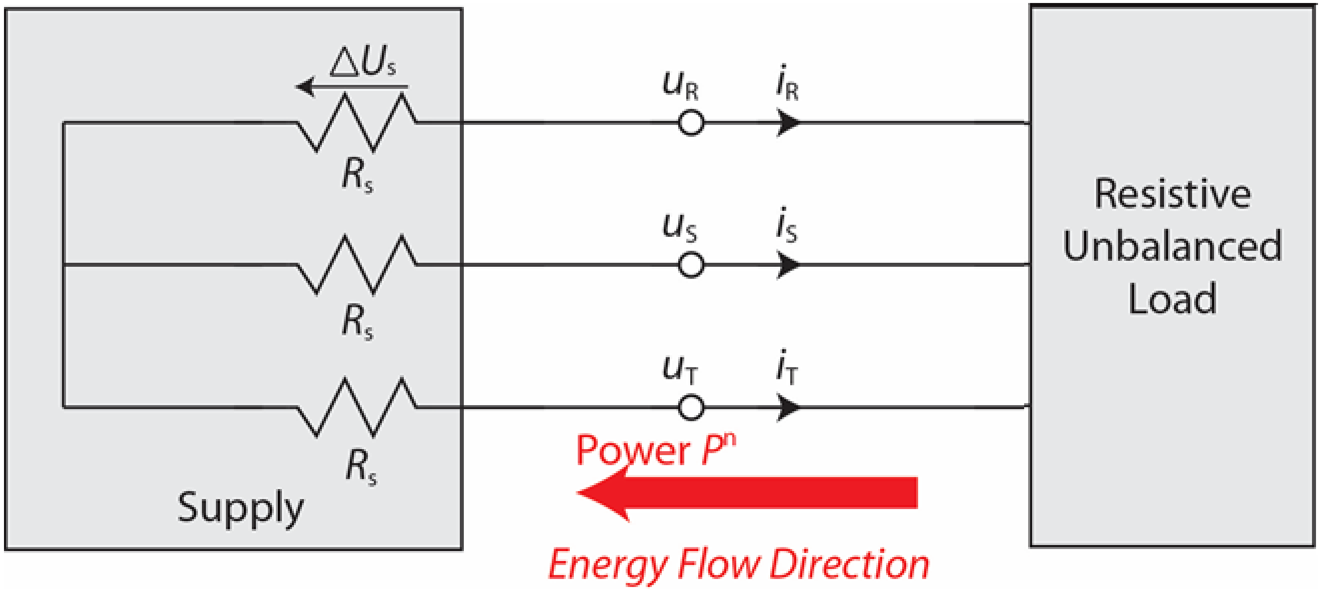
$$P^{\mathrm{p}} = 3U^{\mathrm{p}} I^{\mathrm{p}} \cos\theta^{\mathrm{p}}$$



Reflected Power in Unbalanced Loads

- Additionally, negative sequence components produce the negative sequence power.

$$P^{\mathrm{n}} = 3U^{\mathrm{n}} I^{\mathrm{n}} \cos\theta^{\mathrm{n}}$$



Reflected Power in Unbalanced Loads

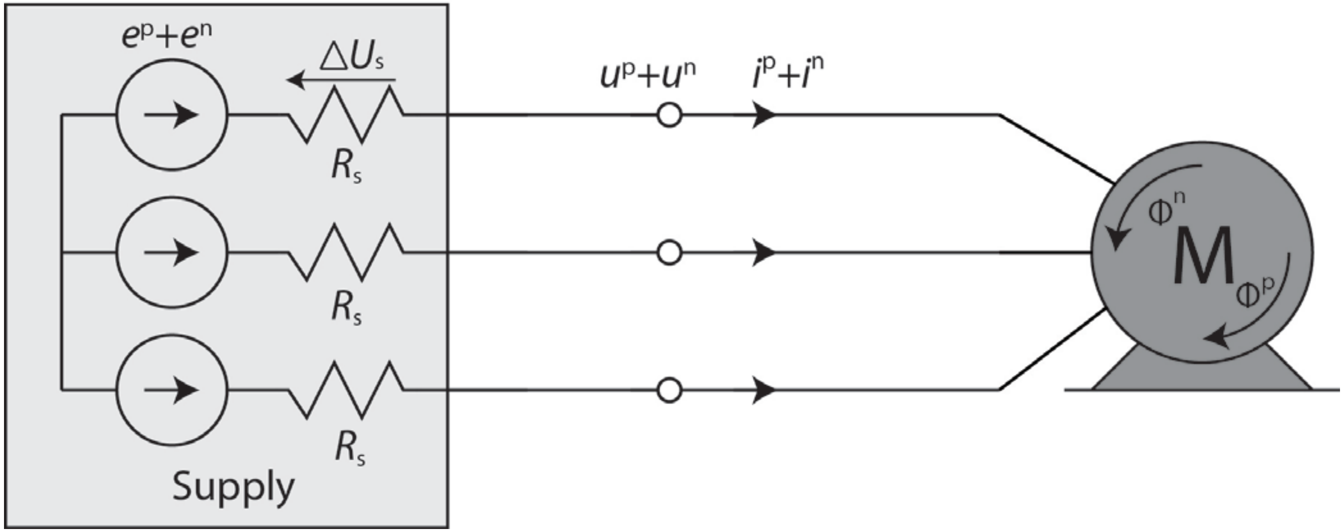
- Thus, the active power at the load terminals consist of

$$\underbrace{P}_{\text{Metered Power}} = \underbrace{P^{\mathrm{p}}}_{\text{Pos. Seq. Power}} + \underbrace{P^{\mathrm{n}}}_{\text{Negative sequence sends energy back}}$$

$$\overbrace{P} = \overbrace{P_{\mathrm{w}}} - \overbrace{P_{\mathrm{r}}}$$

Detrimental Active Power

- Next, consider the situation when the supply voltage contains asymmetry but the load does not.



- Assume supply voltage contains negative and positive sequence components.

Detrimental Active Power

- In response to asymmetrical supply voltage, the motor current contains positive and negative sequence.
- Thus, the active power at the motor terminals consist of,

$$P = \underbrace{P^{\mathrm{p}}}_{} + \underbrace{P^{\mathrm{n}}}_{}$$

Converts to output power*

Reduces motor torque
Increases heat & wear

**Minus losses of the motor*

Detrimental Active Power

- Therefore, P^n should be regarded as ***detrimental active power***,

$$P_d = P^n$$

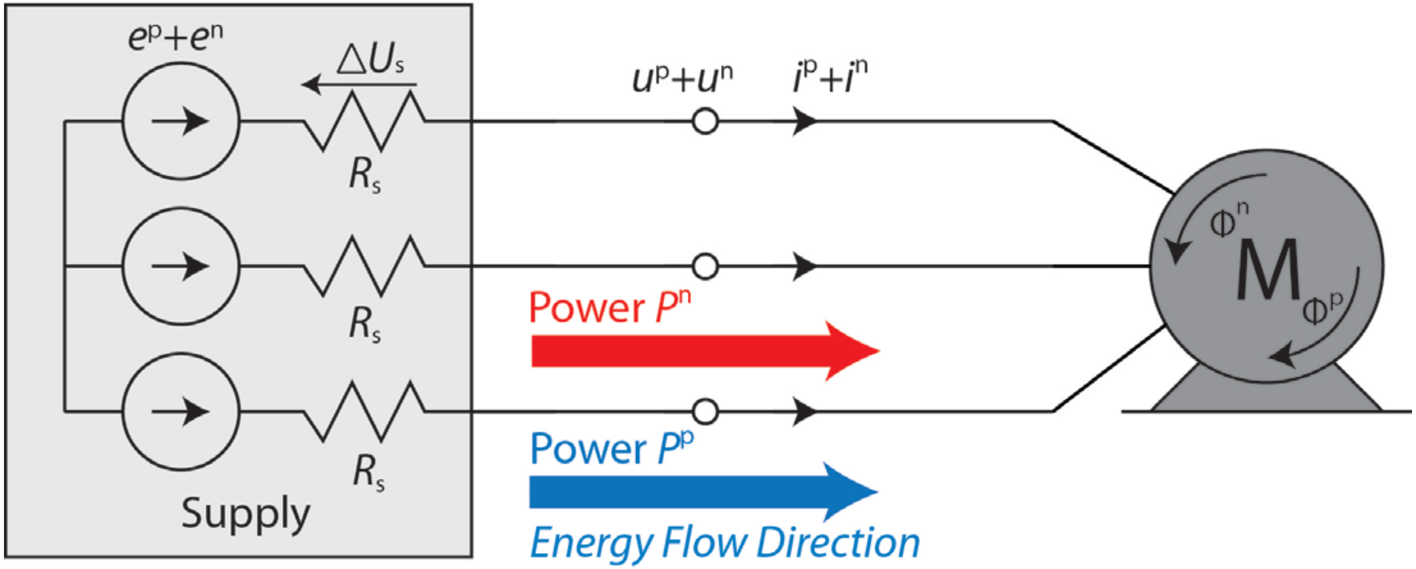
- And P^p should be regarded as ***working active power***,

$$P_w = P^p$$

Detrimental Active Power

- The active power measured at the motor terminals are,

$$P = P^{\mathrm{p}} + P^{\mathrm{n}} = P_{\mathrm{w}} + P_{\mathrm{d}}$$



Detrimental Active Power

- Supply voltage harmonics induces magnetic fields rotating at *n*th order speed that could harm the motor.

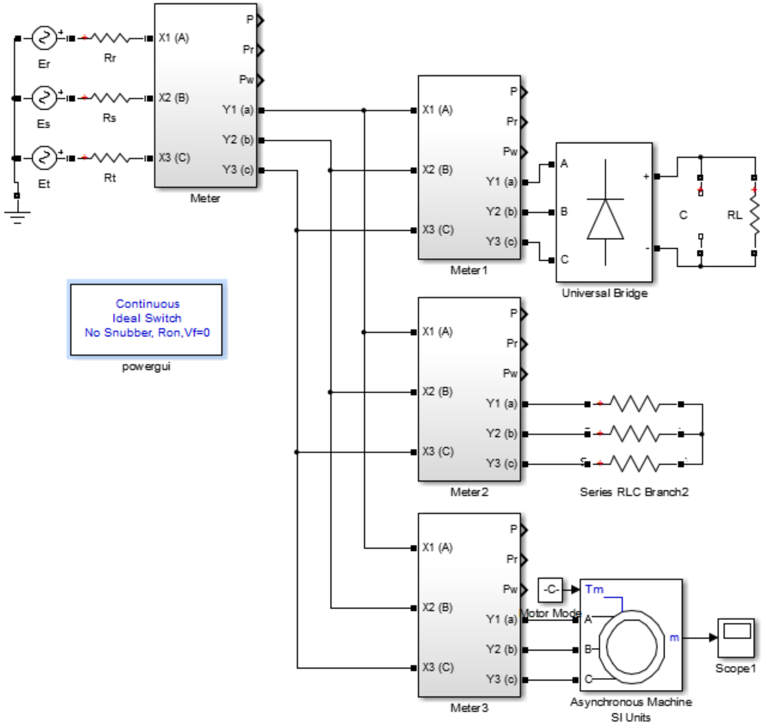
$$P_{\mathrm{h}} = P_2 + P_3 + P_4 + \ldots + P_n$$

- And the harmonic power can be regarded as detrimental

$$P_{\mathrm{d}} = P^{\mathrm{n}} + P_{\mathrm{h}}$$

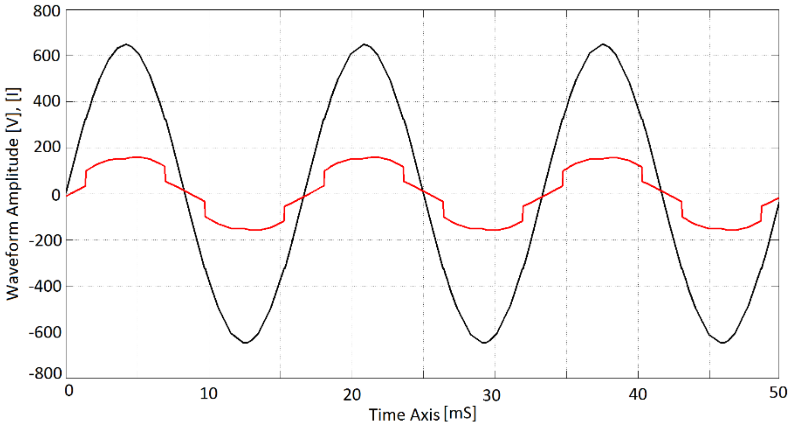
Simulation Setup in Matlab

- Sinusodial, symmetrical supply with a 5% power loss on supply impedance.
- Three loads: resistive load, three phase rectifier, and induction motor.



Experiment #1: Control Test

- Resistive load is balanced, rectifier has no capacitive filtering.

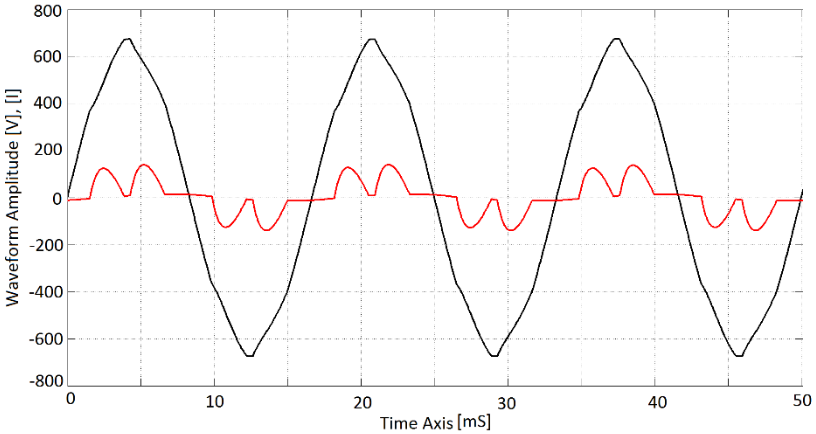


Exp. 1	P [W]	P_w [W]	$P_w - P$ [W]	ΔP/P
Bus	83,514	83,594	80	0.1%
Rectifier	37,750	37,830	80	0.2%
Resistors	37,960	37,960	0	0.0%
Ind. Motor	7,804	7,804	0	0.0%

- Minimal distortion and no asymmetry present.

Exp. #2: Rectifier and Induction Motor

- Resistive load is disconnected, rectifier has capacitive filter with 70% current THD and induction motor running

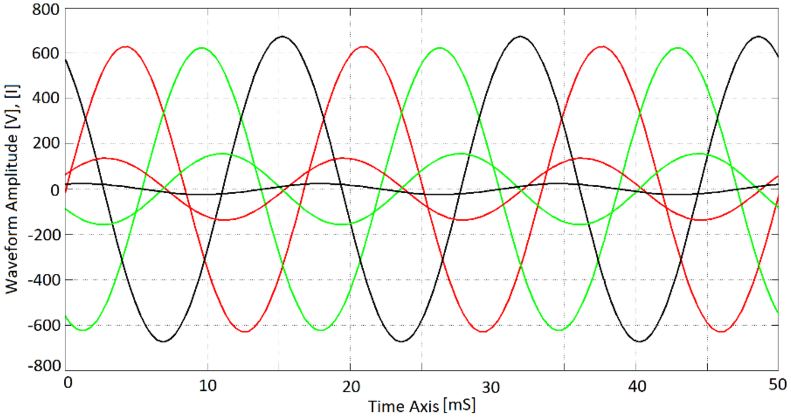


Exp. 2	P [W]	P_w [W]	$P_w - P$ [W]	ΔP/P
Source	83,704	85,571	1,867	2.2%
Rectifier	75,380	77,250	1,870	2.5%
Ind. Motor	8324	8321	-3	0.04%

- Rectifier causes reflected active power that results in an additional 2.2% power loss on the supply.

Exp. #3: Unbalanced Load and Induction Motor

- Resistive load has C phase resistor open circuited

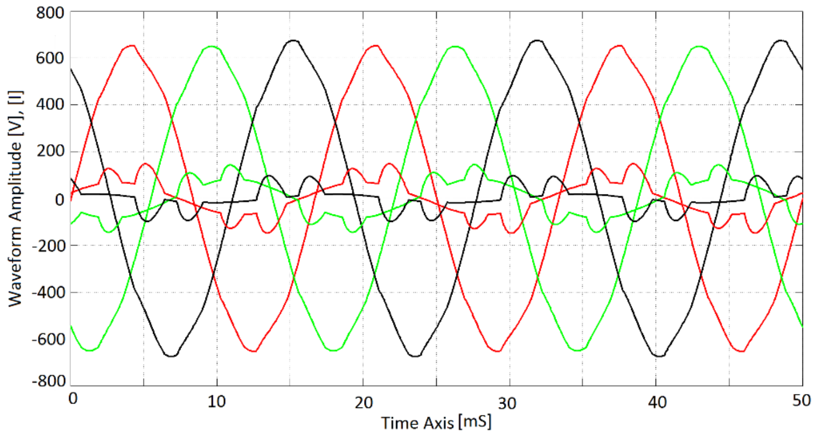


Exp. 3	P [W]	P_w [W]	$P_w – P$ [W]	ΔP/P
Source	83,628	87,380	3,752	4.5%
Unbal. Res.	75,650	79,541	3,891	5.1%
Ind. Motor	7,978	7,839	-139	1.74%

- Unbalanced load causes reflected active power that results in an additional 4.5% power loss on the supply.
- The induction motor is supplied by detrimental active power resulting in a power loss of 1.74%.

Exp. #4: Unbalanced Load, Rectifier, and Induction Motor

- All loads from previous experiments turned on.



Exp. 4	P [W]	P_w [W]	$P_w - P$ [W]	ΔP/P
Source	83,730	85,225	1,495	1.8%
Rectifier	38,590	39,360	770	2.0%
Unbal. Res.	37,290	38,040	750	2.0%
Ind. Motor	7,850	7,825	-25	0.3%

- System suffers from reflected active power that results in an additional 1.8% power loss on the supply.
- The induction motor is supplied by detrimental active power resulting in a power loss of 0.3%.

Experimental Results

- Sources of distortion (rectifier) and asymmetry (unbalanced load) caused a reflected active power component resulting in higher utility power loss.

- Induction motor suffered detrimental active power from asymmetrical supply voltage the most. The voltage distortion affected the motor to a lesser extent. Overall, this causes power loss in the motor and overpayment of the customer.

Summarizing Working Power Concept

- ***Working active power*** is a fair way to bill customers so everyone is accountable for their actions.

$$P_w = P + P_r - P_d$$

- Can easily be integrated into the current advanced metering infrastructure (AMI).

Conclusion

- ***Working power*** concept accurately bills customers for their fair energy usage.
  - Reflected active power refers to revenue loss of utility. (Penalize customer)
  - Detrimental active power refers to customer overpayment. (Reimburse customer)
- Using penalties, this will cause economic incentives to reduce overall distortion and asymmetry in the system.
- Microgrids can benefit the most from the working power concept and can be easily integrated with AMI.

Questions and Comments?

- Are there any questions or comments?

- Contact email: Tracy N. Toups: ttoups2@tigers.lsu.edu

  Leszek S. Czarnecki: lsczar@cox.net

- Thank you for your attention and time.

Aalto University
School of Engineering

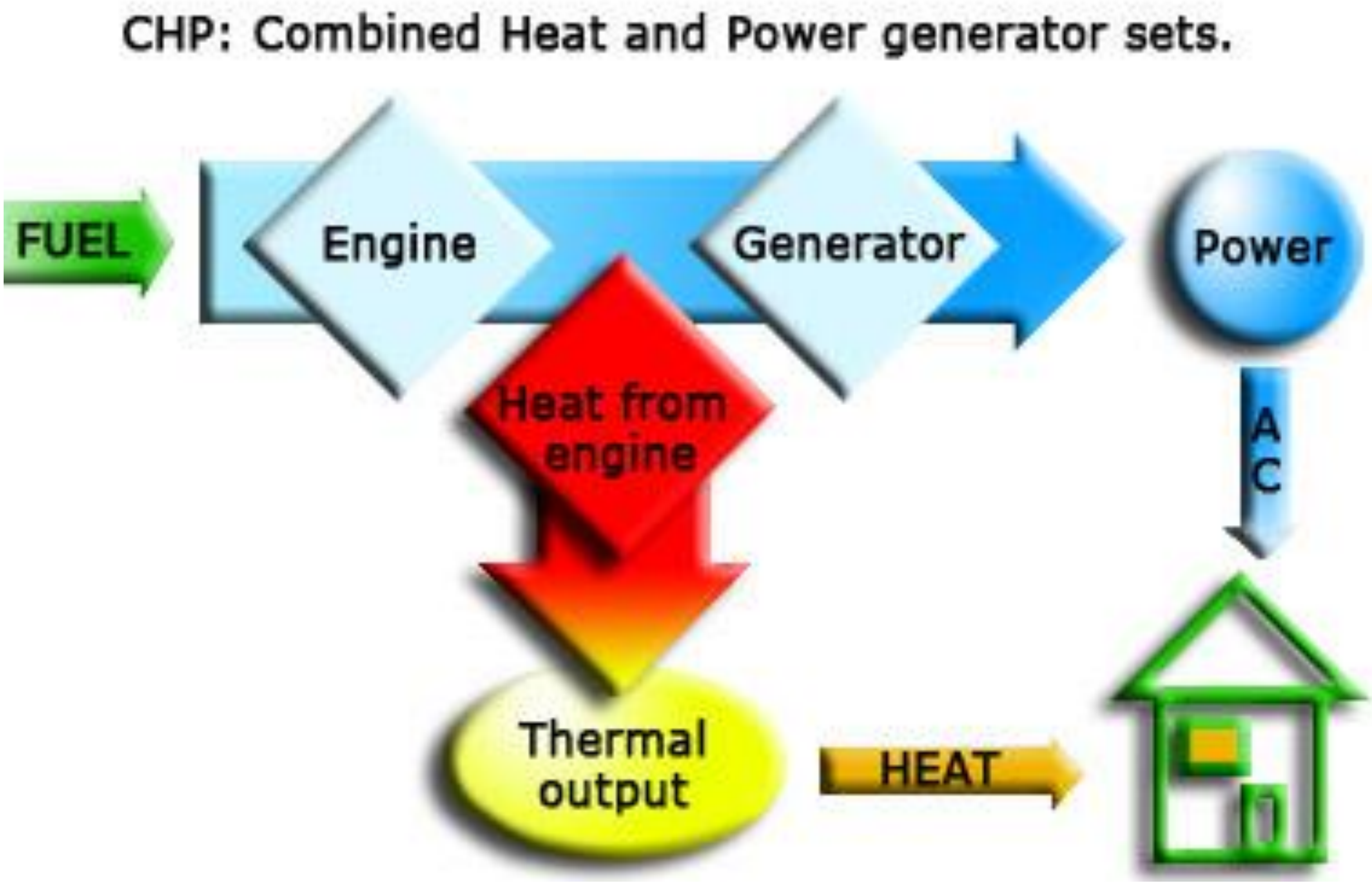
Optimization of energy production of a CHP plant with heat storage

Elnaz Abdollahi, Haichao Wang, Samuli Rinne, Risto Lahdelma
Department of Energy Technology
Elnaz.abdollahi@aalto.fi
24.11.2014

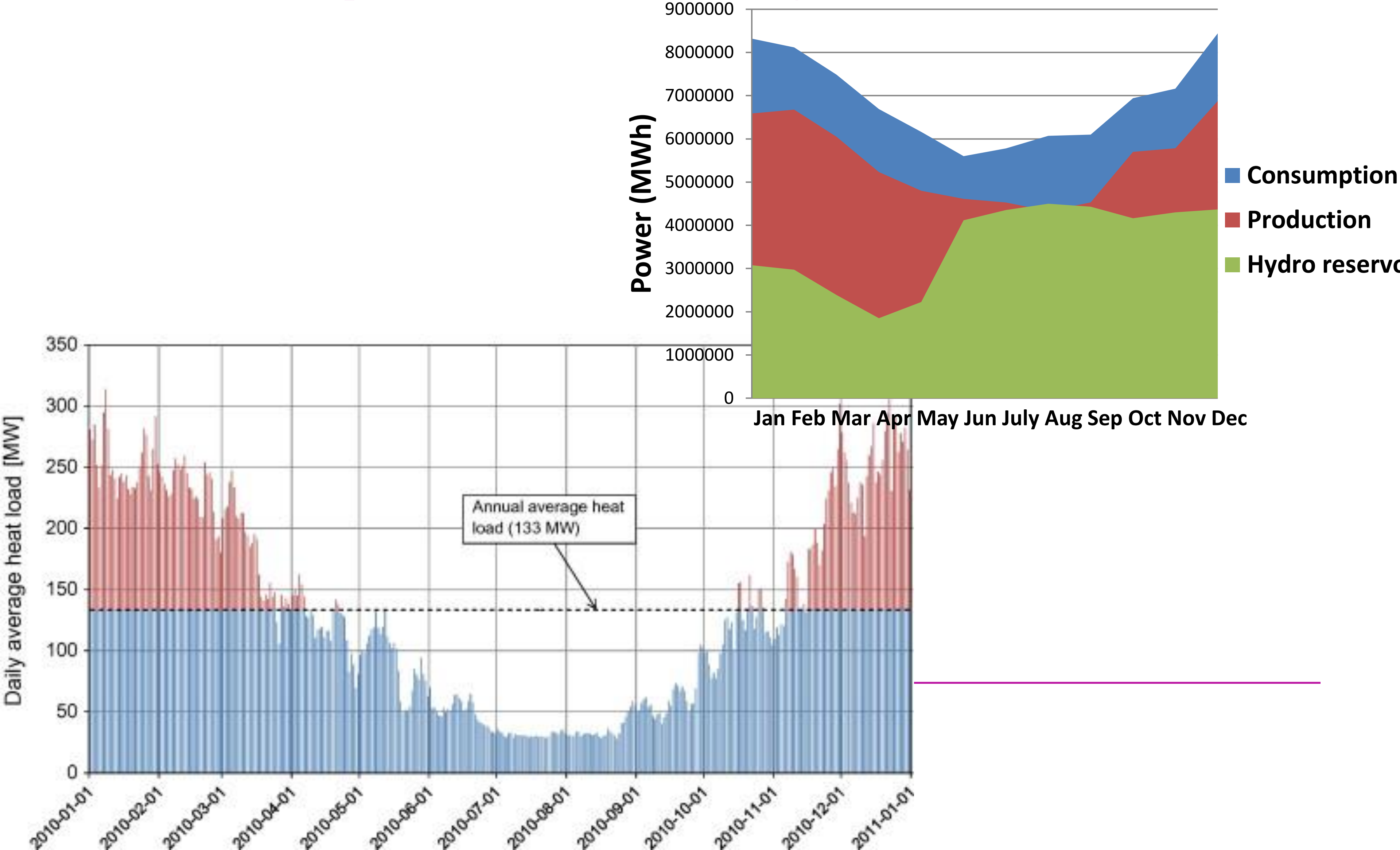
This talk presents a linear programming (LP) model for a CHP plant with heat storage

- **Demand for cheaper and more efficient energy production**
- **Combined heat and power (CHP) optimization**
- **Computational results**

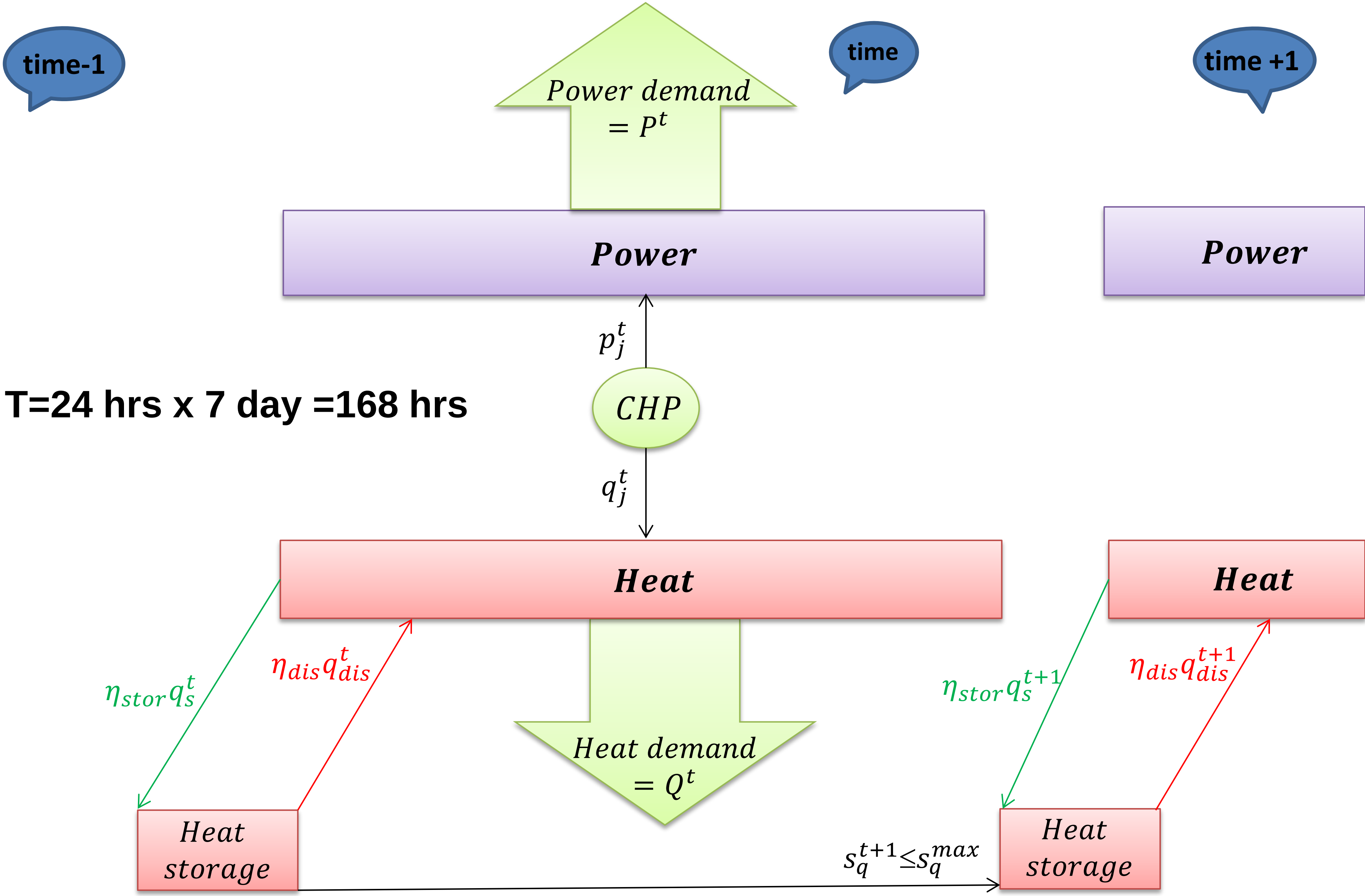
CHP is a more efficient technology than condensing power plants



CHP can satisfy heat and power consumption efficiently



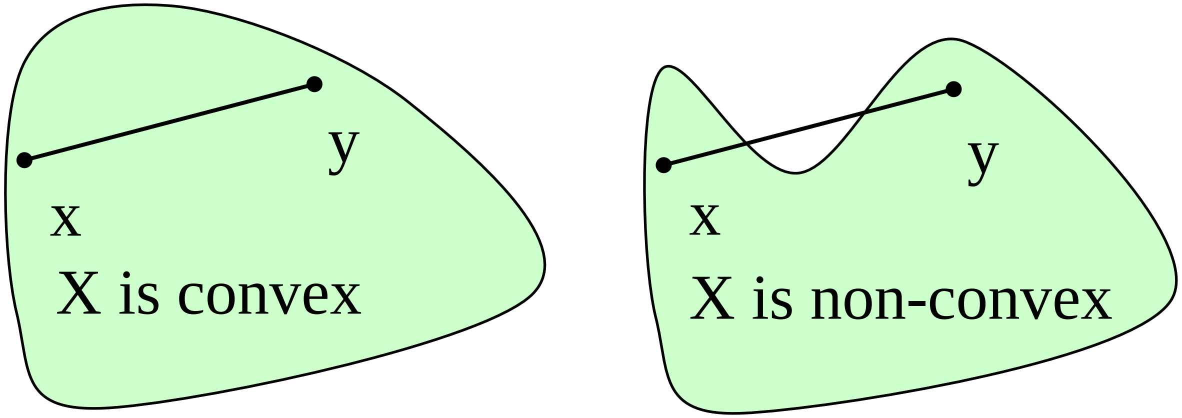
Heat storage combines hourly models



T=24 hrs x 7 day =168 hrs

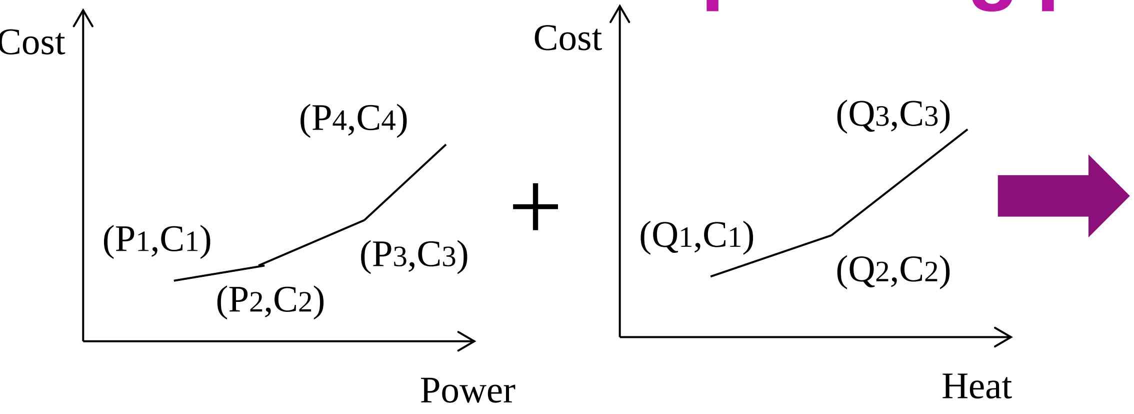
Convexity assumption

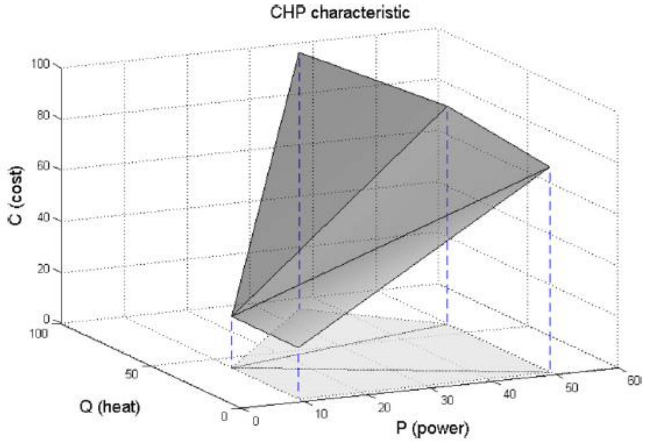
- We assume the CHP plant model is convex:
  - the operating region is convex
  - the objective function to minimize is convex
- A set X is **convex** if the line segment connecting any two points x and y of the set is in the set



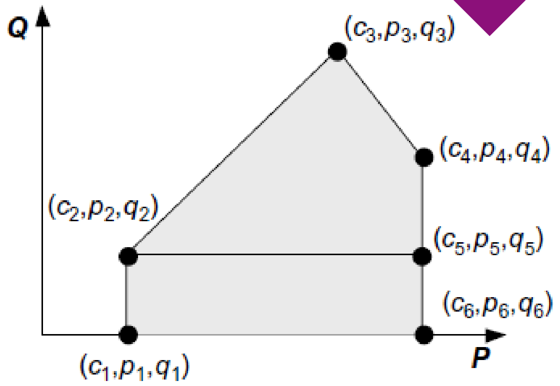
- **Mathematically**
  - If $\mathbf{x},\mathbf{y} \in X$, then $\alpha\mathbf{x}+(1- \alpha)\mathbf{y} \in X$ for all $\alpha \in [0,1]$

Modelling convex operating region of CHP plant as convex combination of characteristic operating points





Feasible operating region of a CHP – 3D characteristic



Feasible operating region of a CHP

$$C = \sum_{j\in J} c_j x_j$$

$$P = \sum_{j\in J} p_j x_j$$

$$Q = \sum_{j\in J} q_j x_j,$$

$$\sum_{j\in J} x_j = 1,$$

$$x_j \ge 0,\ j \in J$$

Nomenclature

- **Symbols**

c_j : production cost at characteristic point $j \in J$

p_j : power generation at characteristic point $j \in J$

q_j : heat generation at characteristic point $j \in J$

η : efficiency ratio

P, Q : demand for power and heat

x : variable used to encode convex combination of operating region

S : storage level

- **Indices**

j : subscript of extreme point

t : time

p, q : subscript for power and heat products

dis : subscript for discharge

s : subscript for storage of heat

- **Index sets**

J : set of extreme points of the operating regions of all plants

T : set of time periods

Linear programming (LP) model with heat storage

Objective function

Fuel price

$$\min \sum_{t=1}^{T}((\sum_{j\in J} c_j^t x_j^t) - c_p^t P^t) \tag{1}$$

Hourly power price

Subject to

$$\sum_{j\in J} x_j^t = 1 \tag{2}$$

$$\sum_{j\in J} p_j^t x_j^t = P^t \tag{3}$$

$$\sum_{j\in J} q_j^t x_j^t - q_{stor}^t + \eta_{dis} q_{dis}^t = Q^t \tag{4}$$

Hourly heat demand

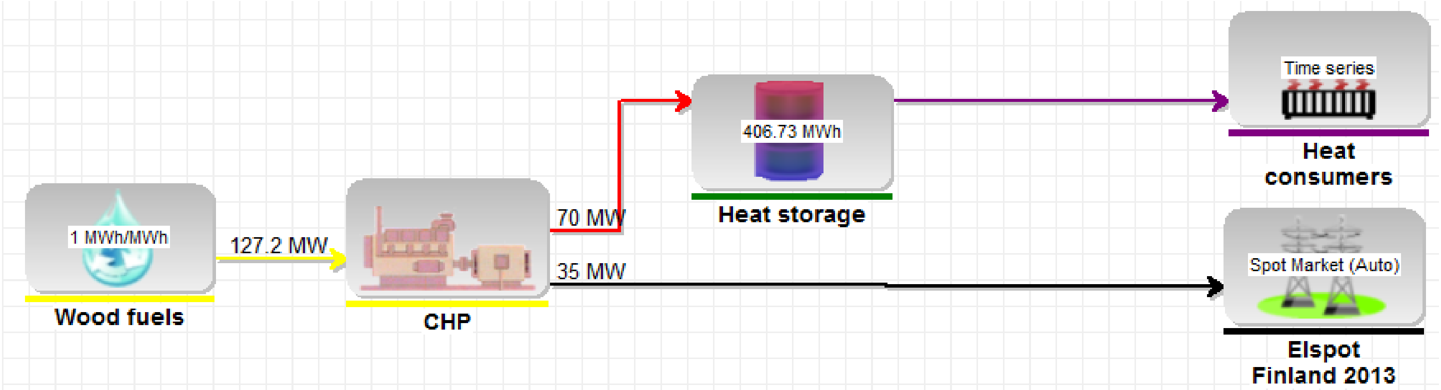
$$S_q^t = \eta_{stor} S_q^{t-1} + q_{stor}^t - q_{dis}^t \tag{5}$$

$$0 \le S_q^t \le S_q^{\max} \tag{6}$$

$$x_j^t \ge 0,\ j \in J \tag{7}$$

$$t = 1,\dots,T \tag{8}$$

Scaled input parameters



	Values
Maximum capacity of CHP plant	Power= 35 MW Heat=70 MW Fuel= 127.27 MW
Heat demand	Weekly heat demand of a Finnish city (MWh)
Power price	NordPool spot price in Finland 2013 (€/MWh)
Fuel price	15 (€/MWh)
Storage capacity 1 Storage capacity 2 Storage capacity 3	406 MWh 90 MWh 80 MWh

Comparison of three output variables

Decision variables	LP	EnergyPRO	EnergyPLAN
Power production (MW)	5 392	5 392	5 338
Fuel consumption (MW)	19 607	19 607	20 000
Total cost (€)	101 716	101 765	110 000
LP Total cost improvement		0.05%	0.08%

Alternative capacities for heat storage

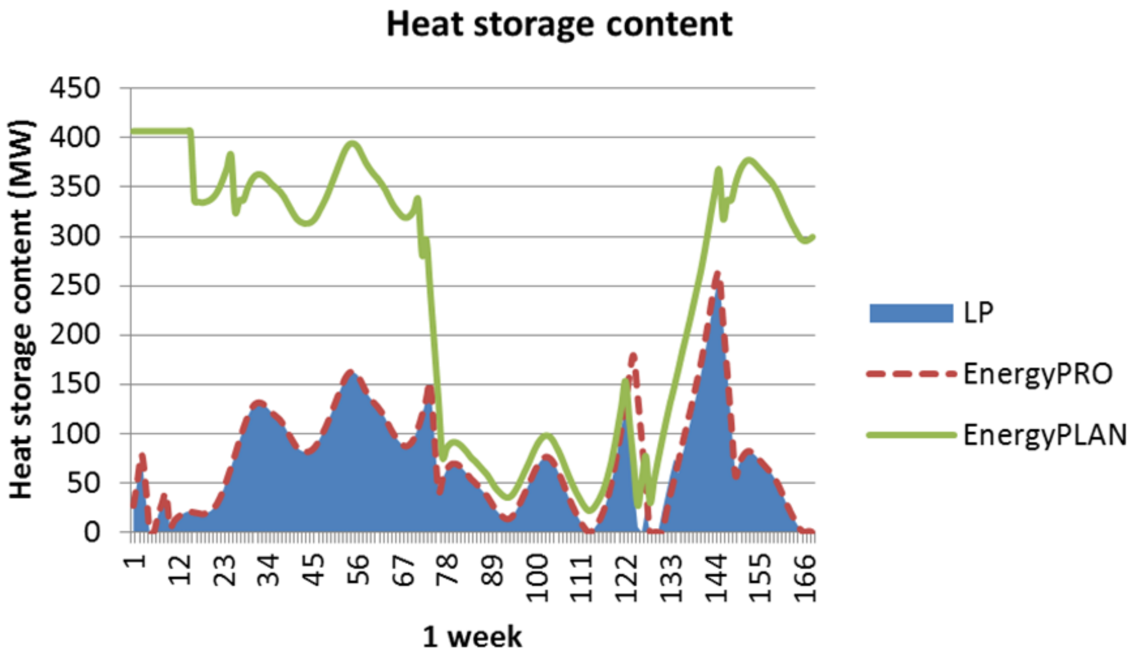
- Heat storage content (101 716 < 101 994)

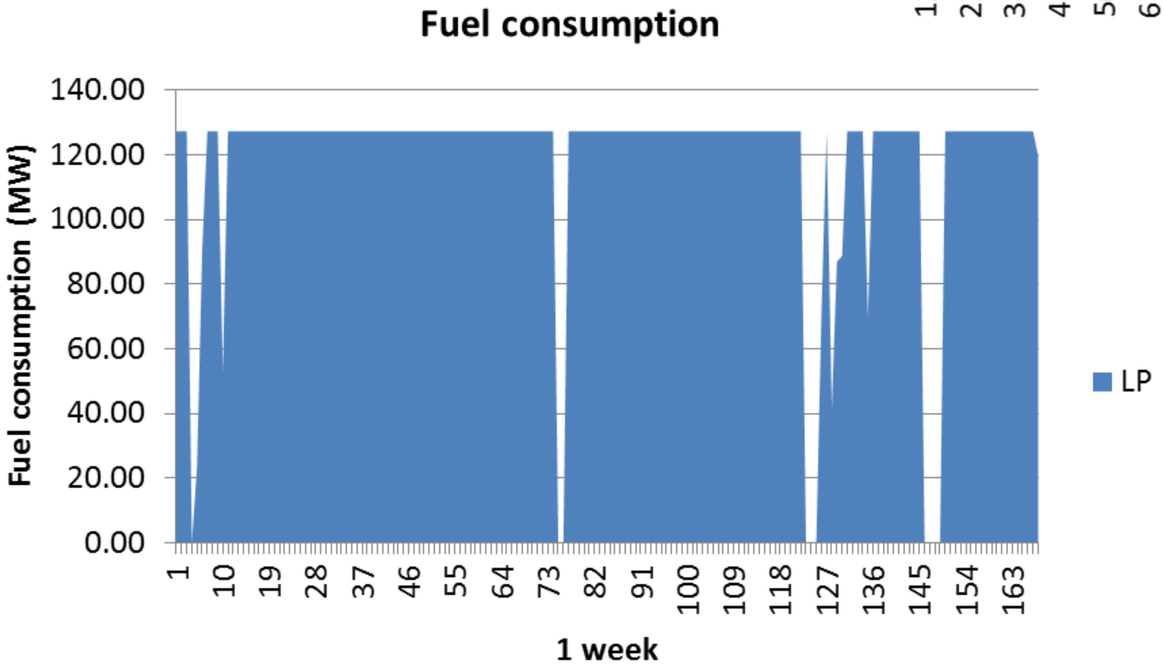
Heat storage (LP)	406 (MW)	90 (MW)	80 (MW)
Total cost (€)	101 716	101 994	Infeasible

- Infeasible solution by EnergyPLAN

Time step	Heat demand (MW)	Heat production (MW)	Storage content	Heat balance (MW)
165	7 652	7 000	103	
166	7 269	7 000	0	103 discharged (166 ?)
167	6 886	7 000	114	

Hourly fluctuations of heat storage content and fuel cons.





Towards more efficient and clean energy

- The proposed model can optimize the CHP with high flexibility.
- Large-scale energy production models should also be developed to facilitate more economic energy production.

Thanks for your attention

Contact email: elnaz.abdollahi@aalto.fi

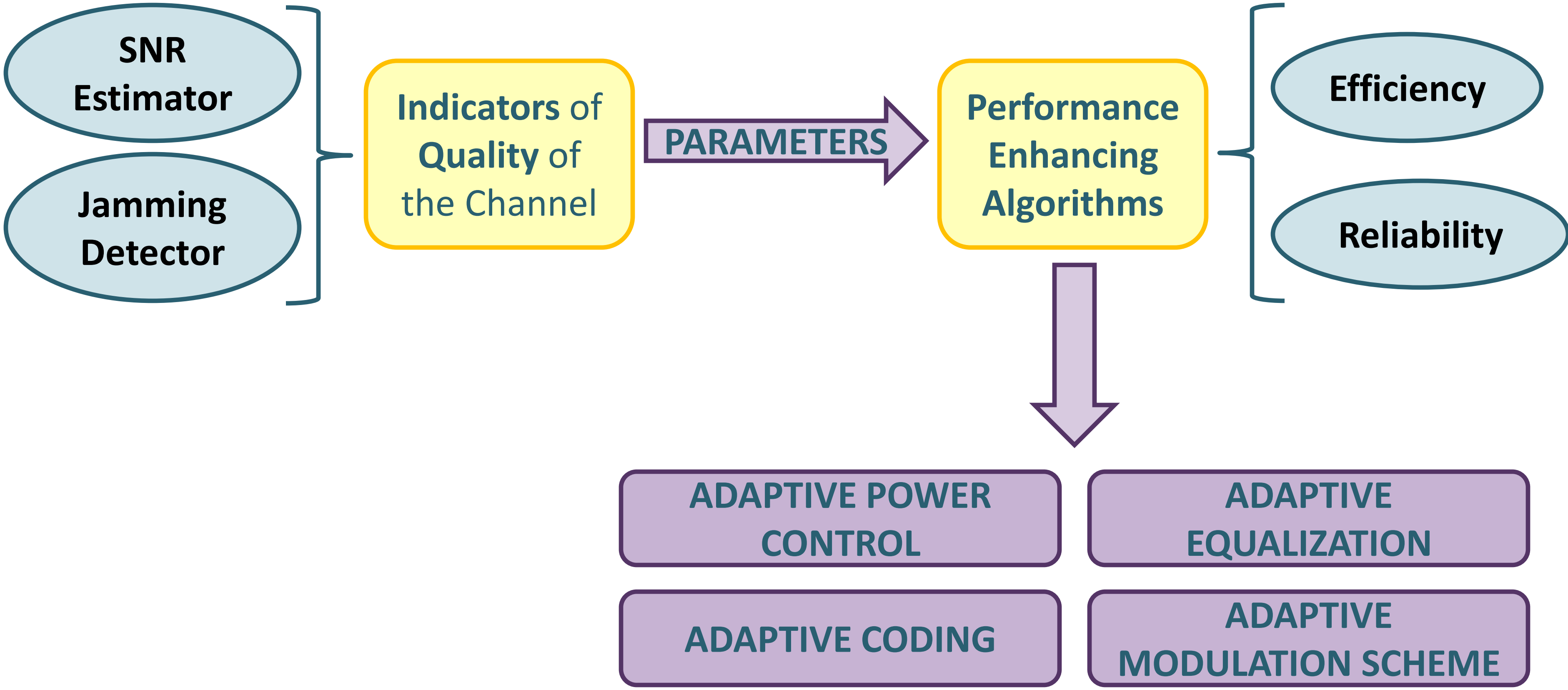
Green Energy and Systems Conference 2014

SNR Estimation and Jamming Detection Techniques Using Wavelets

By: Paula Quintana

California State University, Long Beach

IMPACT ON COMMUNICATION SYSTEMS



SNR Estimator

Jamming Detector

Indicators of Quality of the Channel

PARAMETERS

Performance Enhancing Algorithms

Efficiency

Reliability

ADAPTIVE POWER CONTROL

ADAPTIVE EQUALIZATION

ADAPTIVE CODING

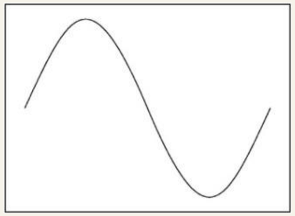
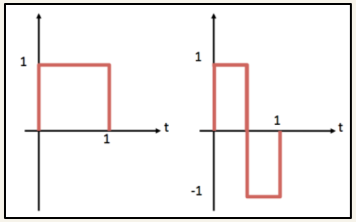
ADAPTIVE MODULATION SCHEME

WHY WAVELETS?

SIGNAL PROCESSING PRINCIPLE

SIGNAL ANALYSIS

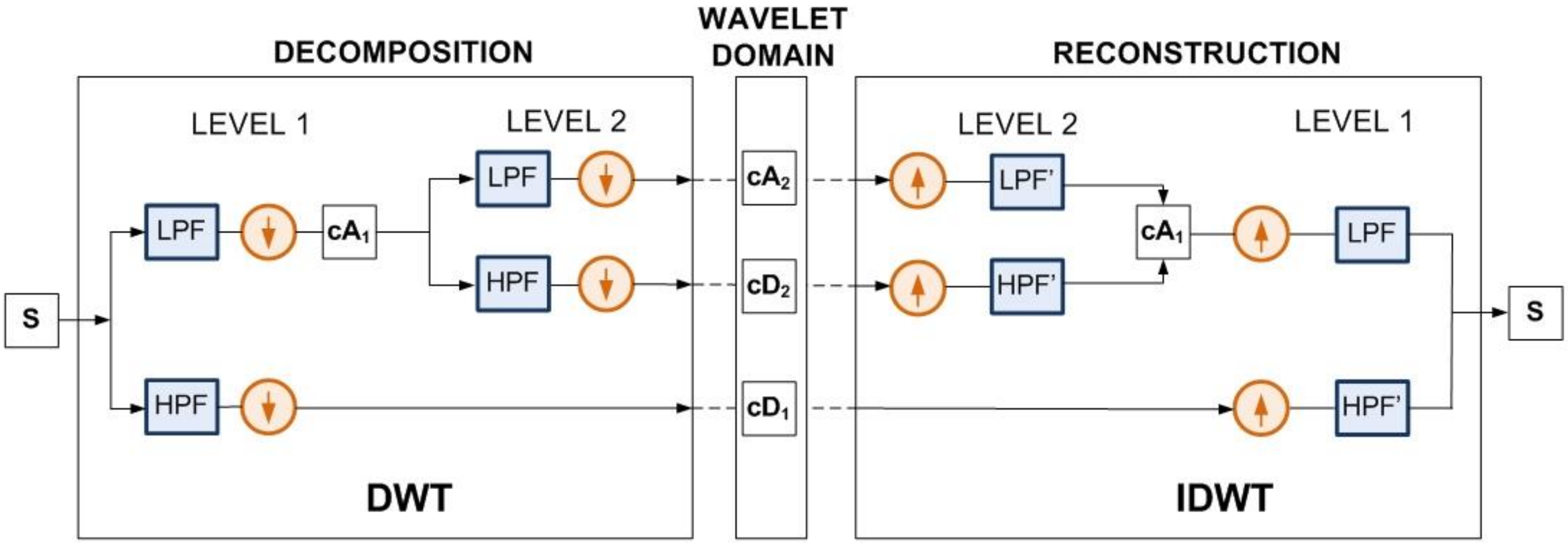
Representation or approximation of a function using a weighted summation of a family of functions (also known as a basis).

FOURIER ANALYSIS	WAVELET ANALYSIS
Frequency domain representation.	Time-Scale representation.
Optimal for "soft" and stationary signals.	Optimal for "sharp" and non-stationary signals.
Basis: Sines and Cosines.	Basis: Wavelets. Example: Haar Wavelet
	

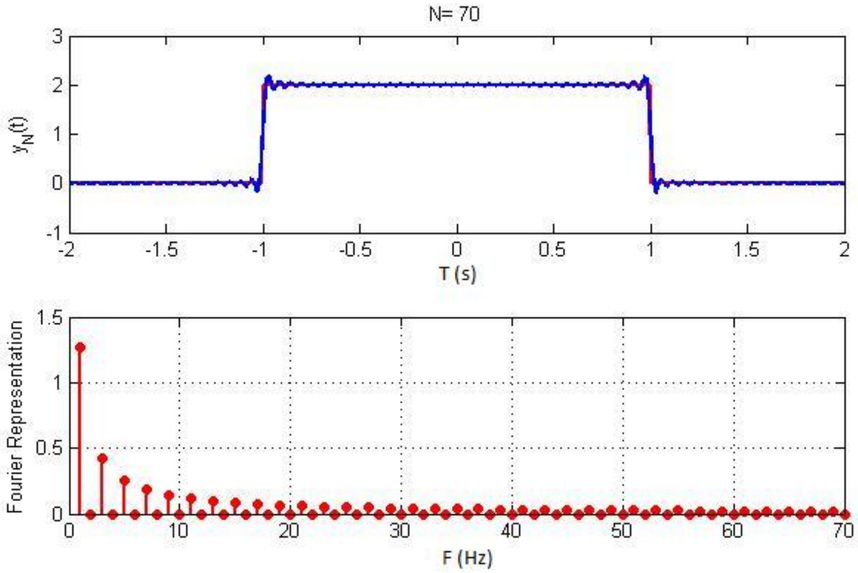
Wavelet Transform &Filter Banks

The **coefficients** in the wavelet domain are a function of both scale and position, and they indicate how correlated the wavelet is to the section of the signal under analysis.
The wavelet coefficients are classified according to the wavelet scale as:

High resolution coefficients / Details (cD): coefficients provide information regarding the rapid-changing details of the signal of interest, and therefore are obtained using low scales (low levels) that compress the wavelet in time.
Low resolution coefficients / **Approximations (cA)**: represent coarse signal features, and are obtained using high scales (high levels) that stretch wavelets in time.

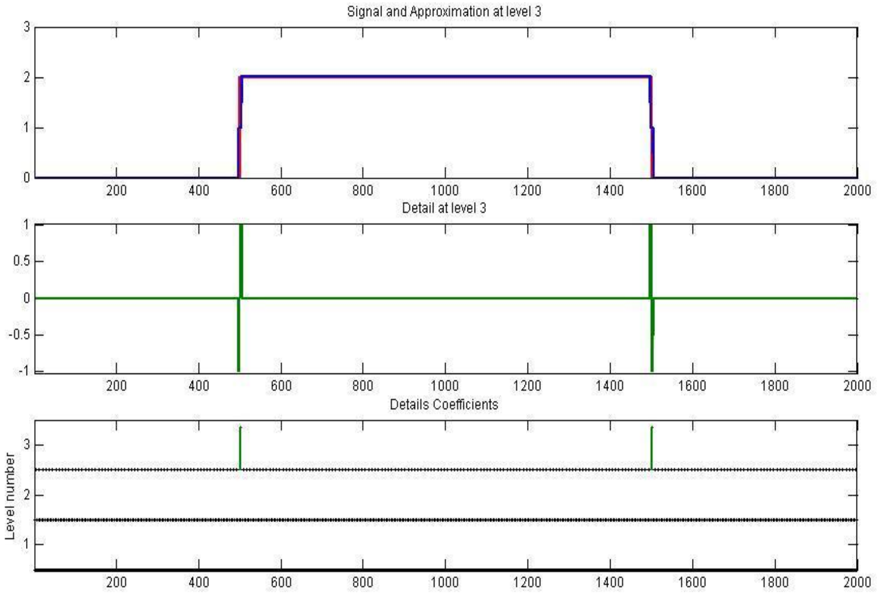


HOW DOES THE SIGNAL OF INTEREST LOOK LIKE IN A DIGITAL RECEVER?



Fourier Expansion

This representation needs 70 coefficients in the Frequency domain, and the approximation is not optimal.



Wavelet Expansion

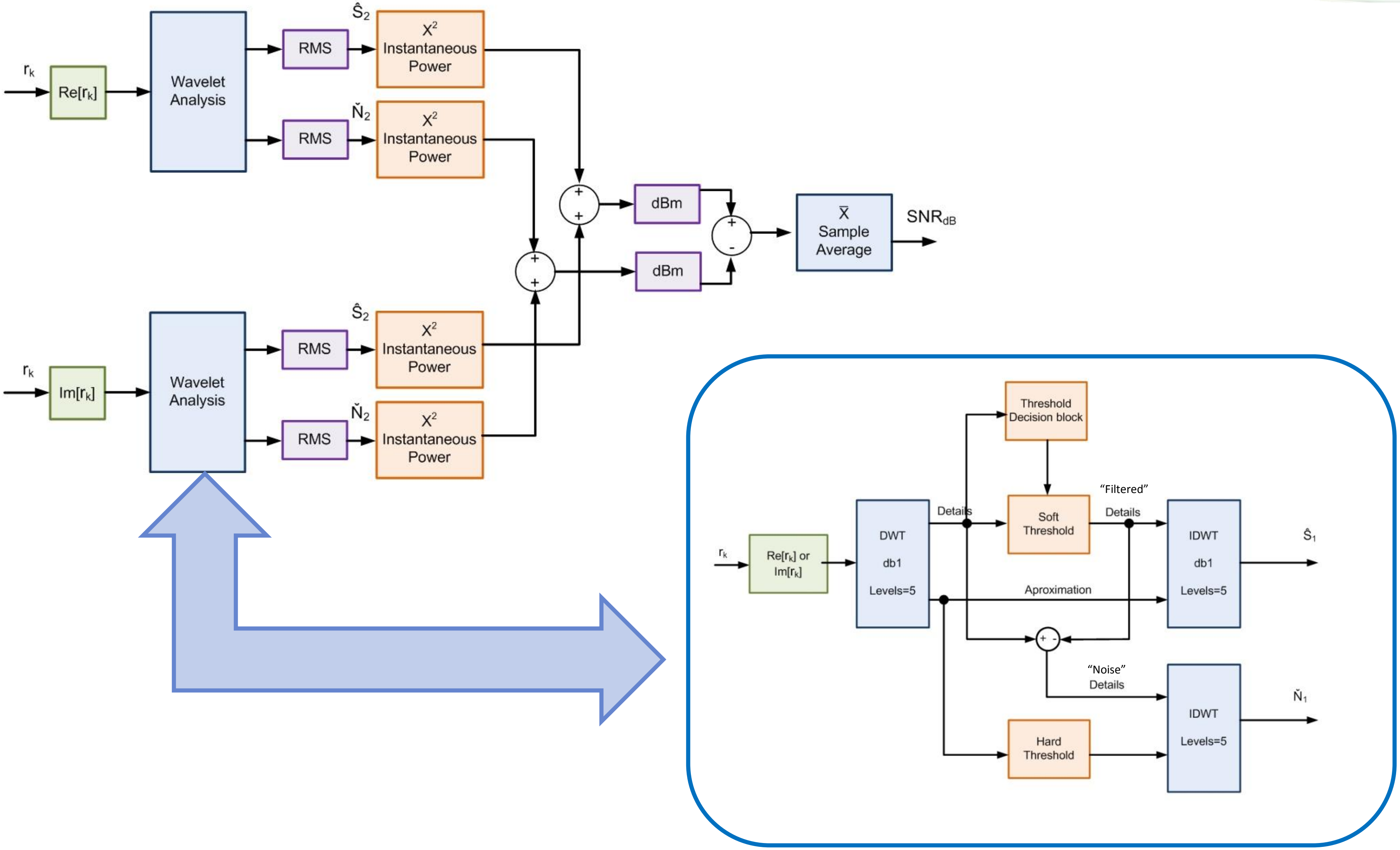
This representation needs 1 detail coefficient, and 1 approximation coefficient. The approximation coefficient in time can be used as the original signal approximation and the representation is near optimal.

Wavelet- Based SNR Estimators

WAVELET ESTIMATOR 1 TREND DETECTOR	WAVELET ESTIMATOR 2 SELF-SIMILARITY DETECTOR
Principle:	**Principle:**
Extract the **amplitude trend**, based on the principle that noise changes at a higher rate.	Operates on the **quadrature components** of the complex envelope, and performs the signal extraction based on the similarity between the mother wavelet and the signal under analysis.

Best Performance: Wavelet-Based Estimator 2.

Wavelet Based Estimator 2: Self-Similarity Detector.



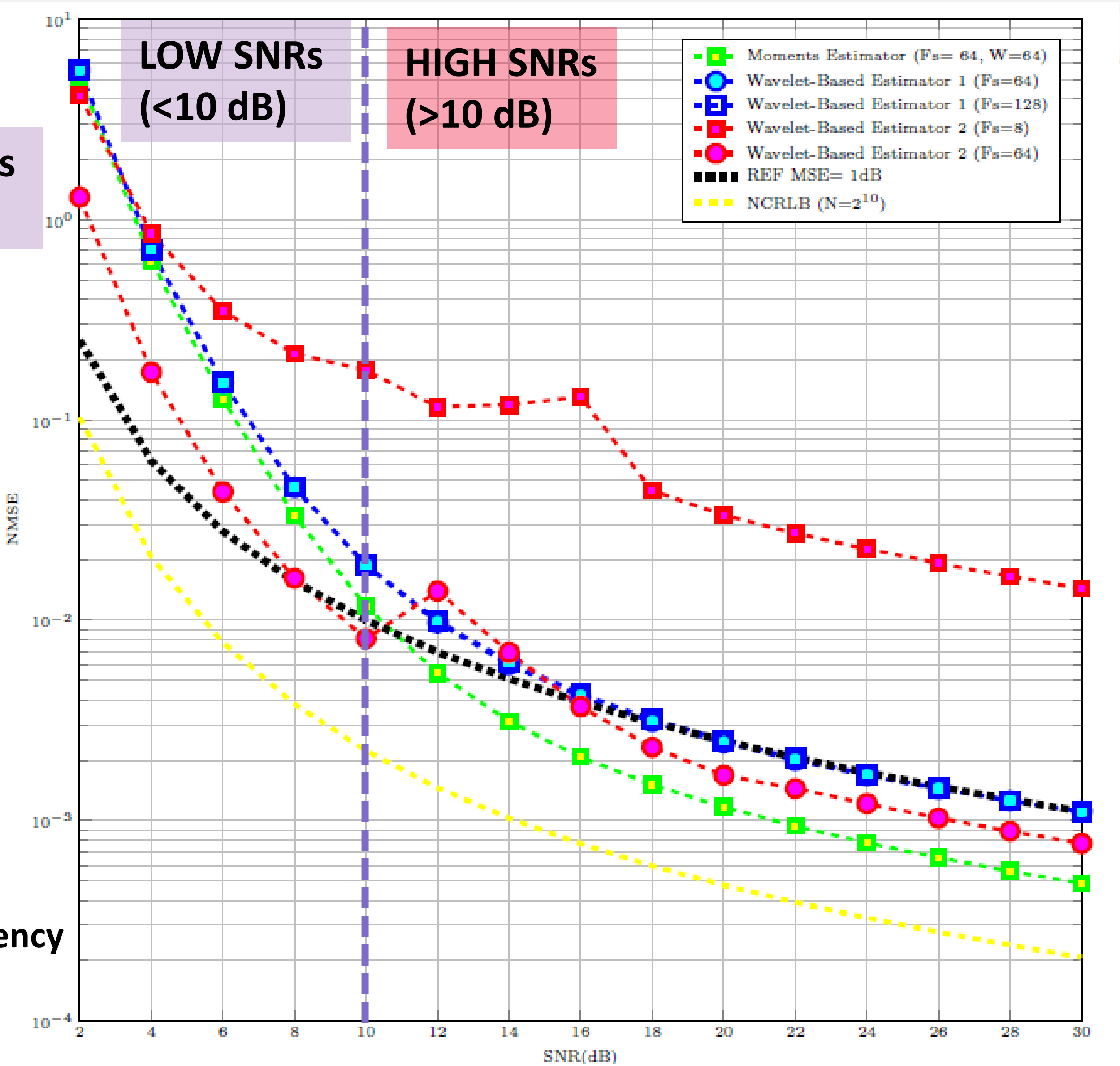
OVERALL RESULTS (NMSE)

LOW SNRs
(<10 dB)

WORST PERFORMANCE WBE #2 Fs=8

BEST PERFORMANCE WBE #2 Fs=64

For WBE #2 the performance improves as the Sampling Frequency increases.



LOW SNRs
(<10 dB)

HIGH SNRs
(>10 dB)

HIGH SNRs
(>10 dB)

WORST PERFORMANCE WBE #2 Fs=8

BEST PERFORMANCE MOMENTS Fs=64

For high SNRs, The typical moments estimator performs better than the wavelet-based estimators.

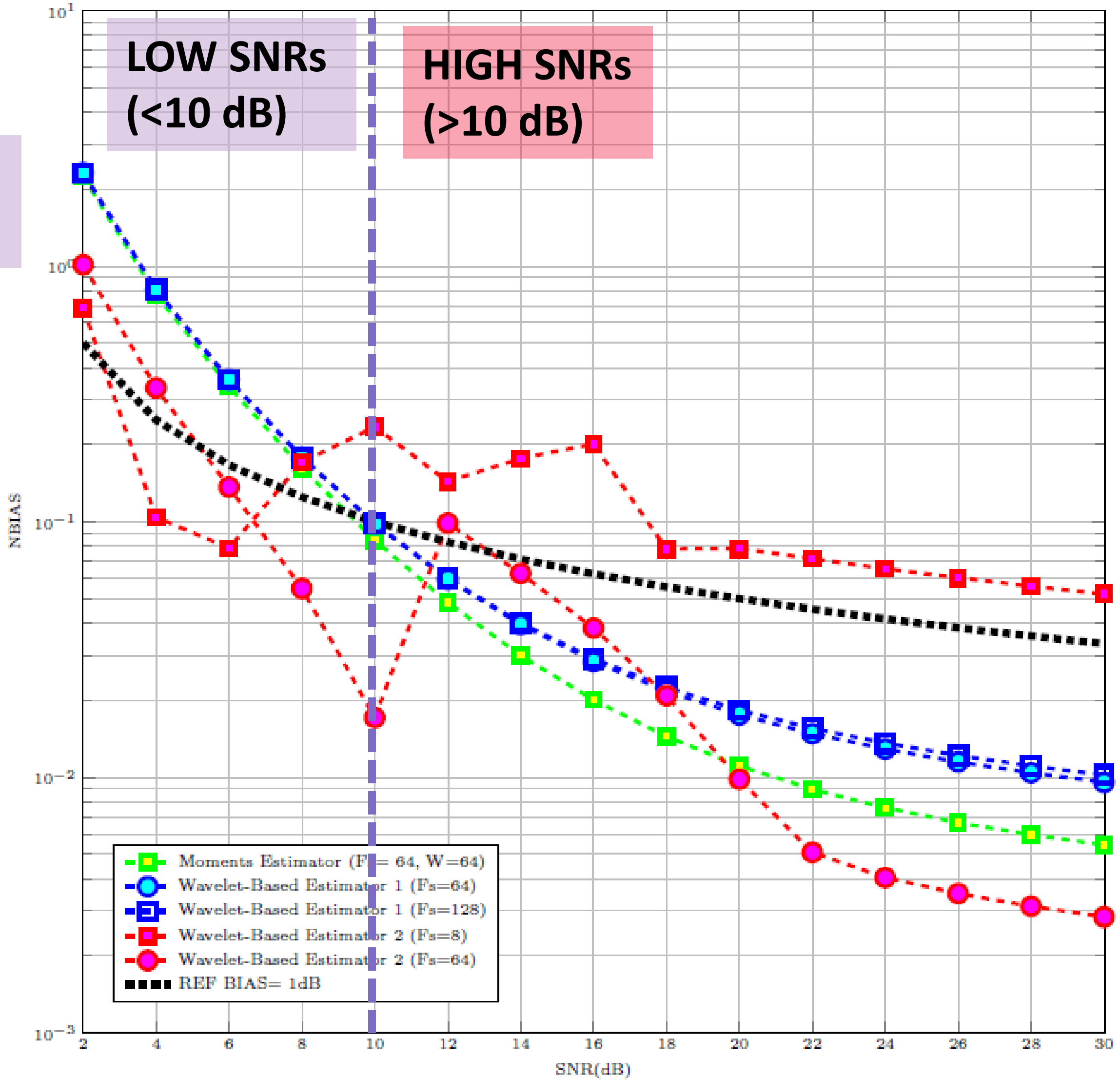
OVERALL RESULTS (NBIAS)

LOW SNRs
(<10 dB)

WORST PERFORMANCE
-WBE #1 Fs=64
-MOMENTS

BEST PERFORMANCE
WBE #2
-Fs=64
-Fs=8

WBE #2 DISPLAYS THE LOWEST BIAS, (EVEN FOR LOW Fs).



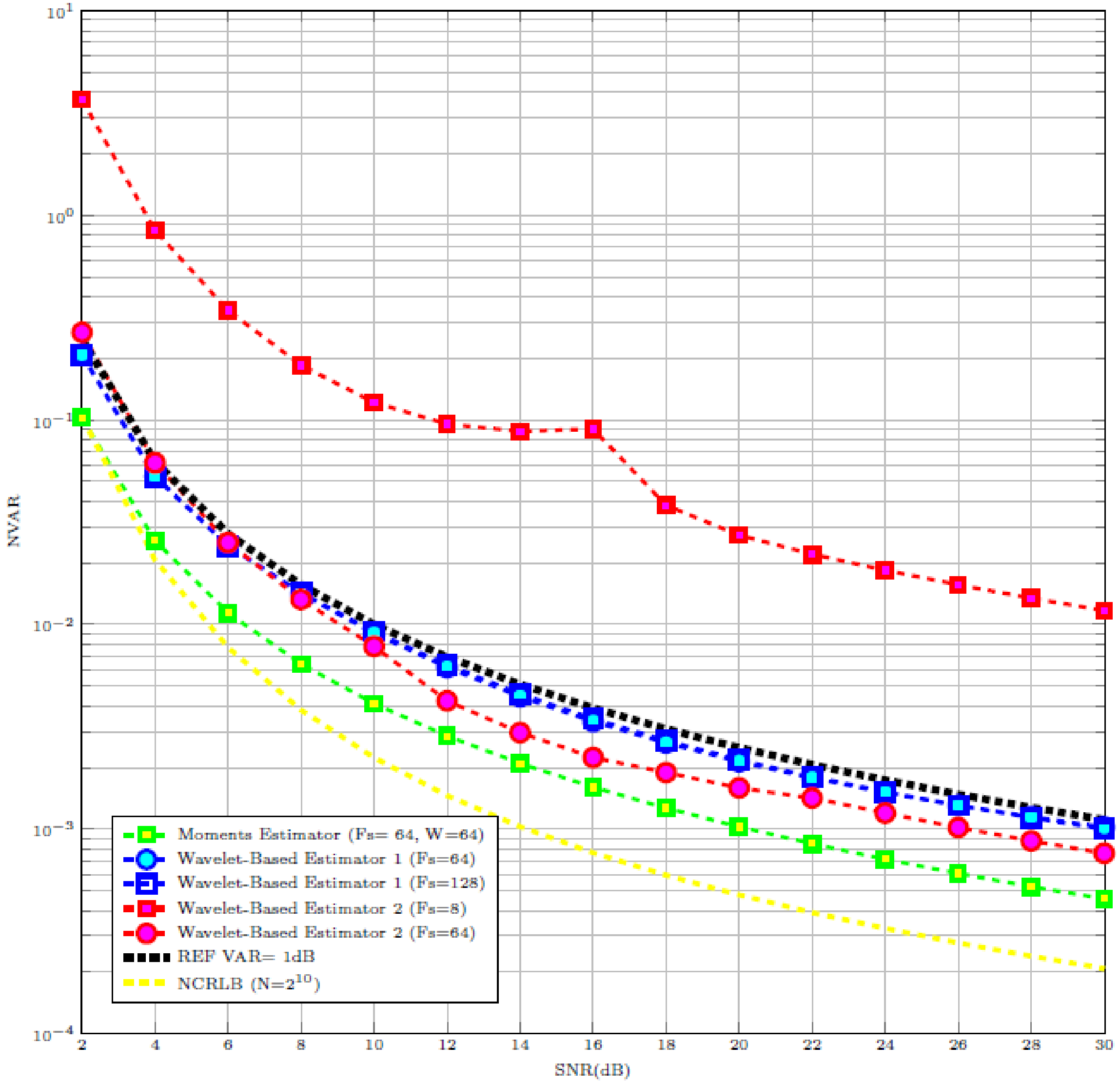
HIGH SNRs
(>10 dB)

WORST PERFORMANCE
-WBE #2 Fs=8

BEST PERFORMANCE
-WBE #2 Fs=64
-MOMENTS

For WBE #2 the performance improves as the Sampling Frequency increases.

OVERALL RESULTS (NVAR)



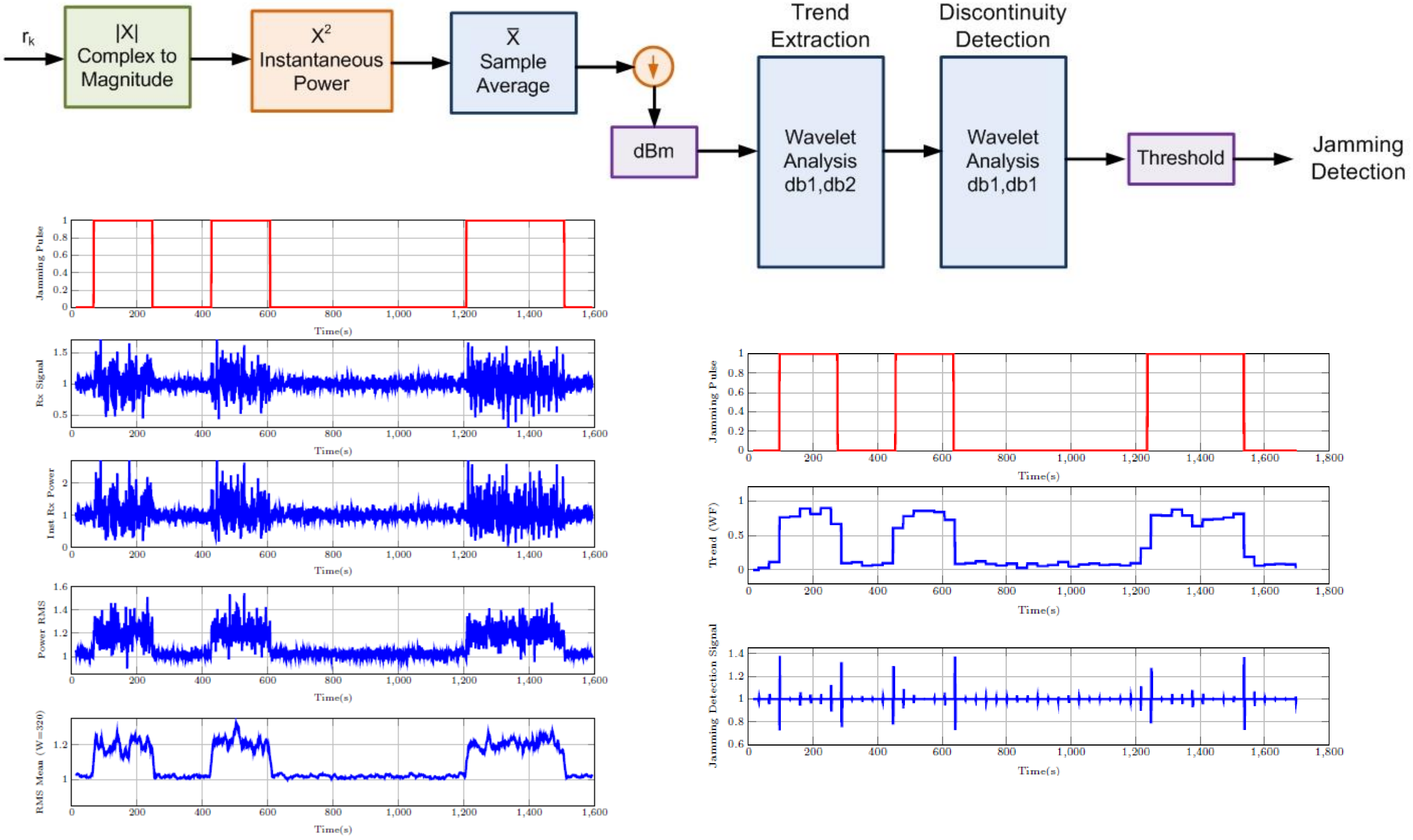
FOR ALL SNRs

BEST PERFORMANCE
OVERALL:
MOMENTS

BEST WBE:
WBE#2 Fs=64

WORST PERFORMANCE
OVERALL:
WBE#2 Fs=8

WAVELET-BASED JAMMING DETECTOR



r_k

|X| Complex to Magnitude

X^2 Instantaneous Power

$\bar{X}$ Sample Average

dBm

Trend Extraction

Wavelet Analysis db1,db2

Discontinuity Detection

Wavelet Analysis db1,db1

Threshold

Jamming Detection

CONCLUSIONS

1. Wavelet-Based estimators result in **lower-biased** estimates than those of the Moments Estimator (statistical approach); specifically for Low SNR cases.
2. The Wavelet-Based technique based on Self-Similarity detection yields better results than those of the Trend detection technique.
3. The statistical approach yields better results than those from the wavelet-based approach, in terms of variance.

Follow-on work: Development of a hybrid implementation that uses both wavelet-based and statistical estimators.

4. The jamming detector is able to predict the start and end times of pulsed noise jamming interference with an average error of less than 2% when the SNR decreases 20dB.

QUESTIONS?

THANK YOU!

PV Ramp Limiting with Adaptive Smoothing through a Battery Energy Storage System (BESS)

Richard Lam

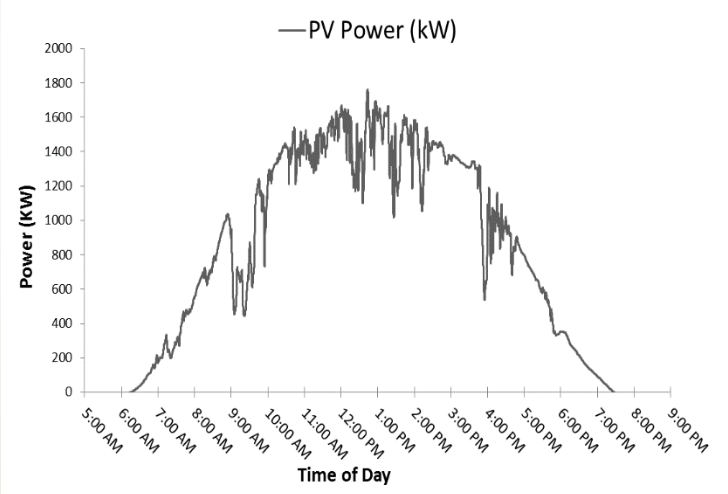
Henry Yeh

Overview

- Solar PV Issues
- BESS Diagram
- PV Smoothing
- Adaptive Smoothing
- Ramp Limiting
- Ramp Limiting & PV Smoothing
- Real World Cases and performance results

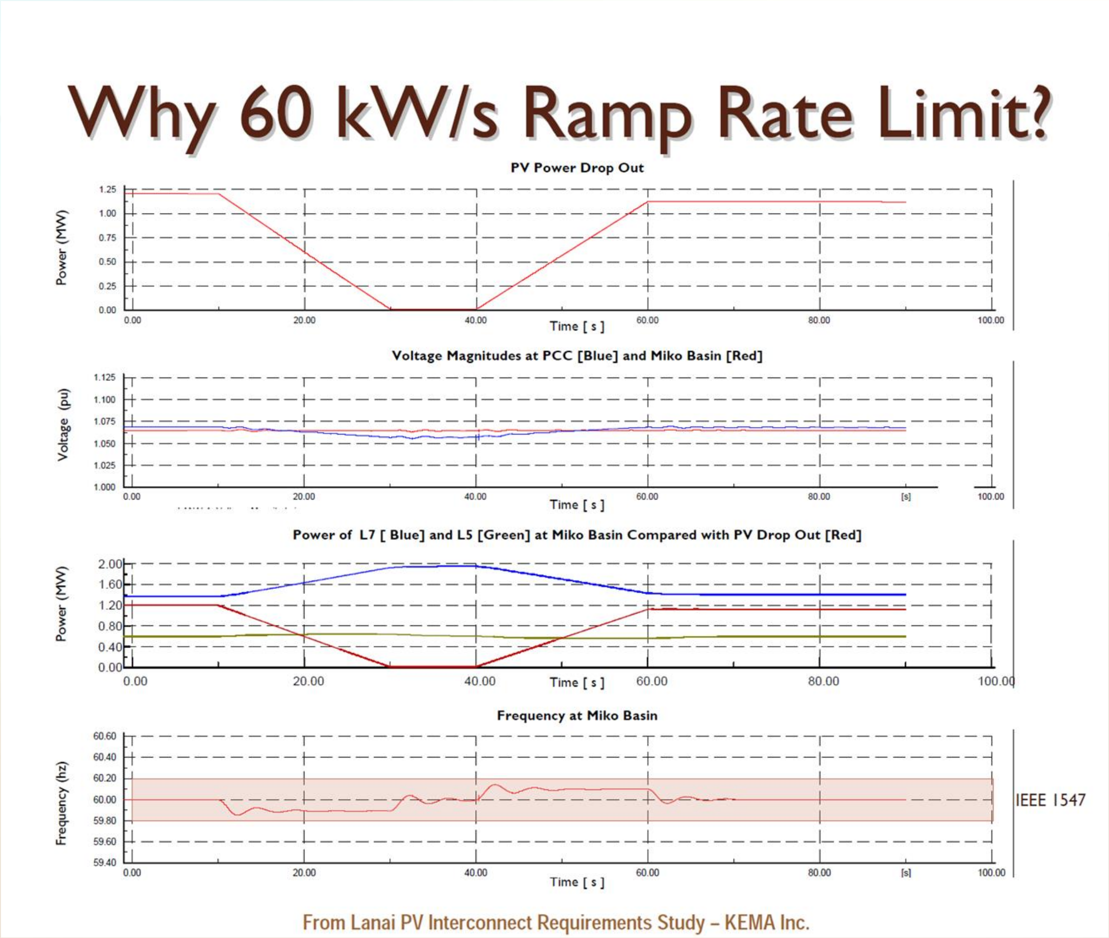
The Issue With Solar Variability

- Solar Photovoltaics (PV) is a variable generation
    - The sun doesn’t always shine!
- Power is dependent on Weather
    - Cloudy days cause issues
    - Solar irradiance can rise and fall rapidly
- Issues with high ramp rates
    - Can cause voltage rapid voltage fluctuations
    - System frequency may become unstable
- High PV penetration is a real issue
    - CA requires 33% renewables by 2020
    - 50% by 2030 may be possible
- Areas with High PV penetration would benefit most
    - Microgrids such as Lanai island in Hawaii
    - Not yet necessary on larger grids…



Issue With Solar Variability Contd.

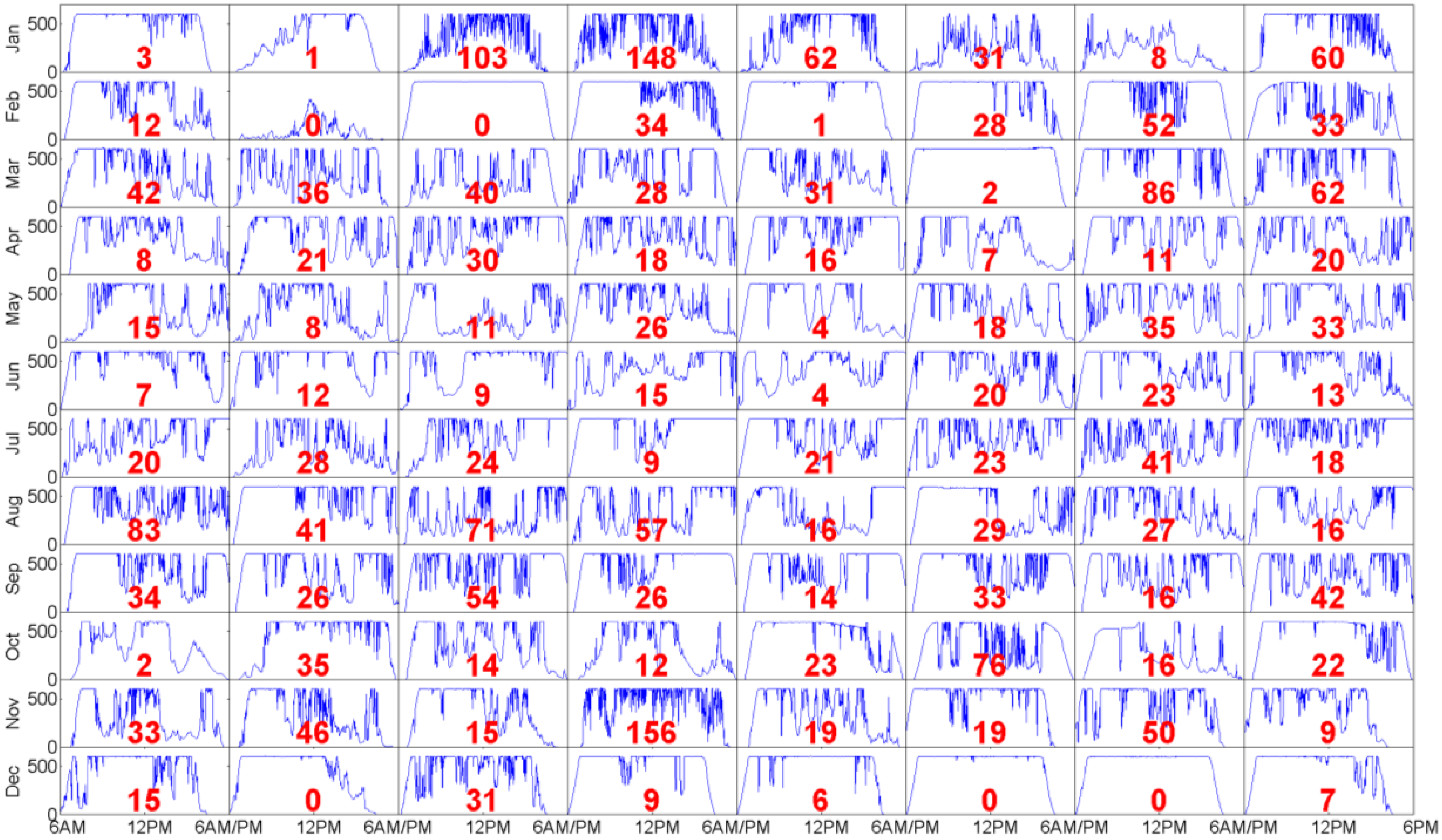
- $R_{RATEPV}(t) = \frac{P_{PV}(t)-P_{PV}(t-1)}{\Delta t}$
- KEMA study shows 3.6 MW/min was the limit for the Lanai 1.2 MW array
- 20% PV Penetration
- Higher ramp rates can cause inverters to trip off - IEEE 1547 Limit
- Grid frequency limits almost exceeded despite local diesel generators providing support
- 1.2 MW PV Array reduced to 600 kW output to limit risk.



Why 60 kW/s Ramp Rate Limit?

From Lanai PV Interconnect Requirements Study – KEMA Inc.

High Ramp Rates in Lanai La Ola System

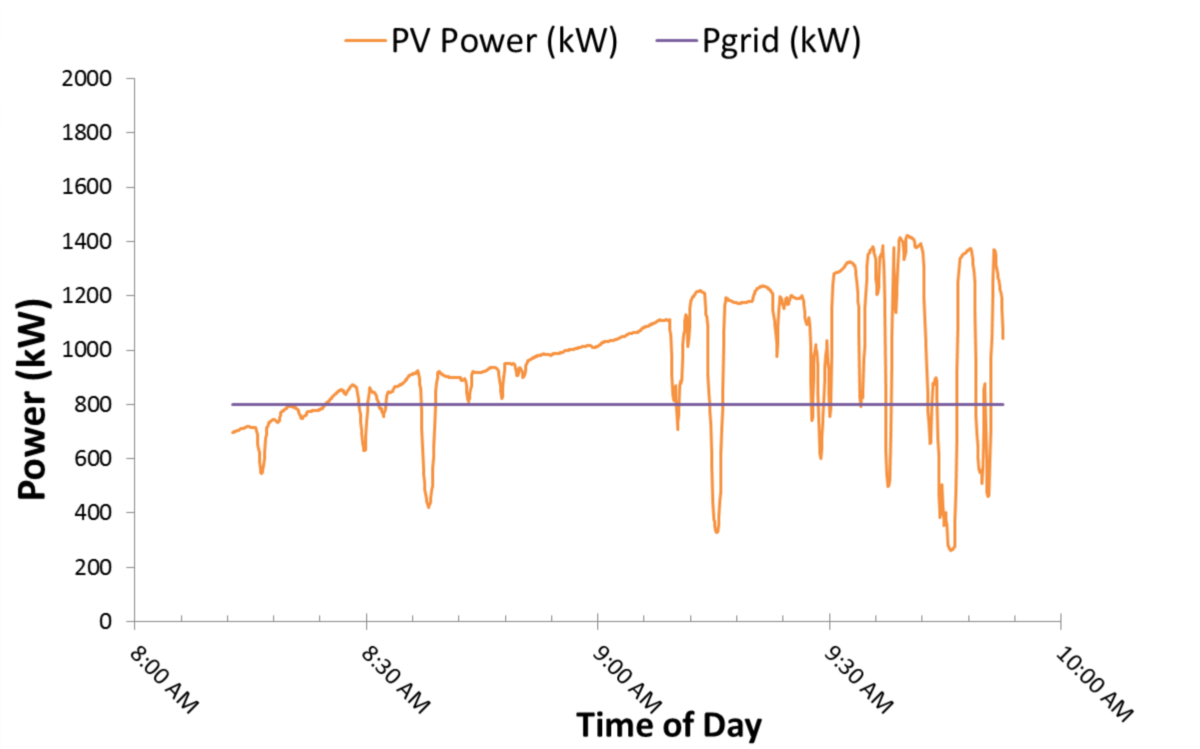


events exceeding 200 kW/min (600 kW PV)

Ref. SAND2011-8848

Battery Energy Storage System for Ramp Limiting

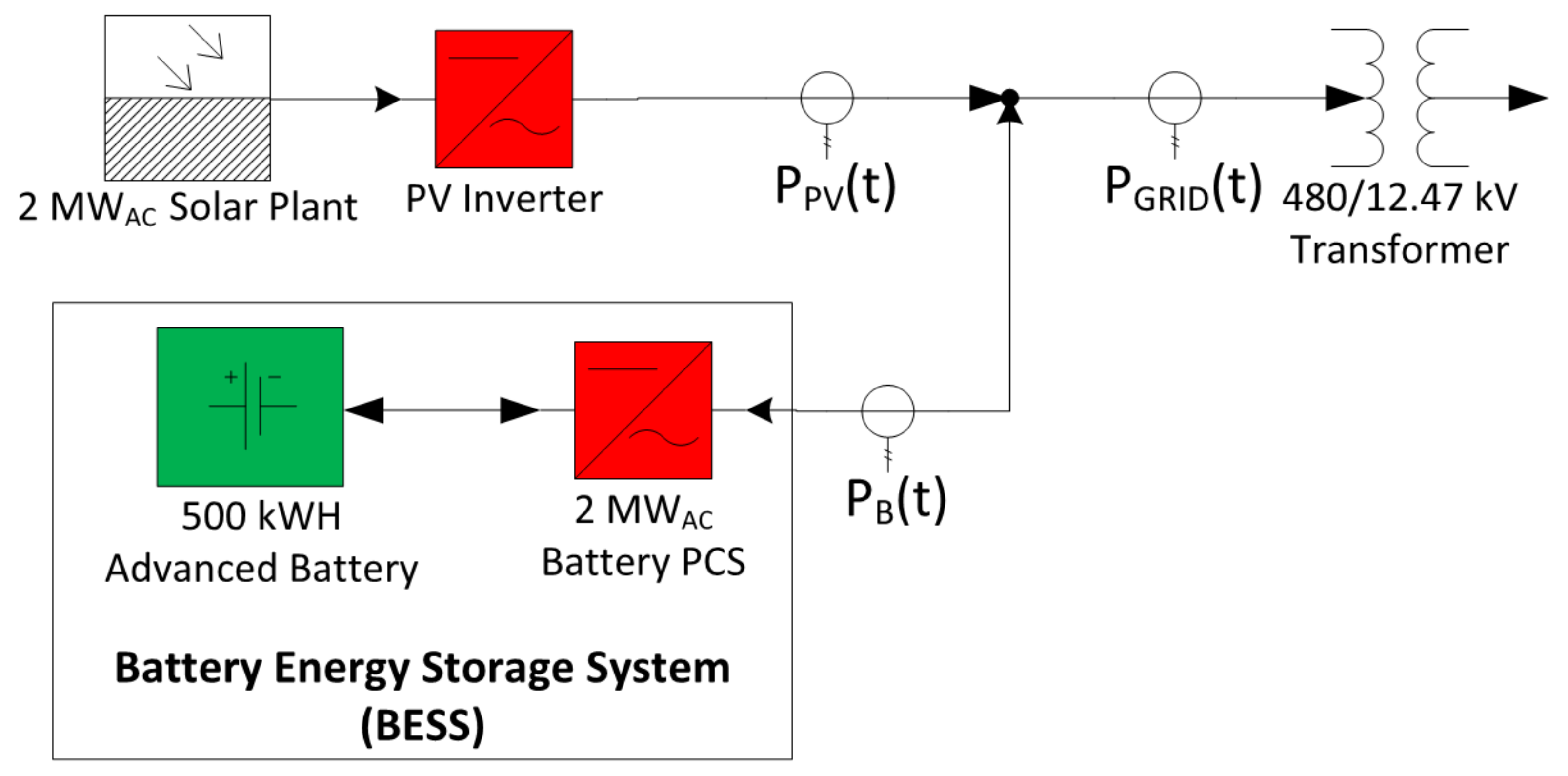
- Batteries can stabilize output from PV array
- Ideal Grid Output from PV array is flat
  - Given unlimited inverter and battery size
- Controls are needed to limit battery size and operation
  - High battery costs means size cannot be infinite
  - Power conversion losses during operation



Actual versus ideal output from PV array

BESS Connection Diagram

- AC coupled to reduce system complexity
- DC coupled would increase efficiency but requires integration
- Case Study on a 2 MW_{AC} PV system with 500 kWh_{AC} BESS
- 3 Power Points: $P_{PV}(t) + P_B(t) = P_{GRID}(t)$



PV Smoothing as Mitigation

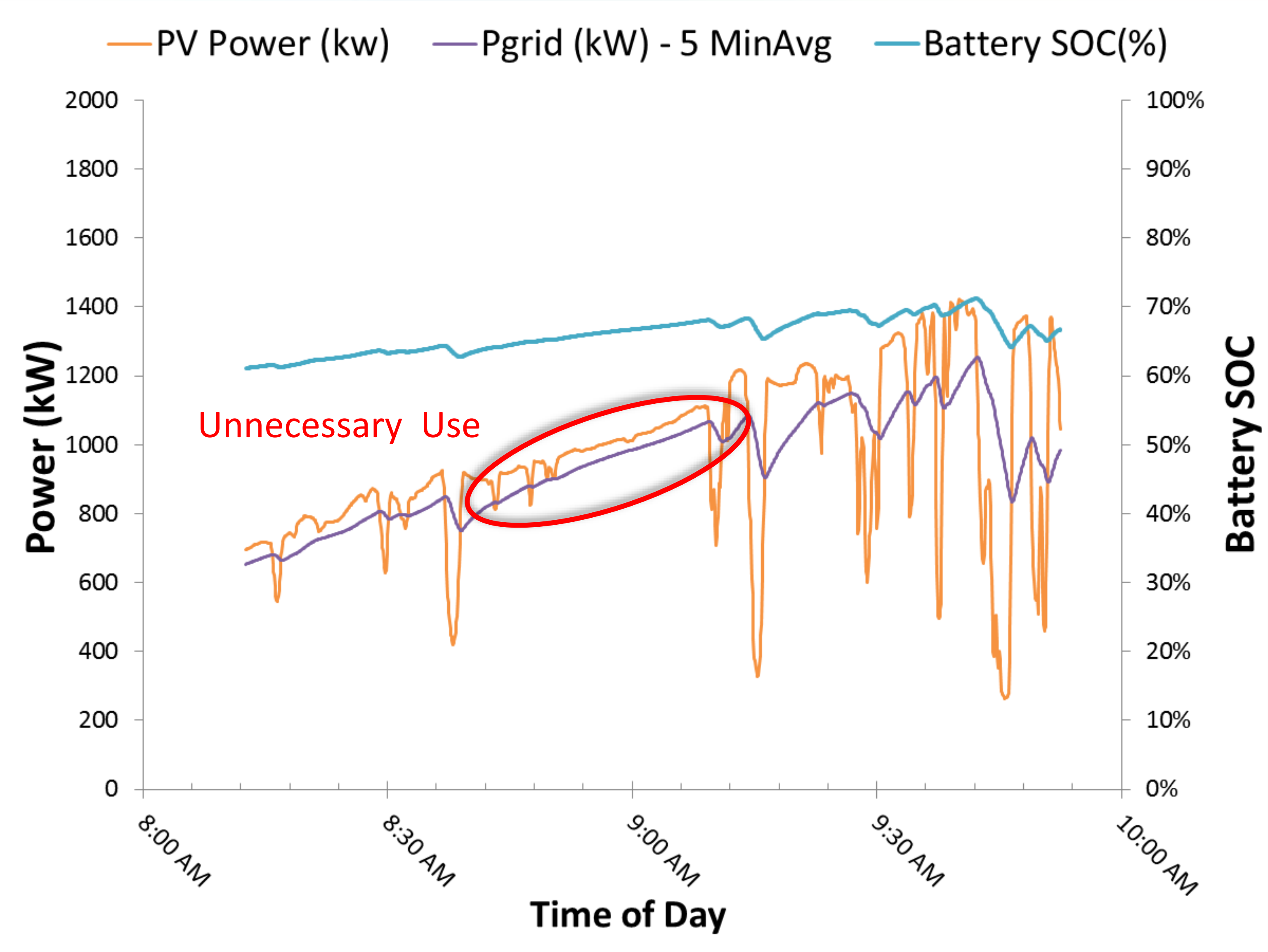
- A power filter for solar variability
- Time series filters introduce a time lag to smooth
  - Smoothing performance is based on lag
  - Too much lag can result in excessive battery use
  - More controls need to eliminate time lag
- Smoothing #1 – Moving Average
  - Smoothing performance based on window duration (k)
  - Large windows needed to improve performance but increases lag

$$s_t = \frac{1}{k}\sum_{n=0}^{k-1} x_{t-n} = \frac{x_t + x_{t-1} + x_{t-2} + \cdots + x_{t-k+1}}{k} = s_{t-1} + \frac{x_t - x_{t-k}}{k},$$

- Smoothing #2 – Exponential Filter
  - Smoothing performance based on smoothing factor α
  - α is a weighting factor for past vs. present
  - Better ramp limiting than moving average

$$s_t = \alpha \cdot x_{t-1} + (1 - \alpha) \cdot s_{t-1}$$

Time Lag with PV Smoothing

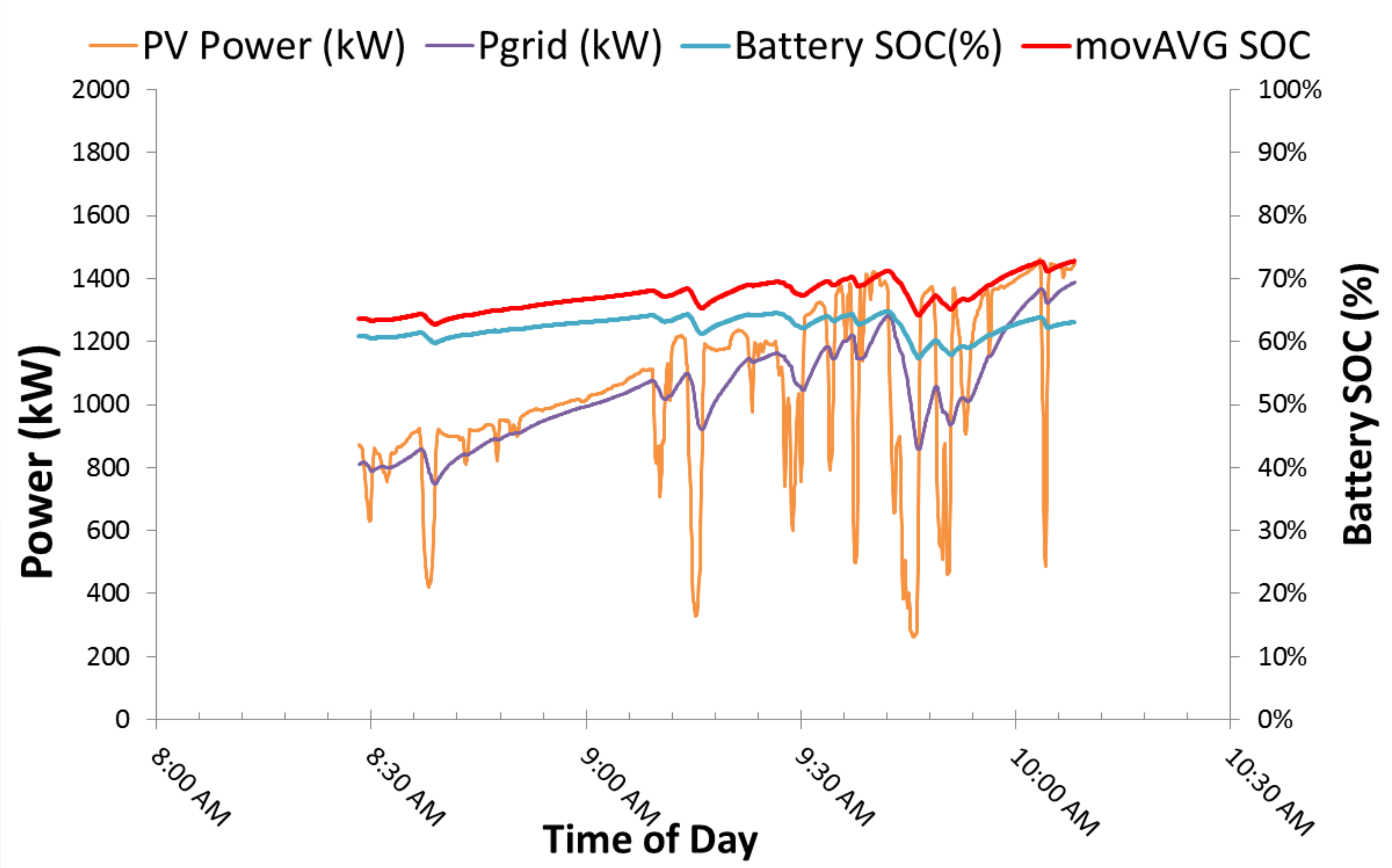


Adaptive Exponential PV Smoothing

- Adjust weighting factor based on PV ramp rates
  - Fixed weighting can cause excessive time lag
  - Better tracking reduces battery use
- $\alpha = \frac{\Delta t}{T_A}$ $, 0 < \ \alpha < 1$
  - where $T_A = \Delta t + |R_{RATEPV}(t) * 60 * 0.001\,|\ ,\ \forall\ T_A \geq 30$
- Grid output:
  - $P_{GC}(t) = \ \alpha * P_{PV}(t) + (1 - \alpha) * P_{GRID}(t-1)$
- Measuring Smoothing Performance:
  - Reduced ramp rates to grid $\mathrm{R_{RATEG}}$
  - Reduced battery energy throughput:
    - $B_{ET} = \ \sum_{t=1}^{T} |P_B(t)| * \Delta t$
    - $B_{CYCLES} = \frac{B_{ET}}{B_{SIZE}}$
  - Smoothing Factor:

$$S_{FACTOR} = \sqrt{\frac{\sum_{t=t_1}^{t_n} \left({R_{RATEPV}}^2 \right)}{t_n - \ t_1}}$$

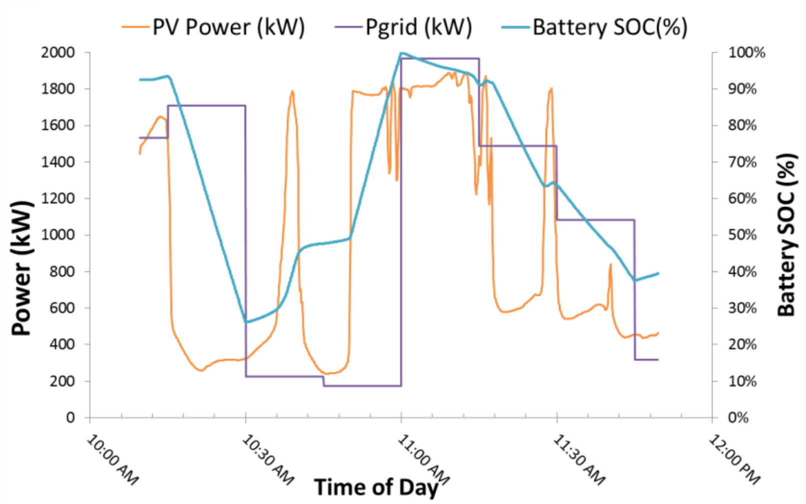
Adaptive Exponential Filter Smoothing

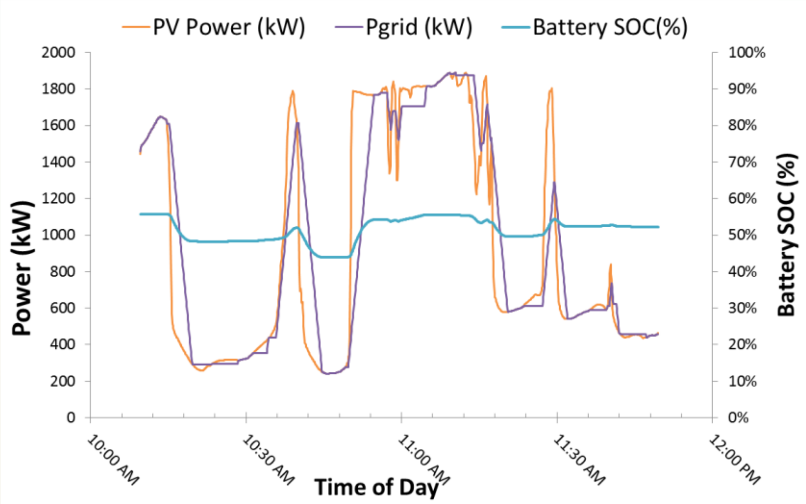


Ramp Limiting as Mitigation

- **Fixed Time Window Ramp Limit (FTWRL)**
  - Output based on average output from previous 15 minutes (or longer)
  - Excessive battery use but method has been used in other systems

- **Variable Time Window Ramp Limit (VTWRL)**
  - Limit ramp rates using PV ramp rate as a trigger
  - Programmable Ramp Limit
  - Only utilize BESS when PV ramp rates are high
  - Significant reduction on battery use B_{ET}





VTWRL - Control Inputs / Outputs

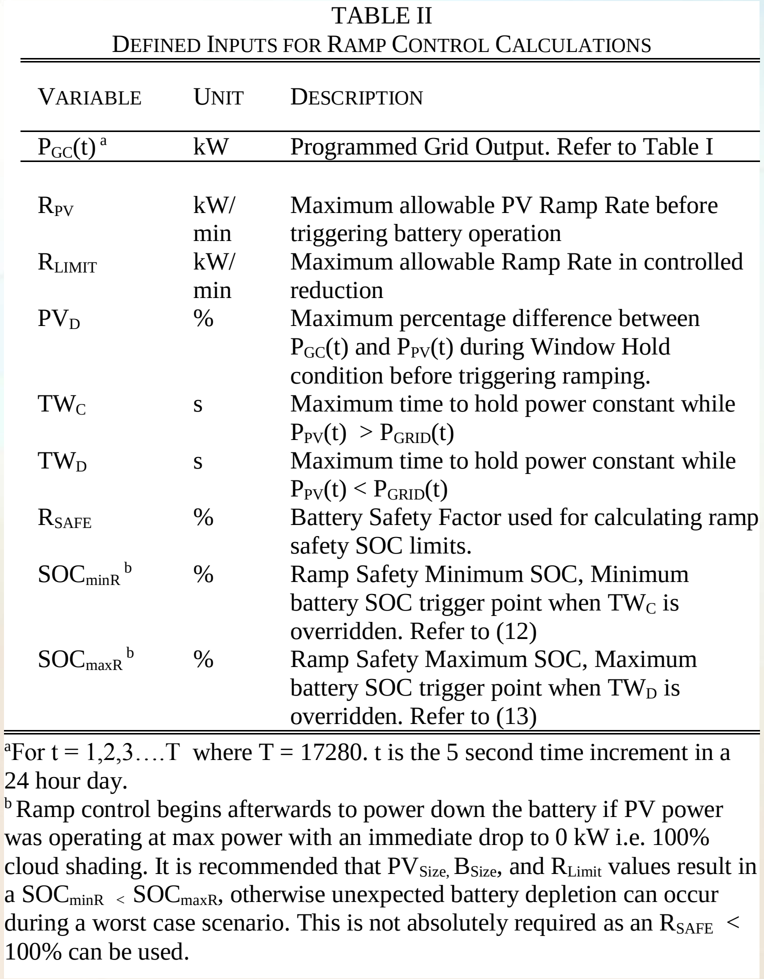


TABLE II
DEFINED INPUTS FOR RAMP CONTROL CALCULATIONS

VARIABLE	UNIT	DESCRIPTION
$P_{GC}(t)$ [a]	kW	Programmed Grid Output. Refer to Table I
R_{PV}	kW/min	Maximum allowable PV Ramp Rate before triggering battery operation
R_{LIMIT}	kW/min	Maximum allowable Ramp Rate in controlled reduction
PV_D	%	Maximum percentage difference between $P_{GC}(t)$ and $P_{PV}(t)$ during Window Hold condition before triggering ramping.
TW_C	s	Maximum time to hold power constant while $P_{PV}(t) > P_{GRID}(t)$
TW_D	s	Maximum time to hold power constant while $P_{PV}(t) < P_{GRID}(t)$
R_{SAFE}	%	Battery Safety Factor used for calculating ramp safety SOC limits.
SOC_{minR} [b]	%	Ramp Safety Minimum SOC, Minimum battery SOC trigger point when TW_C is overridden. Refer to (12)
SOC_{maxR} [b]	%	Ramp Safety Maximum SOC, Maximum battery SOC trigger point when TW_D is overridden. Refer to (13)

[a] For t = 1,2,3….T where T = 17280. t is the 5 second time increment in a 24 hour day.

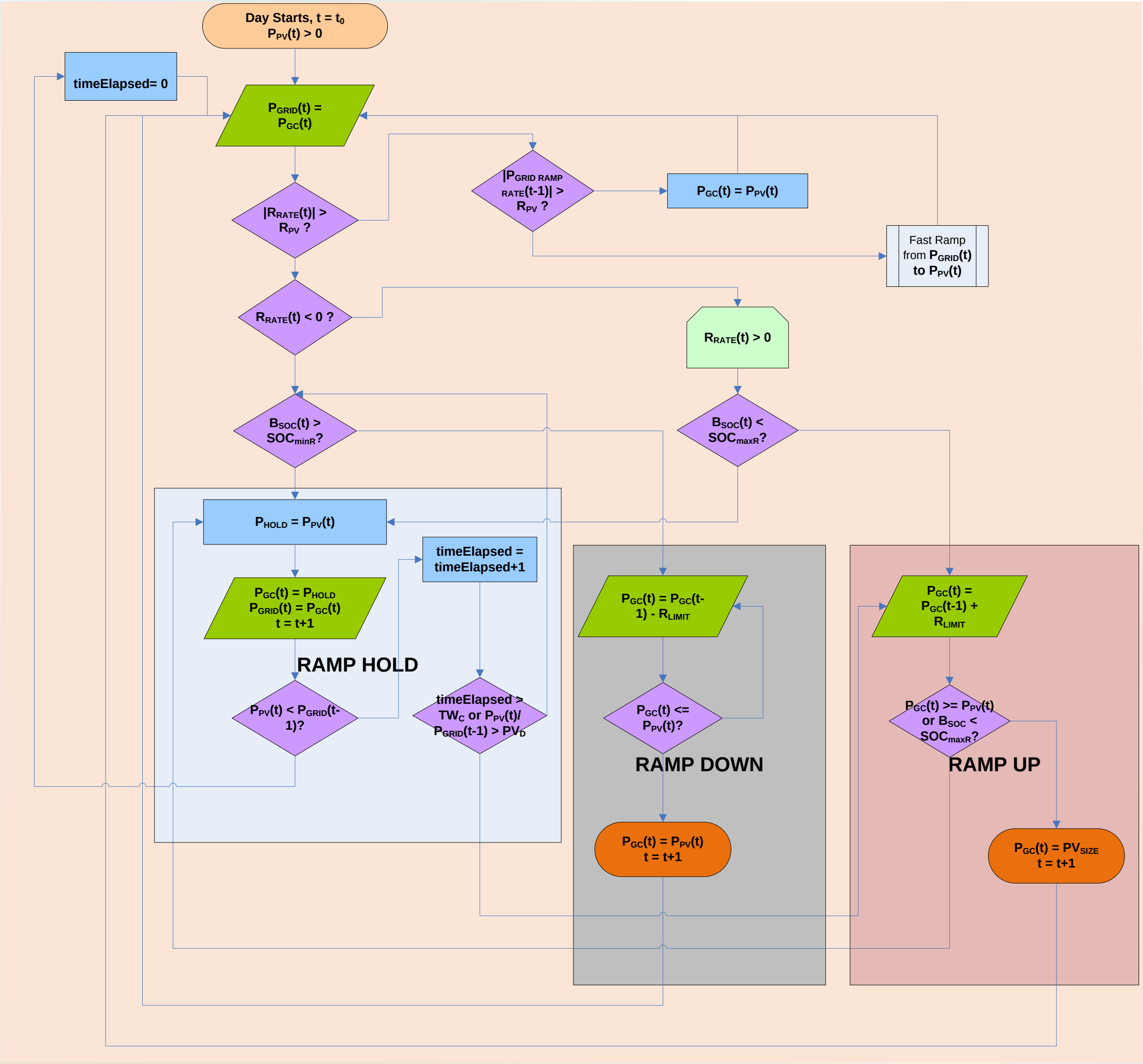
[b] Ramp control begins afterwards to power down the battery if PV power was operating at max power with an immediate drop to 0 kW i.e. 100% cloud shading. It is recommended that PV_{Size}, B_{Size}, and R_{Limit} values result in a $SOC_{minR} < SOC_{maxR}$, otherwise unexpected battery depletion can occur during a worst case scenario. This is not absolutely required as an $R_{SAFE} <$ 100% can be used.

- Control algorithm monitors R_{RATEPV} and compares against programmed limit R_{PV} to trigger BESS on/off.
- Window duration is triggered based on % difference from current P_{PV} and grid output P_{GC}.
- Immediate ramping when triggered
- Additional triggers used in case of unusually high solar variability!
- Based on array size & battery size
  - $SOC_{minR} = \dfrac{{PV_{Size}}^2}{B_{Size}*R_{Limit}} * R_{SAFE} * 100\%$
  - $SOC_{maxR} = 100\% - \dfrac{{PV_{Size}}^2}{B_{Size}*R_{Limit}}$

VTWRL - State Machine Diagram

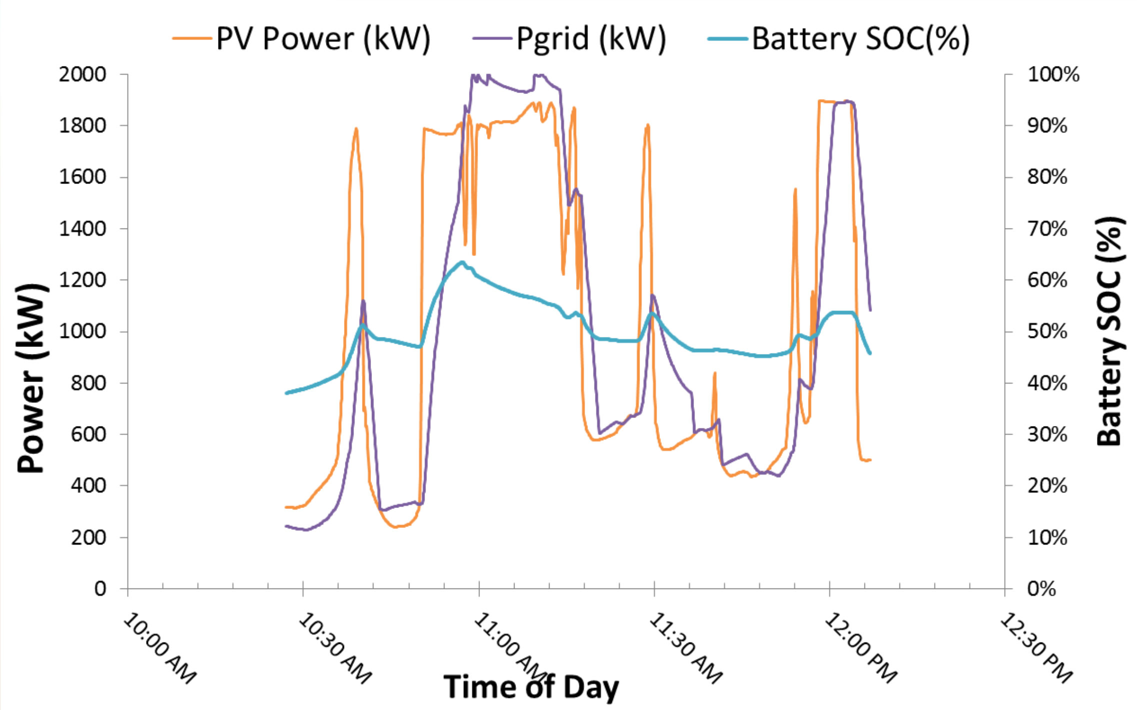
Simplified VTWRL Pseudo Code

```
If ( $R_{RATE}$ (t) > $R_{PV}$) Then
   RAMP HOLD(
      $P_{GRID}$(t+1) = $P_{GRID}$(t)
      If $B_{SOC}$(t) < $SOC_{minR}$ OR $B_{SOC}$(t) > $SOC_{maxR}$
            RAMP UP or RAMP DOWN to $P_{PV}$(t)
            $P_{GRID}$(t) = $P_{GRID}$(t) +  or - $R_{LIMIT}$
            Until $P_{GRID}$(t) = $P_{PV}$(t)
      ElseIf  ($P_{PV}$(t) / $P_{GRID}$(t) – 1) > $PV_{DEADBAND}$
            RAMP UP or RAMP DOWN to $P_{PV}$(t)
            $P_{GRID}$(t) = $P_{GRID}$(t) + or - $R_{LIMIT}$
            Until $P_{GRID}$(t) = $P_{PV}$(t)
      EndIf
      t = t + 1
   )While(t < $TW_C$ or t < $TW_D$)
Else
   BYPASS
   $P_{GRID}$(t) = $P_{PV}$(t)
End If
```



Best of Both Worlds
Ramp Limiting + PV Smoothing
VTWRL + ADEF

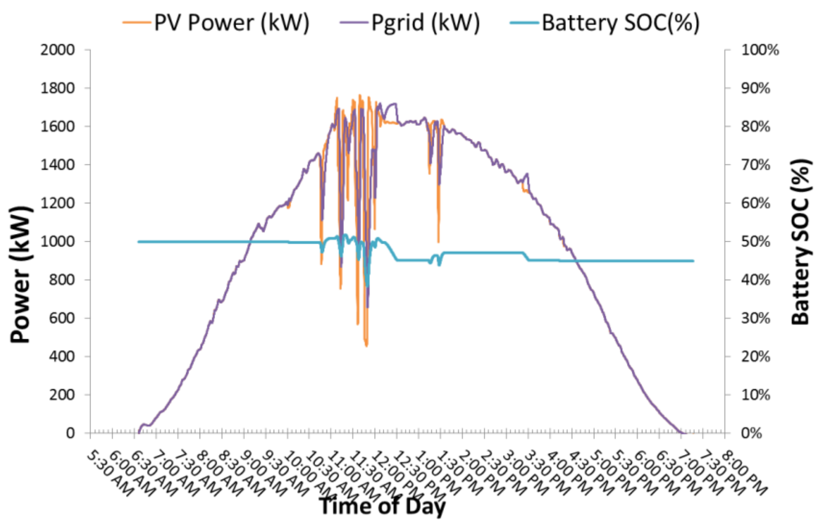
- VTWRL has low B_{ET} but poor smoothing
- Exponential filter has good smoothing but high B_{ET}
- Adaptive smoothing can be further improved by cascading the output or "doubling."
- Adaptive Double Exponential Filter (ADEF)
  - $P_{GC}(t) = \alpha^2 * P_{GCF}(t) + (1 - \alpha^2) * P_{GRID}(t-1)$

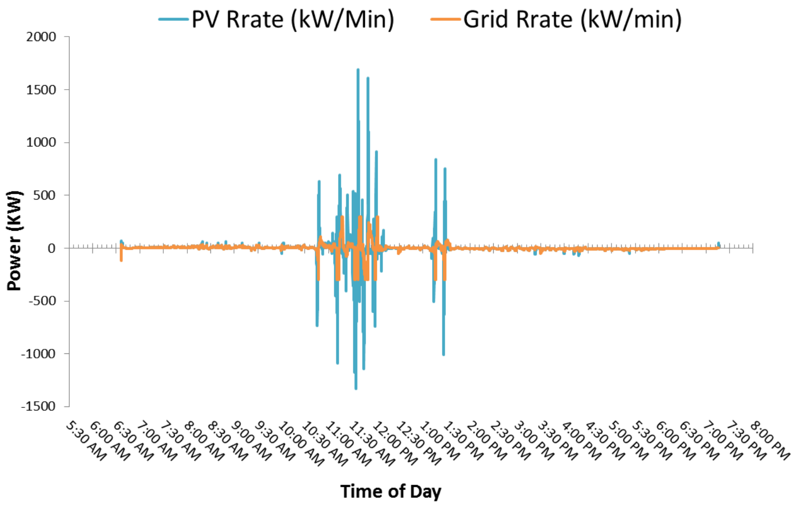


Algorithm Applied to Real World

- Data from a 2 MW_{AC} PV array in Fontana, CA was used to test algorithms.
- Distribution line had a high PV penetration.
  - 40-70% of loads was provided by the array

Performance - Light Cloud Case

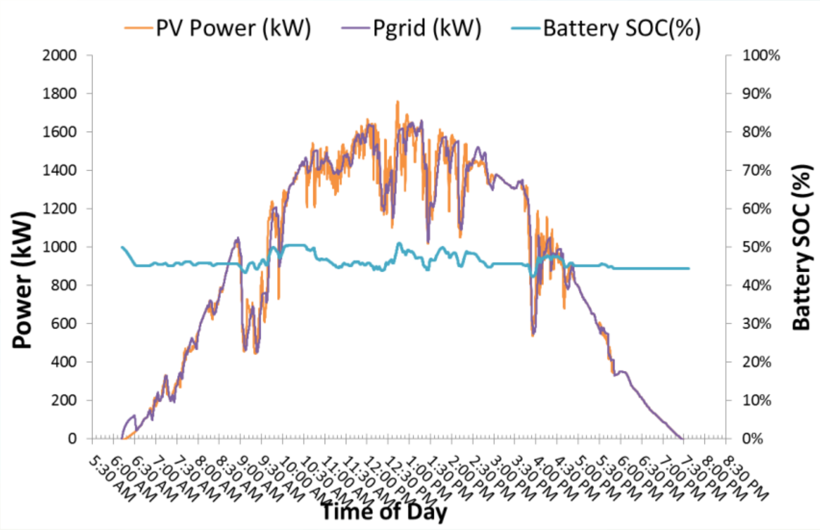


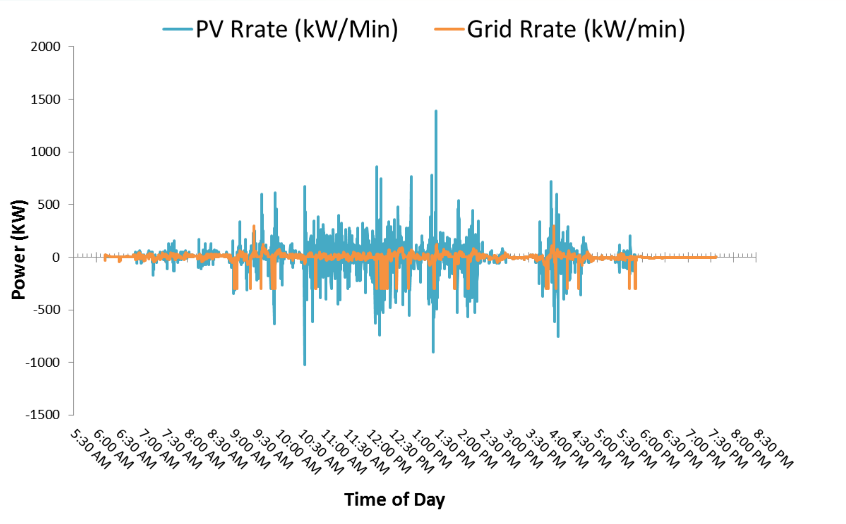


LIGHT

	Min R_{RATE}	Max R_{RATE}	DOD_{MAX}	SOC_{MIN}	SOC_{MAX}	S_{FACTOR}	B_{ET}
No Smoothing	-1332	1692	No Battery			44.6	N/A
Moving Average - 1 Min	-742	1016	3%	50%	53%	35.4	166
VTWRL / 10% PV DB	-250	250	9%	50%	59%	27.0	219
VTWRL / 20% PV DB	-250	250	8%	45%	54%	25.5	286
EF with Fixed 1 Min TC	-612	706	6%	50%	56%	27.0	255
EF with Fixed 5 Min TC	-203	155	28%	50%	78%	9.8	631
EF with Fixed 15 Min TC	-75	39	82%	10%	92%	4.2	1188
EF with Fixed 30 Min TC	-38	17	161%	50%	211%	2.8	1923
Adaptive DEF Filter	-243	210	23%	49%	72%	11.3	555
VTWRL + Fixed 1 Min TC	-250	250	8%	45%	53%	25.5	203
VTWRL + Fixed 5 Min TC	-250	250	14%	36%	50%	22.8	295
VTWRL + Fixed 15 Min TC	-250	250	18%	32%	50%	22.0	335
VTWRL + Fixed 30 Min TC	-250	250	21%	29%	50%	21.3	367
VTWRL + ADEF	-250	250	13%	37%	50%	22.9	294

Performance – Medium Cloud Case

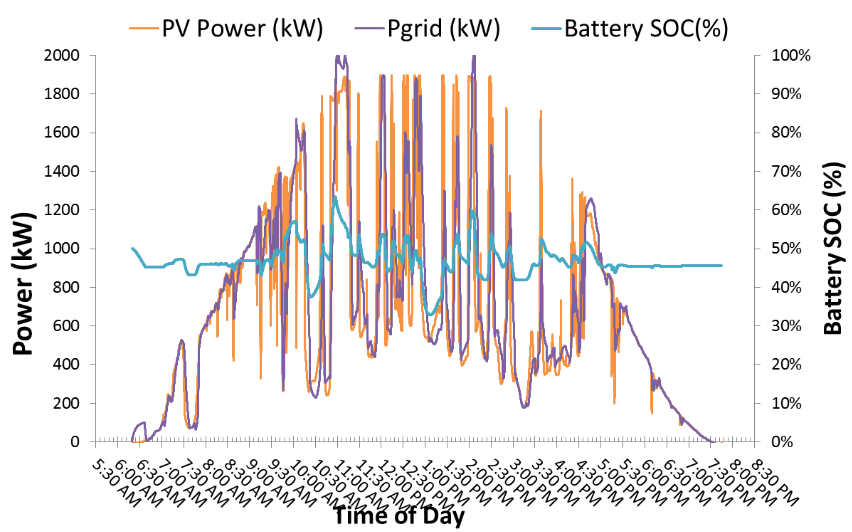


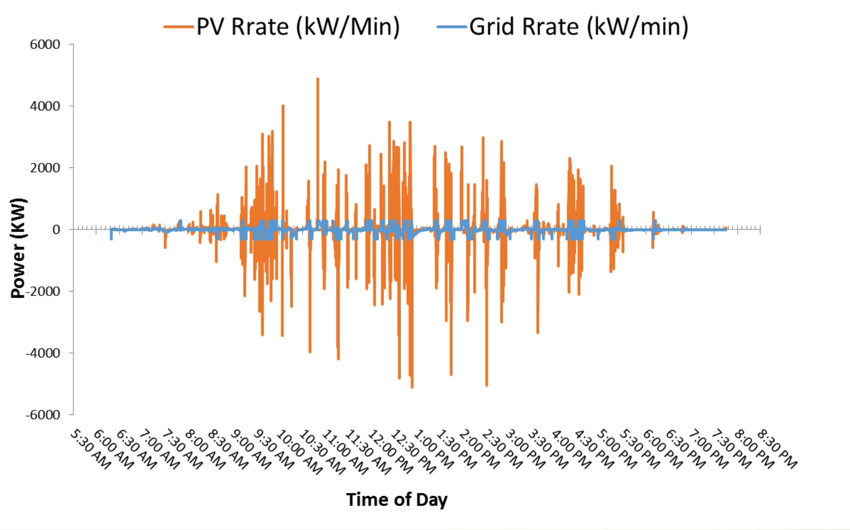


MEDIUM

	Min R_{RATE}	Max R_{RATE}	DOD_{MAX}	SOC_{MIN}	SOC_{MAX}	S_{FACTOR}	B_{ET}
No Smoothing	-1020	1392	No Battery			41.1	N/A
Moving Average - 1 Min	-377	433	3%	50%	53%	27.1	280
VTWRL / 10% PV DB	-250	250	9%	50%	59%	33.4	318
VTWRL / 20% PV DB	-250	250	8%	45%	54%	27.5	473
EF with Fixed 1 Min TC	-282	316	6%	50%	56%	19.9	374
EF with Fixed 5 Min TC	-87	86	28%	50%	78%	7.8	769
EF with Fixed 15 Min TC	-41	35	82%	10%	92%	3.8	1269
EF with Fixed 30 Min TC	-23	19	161%	50%	211%	2.6	1891
Adaptive DEF Filter	-96	96	23%	49%	72%	8.9	679
VTWRL + Fixed 1 Min TC	-250	250	8%	45%	53%	29.2	264
VTWRL + Fixed 5 Min TC	-250	250	14%	36%	50%	27.7	396
VTWRL + Fixed 15 Min TC	-250	250	18%	32%	50%	29.8	414
VTWRL + Fixed 30 Min TC	-250	250	21%	29%	50%	30.6	419
VTWRL + ADEF	-250	250	13%	37%	50%	27.6	398

Performance – Heavy Cloud Case





HEAVY

	Min R_{RATE}	Max R_{RATE}	DOD_{MAX}	SOC_{MIN}	SOC_{MAX}	S_{FACTOR}	B_{ET}
No Smoothing	-5112	4884	No Battery			188.0	N/A
Moving Average - 1 Min	-1134	1377	3%	50%	53%	96.9	790
VTWRL / 10% PV DB	-250	250	9%	50%	59%	60.1	1190
VTWRL / 20% PV DB	-250	250	8%	45%	54%	57.9	1317
EF with Fixed 1 Min TC	-845	1104	6%	50%	56%	70.7	1092
EF with Fixed 5 Min TC	-188	261	28%	50%	78%	25.5	2380
EF with Fixed 15 Min TC	-58	80	82%	10%	92%	10.5	3369
EF with Fixed 30 Min TC	-28	40	161%	50%	211%	5.7	4012
Adaptive DEF Filter	-252	340	23%	49%	72%	28.3	2172
VTWRL + Fixed 1 Min TC	-250	250	8%	45%	53%	55.0	1211
VTWRL + Fixed 5 Min TC	-250	250	14%	36%	50%	49.8	1503
VTWRL + Fixed 15 Min TC	-250	250	18%	32%	50%	48.5	1746
VTWRL + Fixed 30 Min TC	-250	250	21%	29%	50%	48.3	1899
VTWRL + ADEF	-250	250	13%	37%	50%	49.9	1619

Conclusion

- Ramp rates curtailed down to 250 kW/min in all cases.
  - Up to 4x better than a 1 minute moving average
- VTWRL+ADEF allows a reduced battery size compared to existing commercial solutions.
- Smoothing is comparable or better than moving averages with
- Algorithms and equations provide a baseline for further refinement

Questions?

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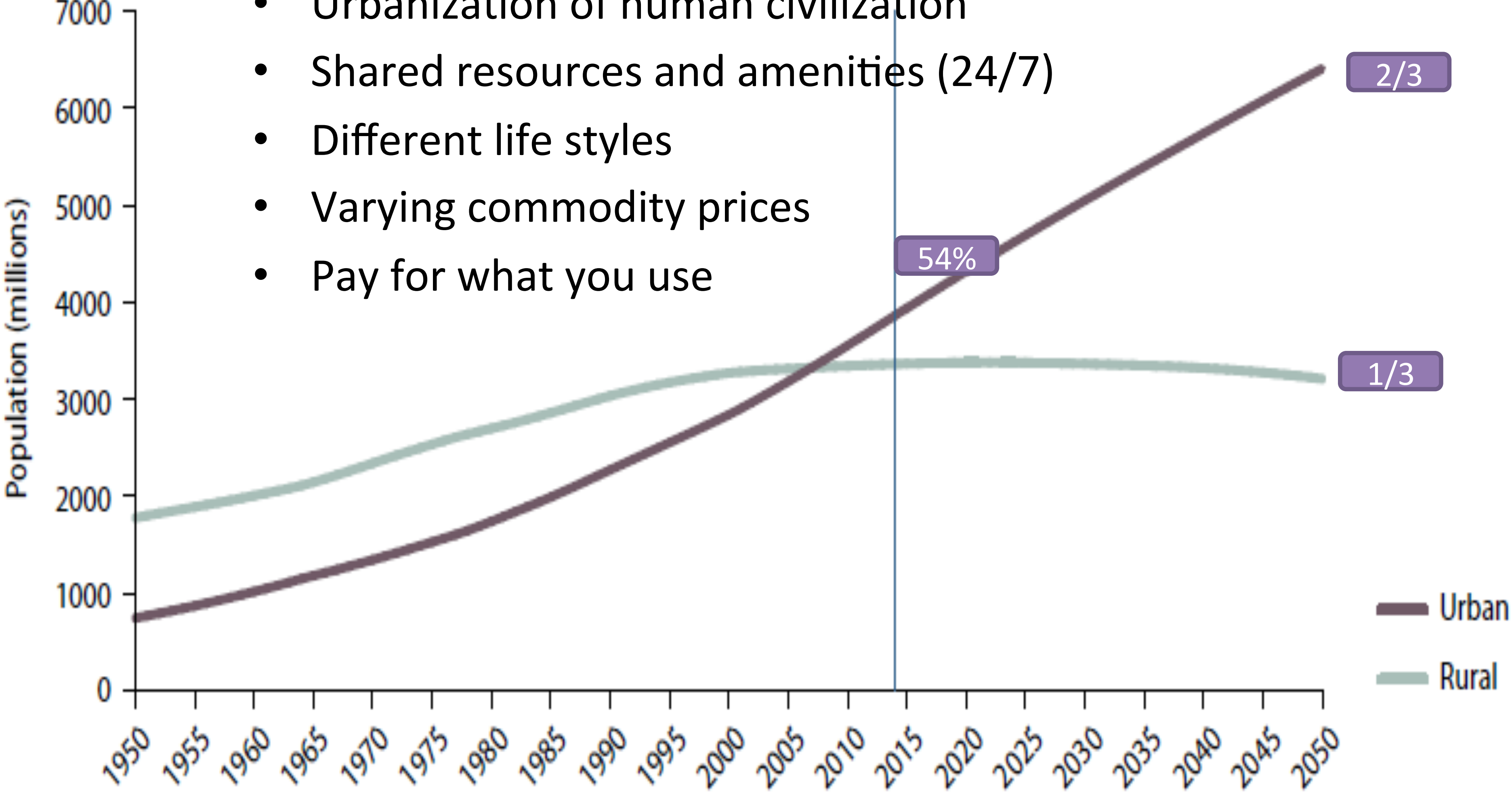
Applicable apportion of commodity bills eased by wearable devices

Vijaya Kumar Tukka
vijay.t@samsung.com

Apoorv Kansal
apoorv.kansal@samsung.com

Motivation

- Urbanization of human civilization
- Shared resources and amenities (24/7)
- Different life styles
- Varying commodity prices
- Pay for what you use



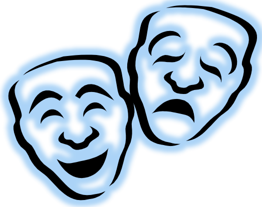
Source : United Nations,

Trends in Urbanization: http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf

Background

- Housing societies in cities (Communities)
- Many shared amenities

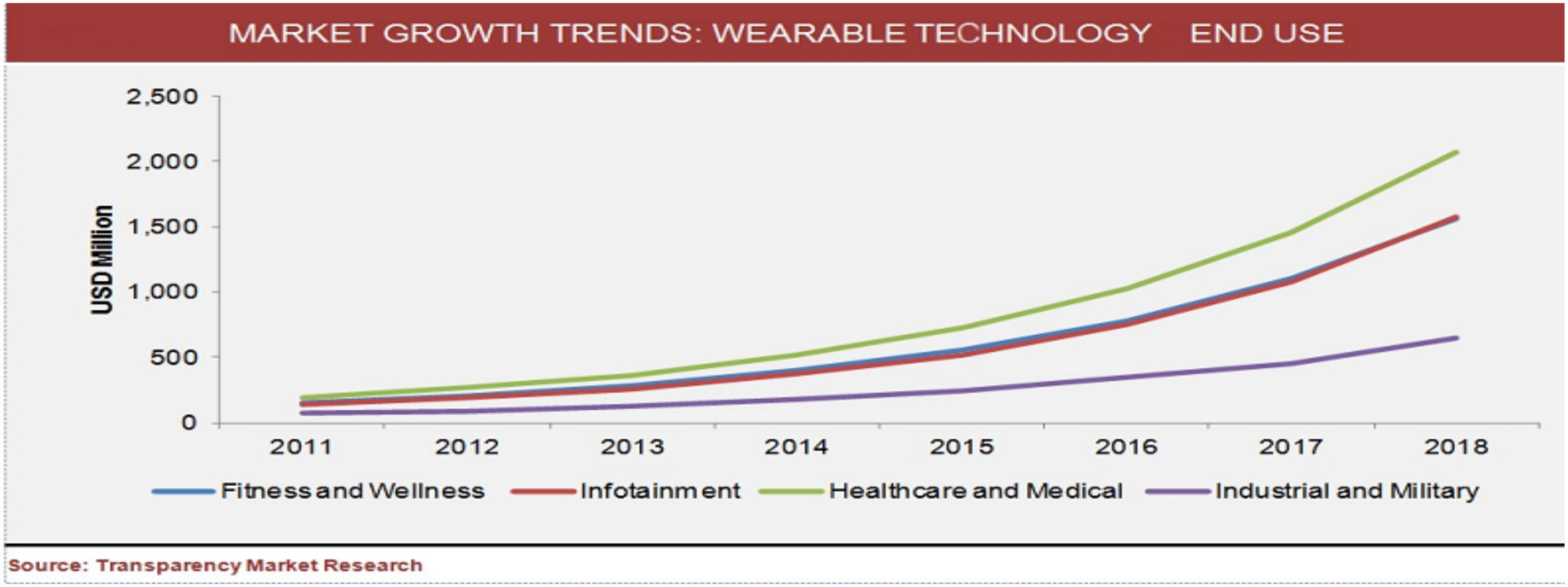
  Fitness Center, Swimming Pool, Garden, Playground, Convention Hall, Roof Top, Parking, Lobby, Lift, etc.
- Single meter to read consumption
- High common area energy consumption ~43%
- Variable electricity pricing (ToU, RTP)
- Equally distributed among all residents… **Not fair!!!**



Overview

This paper discusses :

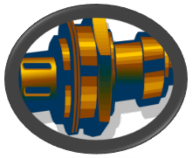
- Multiple methods
- Importance of wearables to log user's presence



Source: Transparency Market Research

Any solutions?

- Occupancy sensors to control light



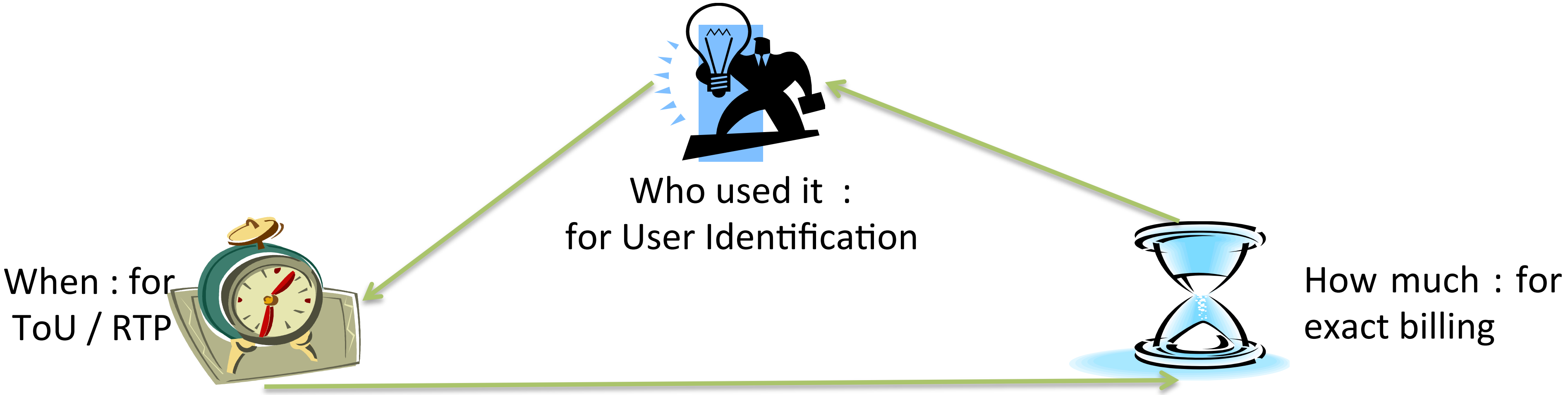
- Use of efficient lighting devices

- Using different sources of energy
  Solar Energy…? Initial setup cost is high

- Change Human Tendency : Difficult

Extend Home automation solutions for shared amenities

Gap



Who used it :
for User Identification

When : for
ToU / RTP

How much : for
exact billing

Proportionate distribution based on usage duration (Method 1)

- Billing amount ∝ Usage Duration
- Does not consider variable pricing
- Let U_1, U_2, U_3 ... U_N be the N users
- Total expense $P = P_{Used} + P_{Maint}$
- Let T_1, T_2, T_3 … T_N be the usage duration for N users respectively
- Total time of usage $T = T_1 + T_2 + T_3 ... + T_N$

Power consumed by a User U_i

$$P_{Ui} = [P_{Used} * (T_i / T)] + [P_{Maint} / N]$$

Billing amount for User U_i

$$X_{Ui} = P_{Ui} * X_{Unit}$$

X_{Unit} is the cost of per unit (kWh) of electricity

Time complexity ??

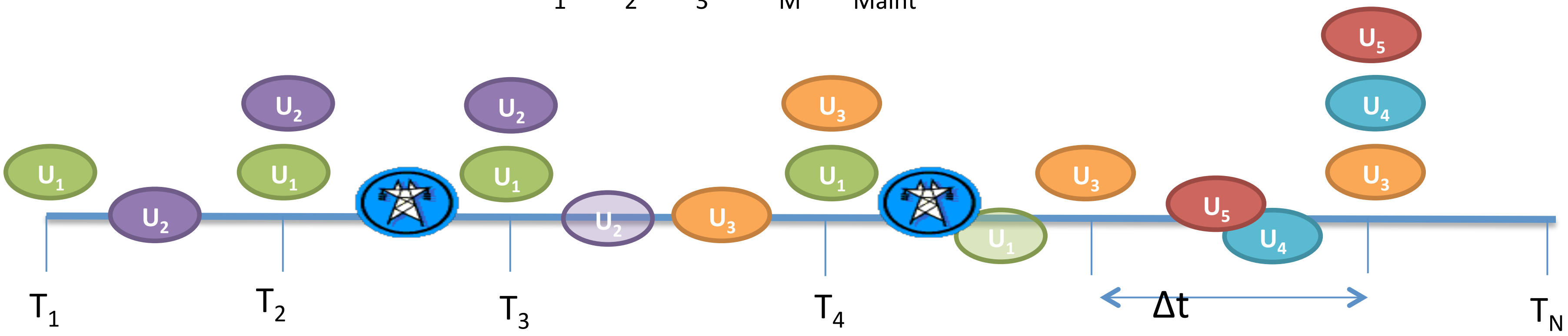
- **Linear O(n).**
- 2*M data points (M entry and M exits) for N users.
- One pass : to get the duration and accumulate it to the user Ids.
- Second pass : to calculate the amount of bill. So the time complexity of this method is O(M + N).

Time based Sampling
(Method 2)

- Billing amount **depends on** (Usage Duration, Time of use)
- Considers variable pricing
- Sampling with an interval Δt
- Let $U_1, U_2, U_3 \ldots U_N$ be the N users
- Let $T_1, T_2, T_3 \ldots T_M$ be the Sampling capture timestamps
- P_{Maint} : Power consumed in the maintenance and corresponding cost is X_{Maint}

Sampling Data at every sampling timestamp:

- $V_1, V_2, V_3 \ldots V_M$: list of users
- $P_{T1}, P_{T2}, P_{T3}, P_{TM}$: Power consumed since last sampling timestamp and corresponding pricing is $X_{T1}, X_{T2}, \ldots X_{TM}$.
- $C_1, C_2, C_3 \ldots C_M$: count of users
- Total Power consumed is $P = P_1 + P_2 + P_3 \ldots + P_M + P_{Maint}$



Power consumed by user U_1 is:

$$P_{Ui} = (\sum j=1 \uparrow M \text{▒} Vj.find(Ui) * PTj \,/\, Cj) + P_{Maint} / N$$

W $$V_j.find(U_i) = \begin{cases} 0 & \text{if } U_i \text{ is not present in } V_j \\ 1 & \text{if } U_i \text{ is present in } V_j \end{cases}$$

Billing amount for User U_i

$$X_{Ui} = (\sum j=1 \uparrow M \text{▒} Vj.find(Ui) * XTj * PTj \,/\, Cj) + X_{Maint} * P_{Maint} / N$$

Time complexity ??

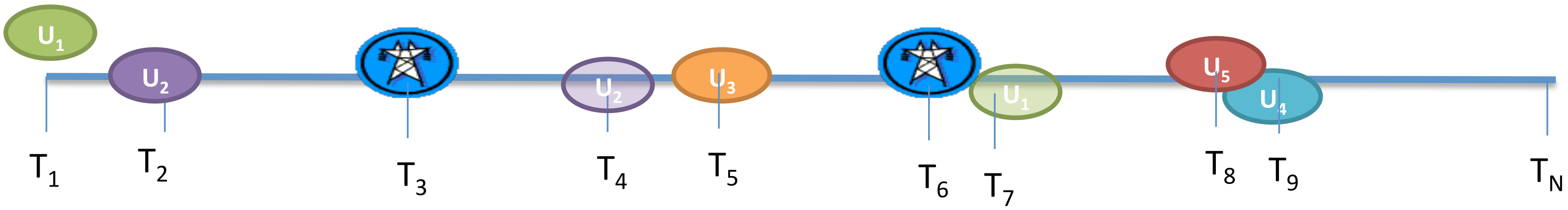
- Time complexity ∝ number of sampling instances
- O(M * N)
- M sampling instances (at an interval of **Δt**) for N users.
- For each sampling instance the cost for users present in user vector V will be updated.

Note :

Δt → 0, M will be large : So we can assume M >> N. The time complexity will lead to O(c * M) → O(M) → O(n).

Event based sampling
(Method 3)

- Billing amount ∝ (Usage Duration, Time of use)
- Considers variable pricing
- Sampling at change event (Enter, Exit, Price Change)
- Let U_1, U_2, U_3 … U_N be the N users
- Let $\{T_{U11}, T_{U12}\}$, $\{T_{U21}, T_{U22}\}$…, $\{T_{UN1}, T_{UN2}\}$ be the entry / exit times of N users ………**(1)**
- T_{E1}, T_{E2}, …T_{EK} : timestamps for electricity pricing changes ………**(2)**
- T_1, T_2… T_M, : Sampling timestamps in increasing order of time ………**(3)**
- C_{T1}, C_{T2} … C_{TM} : count of users
- P_{T1}, P_{T2}, P_{T3}, P_{TM} : Power consumed since last sampling timestamp and corresponding pricing is X_{T1}, X_{T2}, … X_{TM}.



Power consumed by user U_i can be given like,

$$P_{Uj} = (\sum i = Tuj1 \uparrow Tuj2 \text{▒} PTi\ / CTi\ \ ) + P_{Maint} / N$$

Where summation series index i includes all the timestamps in series (3) lying between the user U_i's entry and exit i.e. from T_{Ui1} to T_{Ui2}.

Billing amount for User U_i

$$X_{Uj} = (\sum i = Tuj1 \uparrow Tuj2 \text{▒} PTi * XTi / CTi\ \ ) + (P_{Maint} * X_{Maint} / N)$$

Time Complexity ??

- Time complexity ∝ number of change events (Entry, Exit, Pricing Change)
- O(M * N)
- There are M sampling instances for N users.
- For each sampling instance the cost for all the present users will be updated.

Note :

On a monthly basis M ≈ 60N (assuming one entry exit of a user per day).

If one user does multiple entries per day the M >> N. In this case the time complexity will be O(c * M) ➔ O(M) ➔ O(n).

Analysis and Results

- Simulated data
- Defined data for categories

Analysis and Results

Simulated data

Emulated typical habits of the user and generated raw data.

- Varying number of users in consecutive fixed time-intervals
- Varying resource usage duration (15 ~ 120 min)
- Some (~10%) users will enter / exit at the same timestamp.
- Usage duration will vary for the users entering at the same timestamp.
- Electricity price change timings are independent and decided by the utility company

User ID	Entry Time (HH:MM:SS)	Exit Time (HH:MM:SS)	Duration spent (Minutes)	Energy pricing Slot (Hour-Hour)
1	5:30:52	6:53:52	83	0-6, 6-7
2	5:32:40	7:08:40	96	0-6, 6-7, 7-8
3	5:33:07	5:51:07	18	0-6
4	5:33:07	6:32:07	59	0-6, 6-7
5	5:36:39	6:01:39	25	0-6, 6-7
…	…	…	…	…
4500	11:05:44	12:43:44	98	11-12,12-13

TABLE I : GENERATED RAW DATA FOR ENTRY/EXIT BY FABRICATOR

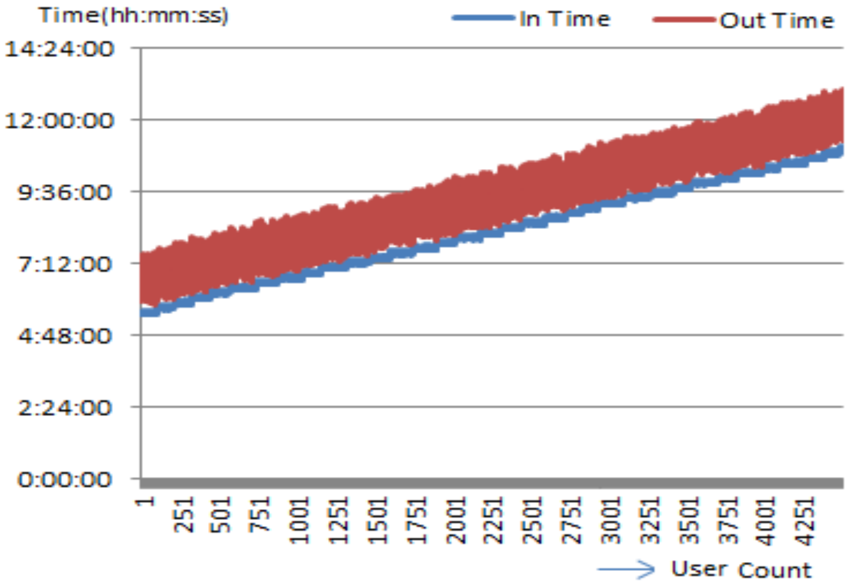


Fig 1: User's **In / Out** time graph (in sorted order of time)

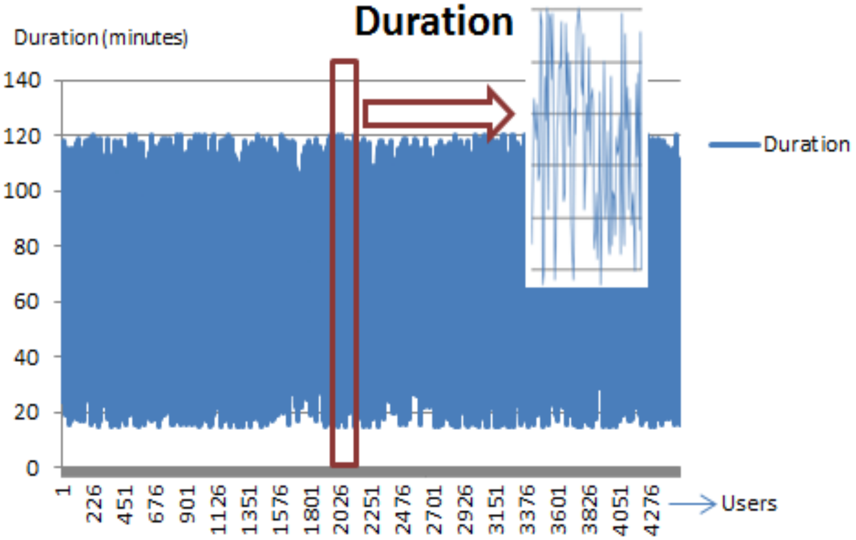


Fig 2: User's resource usage **duration** graph

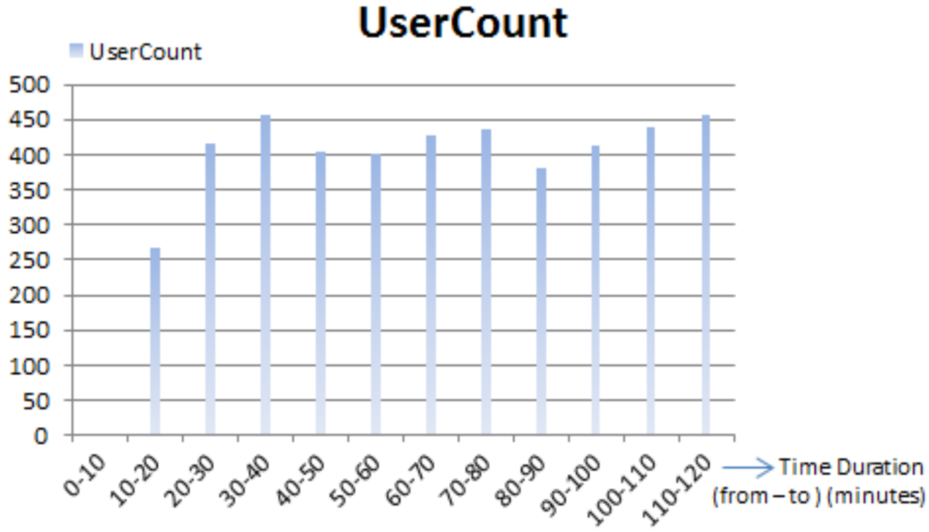


Fig 3: **User counts** in fixed time intervals graph

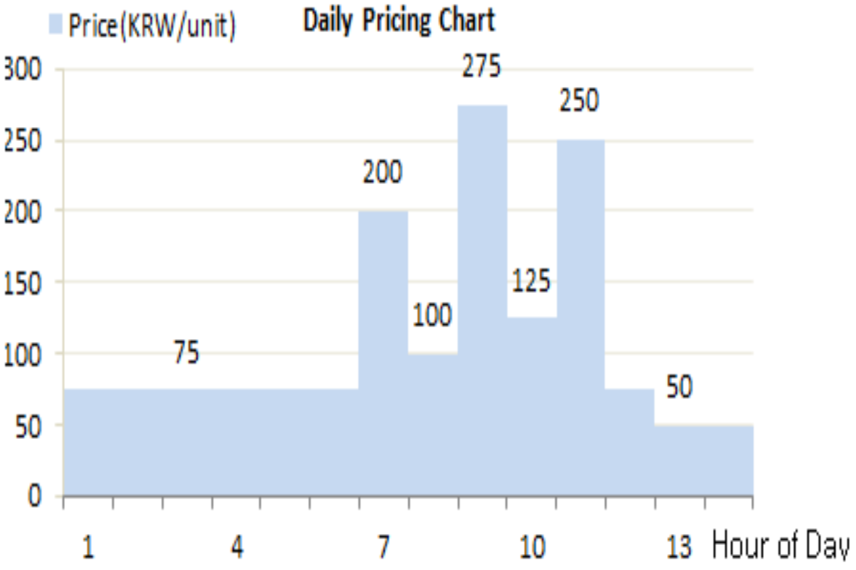


Fig 4: Daily Time based **pricing** for electricity billing

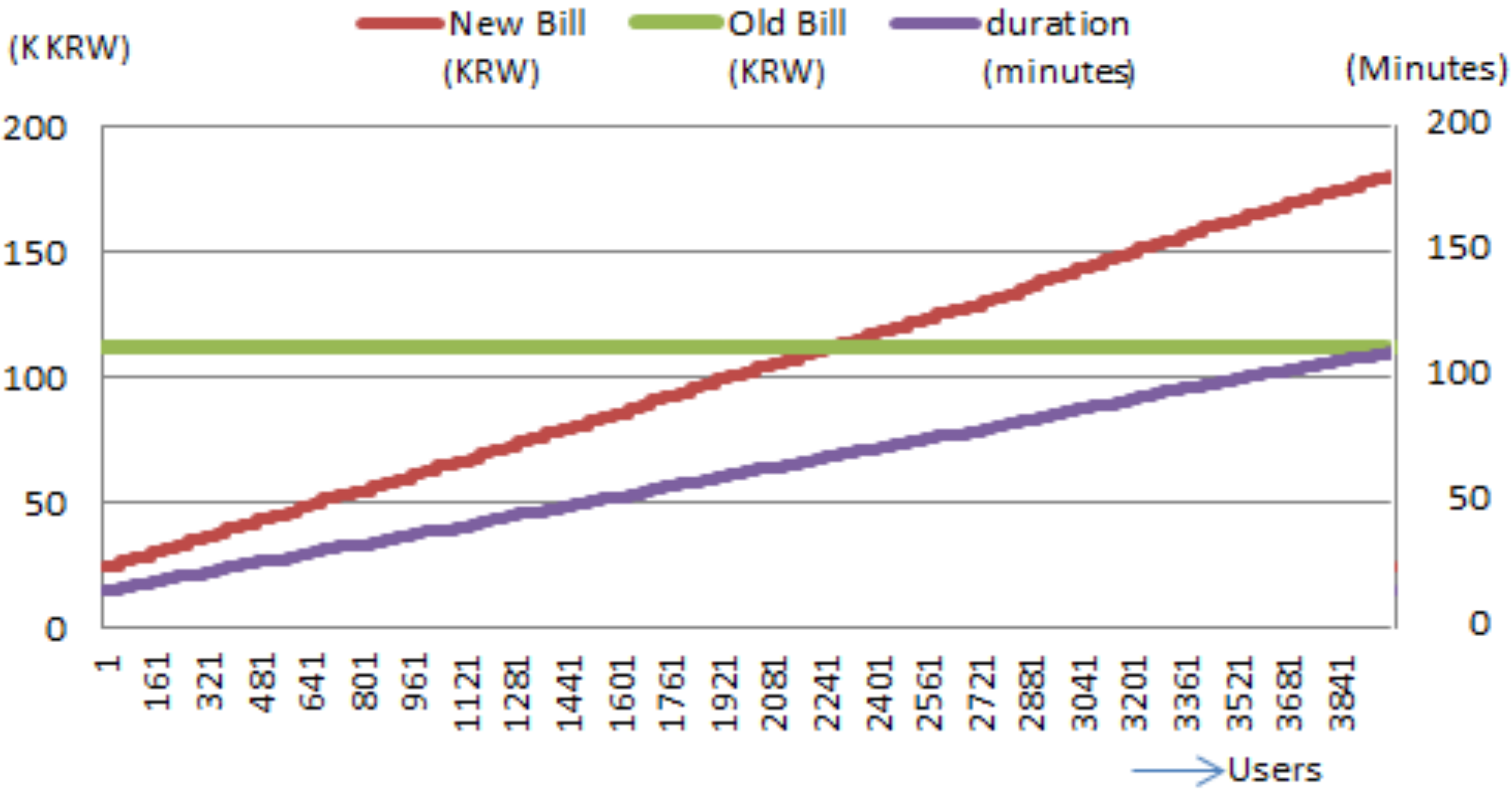


Fig 5: Billing amount comparison : Avg. Method (old) Vs **Method 1**

Observations for method 1:

- Billed amount ∝ Duration of usage . Note Price is fixed
- Meaningful new bill (**Red** line) as compared to the old bill (Green line).

TABLE II

METHOD

2

Sampling Timestamp (**Ti**)	User Vector (**V_i**)	User Count(**C_{Ti}**)	Power Consumed(**P_{Ti}**)	Energy Rate (**X_{Ti}**)
5:30:00	Empty	0	NA	75
5:35:00	1,2,3,4	4	**P_{T1}**	75
5:40:00	1,2,3,4,5	5	**P_{T2}**	75
5:45:00	1,2,3,4,5	5	**P_{T3}**	75
5:50:00	1,2,3,4,5	5	**P_{T4}**	75
5:55:00	1,2,4,5	4	**P_{T5}**	200
6:00:00	1,2,4,5	4	**P_{T6}**	200
6:05:00	1,2,4	3	**P_{T7}**	200
6:10:00	1,2,4	3	**P_{T8}**	200
…	…	…	…	…

TABLE III

METHOD

3

Sampling Timestamp (**Ti**)	Trigger's Cause	User Count(**C_{Ti}**)	Power Consumed(**P_{Ti}**)	Energy Rate (**X_{Ti}**)
0:00:00	Energy Price	0	**0**	75
5:30:52	Use Enter	1	**P_{T1}**	75
5:32:40	User Enter	2	**P_{T2}**	75
5:33:07	User Enter	4	**P_{T3}**	75
5:36:39	User Enter	5	**P_{T4}**	75
5:51:07	User Exit	4	**P_{T5}**	75
6:00:00	Energy Price	4	**P_{T6}**	200
6:01:39	User Exit	3	**P_{T7}**	200
6:32:07	User Exit	2	**P_{T8}**	200
6:53:52	User Exit	1	**P_{T9}**	200
7:00:00	Energy Price	1	**P_{T10}**	100
7:08:40	Exit	0	**P_{T11}**	100

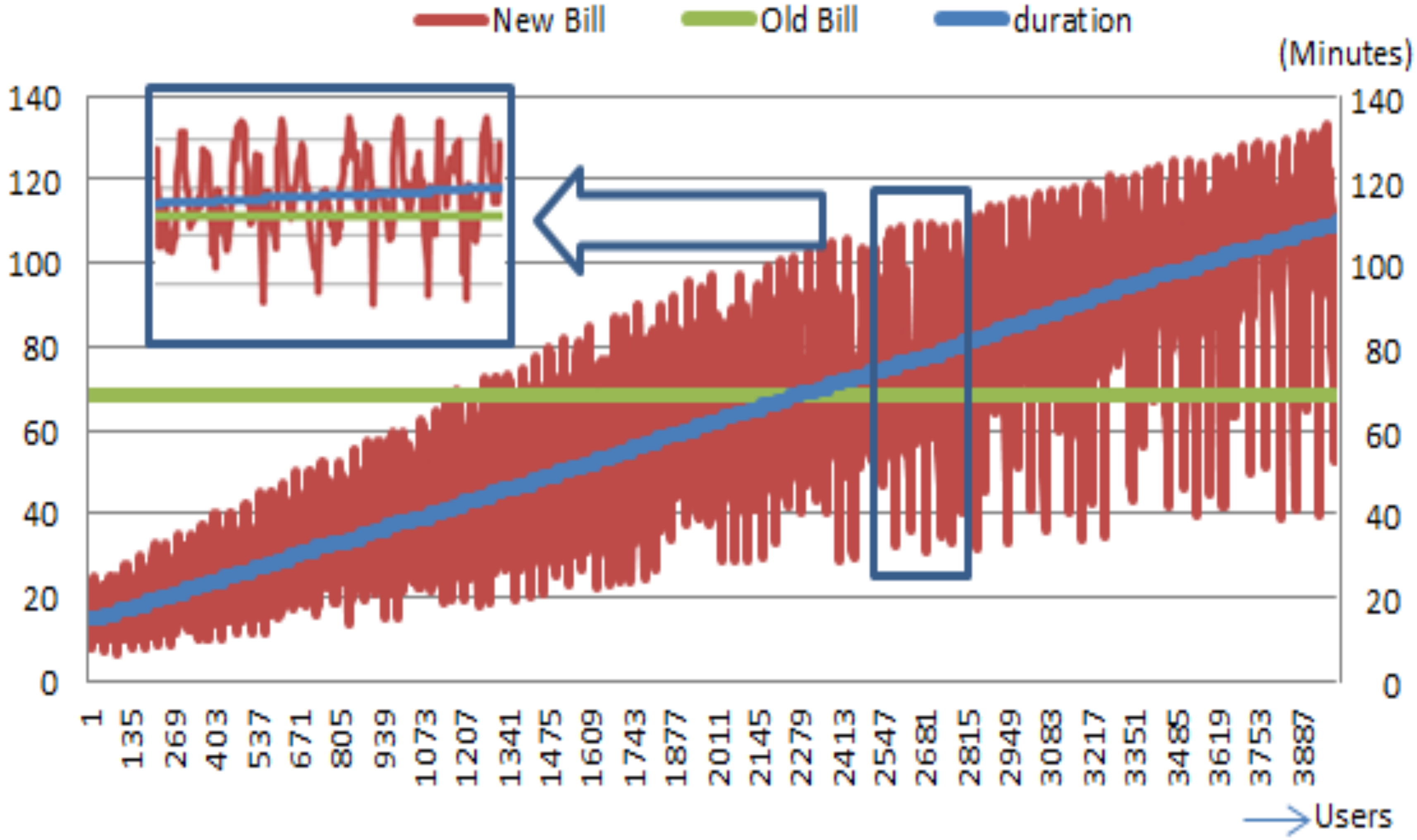


Fig 6: Billing amount comparison : Avg. Method (old) Vs **Method 2**

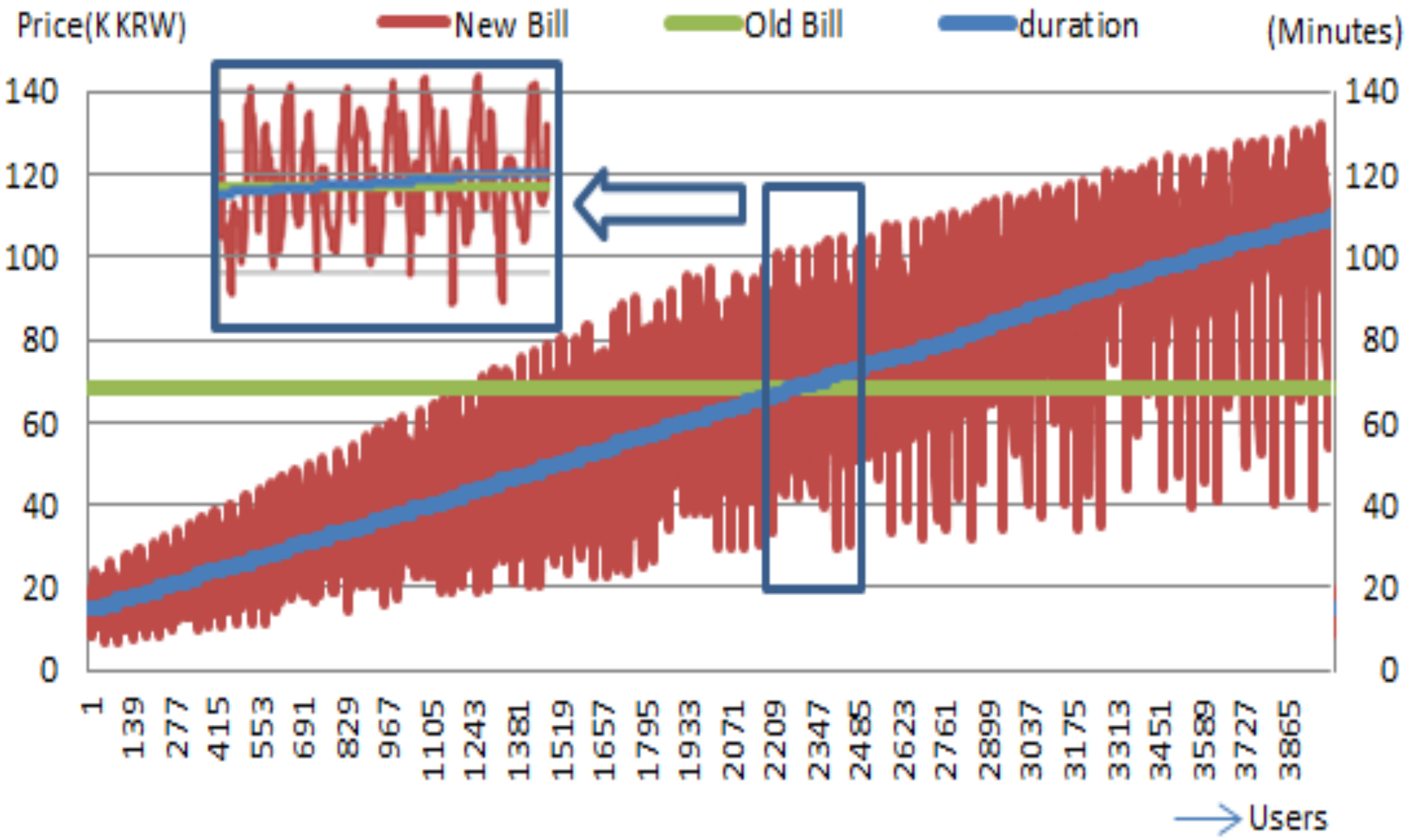


Fig 7: Billing amount comparison : Avg. Method (old) Vs **Method 3**

Observations for method 2 and method 3:

- Billed amount ∝ {Usage duration, Varying price}
- Red graph points below the duration curve : Users who consumed during <u>low pricing time</u>
- The zigzag nature of the curve : Two users using the resource for almost same duration have a lot of difference in the pricing. This difference is because they used the resource at different time.
- But method 3 is generating billing amount more accurately than method 2.
- The graph of method 2 approaches to graph of method 3 as the sampling time Δt approaches to zero (infinitely small).

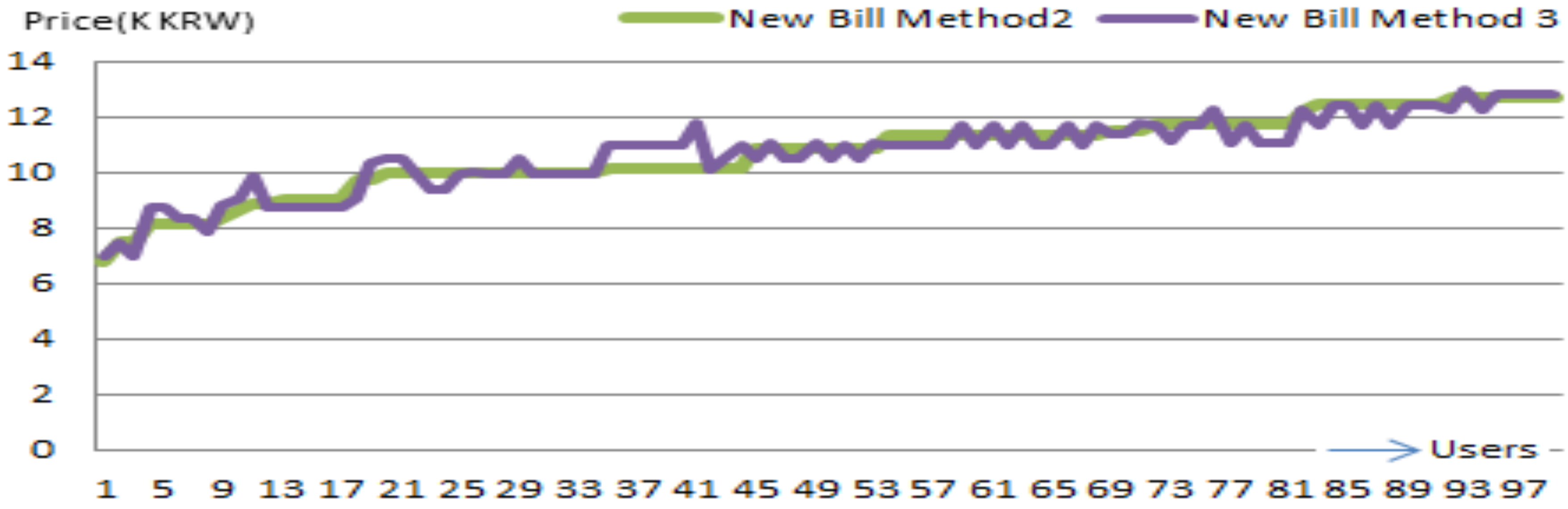


Fig 8: Billing amount comparison : **Method 2 Vs Method 3** (For first 100 users)

Analysis and Results

Defined data for categories

Defined 3 categories of users and corresponding data.

- Crazy (User A) : Excessive users of shared amenities
- Lazy (User B) : Mediocre user of shared amenities
- Elderly (User C) : Rare user of the shared amenities

Slot (HH - HH)	Price (Korean Won - KRW) / kWh	User presence vector	Power Consumed by resource(kWh)	Cost (KRW)
00 - 06	75	A	12	900
06 - 07	200	A	6	1200
11 – 12	75	B, C	12	900
12 - 13	50	C	4	200
Total			34	3200

TABLE IV : POWER CONSUMPTION AND PRICING AT FITNESS CENTER

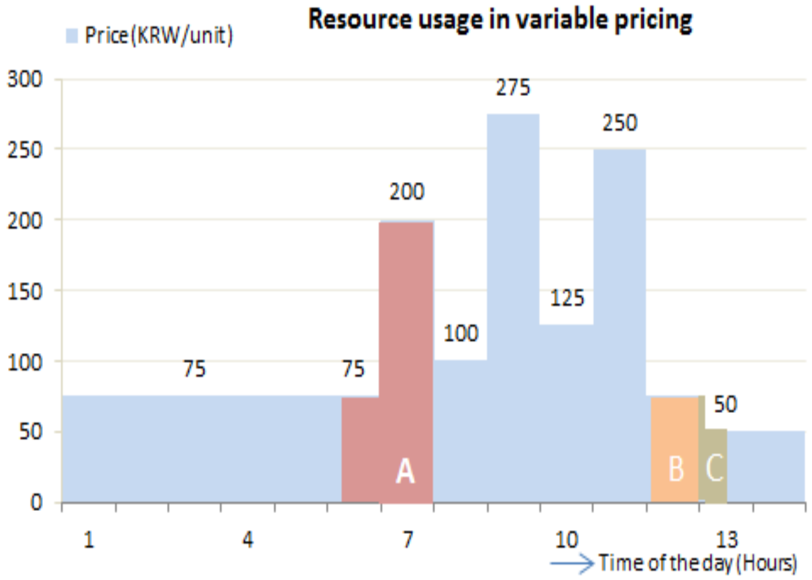


Fig 9: Usage on a time based pricing curve (for 3 categories)

Fig 10: Billing amount of different categories with Method 1, 2 and 3

Fitness Center - Results							
Usage Data				**Cost distribution among all users (KRW)**			
User Category	Usage Time (minutes)	Enter Time (HH.MM)	Exit Time (HH.MM)	Avg. Method	Method 1	Method 2 with Δt=10 Minutes	Method 3
A	90	05.30	07.00	1066.67	1645.71	2100	2100
B	60	11	11.55	1066.67	1097.14	750	825
C	25	11.55	12.20	1066.67	457.14	350	275
Sum	145	NA	NA	3200	3200	3200	3200

TABLE V : USAGE PATTERN AND CORRESPONDING BILLED AMOUNT

Conclusion

- Method 1
  - Price of commodity does not vary with time
  - Useful for : Developing nations
- Method 2
  - No of Residents are too large
  - Granularity of Δt can control the computation time
  - Slight trade off with accuracy (error for max one Δt consumption)
- Method 3
  - Accurate
  - Computation time increase for large number of users

Note: All methods are verified with simulated data for large number of users(approx. 1 Million users).
Method 3 gets slower with increased amount of users.

Future Direction

- More analysis with real data
- Large data need to consider other computation techniques to reduce computation time
- Make adaptive sampling (Δt) for Method 2

Thank You