SmartCoDe Expert Cooperation Workshop

ENERGY MANAGEMENT IN HOUSEHOLDS & BUILT ENVIRONMENTS:

Assessment of PV and Wind Micro-generation

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Renewable Generation in Built Environment (I)

General Characteristics:

- highly variable (spatially and temporally)
- micro/small systems – Micro-generation
- highly dispersed (e.g. in a large urban area)
- mix of different technologies (wind, PV…)

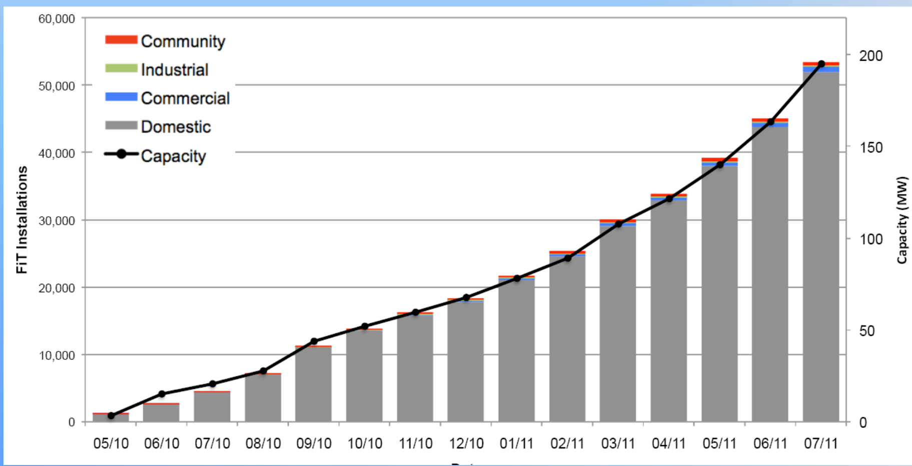
Similarity with Load Analysis, e.g. Demand Side Management (DSM) (both are Energy Management functionalities in future "Smart Grids")

Large number of small in size and highly dispersed individual units, connected in parallel to LV networks, exhibiting short, medium and long-term variations, as well as large changes from one geographic or network location to another

Renewable Generation in Built Environment (2)

The analysis of MG is connected with uncertainties and requires assessment of stochastic variations

When present in high numbers, aggregate effects of MG & DSM (e.g. at bulk supply points at MV) can be significant…



After introducing Feed-in Tariffs in the UK…

[Ofgem data]

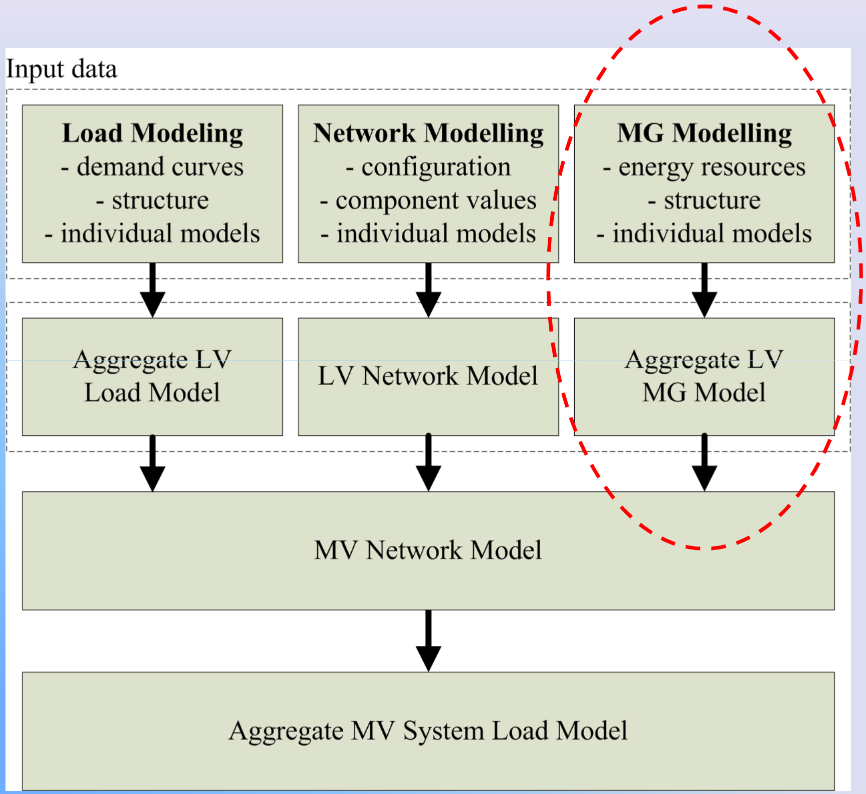
Lecture Overview

Energy Management in Households/Built Environments: Assessment of PV and Wind Micro-generation (and Demand Side Management)

Effects of MG & DSM (individual/combined) on network operation/performance:

- Detailed network model (typical LV/MV residential distrib. network)
- Two renewable MG technologies: µPV and µWind
- Assessment of input solar and wind energy resources
- Description of residential load mixes and daily load curves
- Aggregate residential load model (with identified DSM-portion)
- Correlation of µPV and µWind outputs with loads/demands
- Illustrated using Midlothian region in Scotland, UK (around the city of Edinburgh)

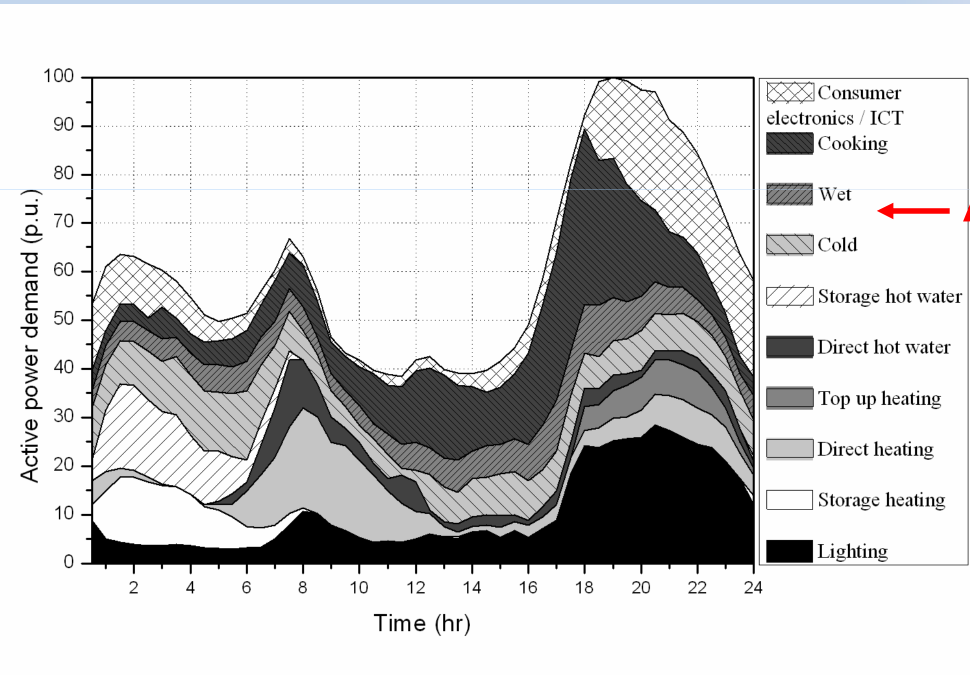
Aggregation Methodology



Aggregate LV Load Model (1)

Daily Load Curves Available (at 11kV or higher levels)

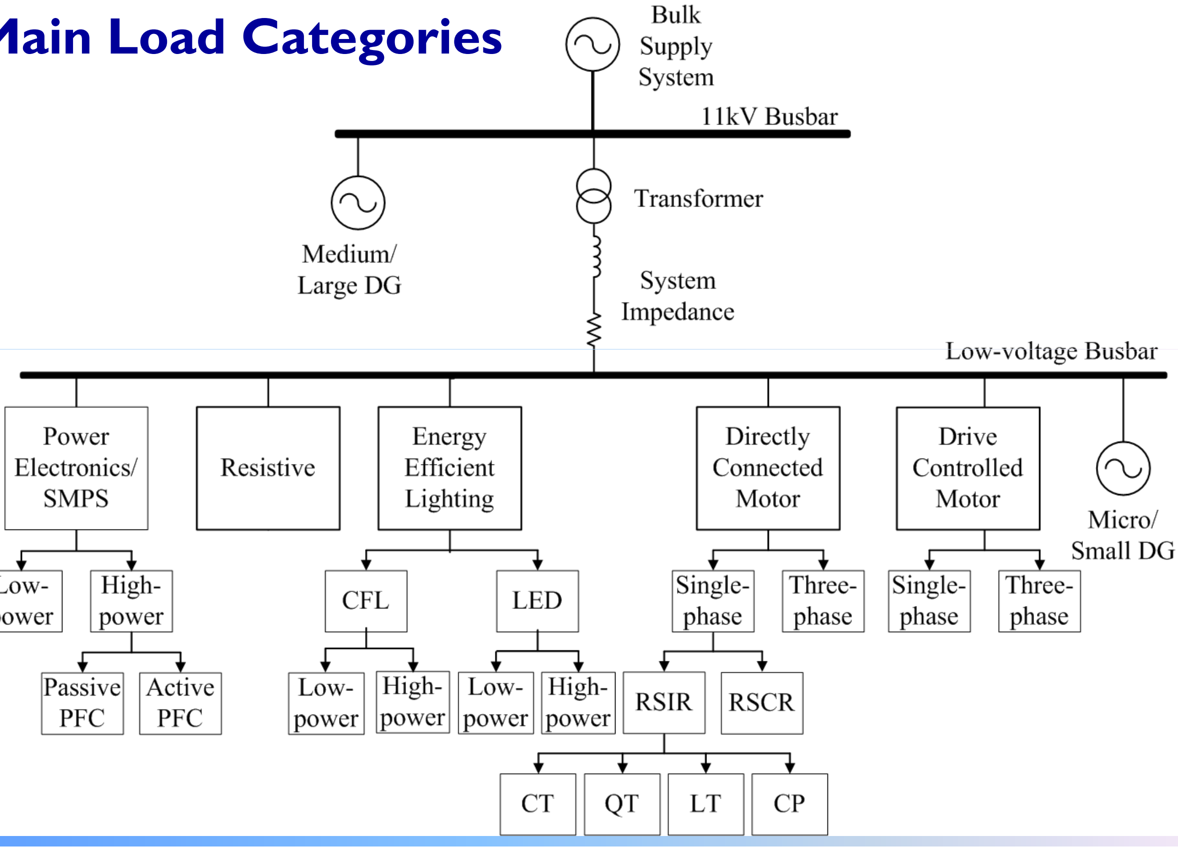
Should be "Decomposed" in Main "Load Categories"



Available for DSM

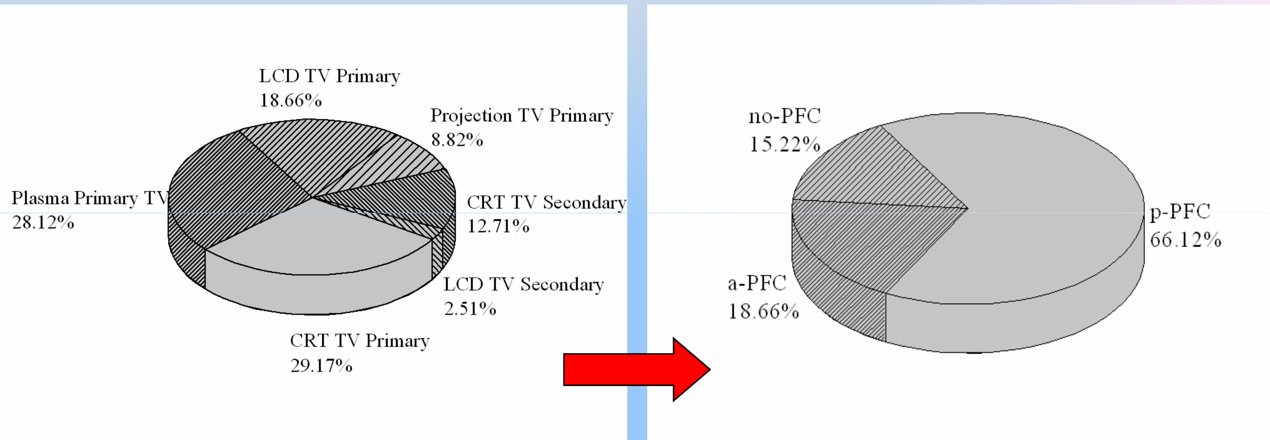
Aggregate LV Load Model (2)

Main Load Categories



Aggregate LV Load Model (3)

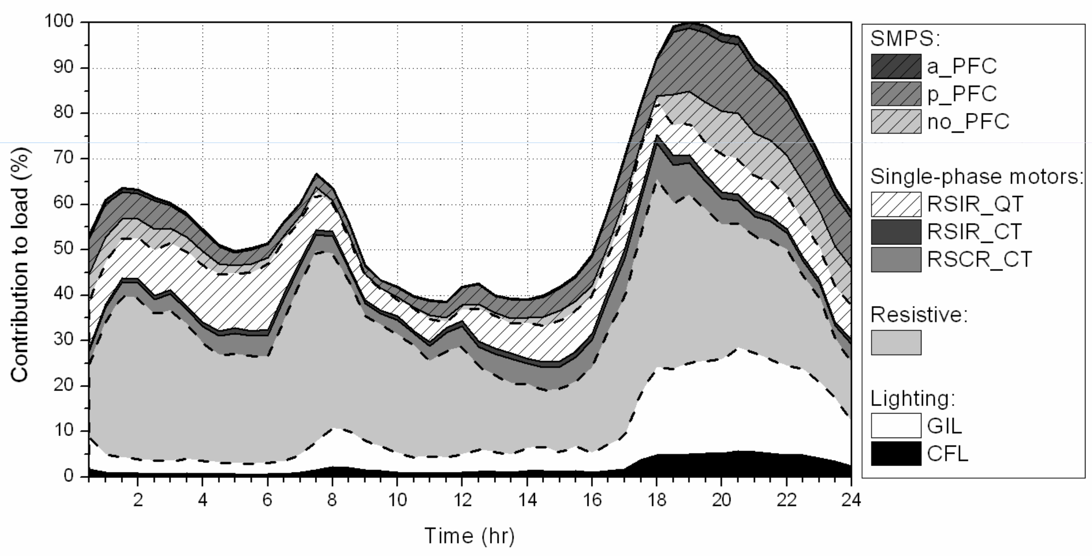
From (End-use) Load Type to (Modelling) Load Category



It is only an example – can be applied to all other types of loads…

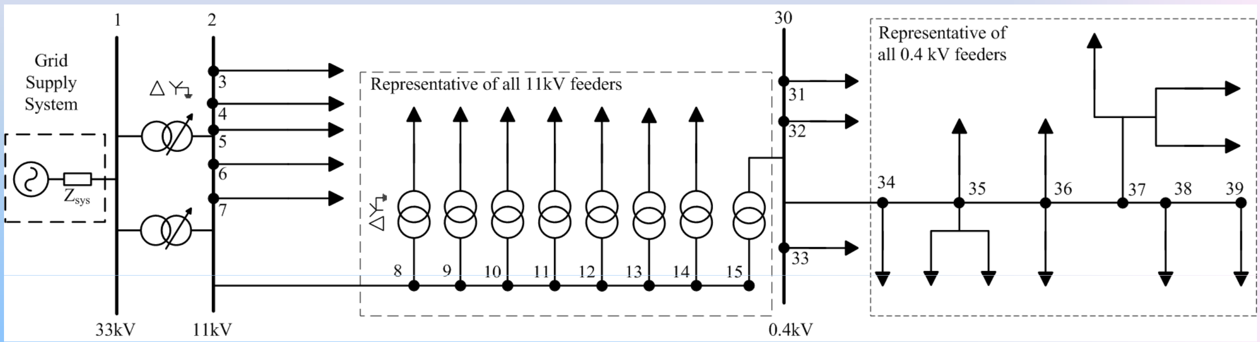
Aggregate LV Load Model (4)

Decomposition of Daily Load Curve



LV Network Model

Typical LV/MV Residential Network (Configuration & Parameters)



Cables:

Operating Voltage (kV)	Feeder Type	Max. Length (km)	Cross section (mm^2)	R/km	X/km	B/km
				(p.u. on 100MVA)		
11	Cable	10	185	0.12271	0.06575	0.00023954
			95	0.14403	0.06662	0.00017804
0.4		0.2	185	89.84	43.68	-
			95	171.12	53.47	-

Transformers:

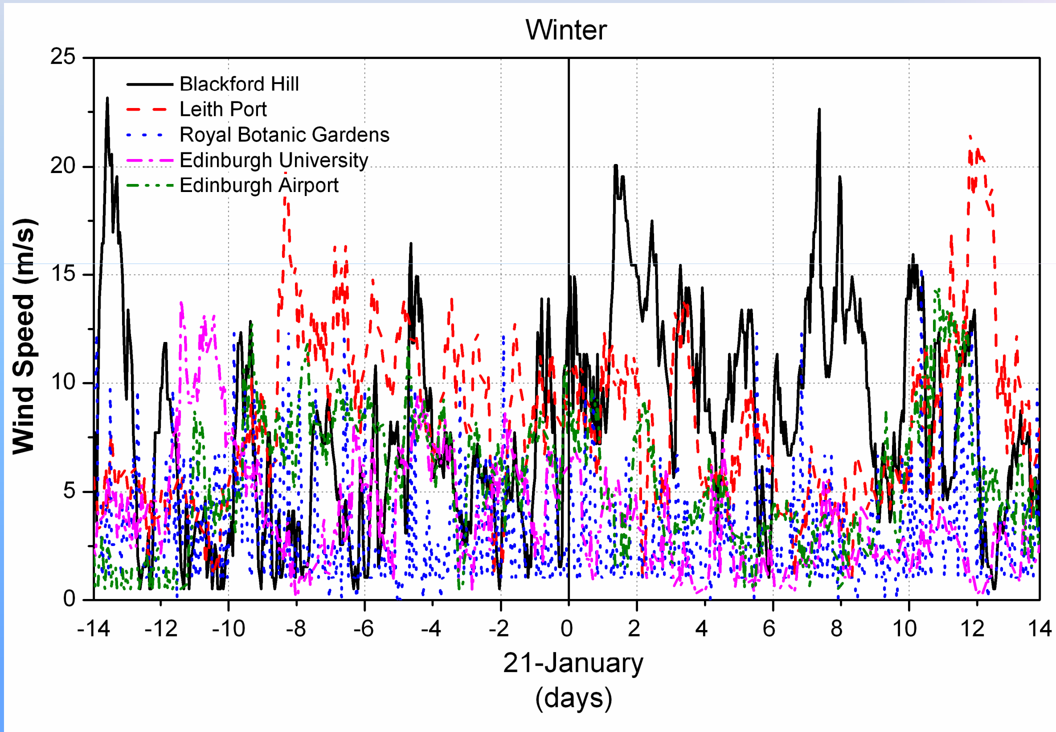
Operating Voltage (kV)	Vector Group	Rating (MVA)	R	X	Tap range (p.u.)		Tap step (p.u.)
			(p.u. on 100MVA)		Min	Max	
33/11	Dyn11	15	0.06	1	0.8	1.05	0.0143
11/0.4	Dyn11	0.5	2.04	9.28	0.95	1.05	0.025

Aggregate Micro-generation Model (1)

Assessment of Input Energy Resources: City of Edinburgh (15km x 15km)

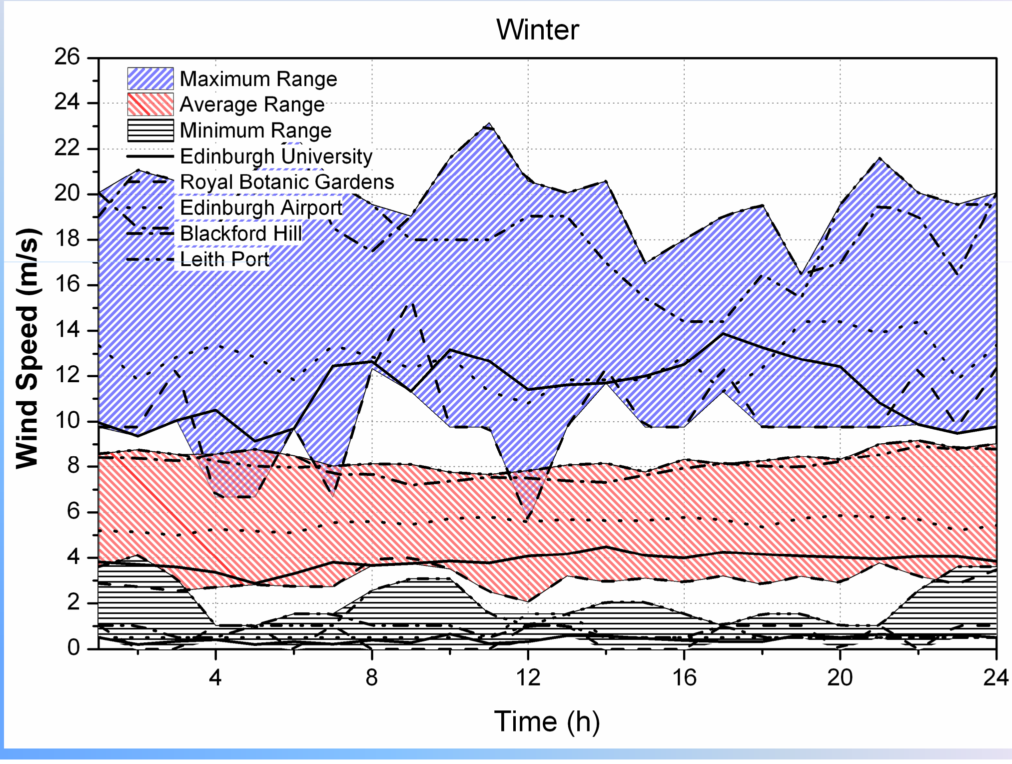
Aggregate Micro-generation Model (2)

Assessment of Wind Energy Resources: 5 Sites, ±14 Days



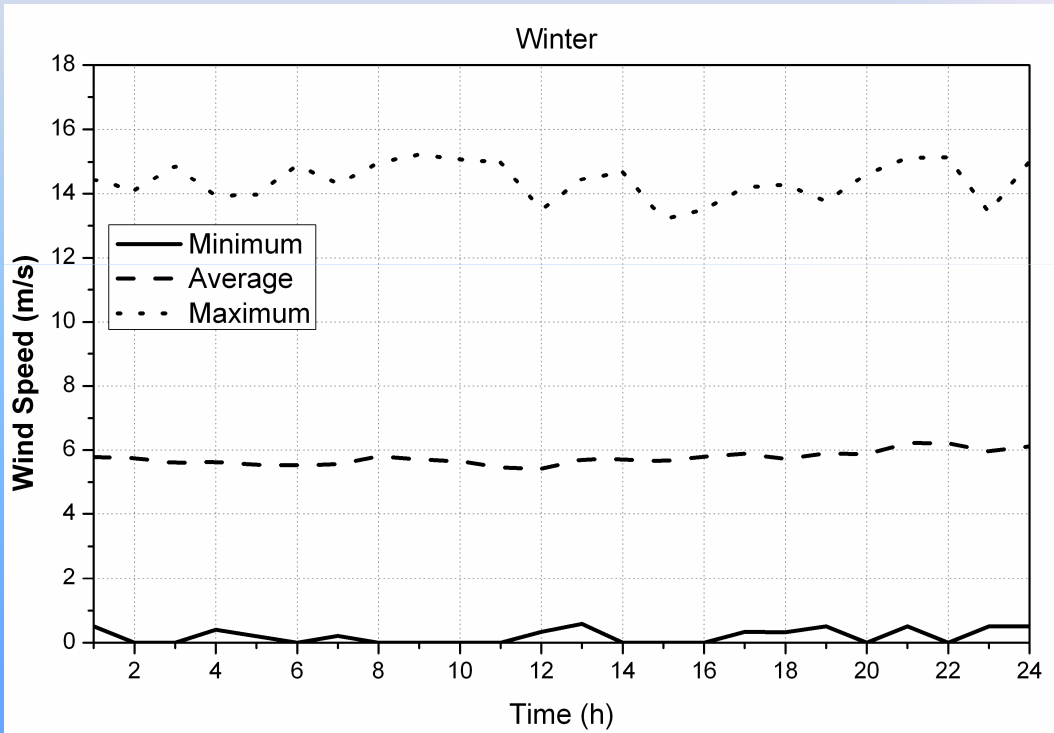
Aggregate Micro-generation Model (3)

Assessment of Wind Energy Resources: 5 Sites, Averages



Aggregate Micro-generation Model (4)

Assessment of Wind Energy Resources: All Sites, Max/Min/Ave



Aggregate Micro-generation Model (5)

Assessment of Power Outputs: Generic µWind Models:

- Database with ~190 µWTs from 60+ manufacturers
- Manufacturers from US, UK, China, Canada, Spain, Ireland…
- Horizontal/Vertical Axis Systems (168xHAWTs, 20xVAWTs)
- 95% with rated power <10 kW
- For ~140 µWTs, power curve provided in specification
- Four Generic µWTs → represent majority of µWTs on the market

$P_{G\mu WT\_1} = -7.29v + 3.12v^2$, for $v \geq 2.4$ m/s ……………………Generic µWT_1

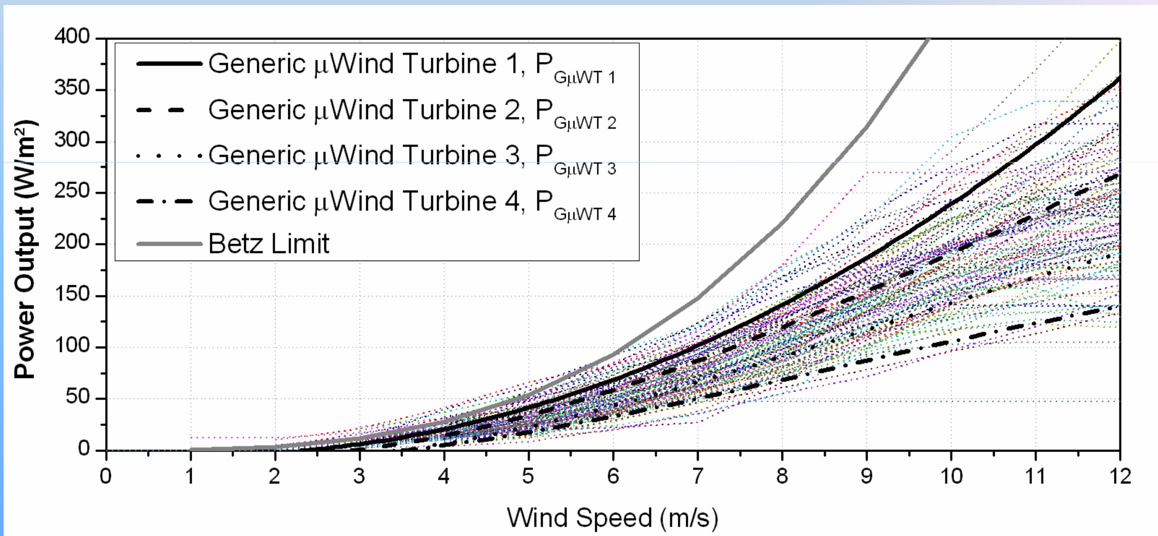
$P_{G\mu WT\_2} = -11.47v + 4.26v^2 - 0.12v^3$, for $v \geq 3$ m/s …………Generic µWT_2

$P_{G\mu WT\_3} = -13.1v + 4.34v^2 - 0.16v^3$, for $v \geq 3.2$ m/s …………Generic µWT_3

$P_{G\mu WT\_4} = -6.2v + 2.86v^2 - 0.11v^3 - 6$, for $v \geq 3.3$ m/s ………Generic µWT_4

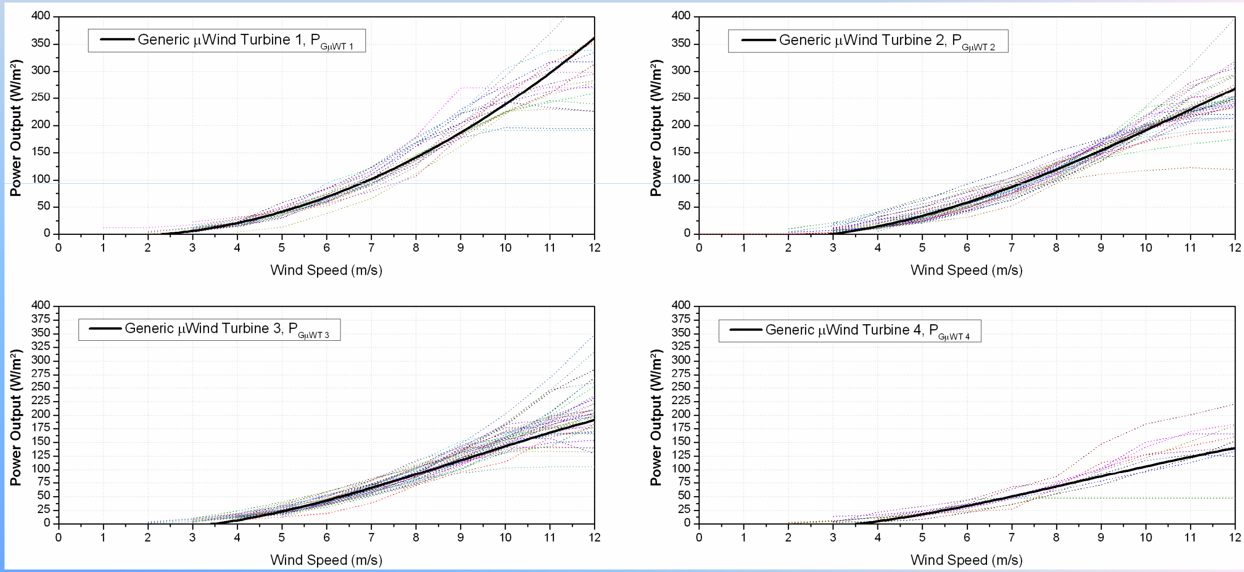
Aggregate Micro-generation Model (6)

Generic µWind Turbine Models: Power Curves



Aggregate Micro-generation Model (7)

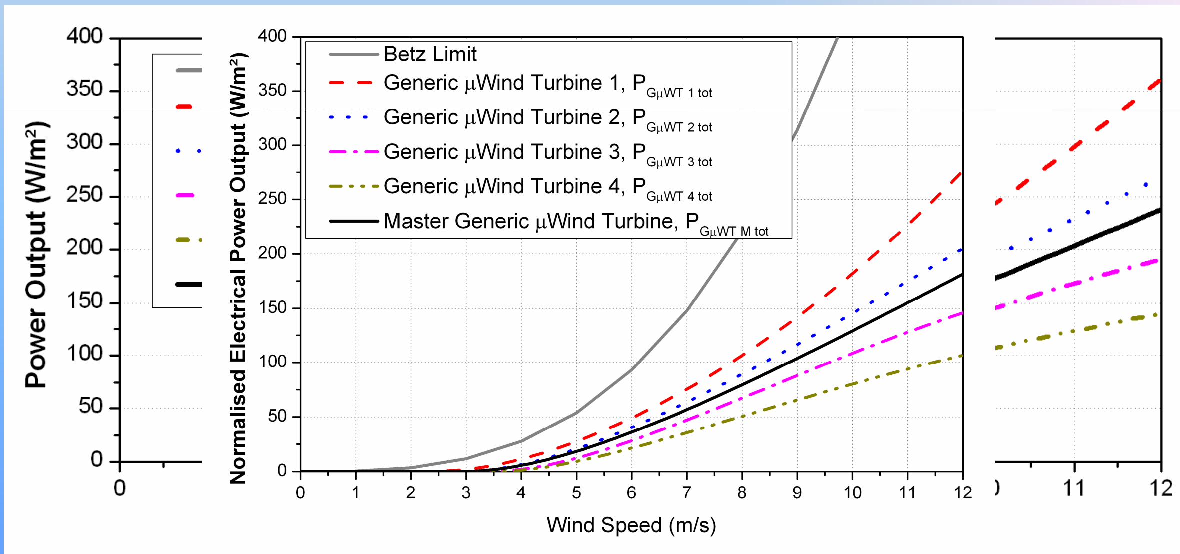
Generic μWind Turbine Models: Power Curves



Aggregate Micro-generation Model (8)

Aggregate ("Master") Generic μWind Turbine Model

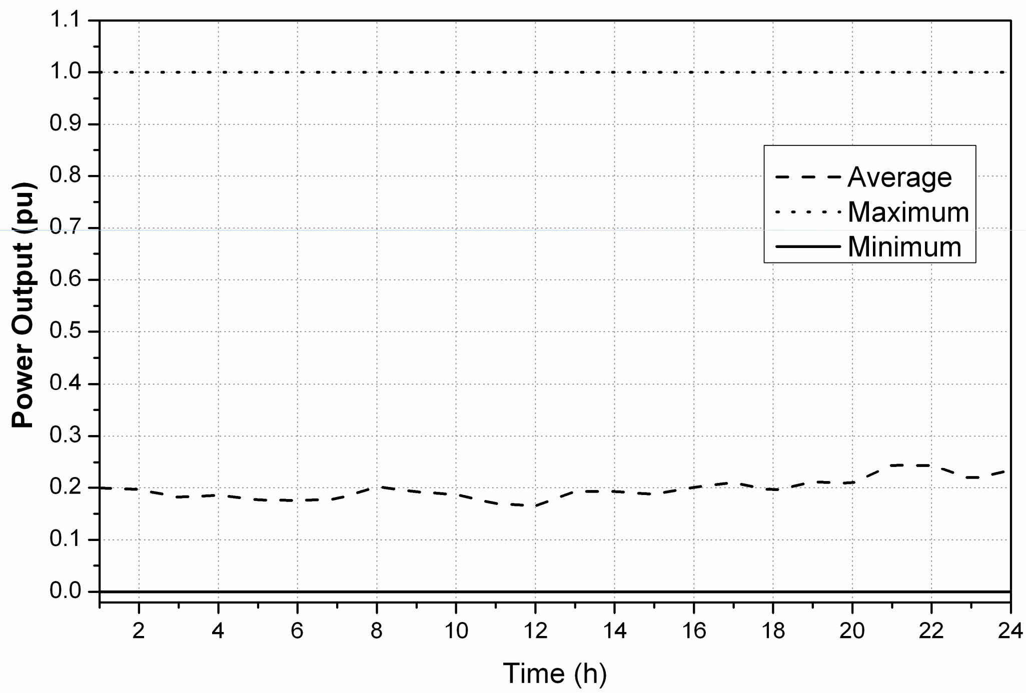
Mix/Aggregation of Generic μWT1 - 18%, Generic μWT2 - 32%
Generic μWT3 - 32%, Generic μWT4 - 18%



$$P_{G\mu WT\_M\_tot} = (1 - e^{-0.75(v-3)})(-7.87v + 2.92v^2 - 0.084v^3)\ ,\ \text{for}\ \ v \geq 3\ \text{m/s}$$

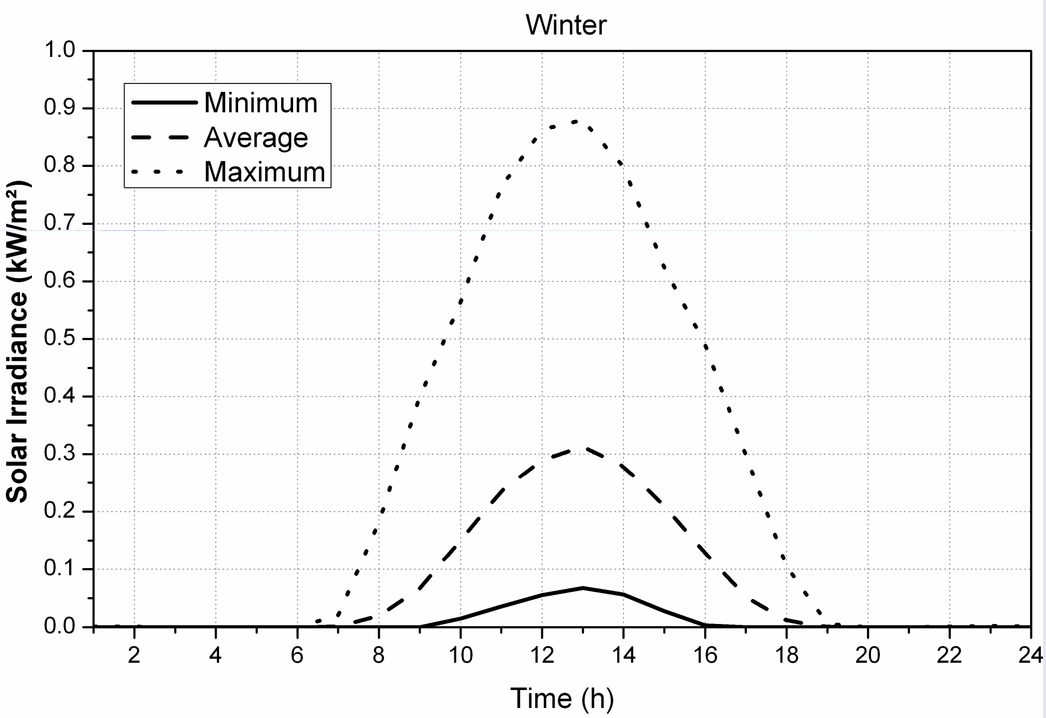
Aggregate Micro-generation Model (9)

µWind Power Outputs for Estimated Wind Resources



Aggregate Micro-generation Model (10)

Assessment of Solar Energy Resources: Following the Same Procedure as for Wind Energy Resources…



Aggregate Micro-generation Model (11)

Assessment of Power Outputs: Generic µPV Models:

- Database with 240+ µPV systems from few dozen manufacturers
- Again, manufacturers from around the World
- Four main technologies
- Monocrystalline, polycrystalline, thin film and amorphous
- Manufacturer's specifications thoroughly examined
- Four Generic µPVs → represent majority of µPVs on the market

$P_{G\mu PV\_1} = 0.134(1 - e^{-0.04 S_{irr}}) S_{irr}$ ……………………………..Generic µPV_1

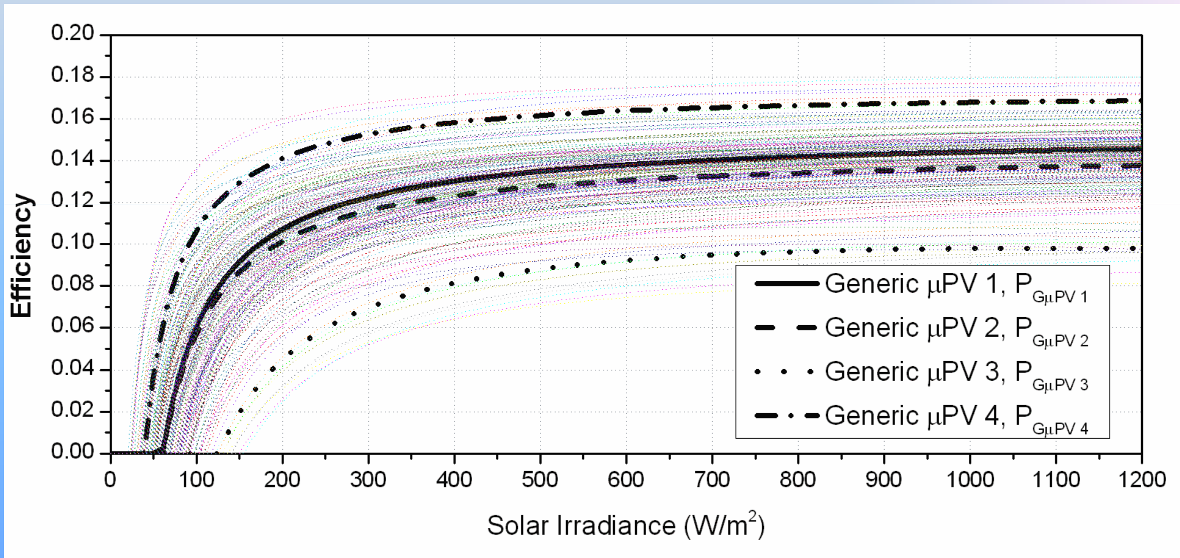
$P_{G\mu PV\_2} = 0.136(1 - e^{-0.04 S_{irr}}) S_{irr}$ ……………………………..Generic µPV_2

$P_{G\mu PV\_3} = 0.09(1 - e^{-0.04 S_{irr}}) S_{irr}$ ……………………………..Generic µPV_3

$P_{G\mu PV\_4} = 0.163(1 - e^{-0.04 S_{irr}}) S_{irr}$ ……………………………..Generic µPV_4

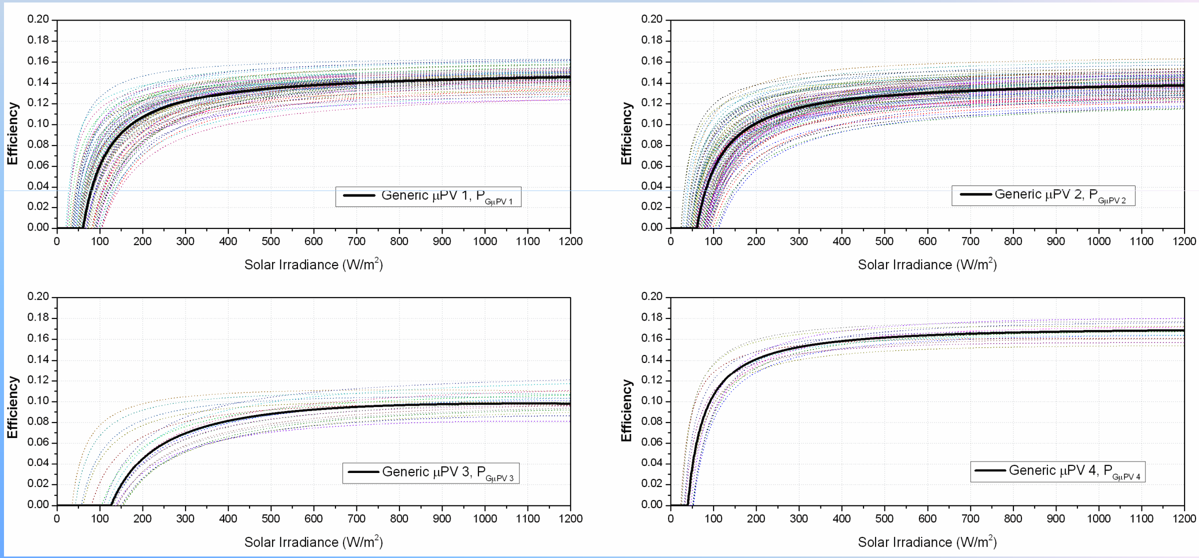
Aggregate Micro-generation Model (12)

Generic µPV Models: Efficiencies



Aggregate Micro-generation Model (13)

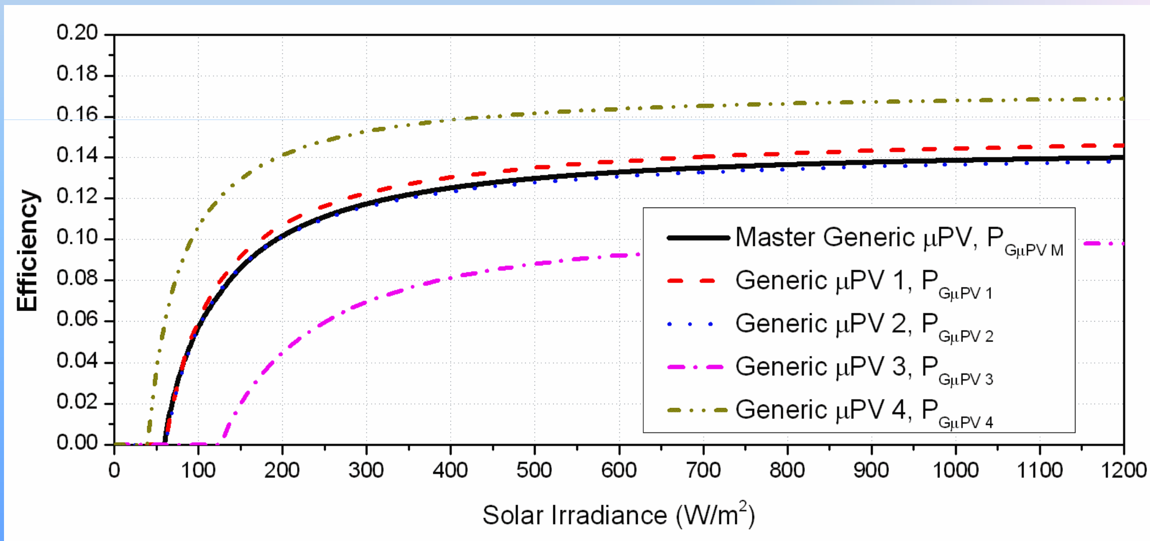
Generic µPV Models: Efficiencies



Aggregate Micro-generation Model (14)

Aggregate ("Master") Generic µPV Model

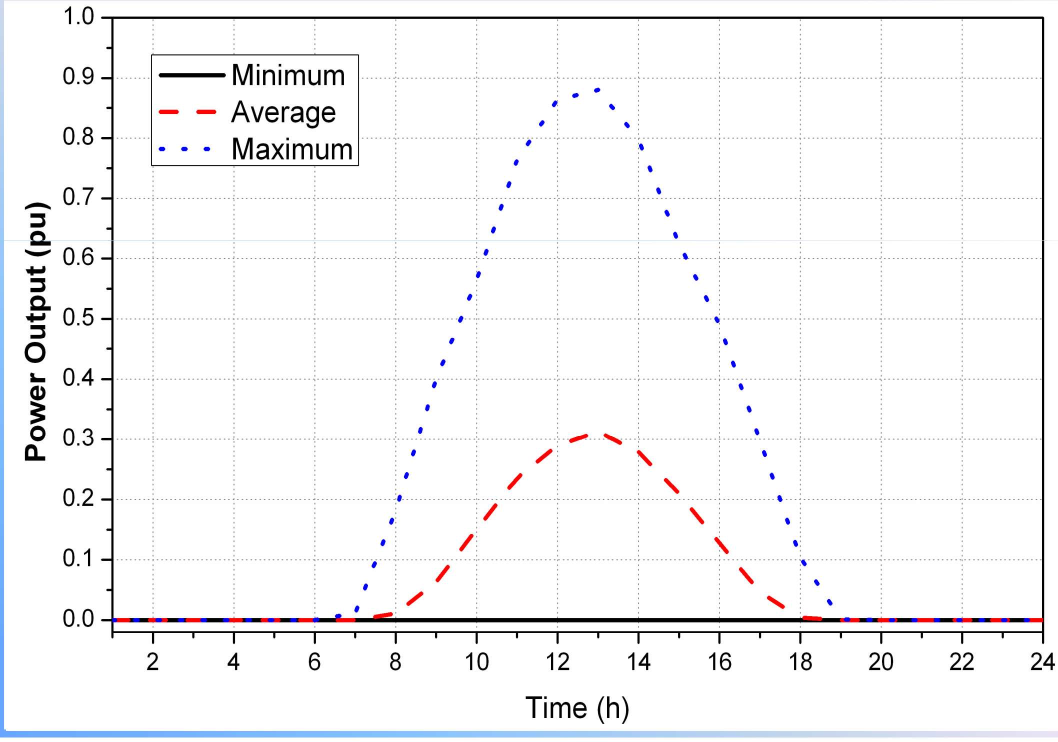
Mix/Aggregation of Generic µPV1 - 40%, Generic µPV2 - 43%
Generic µPV3 - 9%, Generic µPV4 - 8%



$$P_{G\mu PV\_M} = 0.133(1 - e^{-0.04 S_{irr}}) S_{irr}$$

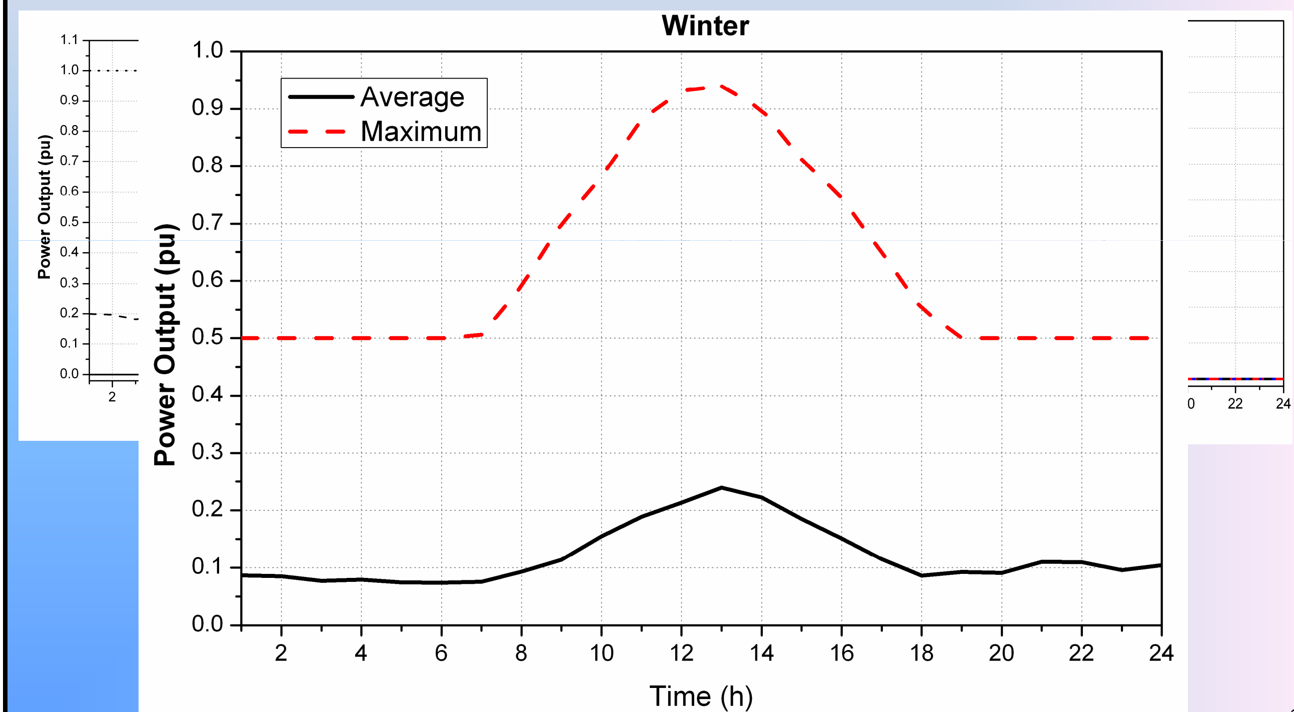
Aggregate Micro-generation Model (15)

μPV Power Outputs for Estimated Solar Resources



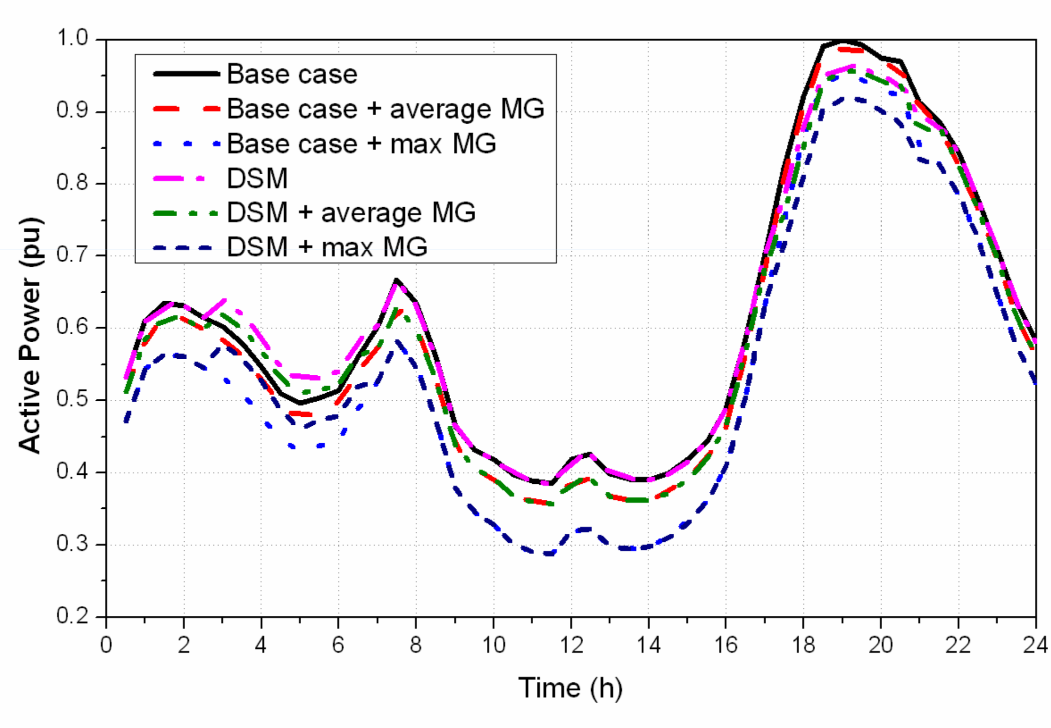
Aggregate Micro-generation Model (16)

Combined μWind & μPV (50%-50%) Power Outputs



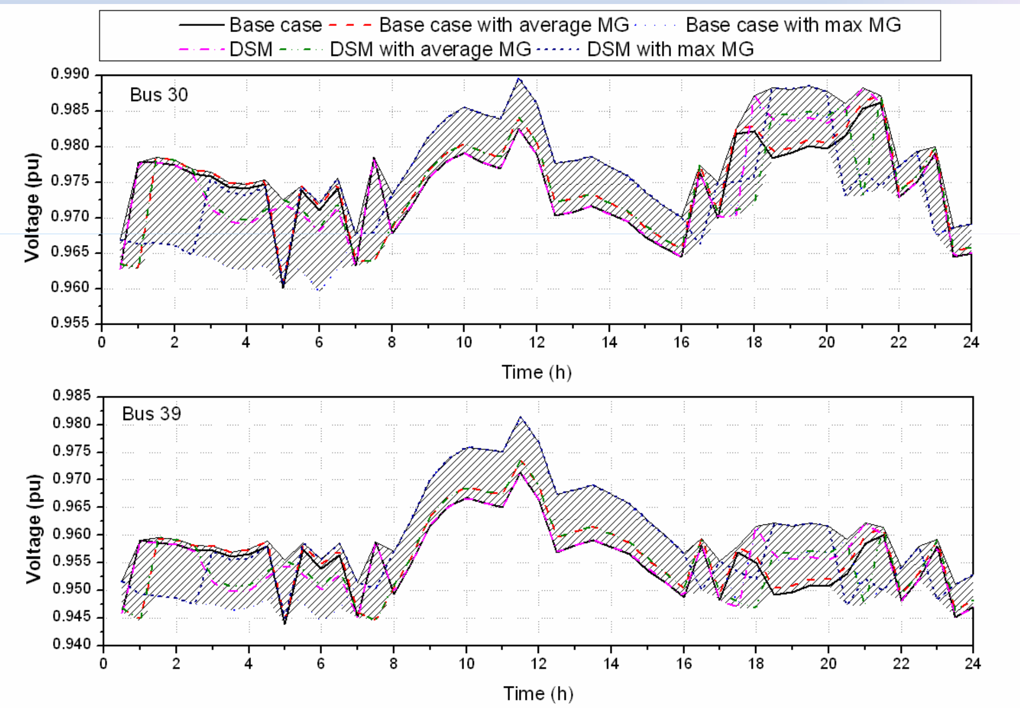
Impact & Performance Assessment (1)

Change in Active Power Demand:



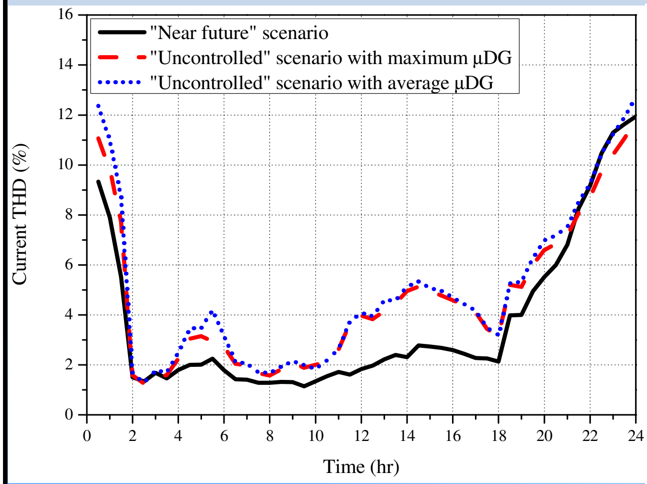
Impact & Performance Assessment (2)

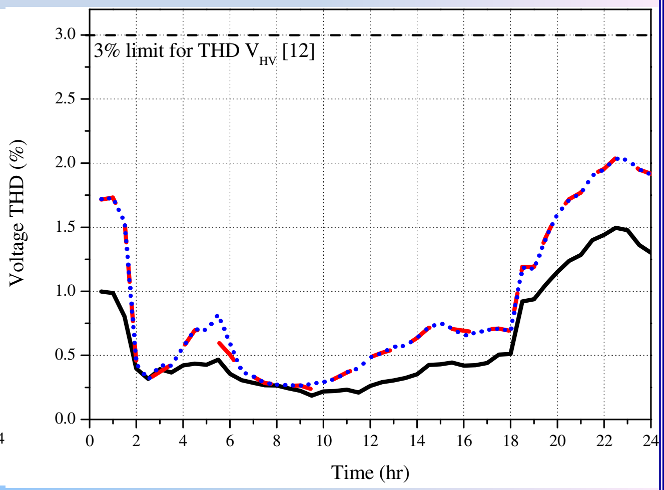
Change in Voltage Profiles:



Impact & Performance Assessment (3)

Harmonic Distortion (MG & Incandescent → CFL):





THANK YOU!

Discussion & Questions?