TNB RESEARCH

Innovate With The End In Mind

Direct Load Analysis and Modeling System

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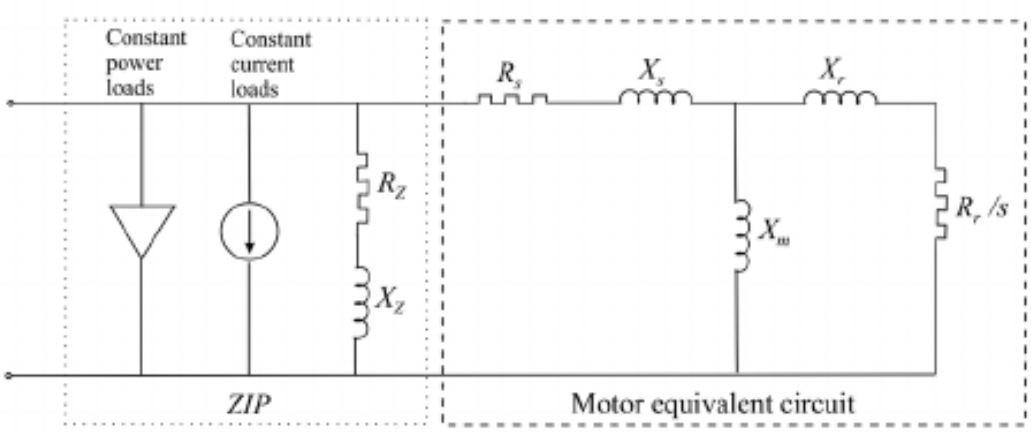
Presentation Outlines

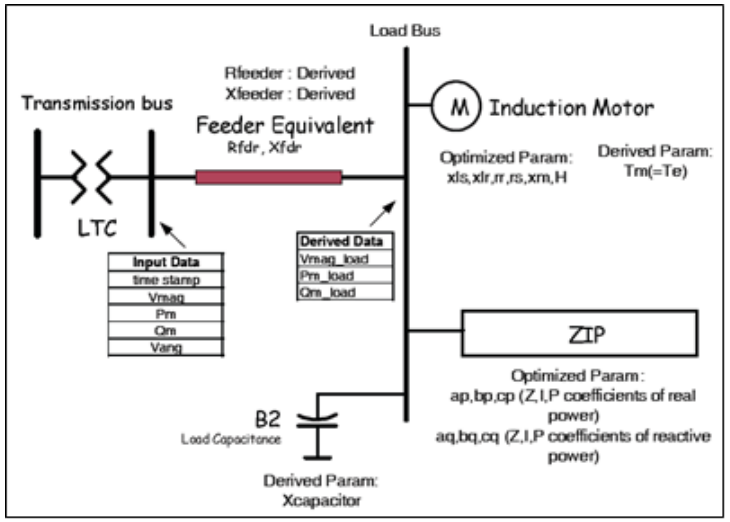
1	Introduction- Load Modeling in General
2	Direct Load Analysis & Modeling System
3	Data requirement for Load Analysis & Modeling
4	Load Model Parameters Derivation
5	Load Model & Demand Reduction
6	Conclusion

Load Modeling in General (1)

Load model is the mathematical description of the relationship between the voltage, real power and reactive power of the bus. Power system planning and operation decisions require system studies which involve modeling of the entire system including the loads.

Representation of load in power system study (example)





ZIP

$$P_L = P_0\left[a_1(V)^2 + a_2(V) + a_3\right]$$

$$Q_L = Q_0\left[a_4(V)^2 + a_5(V) + a_6\right]$$

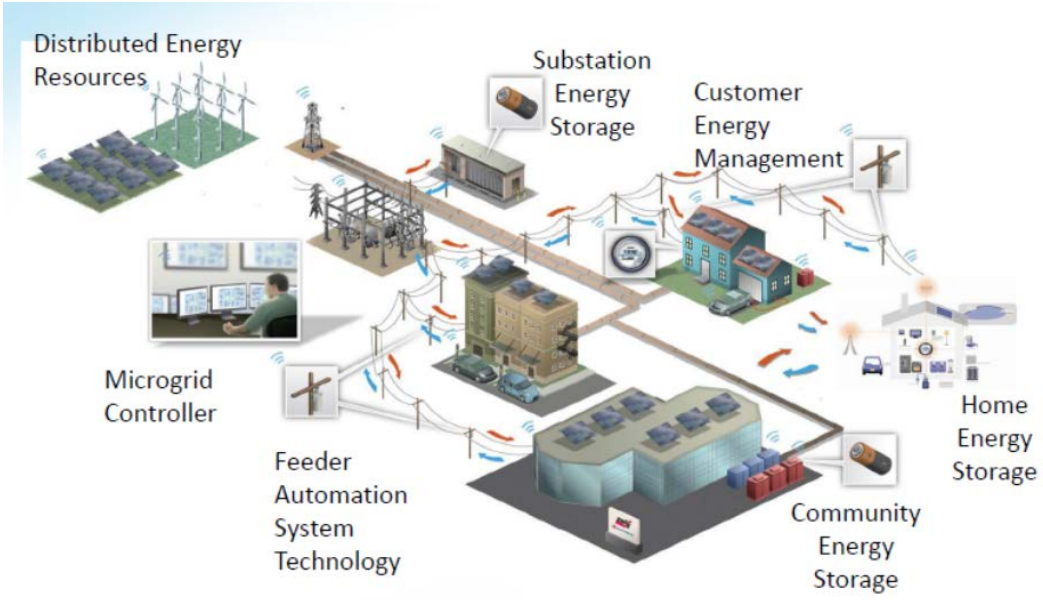
where

$a_1 + a_2 + a_3 = 1$, $a_4 + a_5 + a_6 = 1$.

Load Modeling in General (2)

Grid of the future; advancement of power system with increasing amount of non-linear load type and DER, ES, EV etc. will bring changes on the demand-side. Reasonable models needed to understand the system impacts of these changes.

Advancement of power system



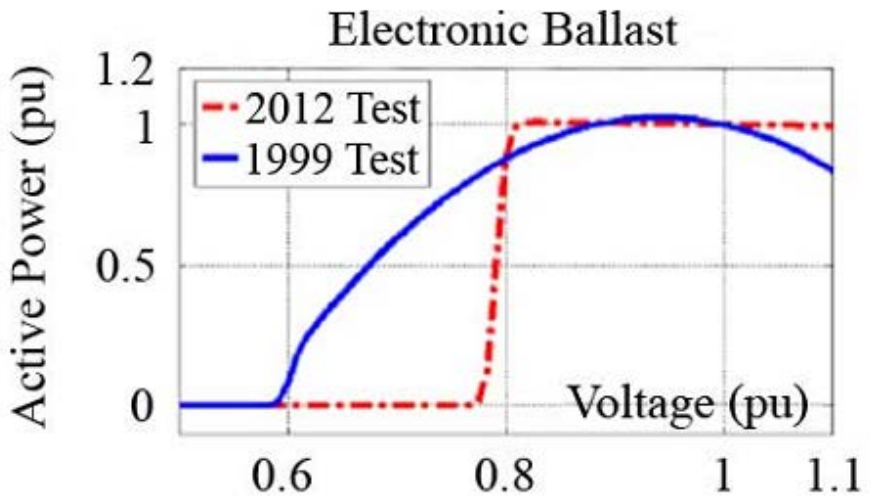
- Electric vehicle (EV) chargers
- Energy storage (ES)
- Power electronic loads, VFD, Inverter AC compressor, LED lights
- Distributed Energy Resources (DER) e.g. PV
- Microgrid

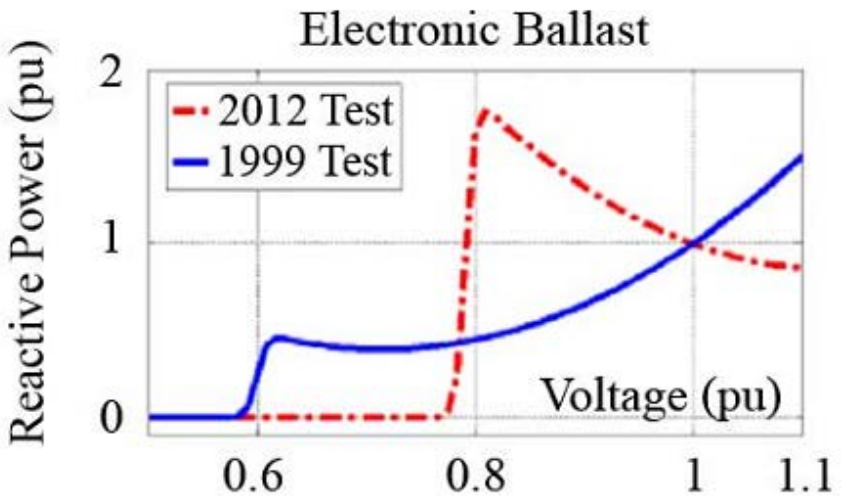
- Resistive-type loads e.g. incandescent lights are phasing out (energy inefficient but exhibit 'grid-friendly' behavior)

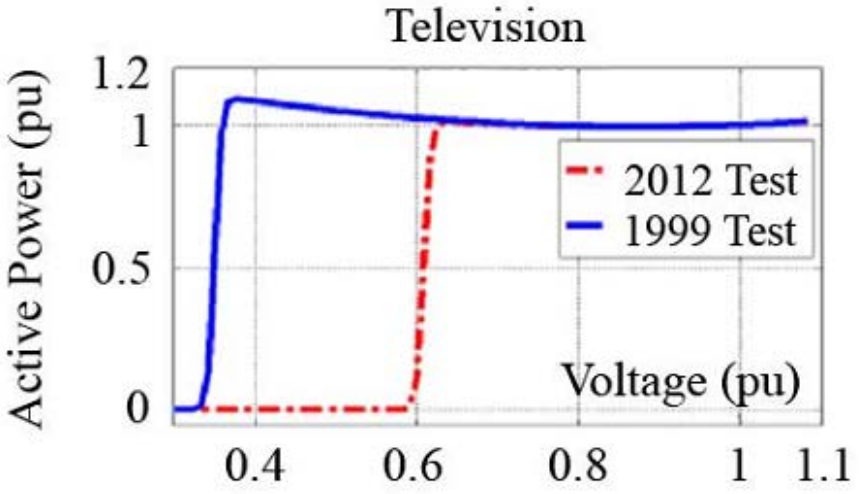
Load Modeling in General (3)

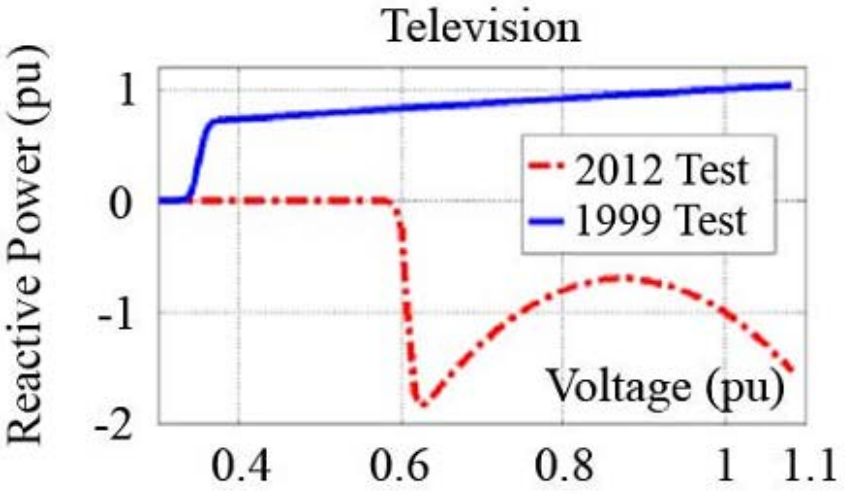
Advancement in technology would change the load behavior.

P&Q vs V response of similar equipment over time









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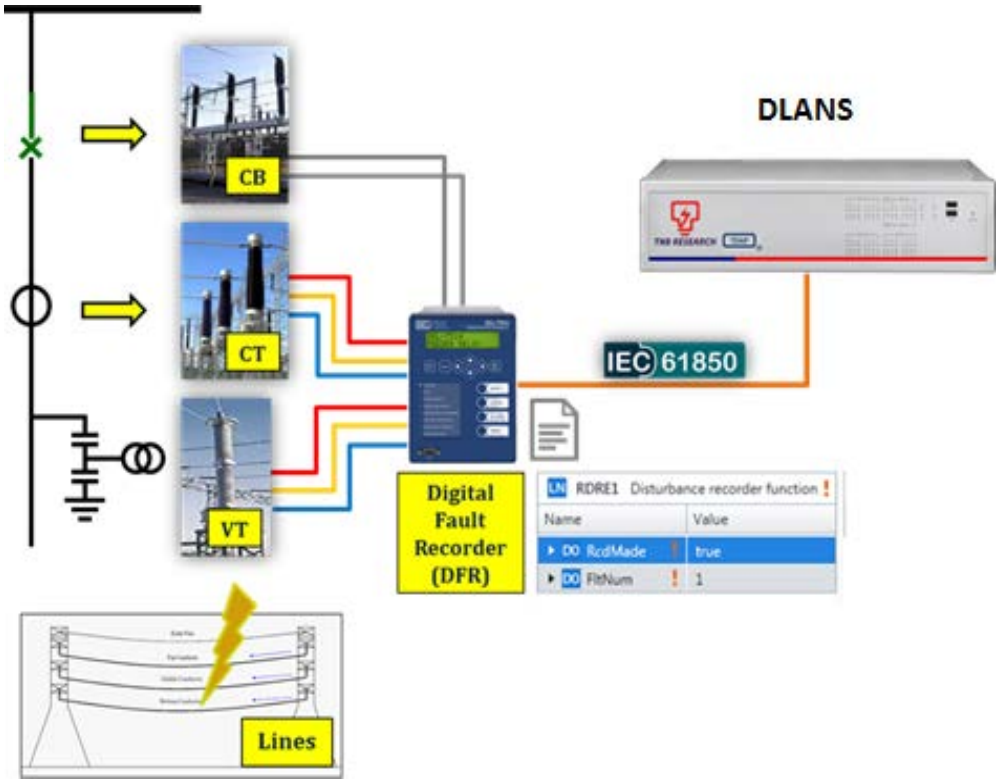
Direct Load Analysis & Modeling System (1)

Direct & automatic system will be installed within substation for generating load model parameters for the distribution substations.

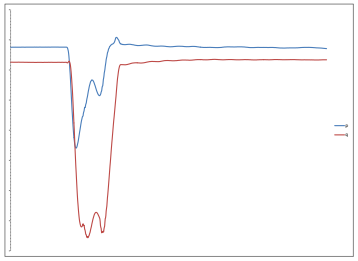


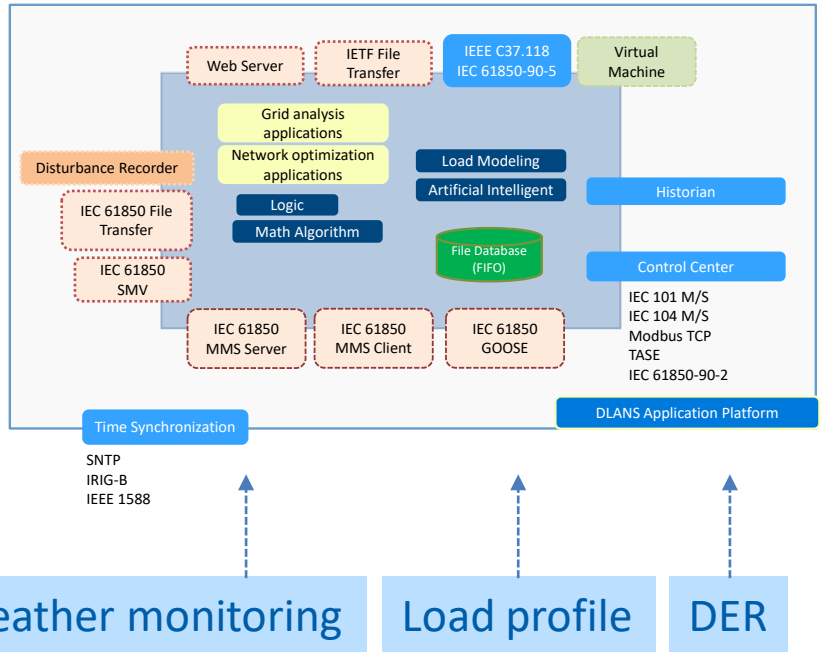
- Automatic acquisition of disturbance data file, leveraging on IEC61850 based Substation Automation System
- Automatic load analysis and modeling application utilizing the system disturbance data
- Communication interface to distributed energy resources (DER), Energy Storage for measurement
- Communication interface to metering device for load profiling

Direct Load Analysis & Modeling System (2)

Load model parameters derivation application based on the system disturbance data. P&Q waveform, curve fitting to find model parameters for ZIP load model structure and motor model. The system continuously capture new event and derive the load models (load is changing and one model can't be used for all cases).

Disturbance Record





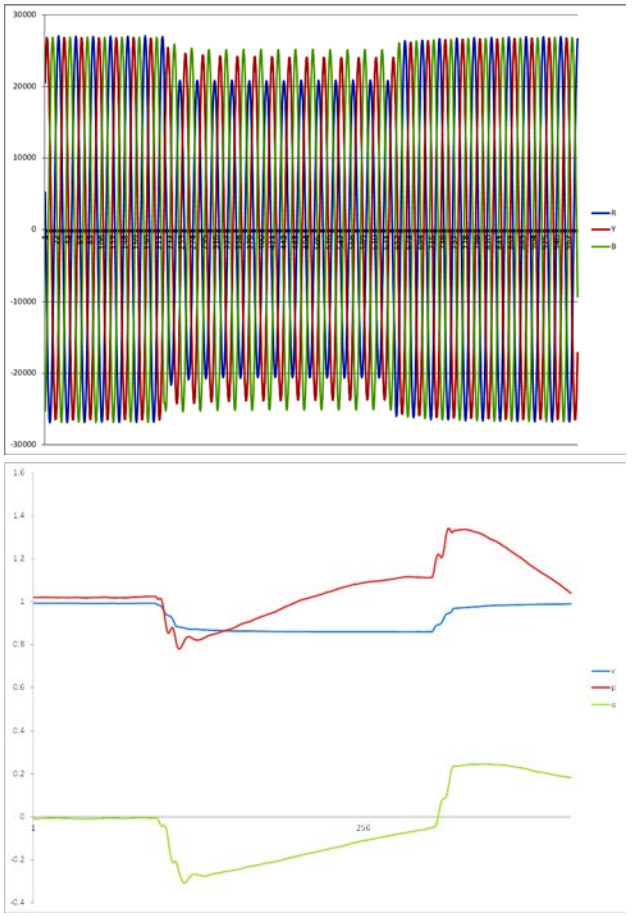
Load model report

```
/ Input File: F:\sample pq data\HOM\2May10\report_HOM2May10.xls
/ Sbase(MVA): 10.000
/ Vbase(kV): 33.000
/ Rf(pu): 0.022
/ Xf(pu): 0.045
/ Capacitor MVAR(pu): -0.141
/ Load Model Structure: 1 Motor + ZIP
/ Mechanical Torque: Ploynomial
/ Beginning of Dynamic Record
1 CIMWBL 1 2 0.300 0.200 5.000 0.100 0.053 0.0 0.0 0.0 0.0 0.0
0.0 10.000 0.0 0.134 0.0 0.0 0.0 0.000 0.002 0.0 0.0 /
1 IEELBL  1 0.703 0.255 0.001 0.999 0.000 0.000 0.0 0.0 2.0 1.0
0.0 2.0 1.0 0.0/
```

Weather monitoring | Load profile | DER

Data requirement for Load Analysis & Modeling

The system disturbance data will be captured by DFR – function in protection IEDs or a dedicated DFR IEDs. Digital fault recorder (DFR), PQ recorder will record V & I waveform whenever there is disturbance occur, depending on the setting.



- System disturbances i.e. voltage dip events or any voltage events
  - External fault in upstream e.g. trees, lightning
  - Transformer tap changes
  - Record the V & I (then convert to r.m.s V, P & Q)
- Capture multiple events for the same feeders
  - Time of the day, seasonal, weekly pattern
- Data resolution
  - 32 samples / cycle for 5 sec is sufficient

Load Model Parameters Derivation

Curve fitting with constrained least square error (LSE). An optimization routine implemented to deliver the best fit with the constraint that the sum of the three ZIP coefficients has to add to 1.

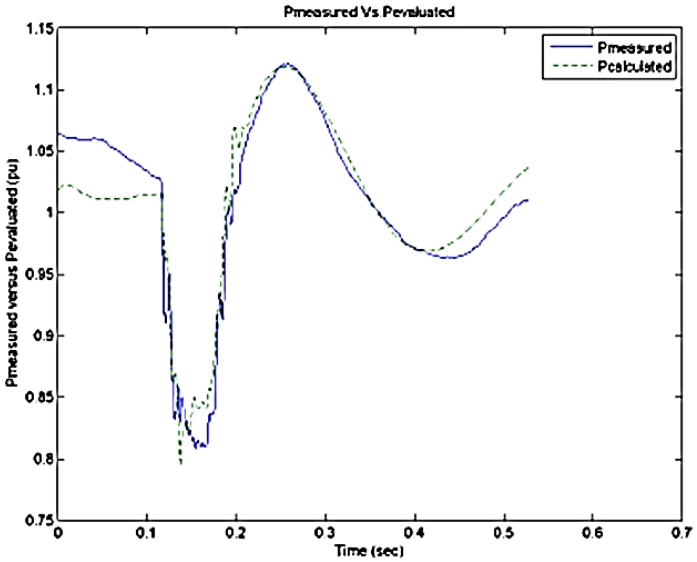
The optimization problem is formulated as follows:

$$min = \left[P_{meas} - P_o \left(Z_p \left(\frac{V_i}{V_o} \right)^2 + I_p \left(\frac{V_i}{V_o} \right) + P_p \right) \right]^2$$

$$min = \left[Q_{meas} - Q_o \left(Z_q \left(\frac{V_i}{V_o} \right)^2 + I_q \left(\frac{V_i}{V_o} \right) + P_q \right) \right]^2$$

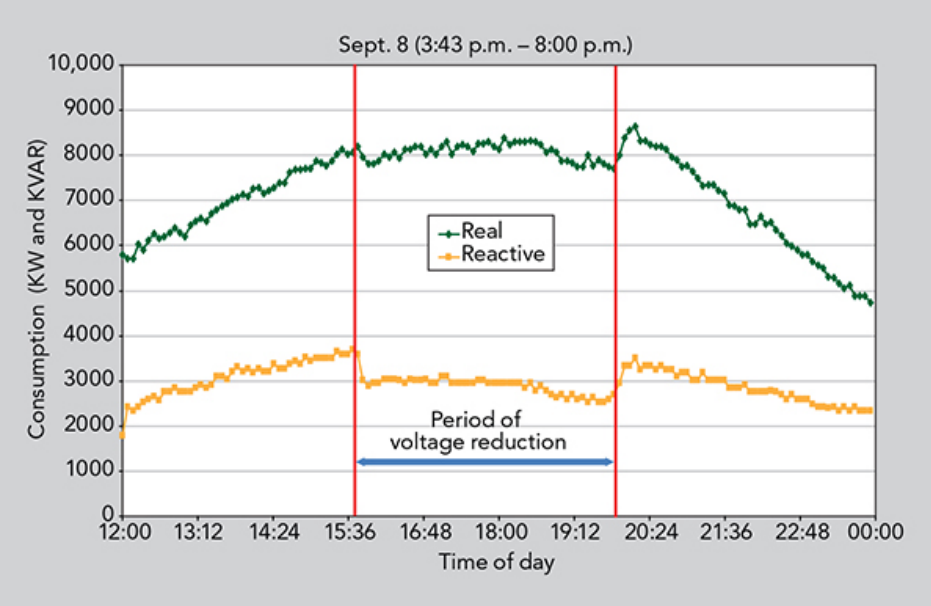
Subject to

$$Z_p + I_p + P_p = 1 \qquad Z_q + I_q + P_q = 1$$

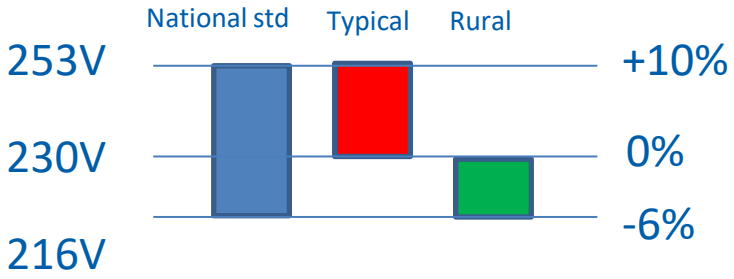


Load model for demand reduction application(1)

Conservation Voltage Reduction(CVR); reduce supply voltage within the regulatory standard (+10% & -6% of 230Vac) to reduce energy consumption and peak demand.



Malaysia standard – steady state supply voltage level



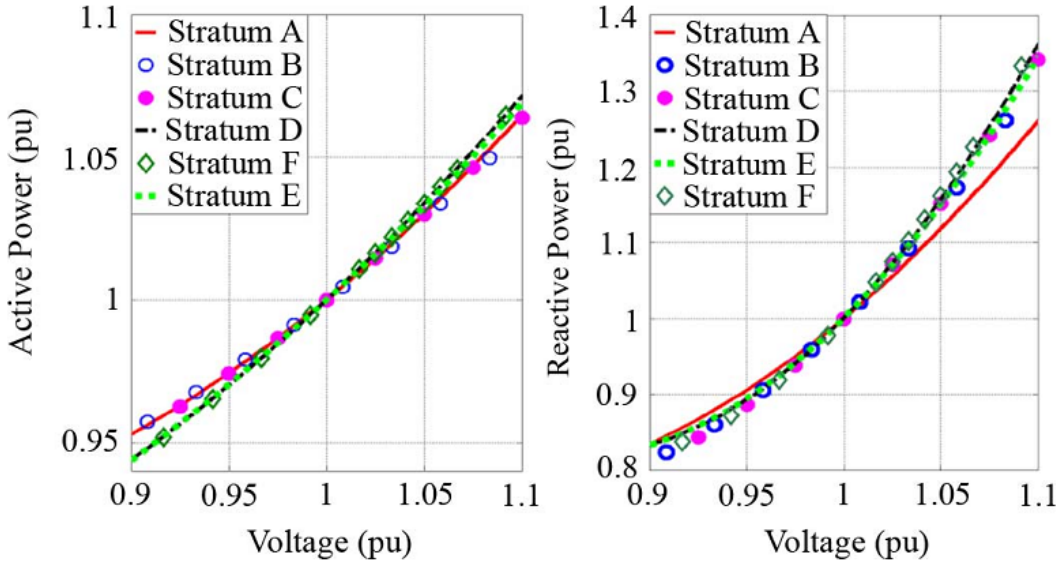
Real and reactive power consumption clearly drop off when voltage is reduced and return to normal values when full voltage is restored

Pee Dee Electric Cooperative in Darlington, South Carolina, U.S

Load model for demand reduction application(2)

Residential ZIP Load model example with >50% is air conditional load. CVR factor is about 1.0 (10% reduction of voltage will save 10% of energy).

Customer class		Z_p	I_p	P_p	Z_q	I_q	P_q
Residential	stratum A	1.5	-2.31	1.81	7.41	-11.97	5.55
	stratum B	1.57	-2.48	1.91	9.28	-15.29	7.01
	stratum C	1.56	-2.49	1.93	10.1	-16.75	7.65
	stratum D	1.31	-1.94	1.63	9.2	-15.27	7.07
	stratum E	0.96	-1.17	1.21	6.28	-10.16	4.88
	stratum F	1.18	-1.64	1.47	8.29	-13.67	6.38



New York City -summer

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Conclusion

1. Direct load analysis and modeling system is a new innovative method for load modeling
2. Automatic system will reduce dependencies to people
3. The system will continuously update the load model as part of substation automation system
4. Produce multiple models for the same load feeders which may suitable for various application such as CVR

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Thank You

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