EE 741

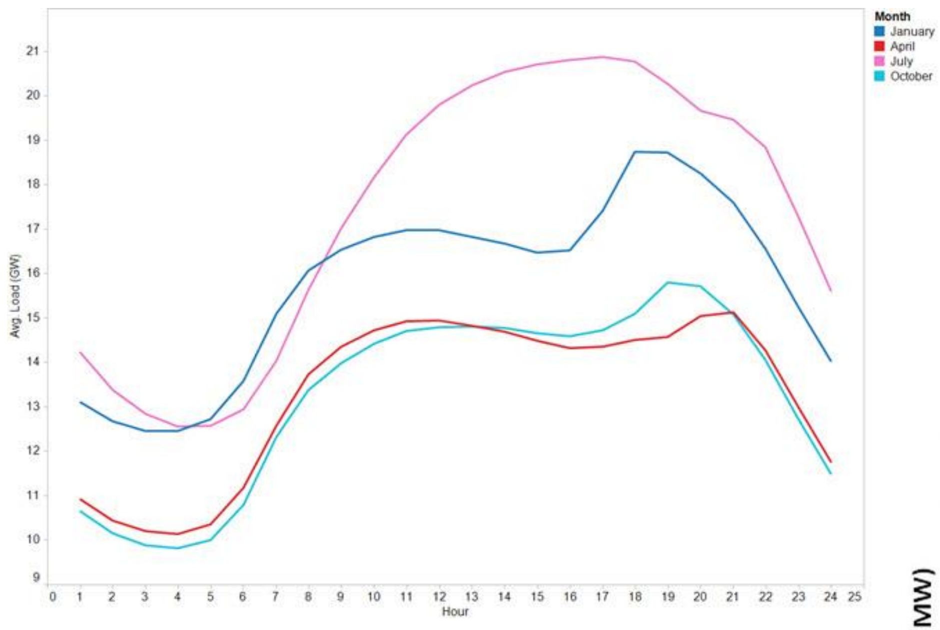
Load Characteristics

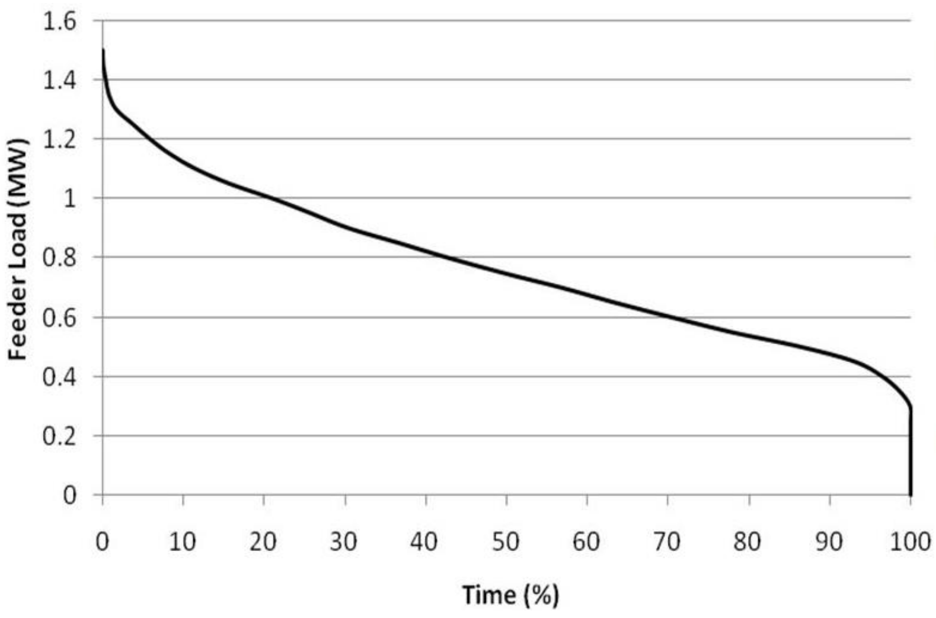
Overview

- Some definitions
- Relation between load and loss factors
- Load models
- Load management
- Rate structure
- Metering
- Load forecasting

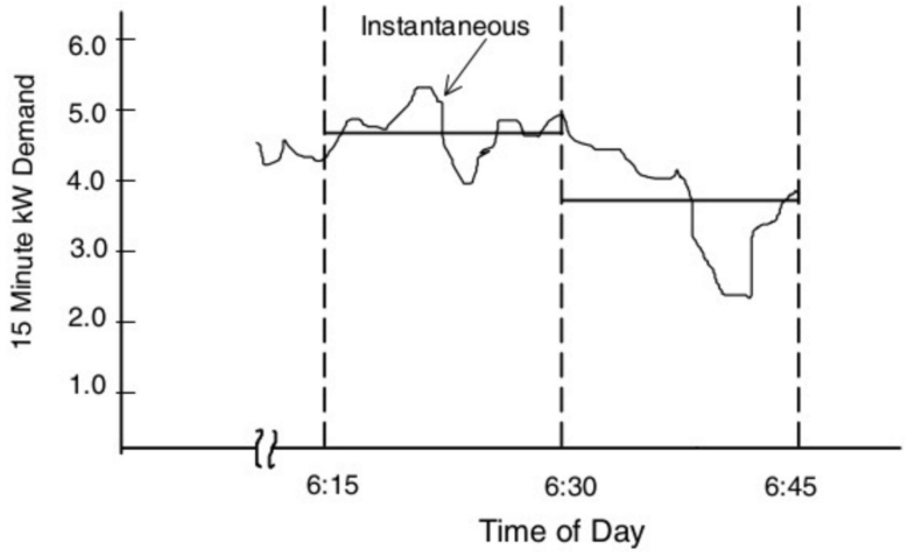
Definitions

- Demand curve, maximum demand, load duration curve



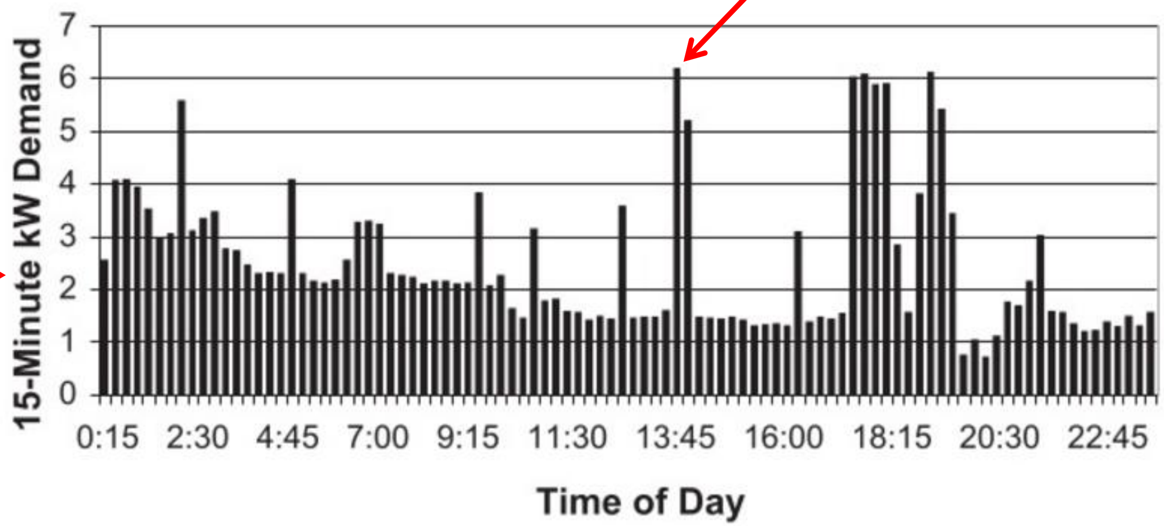


15-min Demand Curve



Maximum 15 min. Demand

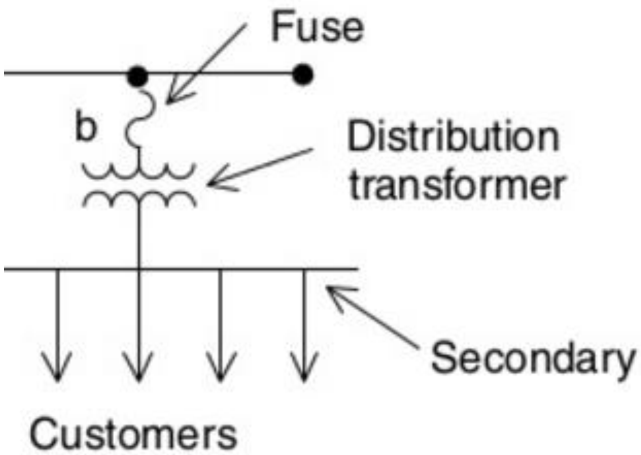
Avg. Demand



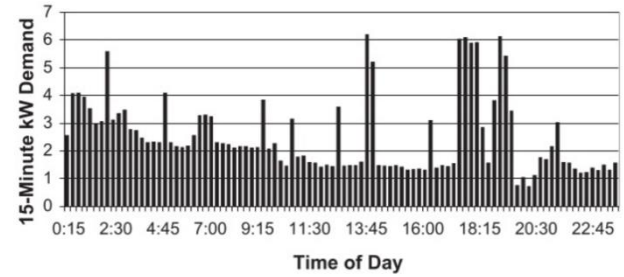
Definitions

- **Demand Factor** = maximum demand/total connected demand
- **Utilization Factor** = maximum demand/rated system capacity
- **Load Factor** (over a designated time period) = average load/peak load
- **Diversity Factor** = sum of individual maximum demands/maximum system demand
- **Loss Factor** = average power loss/power loss at peak load
  - Under steady load, loss factor → load factor
  - Short lasting peak: loss factor → $(\text{load factor})^2$

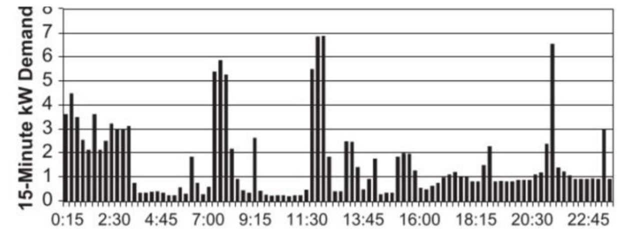
Load Diversity



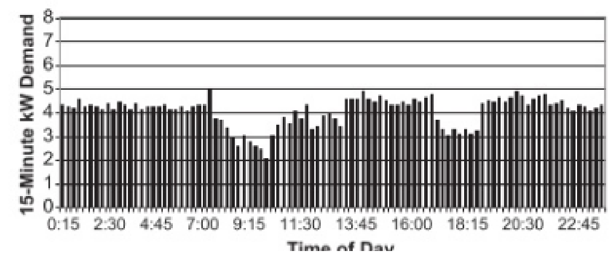
Customer 1



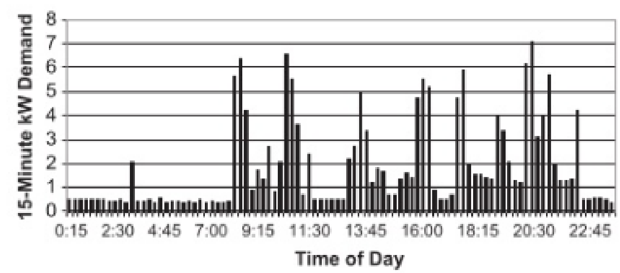
Customer 2



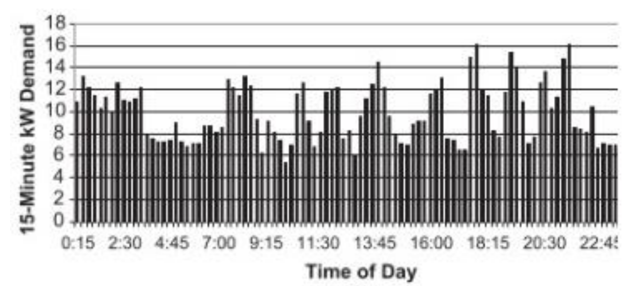
Customer 3



Customer 4



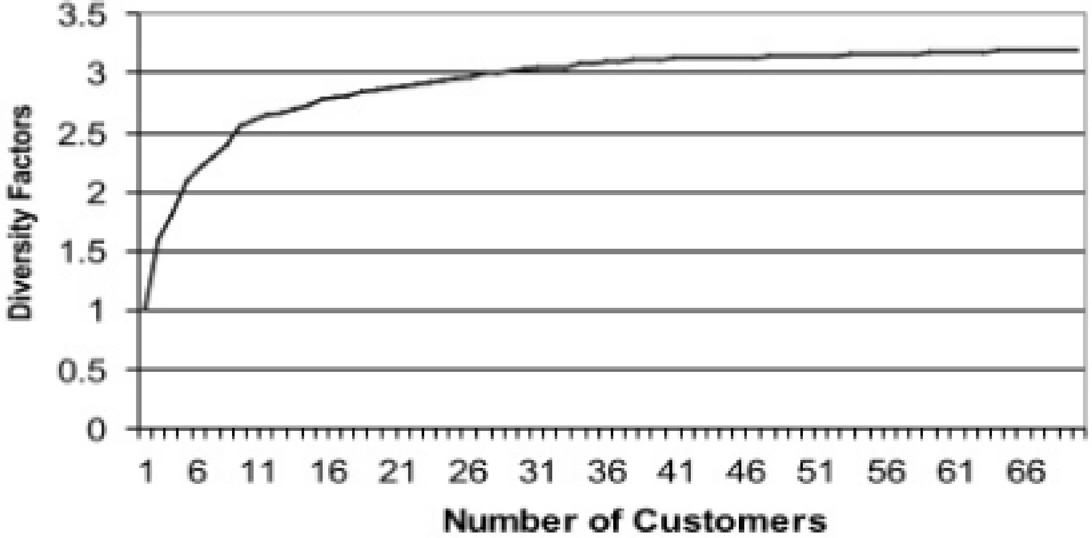
Total



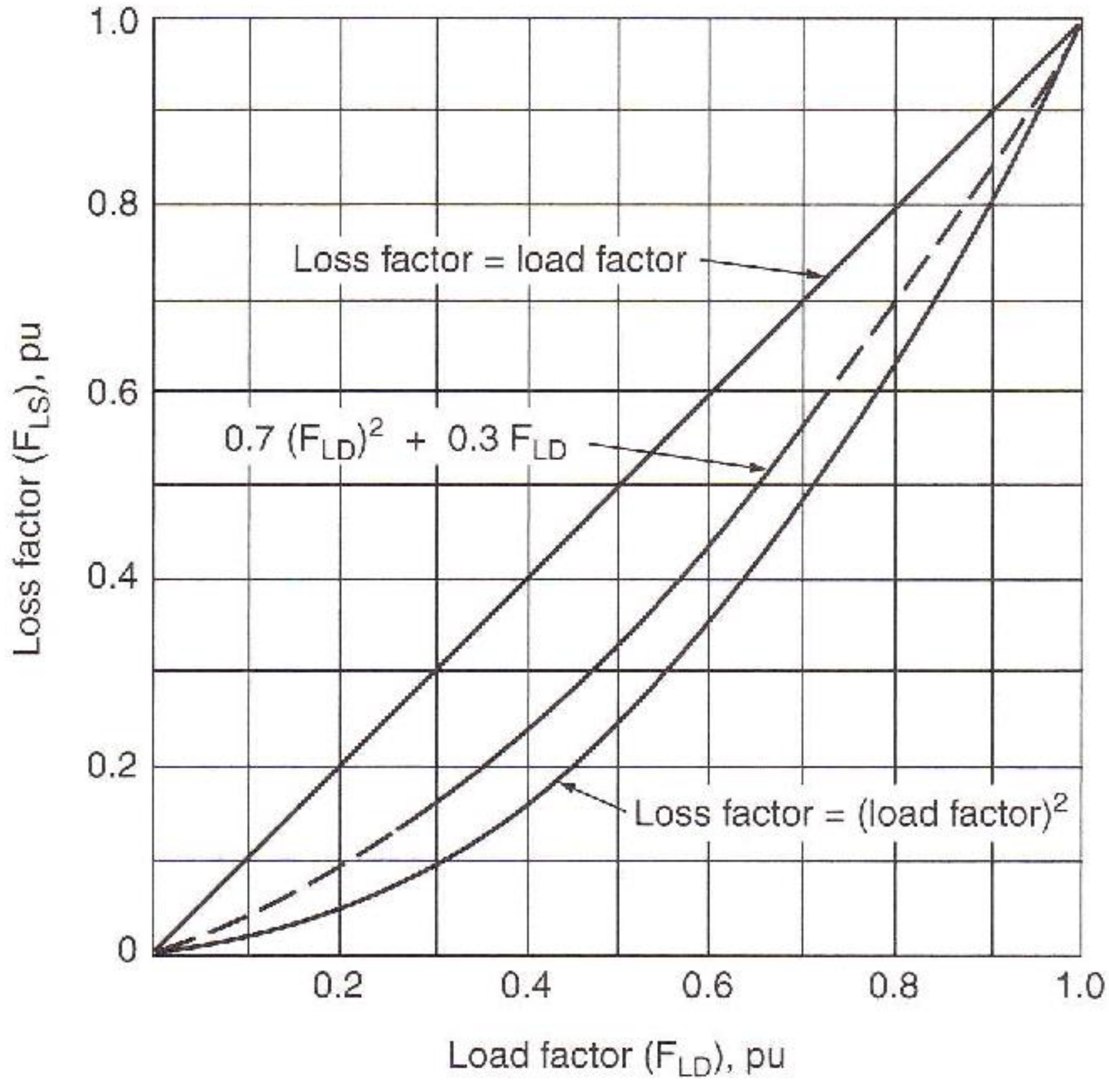
Note that the maximum diversified demand is less than the sum of the Individual maximum demands

Diversity factor ≈ 25/16 = 1.56

Typical Diversity Factor Curve



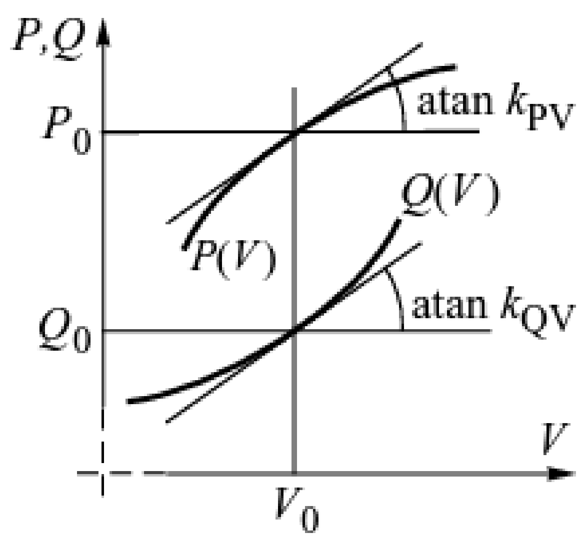
Relation between load factor and loss factor



Power System Loads

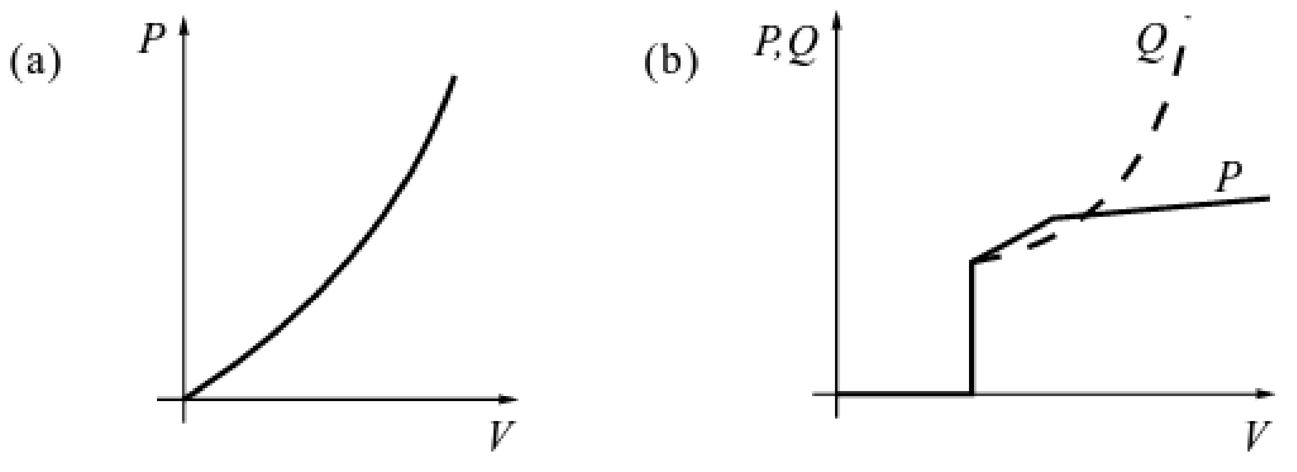
- Only simple static composite load models are described.
- The active and reactive power demand of a static composite load depends on the voltage and frequency.
- *Voltage and frequency sensitivity*: slope of load-voltage or load-frequency characteristics (see fig. below)

$$k_{PV} = \frac{\Delta P / P_0}{\Delta V / V_0}, \quad k_{QV} = \frac{\Delta Q / Q_0}{\Delta V / V_0}, \quad k_{Pf} = \frac{\Delta P / P_0}{\Delta f / f_0}, \quad k_{Qf} = \frac{\Delta Q / Q_0}{\Delta f / f_0},$$



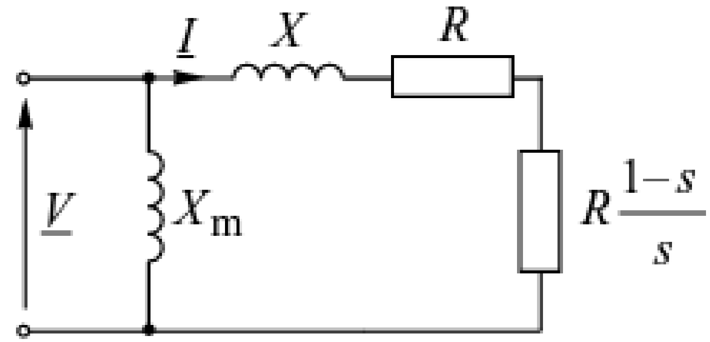
Lighting and heating load characteristics

- Voltage characteristics of incandescent and fluorescent bulbs (see fig. below)
- Heating load equipped with thermostat is considered a constant power load. If not, its is considered a constant resistance load.

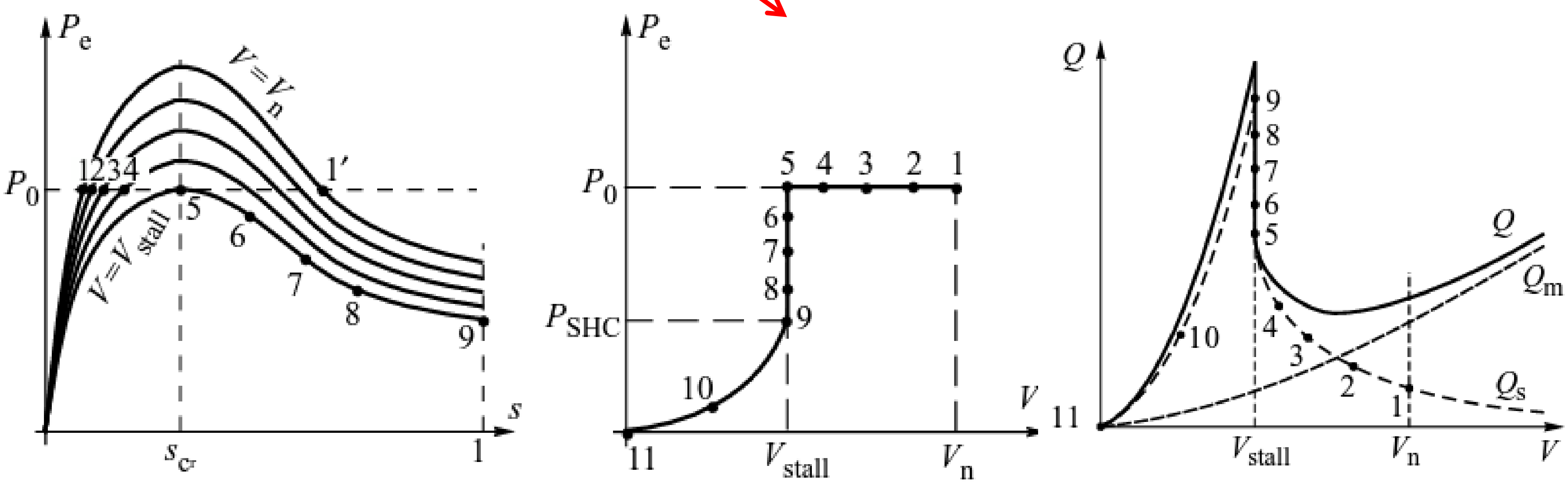


Induction Motors

- Equivalent circuit with stator impedance neglected.

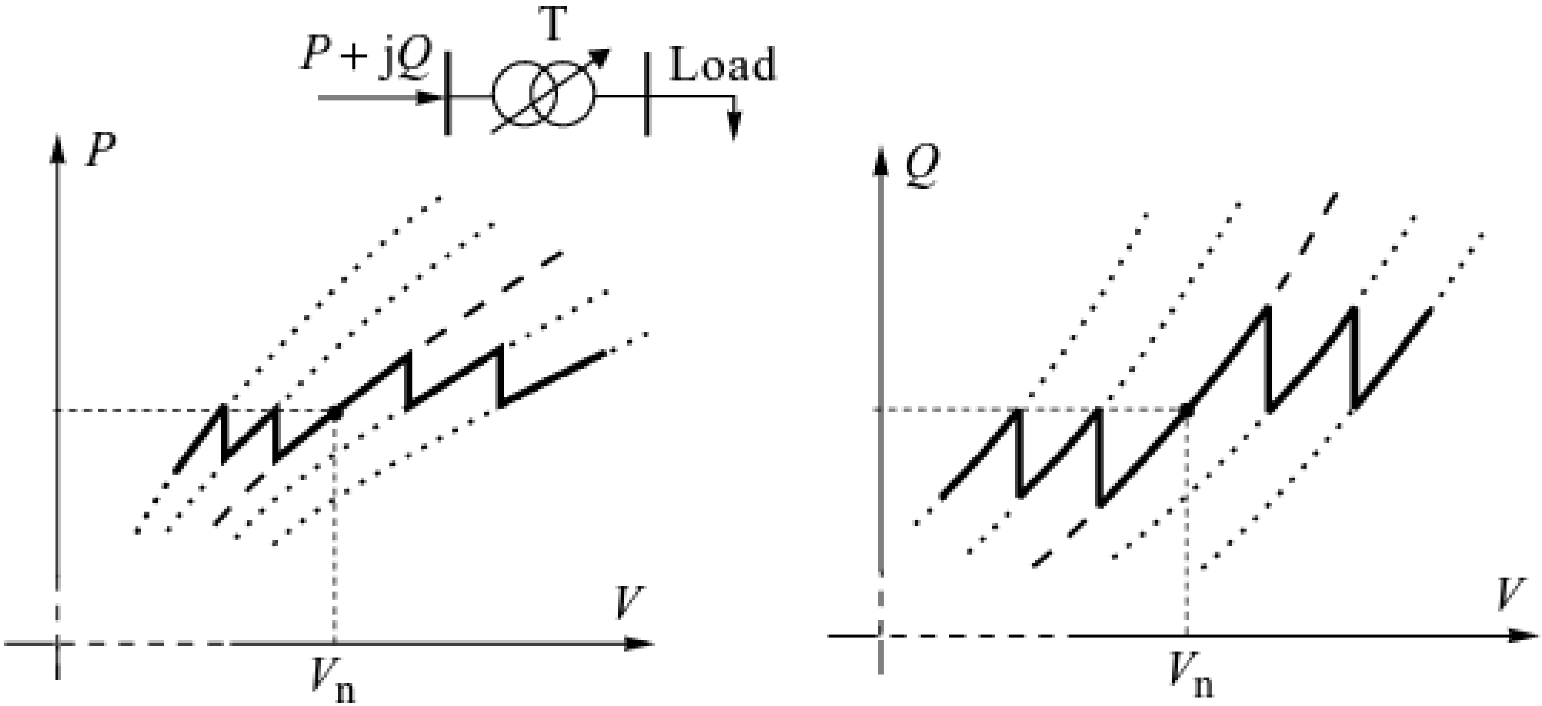


- Voltage characteristic under constant load torque.



(a) (b)

Influence of tap-changing transformer on composite load voltage characteristics



ZIP and Exponential and Frequency-Dependent Load Models

- ZIP model:

$$P = P_0\left[a_1\left(\frac{V}{V_0}\right)^2 + a_2\left(\frac{V}{V_0}\right) + a_3\right]$$

$$Q = Q_0\left[a_4\left(\frac{V}{V_0}\right)^2 + a_5\left(\frac{V}{V_0}\right) + a_6\right],$$

- Exponential model: $P = P_0\left(\frac{V}{V_0}\right)^{n_\mathrm{p}}$ and $Q = Q_0\left(\frac{V}{V_0}\right)^{n_\mathrm{q}}$,

- Frequency dependent model:

$$P = P(V)\left[1 + k_\mathrm{Pf}\frac{\Delta f}{f_0}\right]$$

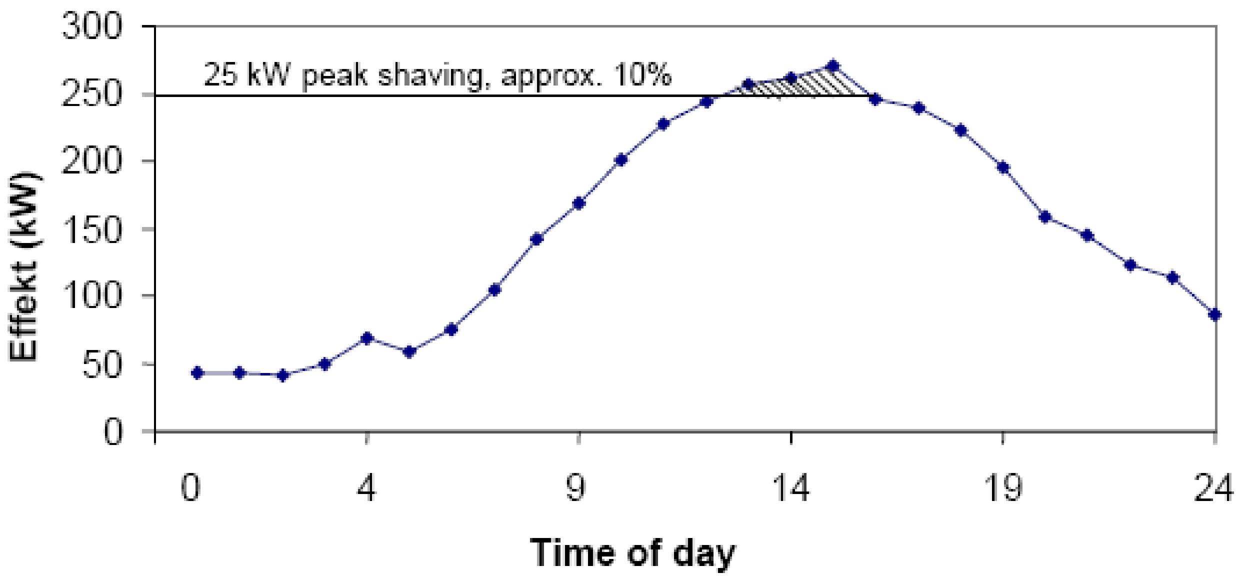
$$Q = Q(V)\left[1 + k_\mathrm{Qf}\frac{\Delta f}{f_0})\right],$$

Load Forecasting

- In order to plan the resources required to supply the future loads in an area, it is necessary to forecast as accurately as possible the magnitude of these loads.
- Such forecasts are often based on historical growth trend, and land use.
  - Trend (or regression analysis) is the study of a time series in the past and its mathematical modeling (curves) so that future behavior can be extrapolated from it.
  - Land use simulation involves mapping existing and likely additions to land coverage by customer classes (i.e., residential, commercial, industrial). The goal is to project changes in the increase of peak demand on a locality basis.

Load Management (i.e., DSM)

- DSM involves remotely controlling individual customer loads. It is beneficial in many ways:
  - Maximize the utilization of existing resources
  - Minimize more costly generation or power purchases
  - Defer capital expenditures
  - Reduce cold load pick-up during re-energization of circuits



Rate Structure NV Energy (see brochure)

- The utility's revenue requirement is determined by the PUC
- The residential rate structure is rather simple (see by latest bill below)
  - Basic Service Charge covers some non-energy costs associated with providing basic services such as bill preparation, meters, meter reading, and customer accounting.
  - monies going to the State of Nevada fund for energy assistance and conservation as set forth in NRS 702.010
  - Green and Renewable Energy fees are to cover the rebates for such resources
- For large customers, the rate schedule can be complex (e.g., go to nvenergy.com and search for rate schedule)

ELECTRIC - RESIDENTIAL SERVICE

Meter Number	Service Category	Service Period From	Service Period To	Bill Days	Meter Readings Previous	Meter Readings Current	Meter Multiplier	Billing Usage
674071676	KWH	Jul 7	Aug 5	29	8232	11075	1	2,843

ELECTRIC CONSUMPTION	2,843.00	KWH	x .1171300	333.00
TEMP. GREEN POWER FINANCING (TRED)	2,843.00	KWH	x .0005900	1.68
RENEWABLE ENERGY PROGRAM (REPR)	2,843.00	KWH	x .0002800	.80
BASIC SERVICE CHARGE				8.00
LOCAL GOVERNMENT FEE			5%	17.17
UNIVERSAL ENERGY CHARGE	2,843.00	KWH	x .0003900	1.11
TOTAL ELECTRIC SERVICE AMOUNT				$361.76

APS (see link below)

- https://www.aps.com/en/residential/accountservices/serviceplans/Pages/demand-rates.aspx

Figure: APS Demand Rate Options

	Basic Service Charge (per month)	Demand Charge ($/kW)**	Summer Energy Charge (On/Off Peak $/kWh)	Winter Energy Charge (On/Off Peak $/kWh)
Extra Small*	$18	None	$0.10324	$0.10324
R-1	$24	$6.60/kW	$0.1516/$0.08070	$0.12730/$0.08070
R-2	$14.50	$8.40/kW	$0.1516/$0.0808	$0.12730/$0.0808
R-3	$24	$16.40/kW summer $11.50/kW winter	$0.0909/$0.05475	$0.06670/$0.05475

* Extra Small option is available for customers using less than 600kWh per month on average. Partial requirements customers are not eligible for this rate.

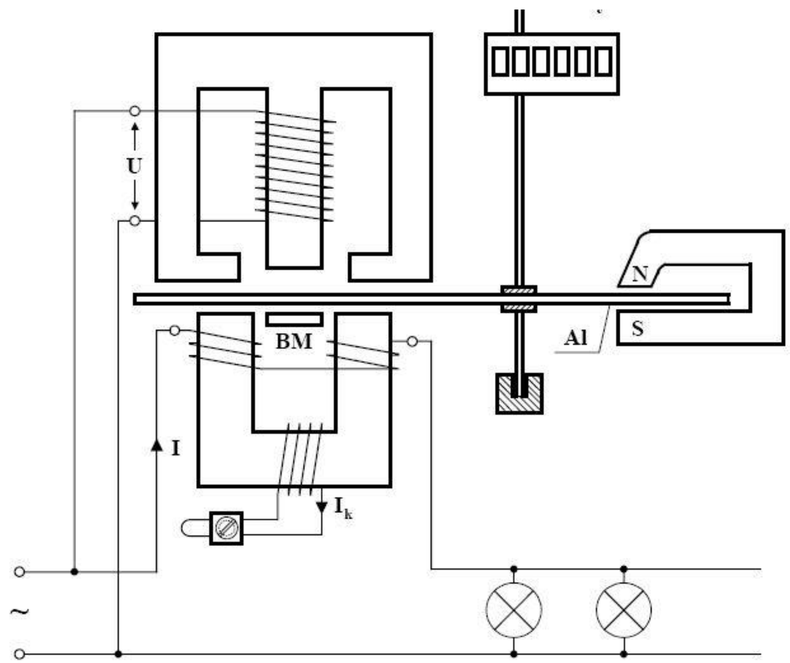
**Demand charge calculated as the average over one hour during the on-peak window only.

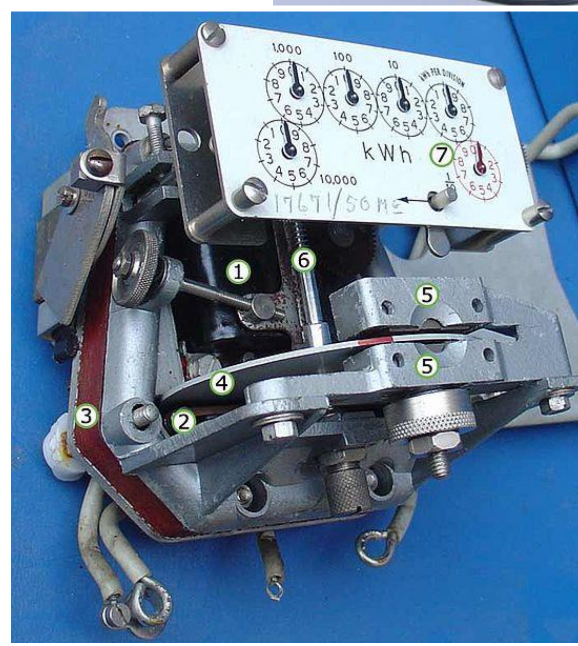
Metering

- Induction Type kilo-watt-hour meters
- Demand meters
- Kilo-Var-hour or kilo-volt-ampere-hour meters (for power factor measurement)
- Solid-State (electronic) meters
- Smart meters

Induction type kilo-watt-hour meter

- Disc speed proportional to real power
- Registers (dials) record total energy consumed to date





Kilo-Var-hour and kilo-volt-ampere-hour meter

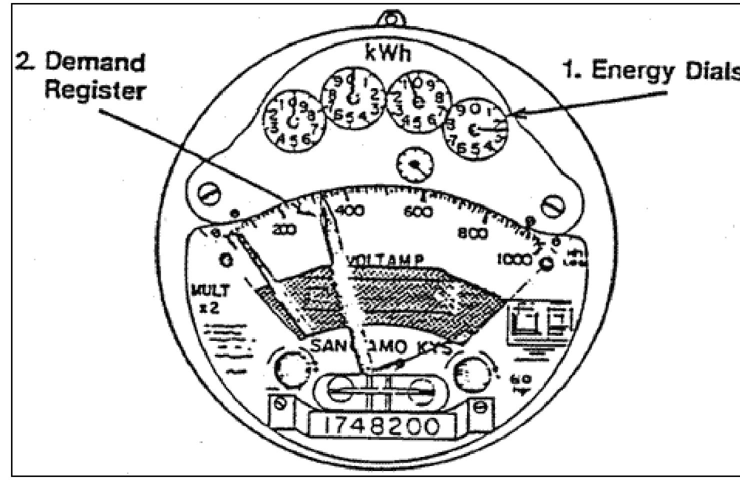
- Power Factor Calculation from (P,S) or (P,Q)

$$PF = \frac{P}{S} = \frac{P}{\sqrt{P^2 + Q^2}}$$

- Need for operation at high power factor
  - Lower current
  - Lower losses
  - Lower voltage drop
  - Release in capacity
- Utilities typically charge additional costs to customers who have a power factor below some limit, which is typically 0.85 to 0.95.

Demand Meter

- The power is averaged for every fifteen- or thirty- minute interval
- Each 15 (or 30) minute period is known as a demand interval.
- Demand (kW), unlike kWh's, however is not cumulative, as demand is billed based upon the highest 15 (or 30) minute demand interval for the billing period.



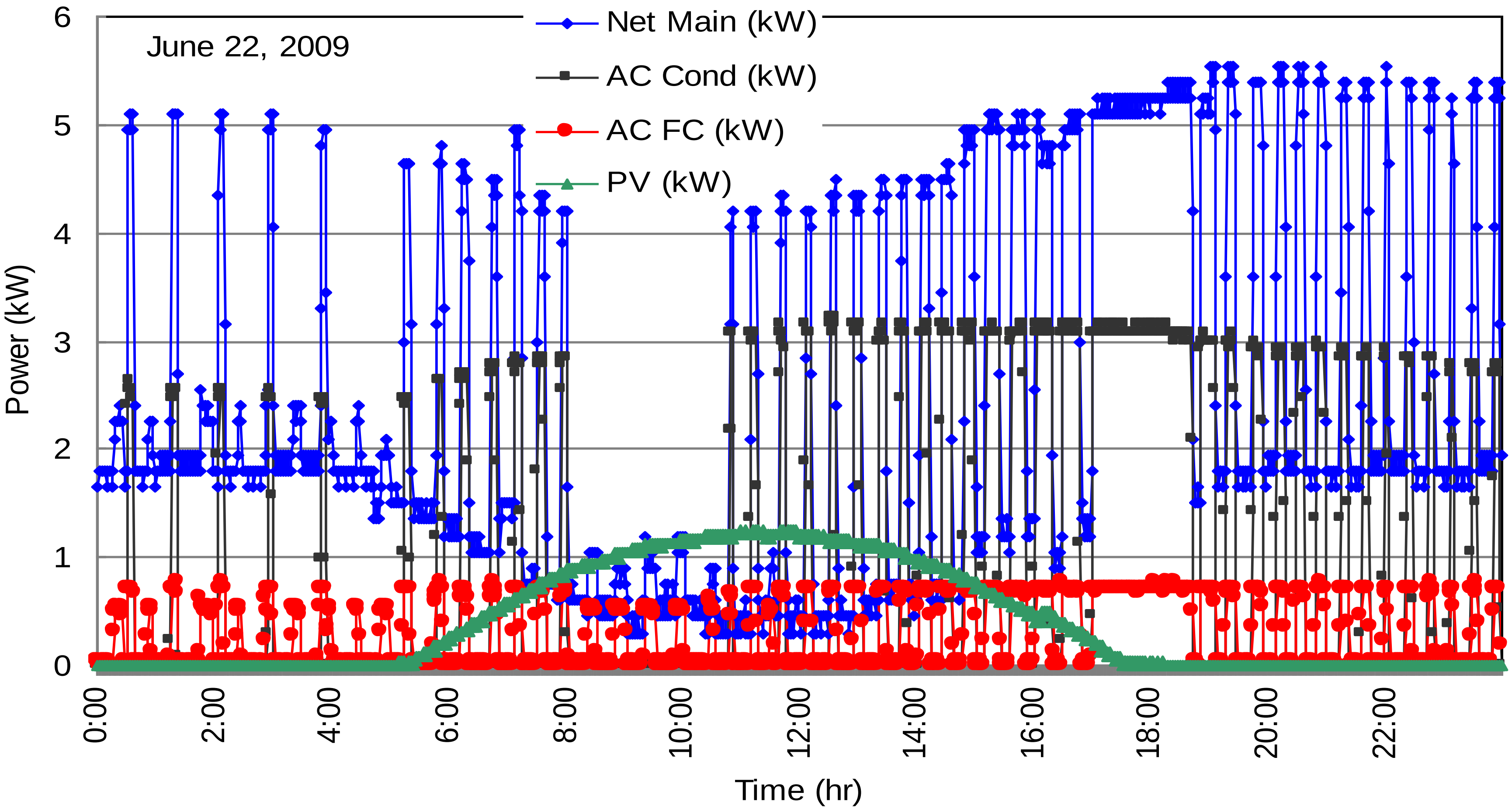
Electronic electric utility meter

- Electronic meters display the energy used on an LCD display, and can also transmit readings to remote places.
- In addition to measuring energy used, electronic meters can also record other parameters of the load and supply such as maximum demand, power factor and reactive power used etc.
- They can also support time-of-day billing, for example, recording the amount of energy used during on-peak and off-peak hours.

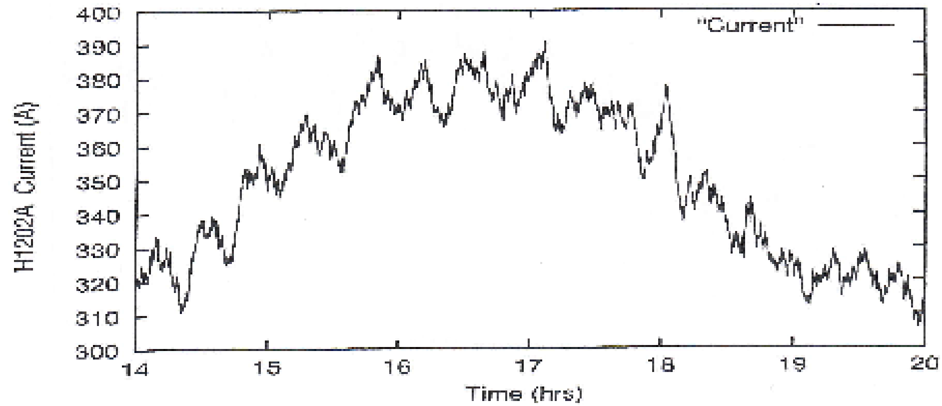
Smart meter

- Records kW, kVAR, KVA, PF, kWhr, peak demand, power quality disturbances, etc…
- Communicates with utility Energy Management System
- Remote power disconnect/reconnect
- Communicates with major home appliances

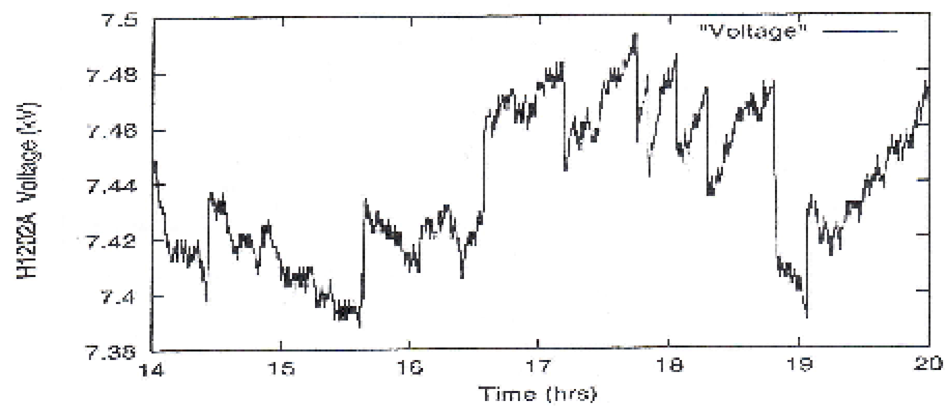
Electrical power used/generated by important components of a home with PV



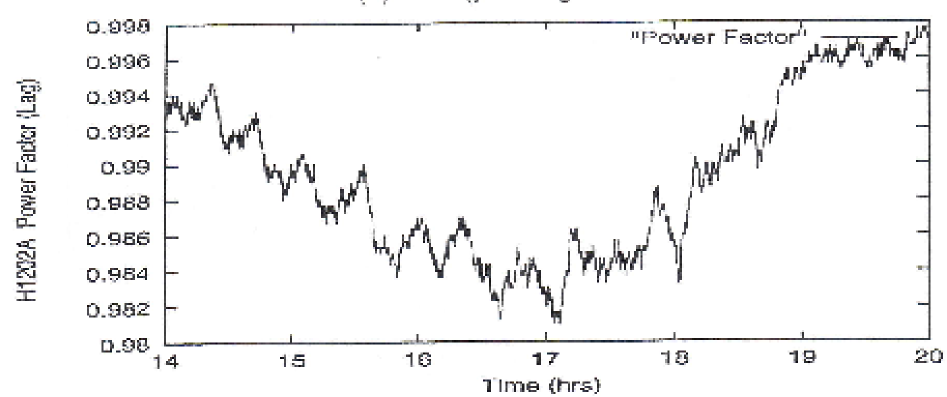
Average current, phase voltage and power factor variation on a feeder over a 6-hour period



(a) Average Current

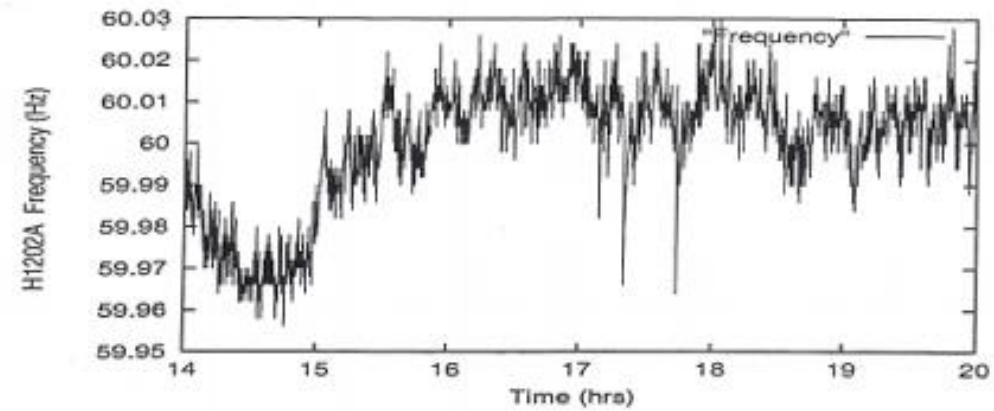


(b) Average Voltage

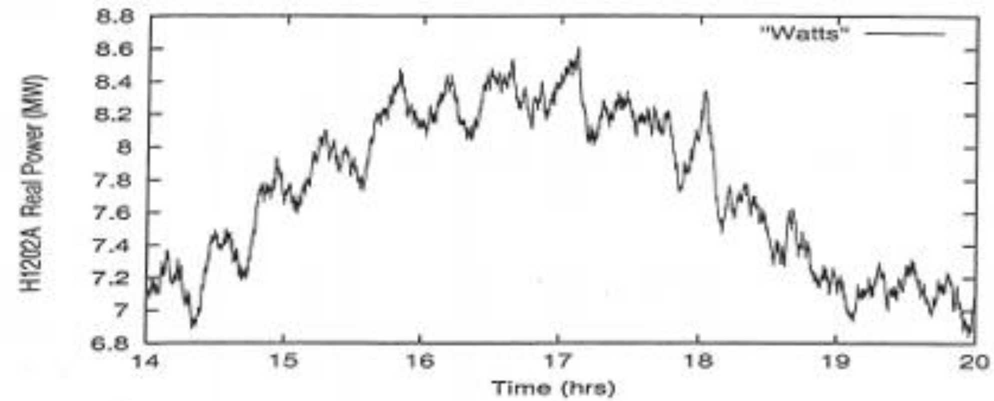


(c) Average Power Factor

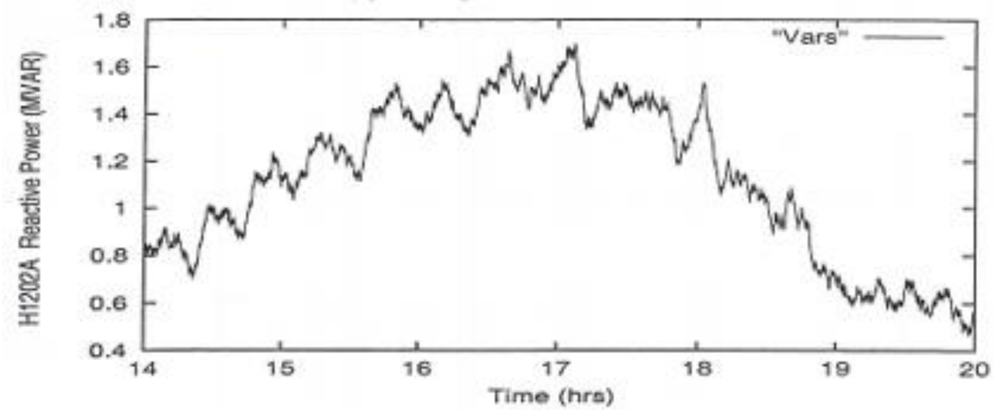
Frequency, real and reactive power variation on a feeder over a 6-hour period



(d) Frequency

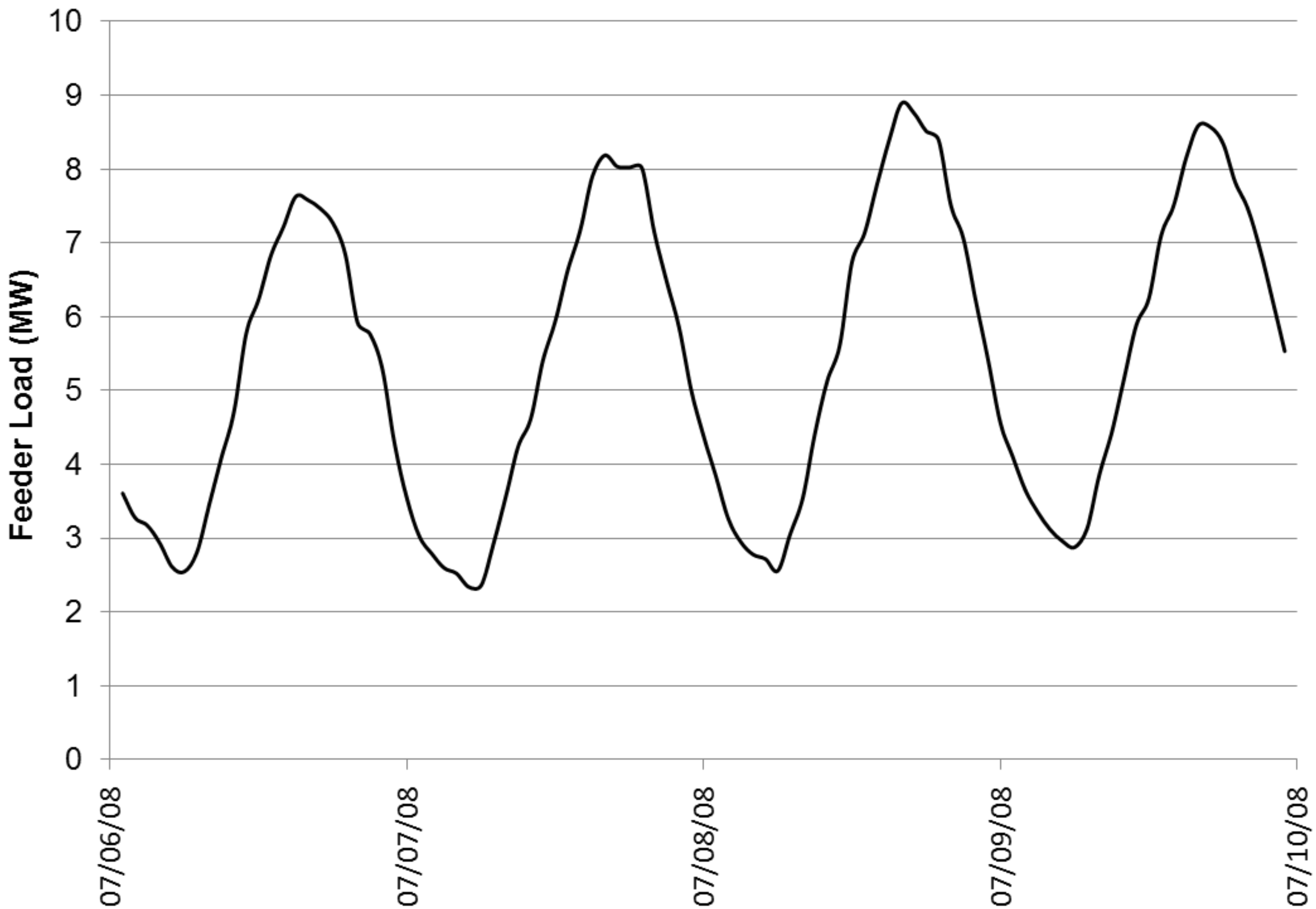


(e) Average Active Power

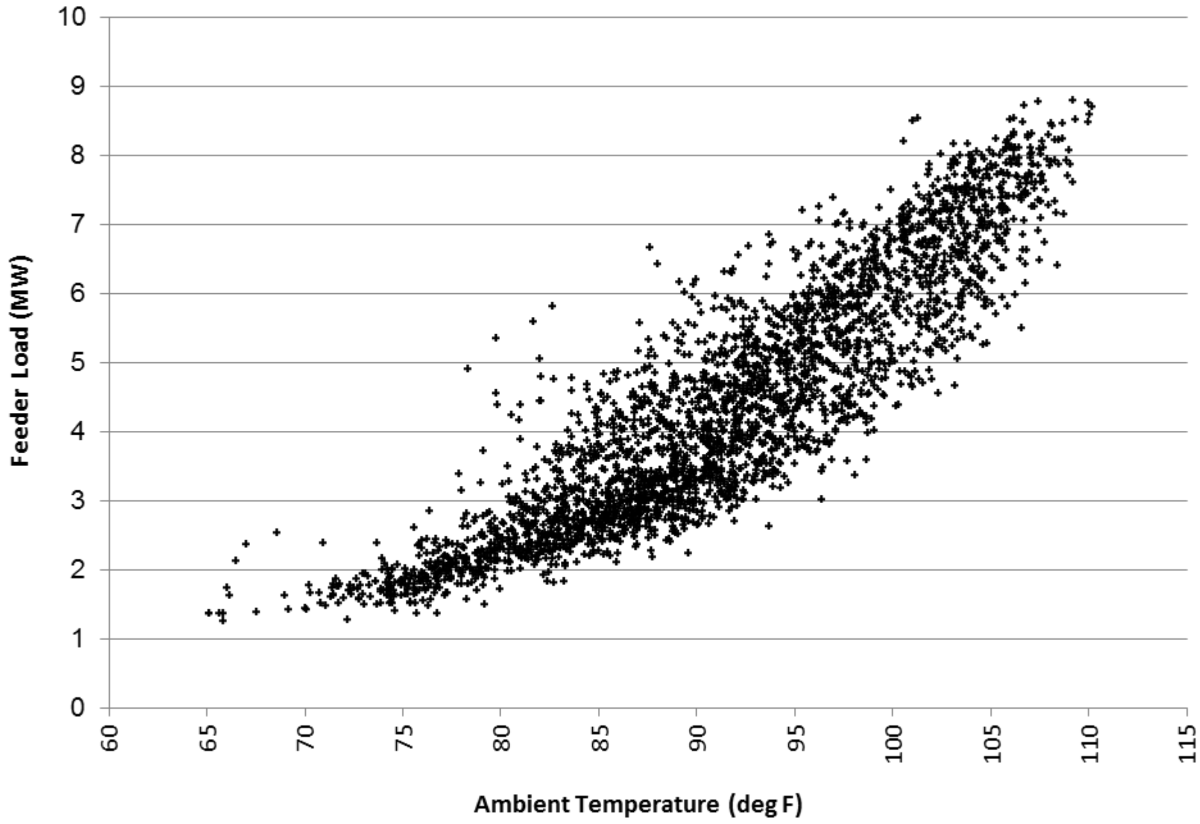


(f) Average Reactive Power

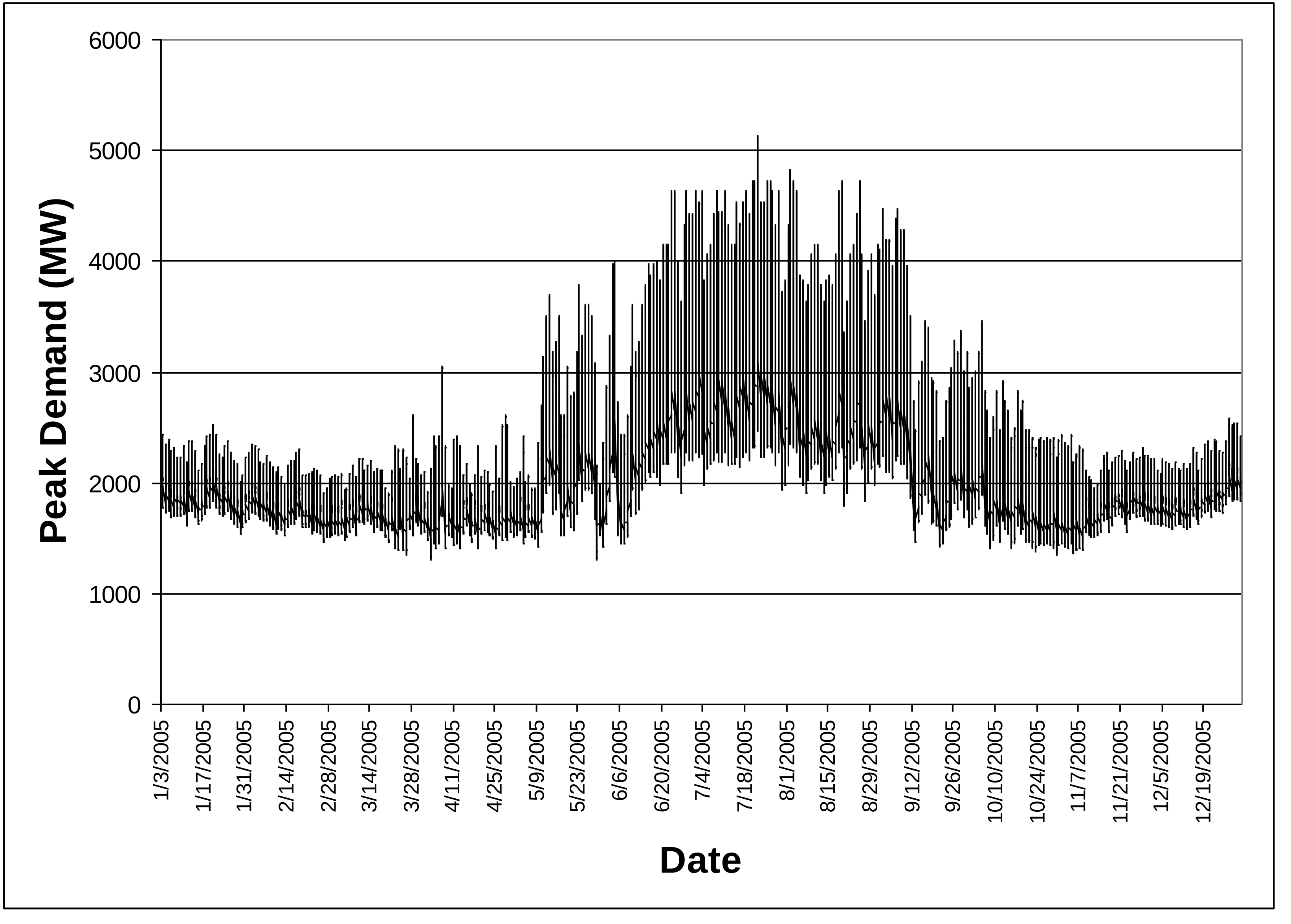
Local Feeder demand curve – 4 day period



Load- Temperature Curve



Local System Load (2005)



Exercises

Problem 1: Consider the following motor data – 4-pole, 60 Hz

25 Hp, 208 V operating with slip = 0.035

$$Zs = 0.0774 + j0.1843\ \Omega$$

$$Zm = 0 + j4.8384\ \Omega$$

$$Zr = 0.0908 + j0.1843\ \Omega$$

Compute the following

(1) The input line currents and complex three-phase power.

(2) The currents in the rotor circuit.

(3) The developed shaft power in Hp.

(4) Determine the motor active and reactive power when the supply voltage is reduced by 10%. Assume the mechanical torque is constant.

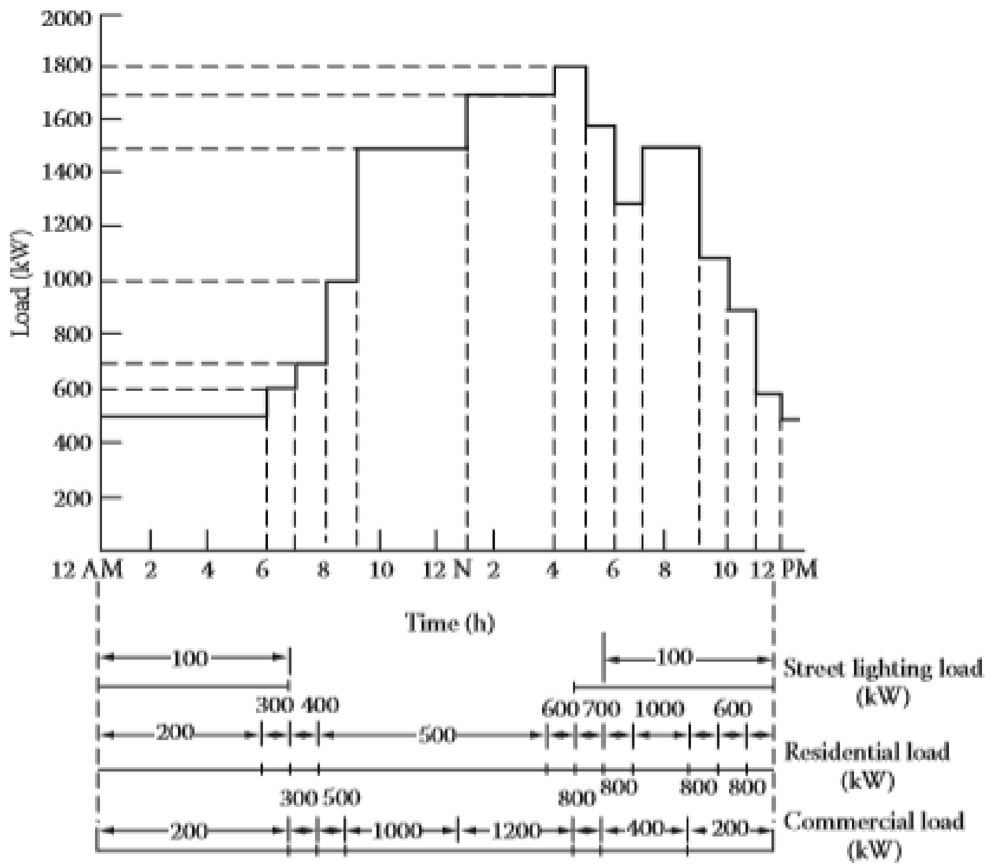
$$\tau_{ind} = \frac{1}{\omega_s} \frac{3V_{TH}^2 \left(\frac{R_2}{s}\right)}{\left(R_{TH} + \frac{R_2}{s}\right)^2 + (X_{TH} + X_2)^2}$$

$$V_{TH} \approx V_\phi \frac{X_M}{X_1 + X_M}$$

$$R_{TH} \approx R_1 \left(\frac{X_M}{X_1 + X_M}\right)^2$$

$$X_{TH} \approx X_1$$

Problem 2: consider the following load curve on a feeder that serves commercial, residential and lighting load.



Compute the diversity factor, load factor, and loss factor.