EE2022 Electrical Energy Systems

Cost of Electricity

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Department of Electrical and Computer Engineering

Detailed Syllabus

Topic 1	**Transformer**: Principle of transformer. Ideal transformer. Reflected load. Impedance matching. Practical transformer. Examples
Topic 2	**Renewable Energy Sources:** Sustainable and clean energy sources; Solar Photovoltaic, Wind Energy; Examples
Topic 3	**Per unit analysis**: Single-phase per unit analysis. Three-phase transformer, Three-phase per unit analysis. Examples.
Topic 4	**Generator**: Simple generator concept. Equivalent circuit of synchronous generators. Operating consideration of synchronous generators, i.e. excitation voltage control, real power control, and loading capability. Examples.
Topic 5	Electric energy market operation; Cost of Electricity

Outline

- Electricity Market
- Cost of Electricity

Power Market

Market Restructuring Models

Market Clearing Price

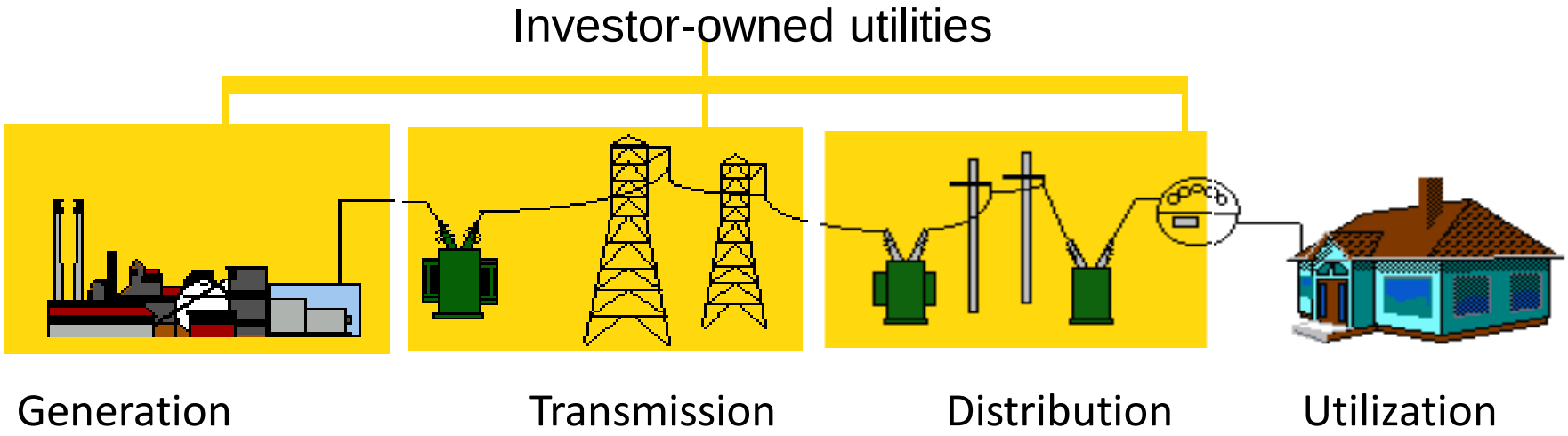
ELECTRICITY MARKET

Electricity Market vs Other Markets

- Electricity → Product
- Transmission → Service
- Buyers and Sellers agree on a Price
- Electricity cannot be stored in large quantities
- Electricity cannot be labelled
- Power flow cannot be controlled by financial instruments

Traditional Power Market

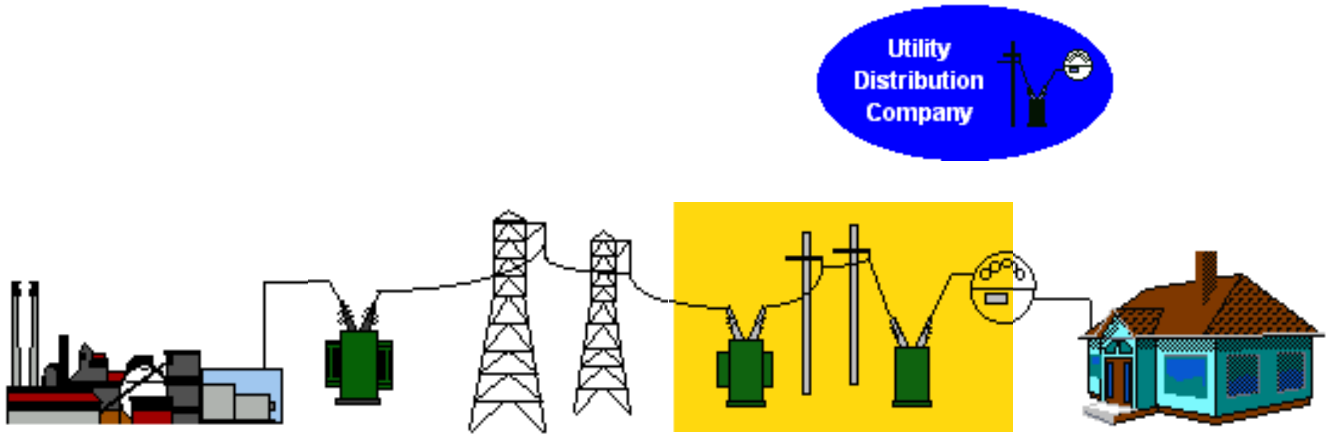
- Structure before 1990s
- Power Utilities provided bundled service including generation, transmission, and distribution



New Industry Structure

- Aim: To improve the efficiency by providing a more reliable energy at minimum cost to customers
  - Services are unbundled
  - Public → Private Ownership
- Deregulation and Restructuring
  - Raising revenue for state
  - Increase competition
  - Increase Efficiency

Competition in Electricity Market



Generation Transmission Distribution Customers

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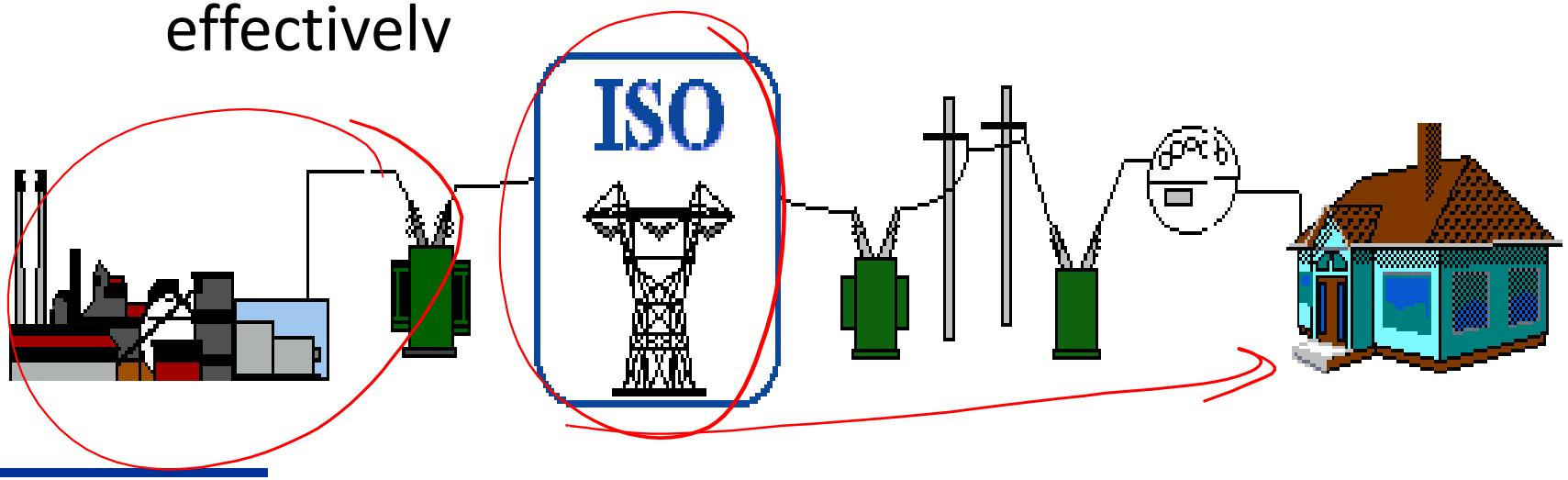
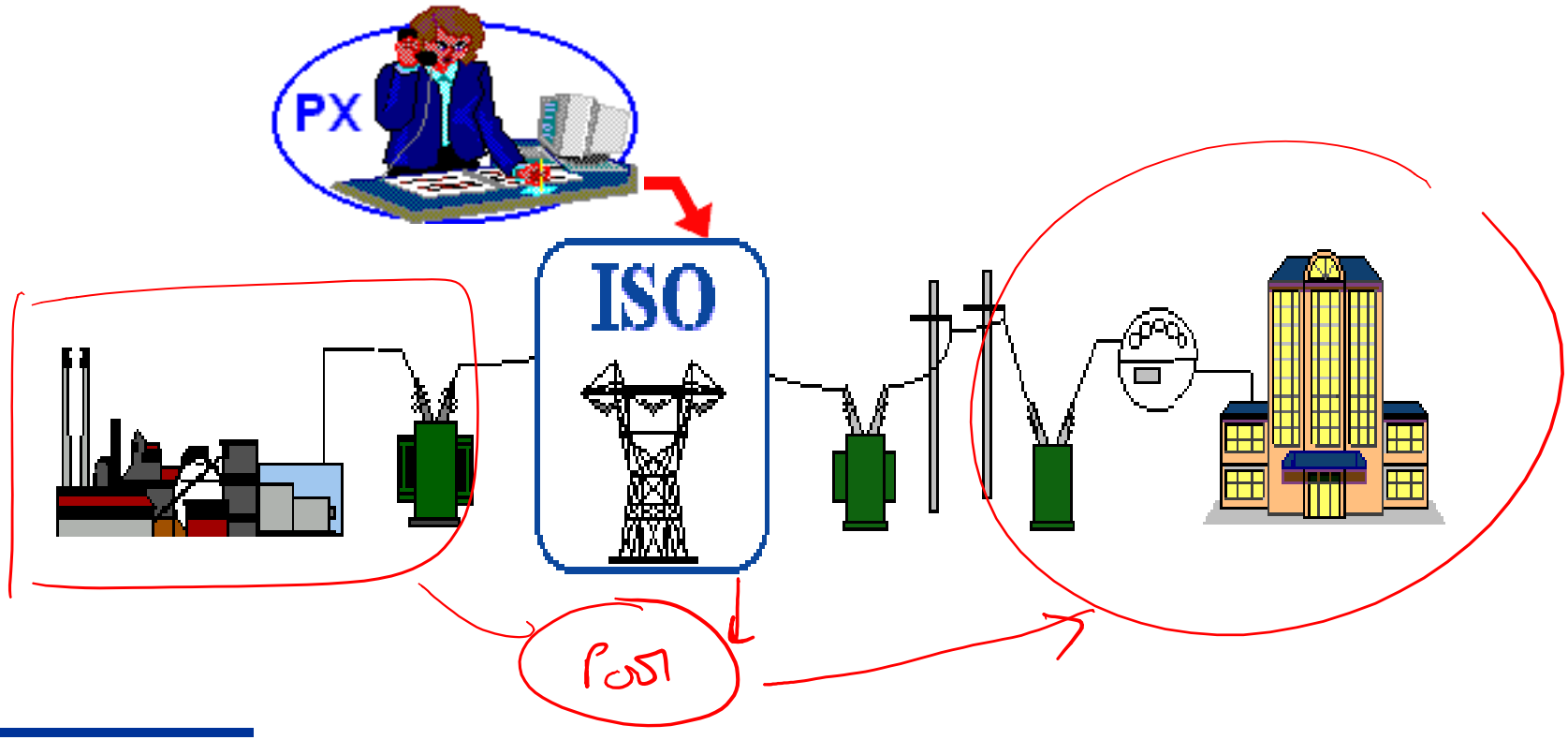
How to Restructure the System???

- Independent System Operator (ISO)
  - Energy reaches its destination safely and reliably
  - Access to transmission system is open and non-discriminatory
  - Electricity markets function efficiently and effectivelv



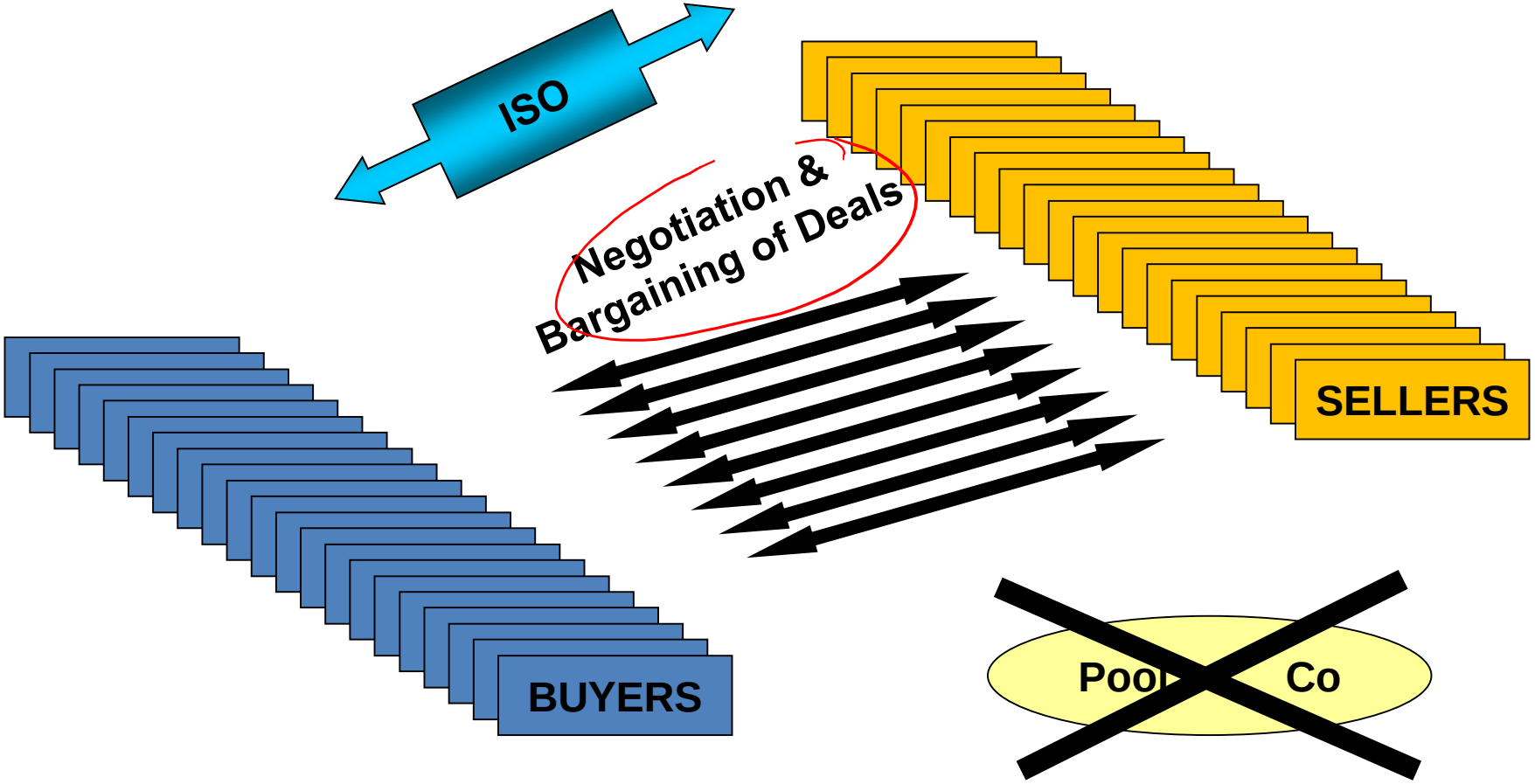
Market Restructuring Models

- PoolCo Model



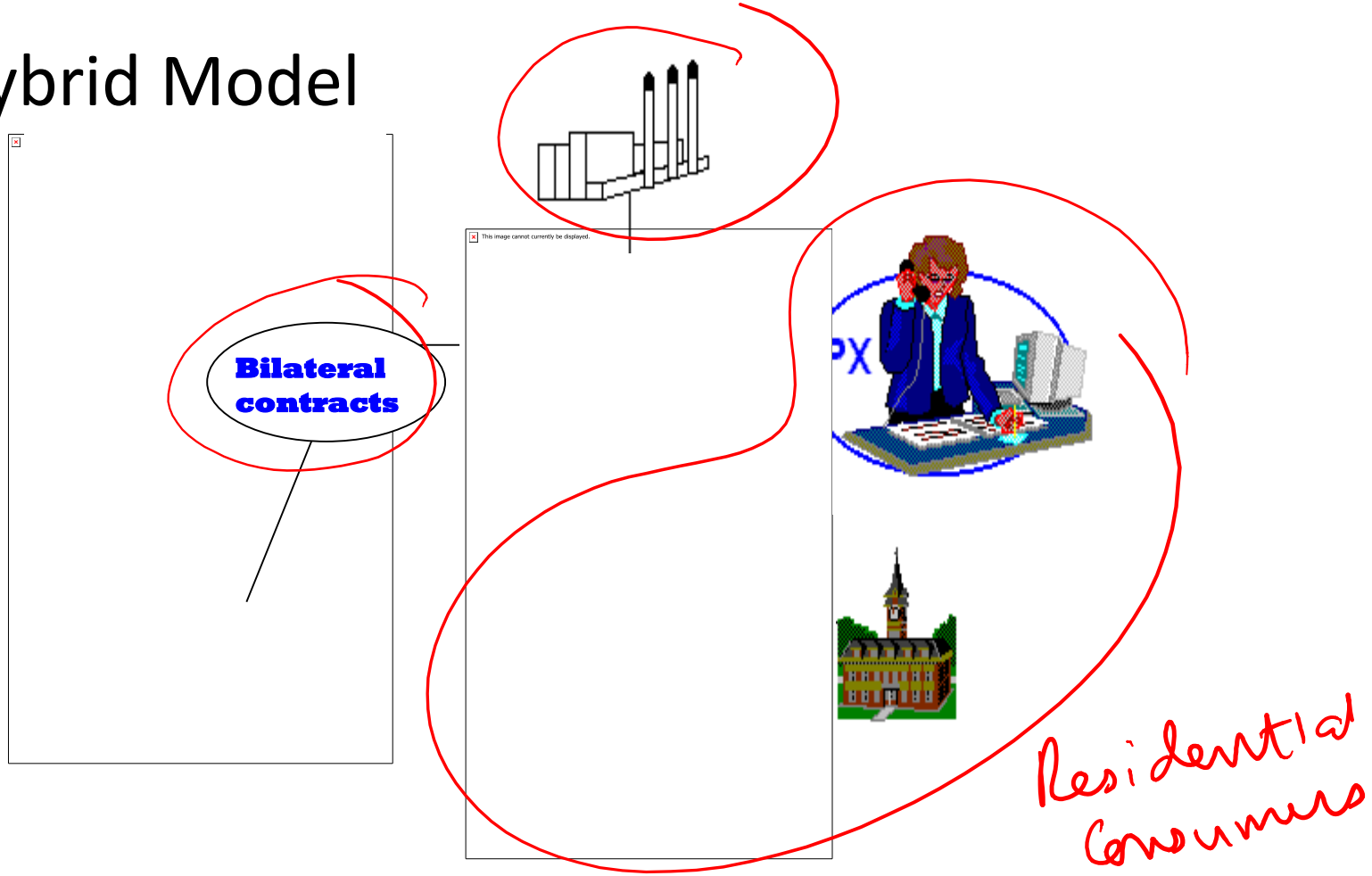
Market Restructuring Models

- Bilateral Model

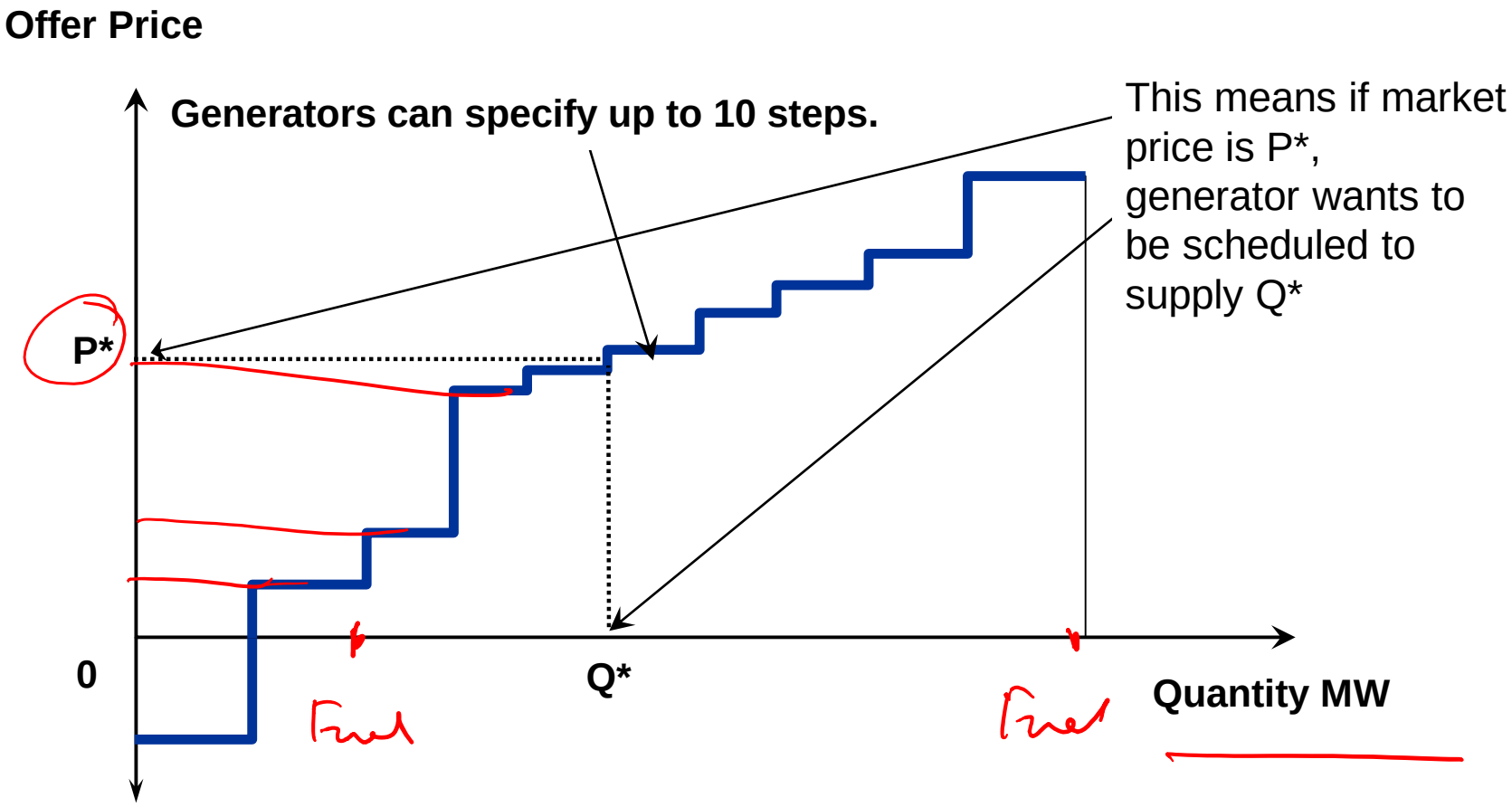


Market Restructuring Models

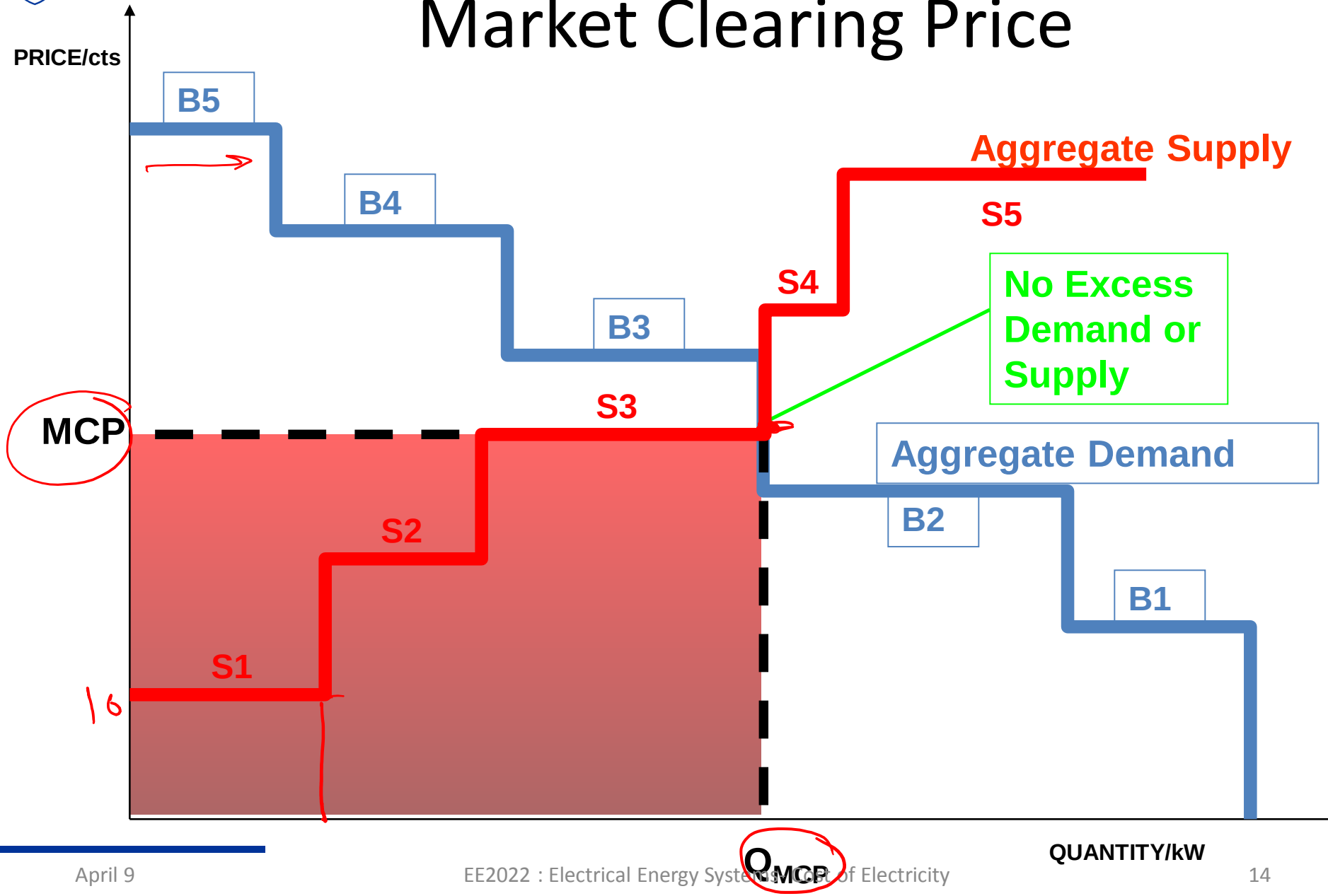
- Hybrid Model



How is Price of Electricity Decided???



Market Clearing Price



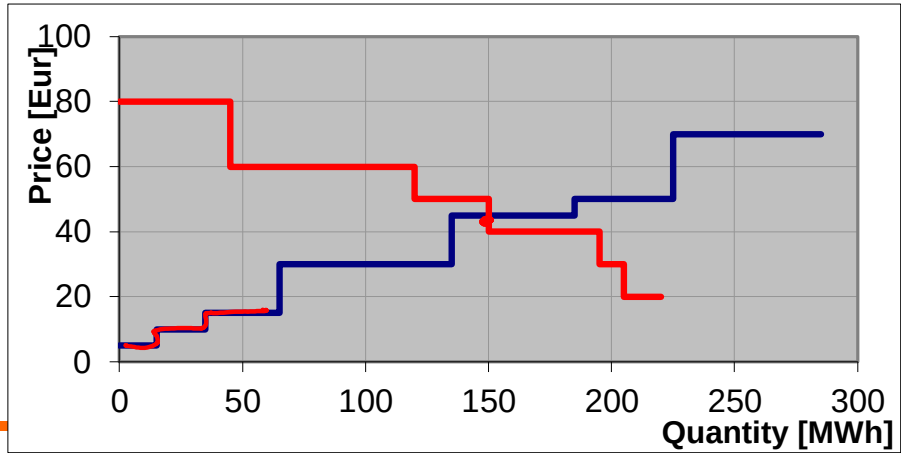
Market Clearing Price

Gen 1 Gen 2

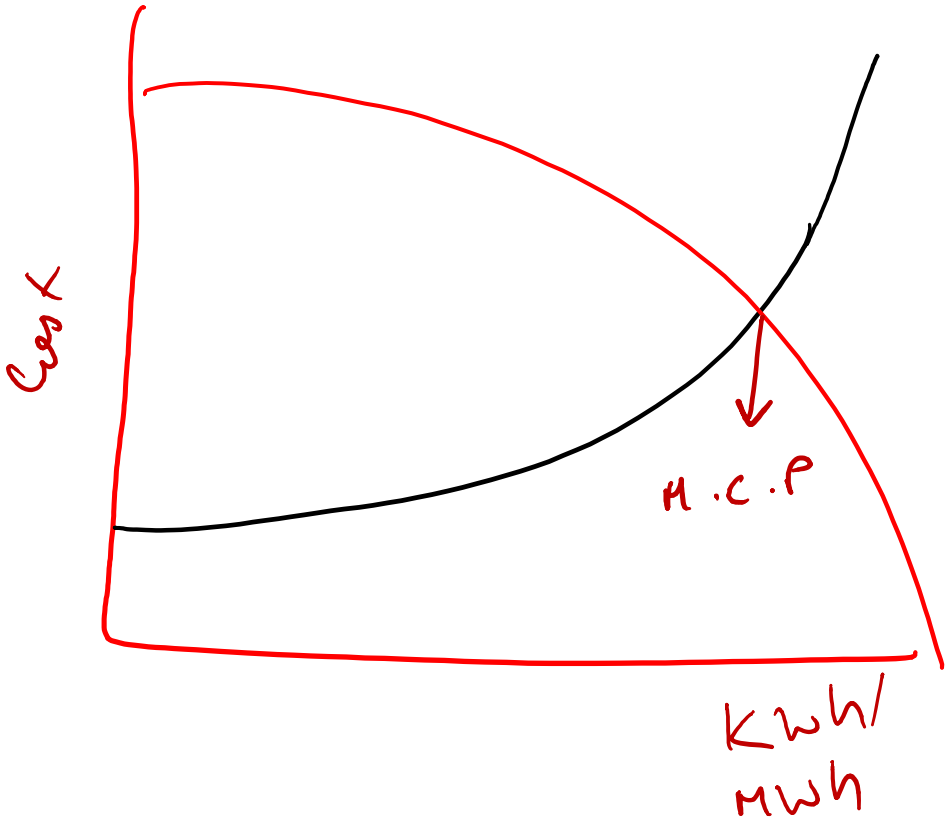
producer1		producer2	
Price [€/MWh]	Volume [MWh]	Price [€/MWh]	Volume [MWh]
10	20	5	15
30	30	15	30
50	40	30	40
70	60	45	50

consumer1		consumer2	
Price [€/MWh]	Volume [MWh]	Price [€/MWh]	Volume [MWh]
60	40	80	45
50	30	60	35
40	20	40	25
30	10	20	15

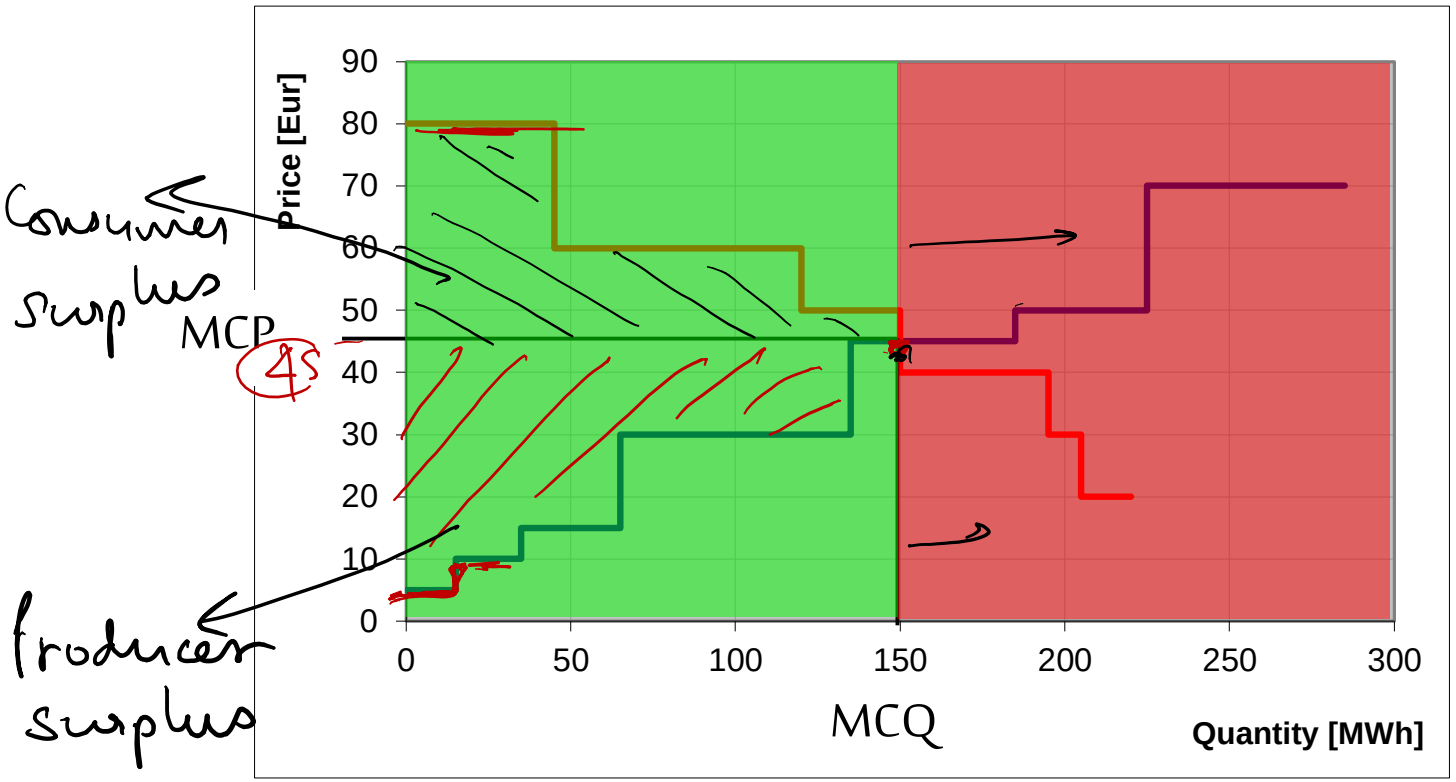
aggregated supply		aggregated demand	
Price [€/MWh]	Volume [MWh]	Price [€/MWh]	Volume [MWh]
5	0 - 15	80	0 - 45
10	15 - 35	60	45 - 120
15	35 - 65	50	120 - 150
30	65 - 135	40	150 - 195
45	135 - 185	30	195 - 205
50	185 - 225	20	205 - 220
70	225 - 285		



Market Clearing Price



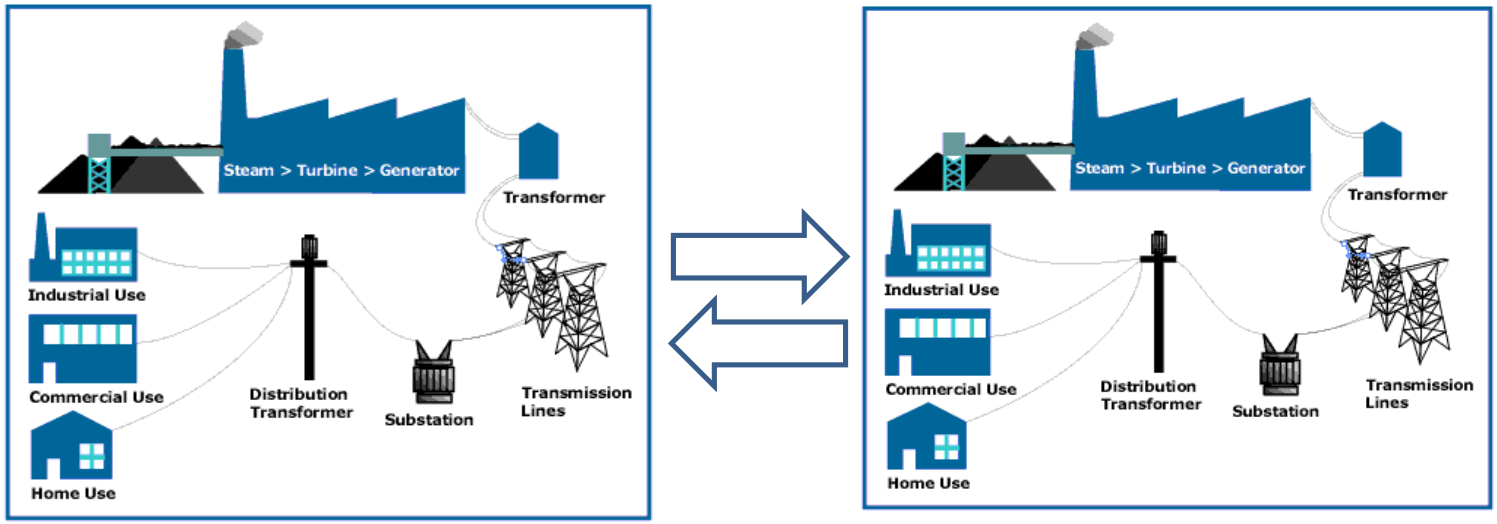
Market Clearing Price



Interconnected power systems

Area 2

Area 1



Market Clearing Price

aggregated supply		aggregated demand	
Price [€/MWh]	Volume [MWh]	Price [€/MWh]	Volume [MWh]
5	0 - 15	80	0 - 45
10	15 - 35	60	45 - 120
15	35 - 65	50	120 - 150
30	65 - 135	40	150 - 195
45	135 - 185	30	195 - 205
50	185 - 225	20	205 - 220
70	225 - 285		

+ 50 MWh

0 - 95

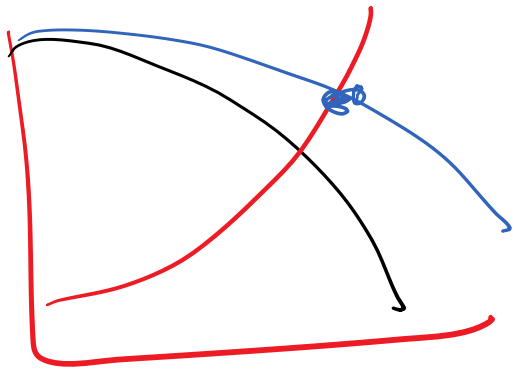
95 - 170

170 - 200

200 - 245

245 - 255

255 - 270



How is Electricity Tariff Determined?

Electricity Rate Structure and Billing

Demand Charge and Energy Charge

Demand Charge Based Rate Schedule

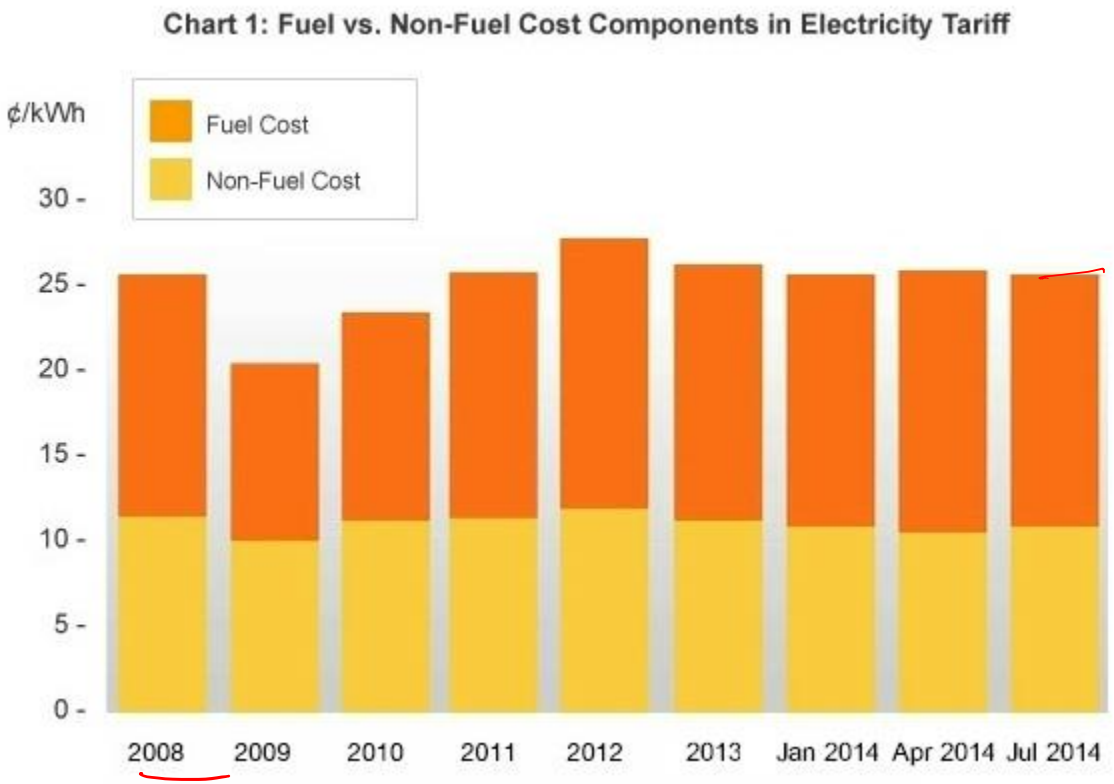
Time of Use Rate Schedule

Real Time Pricing

COST OF ELECTRICITY

How is Electricity Tariff Determined???

- Fuel Cost

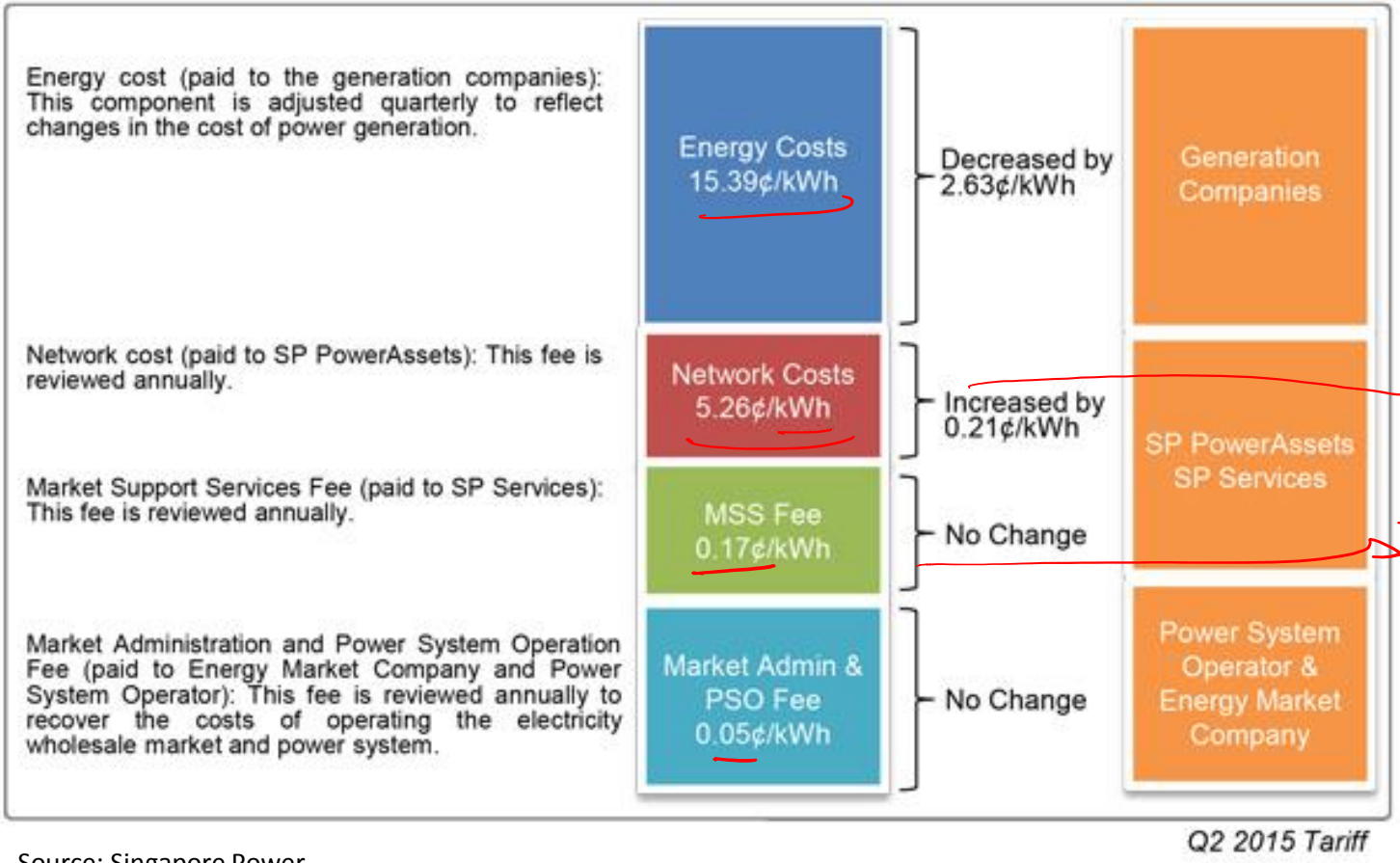


Source: Energy Market Authority

- Non- Fuel Cost
  - Power Generation Cost
  - Grid Charge
  - Market Support Services Fee
  - Power System Operation & Market Administration Fees

How is Electricity Tariff Determined???

- 20.87 cents per kWh (1 Apr 15 - 30 June 15)



Source: Singapore Power

Energy Charges

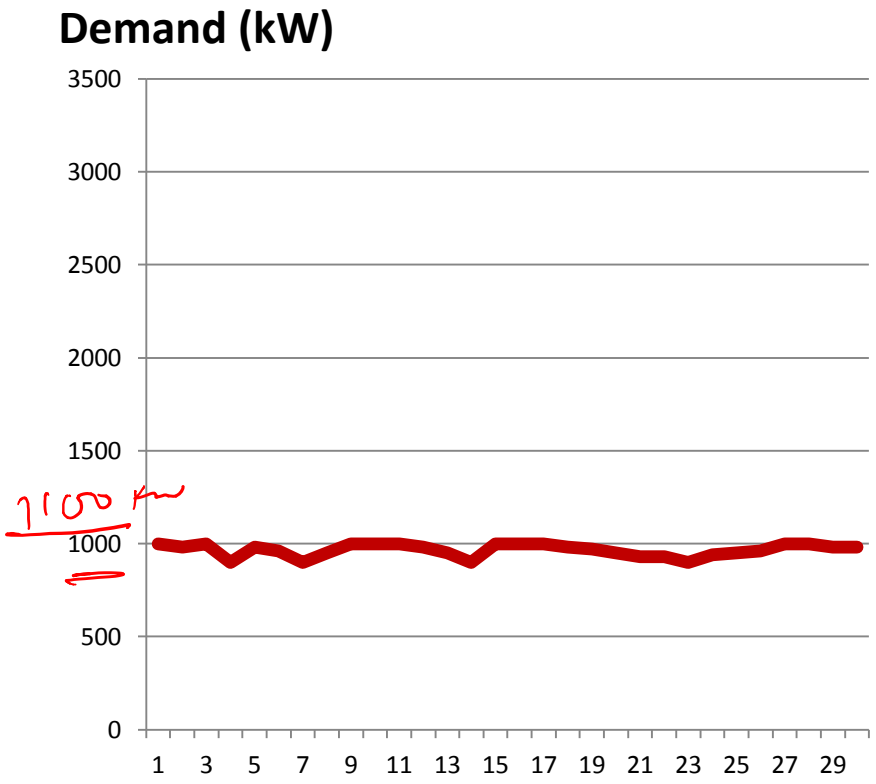
- Fuel Cost
- Power Generation Cost
- **Energy Charge = Total Consumption in a month * Cost per unit (kWh) of Electricity**
-

100 kWh x 20.87 c/kWh

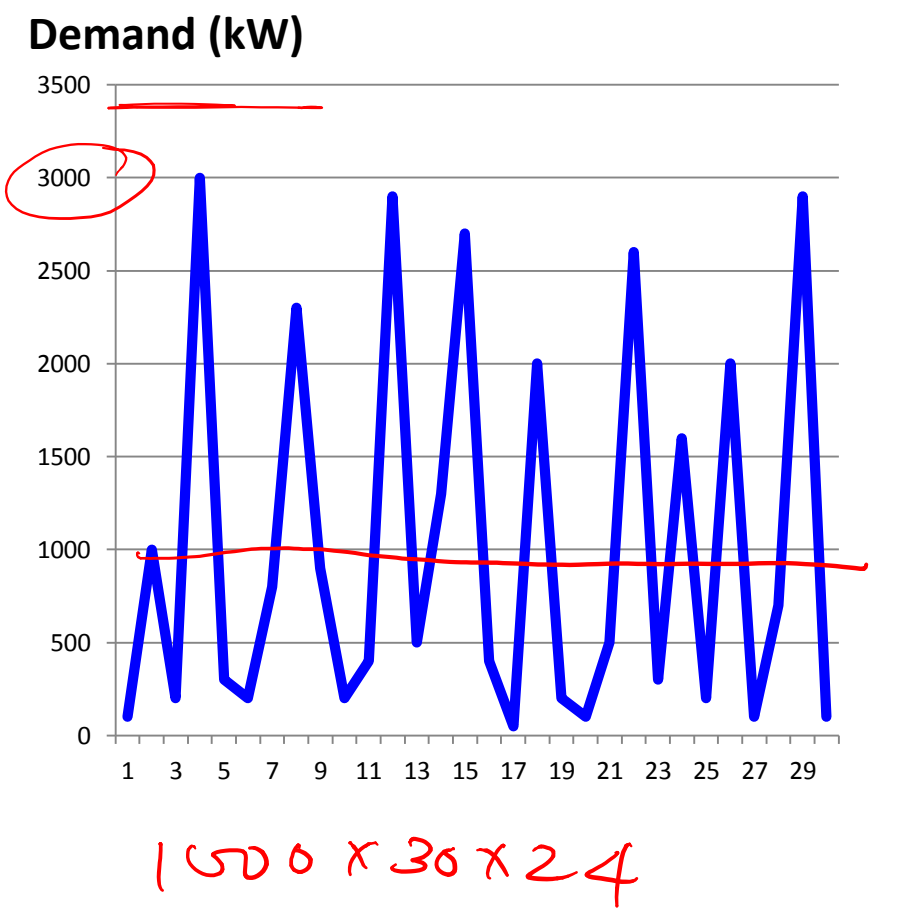
= 20.87 $

Peak Demand

Factory A

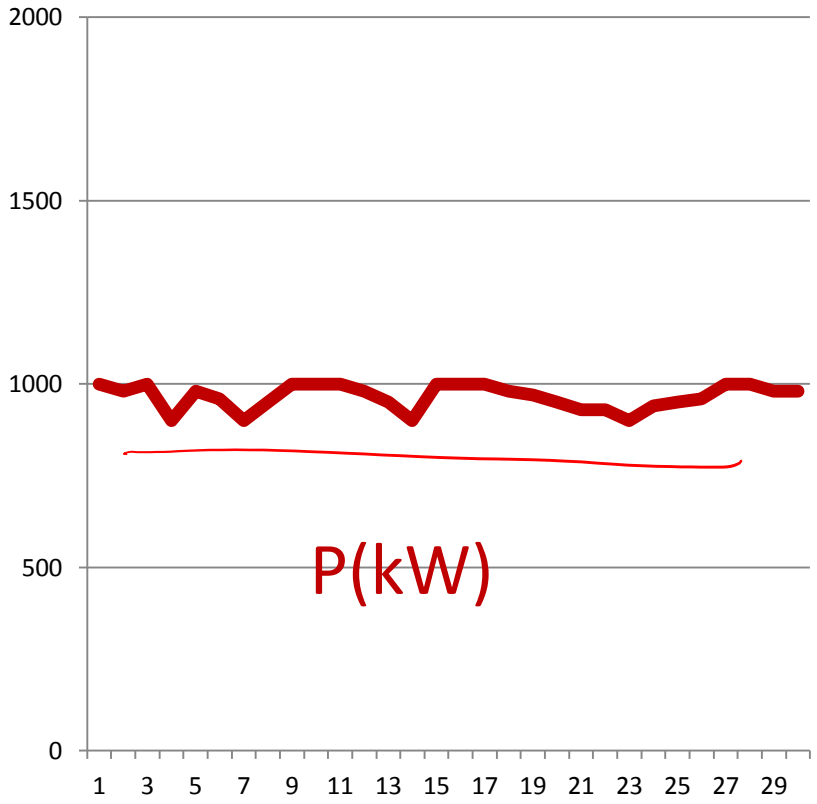


Factory B

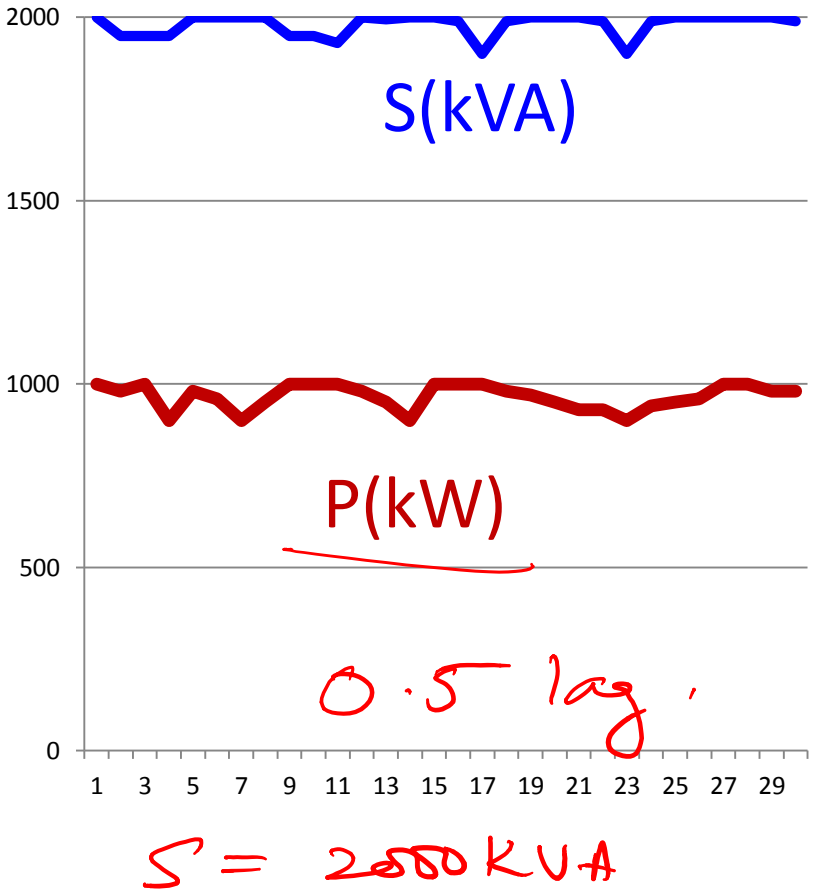


Power Factor

Factory A



Factory B



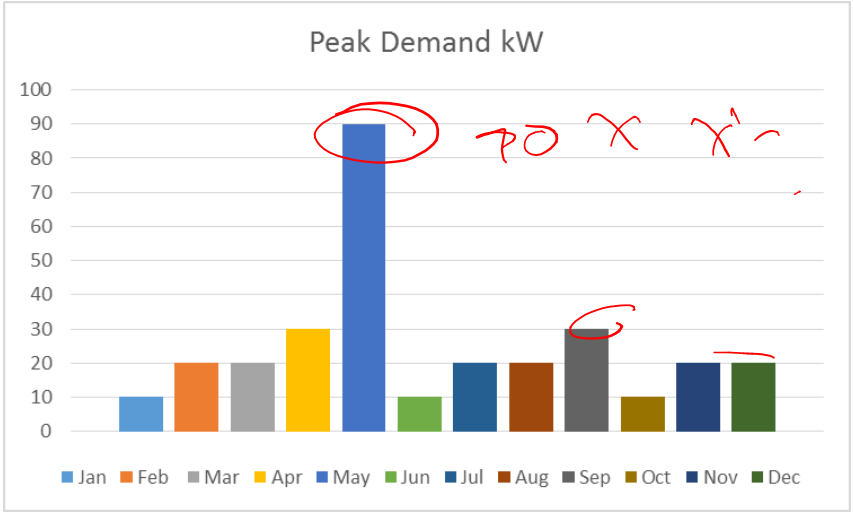
Demand Charges

- Based on Peak demand - the maximum amount of power **kW** or **kVA** that a facility draws from the system
- Typically apply to commercial and industrial customers
- Irrespective of time of day the customer draws this power
- **Demand Charge = Peak Demand * Demand Charge per kVA**

10 $/kW

Ratcheted Demand Charges

- Demand charges be ratcheted to a X% of annual peak demand
- Additional demand charge to the customers

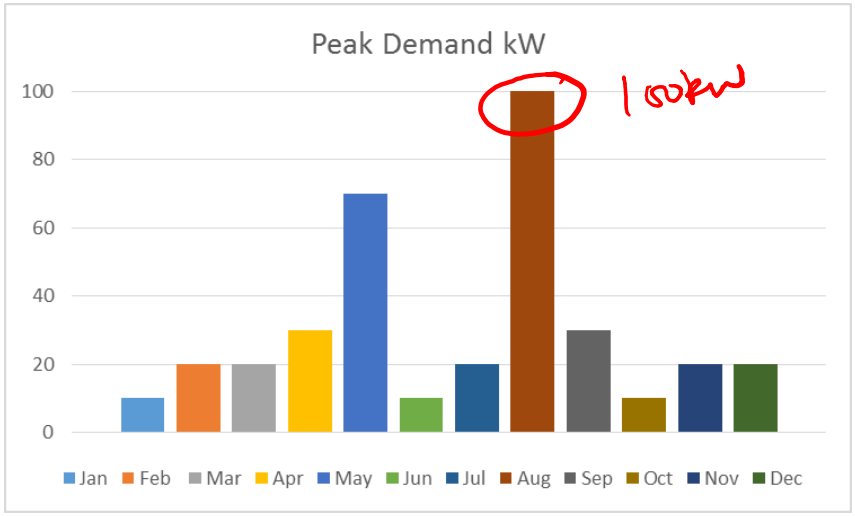


Example 1: A customer's highest demand for power comes in August when it reaches 100 kW. The peak in every other month is less than 70 kW. A proposal to dim the lights for 3 h during each of the 22 workdays in August will reduce the August peak by 10 kW. The utility's energy charge is 8¢/kWh and its demand charge is $9/kW-mo with an 80% ratchet on the demand charges.

a) What is the current annual cost due to demand charges?

b) What annual savings in demand and energy charges will result from dimming the lights?

Example 1



Aug → Demand Charge =

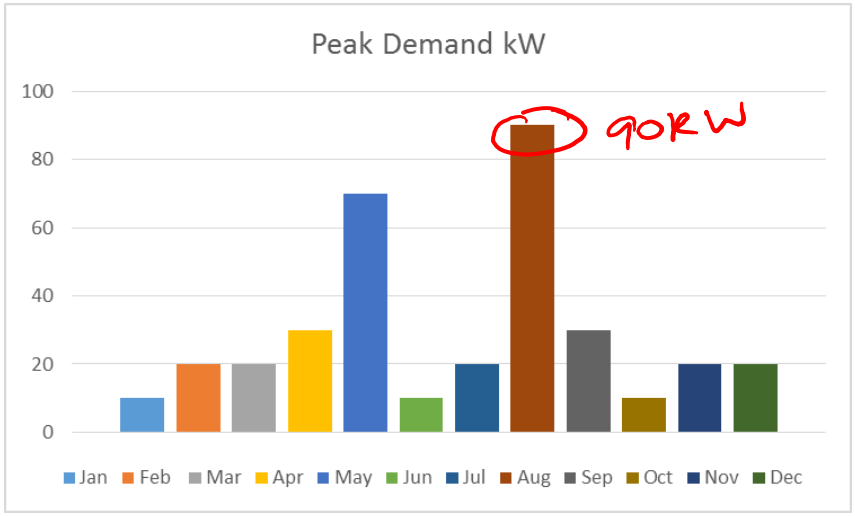
$100 \times 9 = 900$

All remaining months

$= 11 \times 100 \times 9 \times 0.8$

$= 7920$

$\$ = 8820$



Aug → $90 \times 9 = \$810$

Remaining months

$= 11 \times 90 \times 0.8 \times 9$

$= \$7128$

Total $\$ = \$7938$

Example 1

Savings in demand annually = 8820 − 7938

= $882

August Energy savings = 10 kW × 8 h/day × 22 day × 0.08 ¢/kWh

= $52.80

Total savings = 882 + 52.80

= $934.80

Example 2: Suppose that a customer subject to the rate structure in Table below uses 1200 kWh/mo during the summer.

a. What would be the total cost of electricity ($/mo, ignoring monthly service charge)?

b. What would be the value (¢/kWh) of an efficiency project that cuts the demand to 900 kWh/mo?

Tier Level	Winter: November–April		Summer: May–October	
Tier I	First 620kWh	7.378¢/kWh	First 700kWh	8.058¢/kWh
Tier II	621–825	12.995¢/kWh	701–1000	13.965¢/kWh
Tier III	Over 825	14.231¢/kWh	Over 1000	15.688¢/kWh

1) 700kwh x 8.058 ¢ +

2) 300kwh x 13.965 ¢ +

3) 200 kwh x 15.688 ¢

= $(29.68)/mo

a) 700kwh x 8.058 ¢

200kwh x 13.965

= $ 84.34/mo

(129.68 − 84.34) / 300

Demand Charge Based Rate Schedule

- There is an Energy Charge

(Total kWh * cost per kWh)

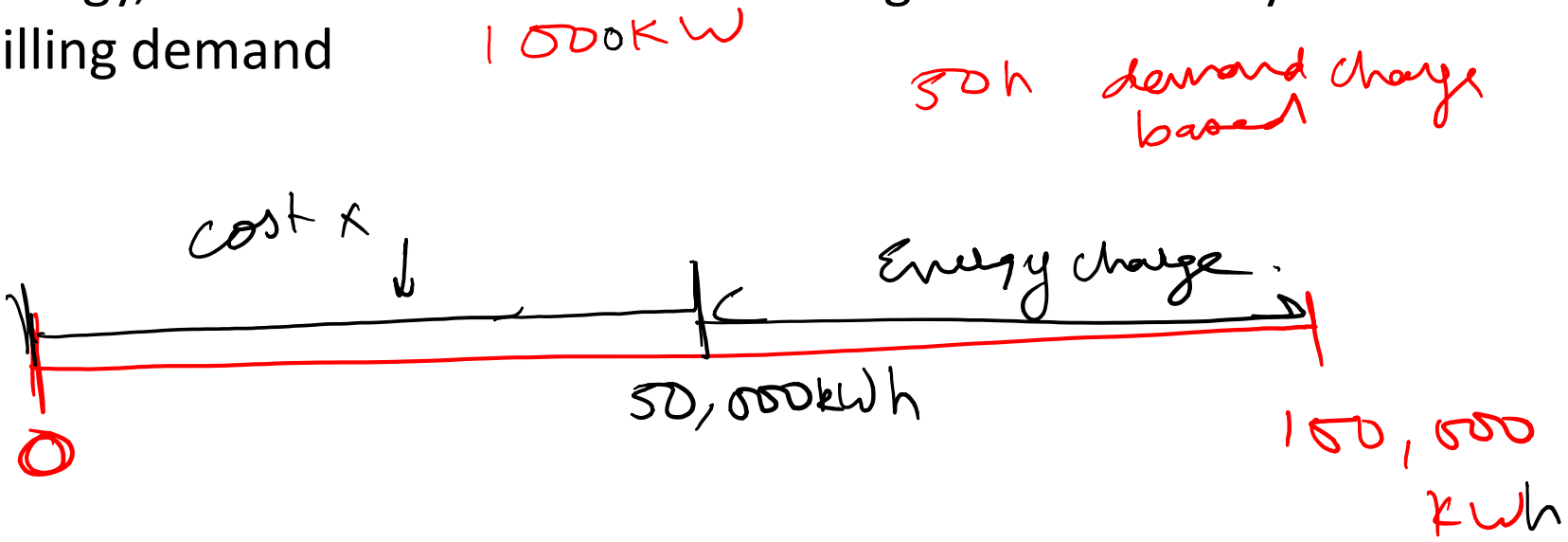
- There is a Demand Charge

(Peak Demand * Demand Charge per kW or kVA)

- Total Cost of Energy = Demand Charge + Energy Charge

Energy Block Based Rate Schedule

- Most commercial and industrial electricity rates are set up to give a discount on the energy portion of the bill to customers whose energy consumption is large relative to their demand.
- This is done by apportioning the total number of kWh consumed during the billing period between two "blocks" of energy, the size of the first block being determined by the billing demand



Example 3: Assume that an industry's 215 kVA demand reading is accompanied by a 110,000 kWh energy consumption reading. Follow the following Rate Schedule to calculate the total energy charges

Energy Charge	\$0.08/kWh for the first 200 hours of billing demand
	\$0.06/kWh for the remaining energy

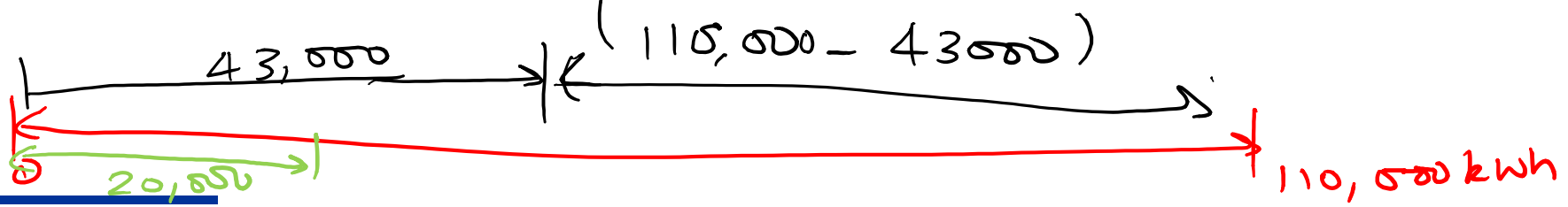
1st block = $215 \times 200 = 43{,}000$ kwh

cost = $43{,}000 \times 0.08 = 3440$

2nd block = $110{,}000 - 43{,}000 = 67000$

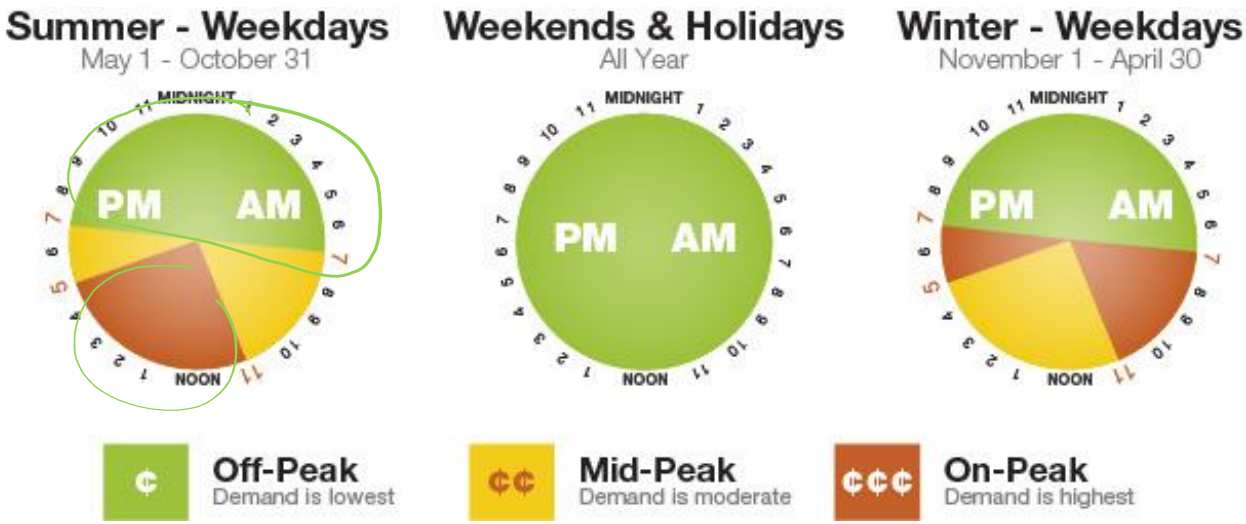
cost = $67000 \times 0.06 = \$4020$

Total cost = $4020 + 3440 = \$7460$



Time of Use Rate Schedule

- In most countries time-of-use rates, which favor off-peak electrical use, are available
- Under time-of-use rates, energy and demand charges vary during different block periods



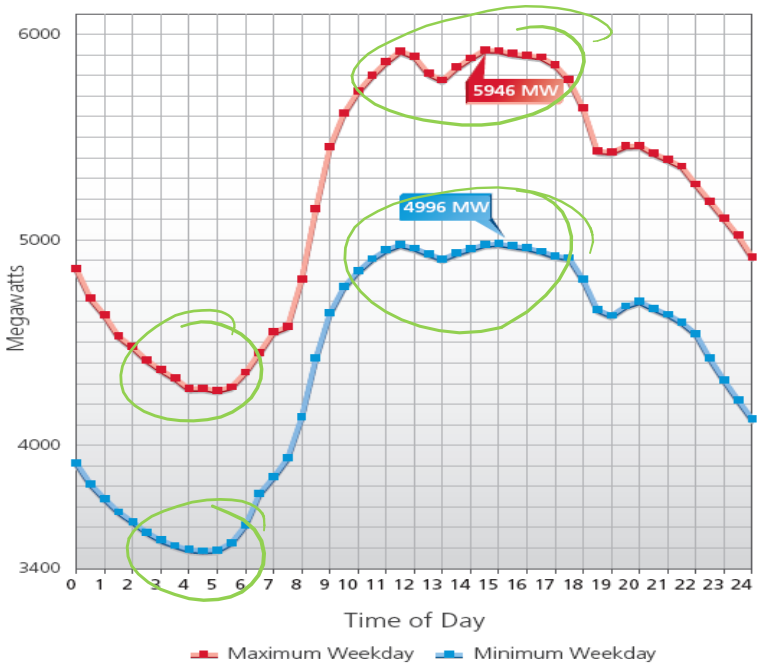
Source: www.notlhydro.com

Time of Use Rate Schedule

	November–April		May–October	
On-peak	7–10 A.M., 5–8 P.M.	8.335 ¢/kWh	2–8 P.M.	19.793 ¢/kWh
Off-peak	All other times	7.491 ¢/kWh	All other times	8.514 ¢/kWh

On peak → Charged higher

Off peak → Charged lower.



Example 4: During the summer, a rooftop PV system generation and customer usage are given in table on the left. For a 30-day month in the summer, find the electric bill for this customer if the TOU rates of Table on the right apply

	PV supply	Demand
On-peak	10kWh	22kWh
Off-peak	10kWh	18kWh
Total	20kWh/day	20kWh/day

May–October	
2–8 P.M.	19.793 ¢/kWh
All other times	8.514 ¢/kWh

Saving 8 kWh on-peak

Credit = 8kWh × 30day × 19.793¢

= $ 47.50

Consuming extra 8kwh off peak = 8 × 30 × 8.514¢

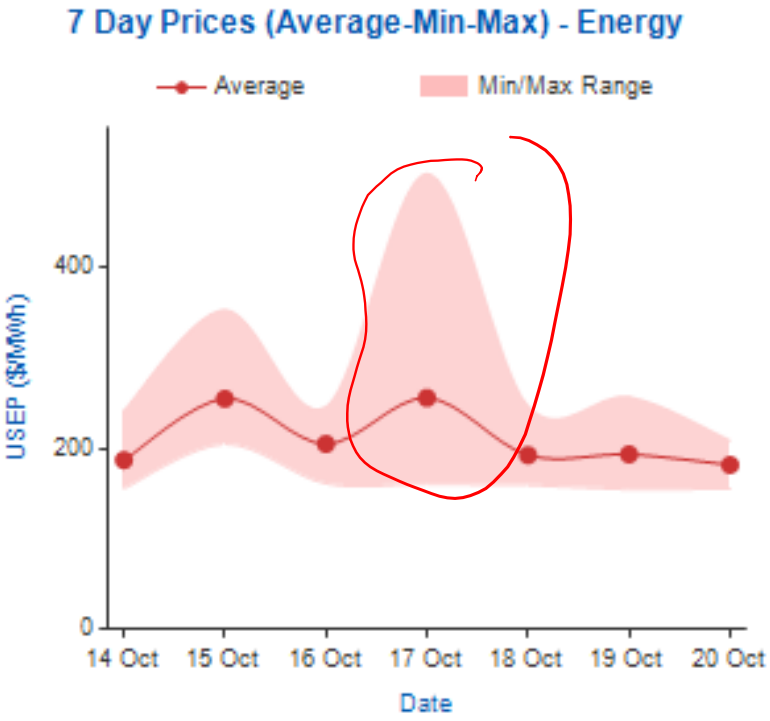
= $20.43

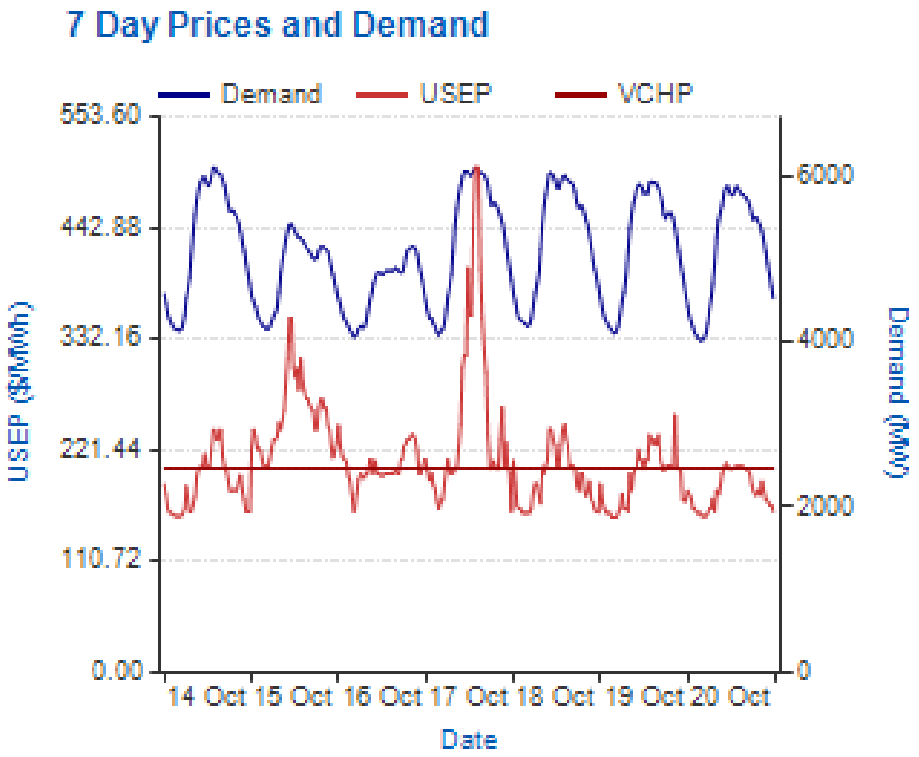
Bill = 20.43 − 47.5

= −27.07

Bill = − $27.07/mo

Real Time Pricing (Dynamic Pricing)





Uniform Singapore Energy Price (USEP)

Real Time Pricing

- Electricity prices may change as often as hourly
- Price signal is provided to the user on an advanced or forward basis, reflecting the utility's cost of generating and/or purchasing electricity at the wholesale level
- The real-time pricing program customers pay lower prices for electricity during off-peak hours, including nights and weekends
- Substantial potential savings obtained from using less electricity when electricity costs are high and shifting the use of power-hungry appliances to lower-priced hours
- Real-time pricing may result in major efficiency improvements in the consumption and production of electric power

Summary

- Market clearing Price
- Energy charge
- Demand charge
- Demand charge based schedule
- Time of use charge based schedule
- Energy block based schedule
- Real Time Pricing.