Carnegie Mellon

Electric Energy Systems Group

Electrical & Computer ENGINEERING

Retail Market Mechanism in Support of Differentiated Reliable Electricity Services

Siripha (Pui) Junlakarn
Department of Engineering and Public Policy
Advisor: Marija Ilíc
Department of Electrical Engineering/Engineering and Public Policy

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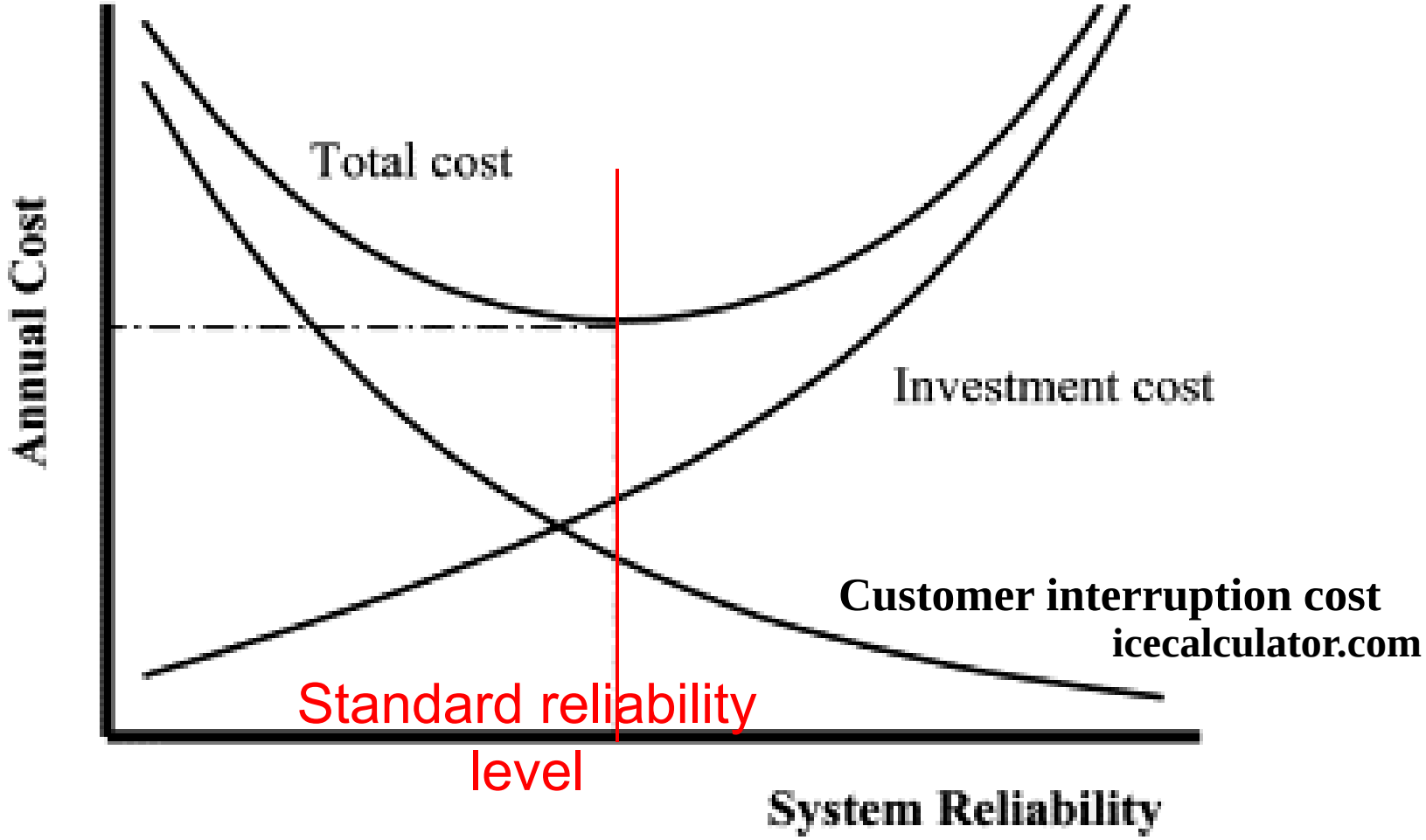
Why Differentiated Reliability?



A. A. Chowdhury, D. O. Koval, "**Current Practices and Customer Value-Based Distribution System Reliability Planning",** IEEE Transactions on Industry Applications, Volume 40, Issue 5, 2004, 1174 - 1182

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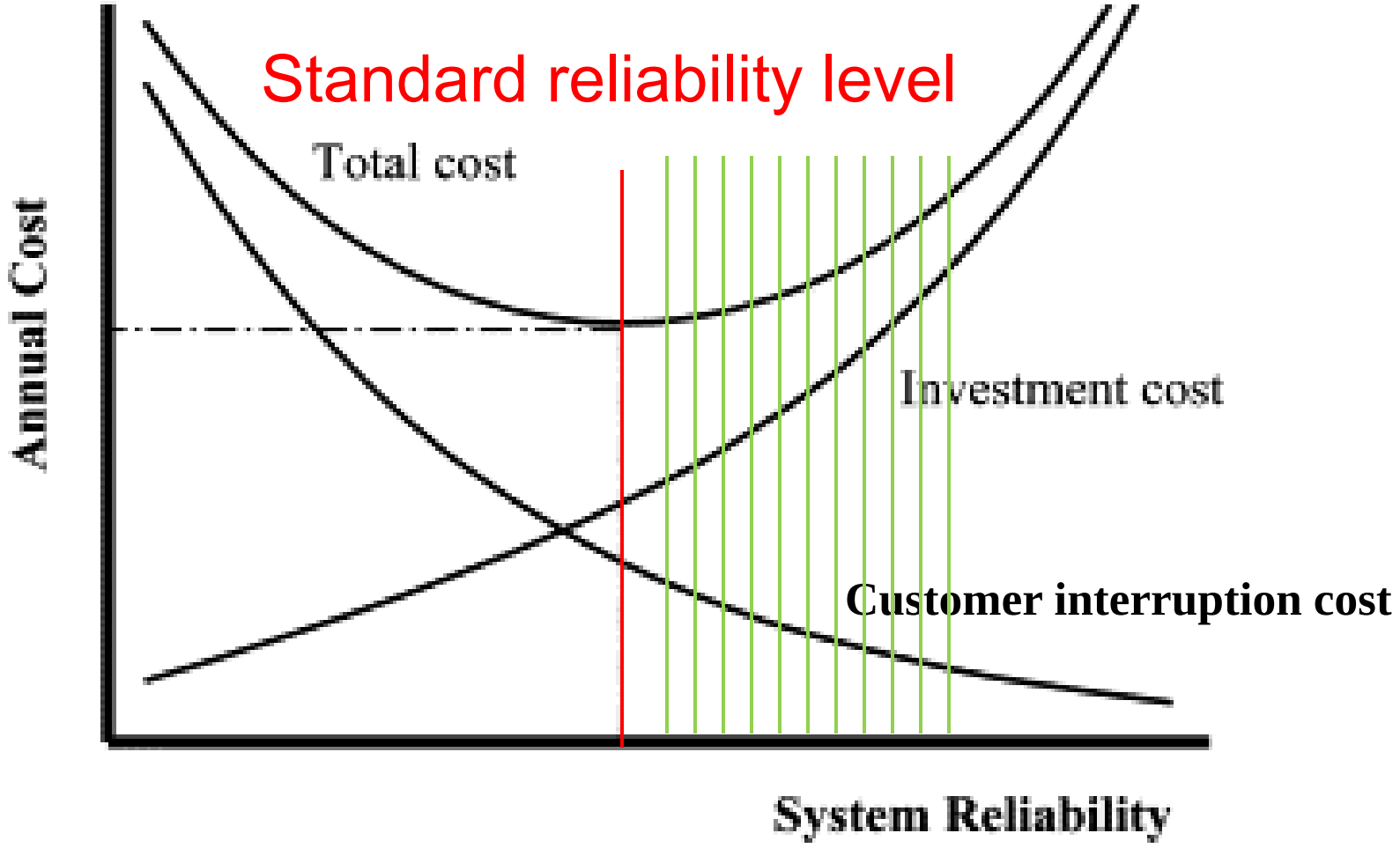

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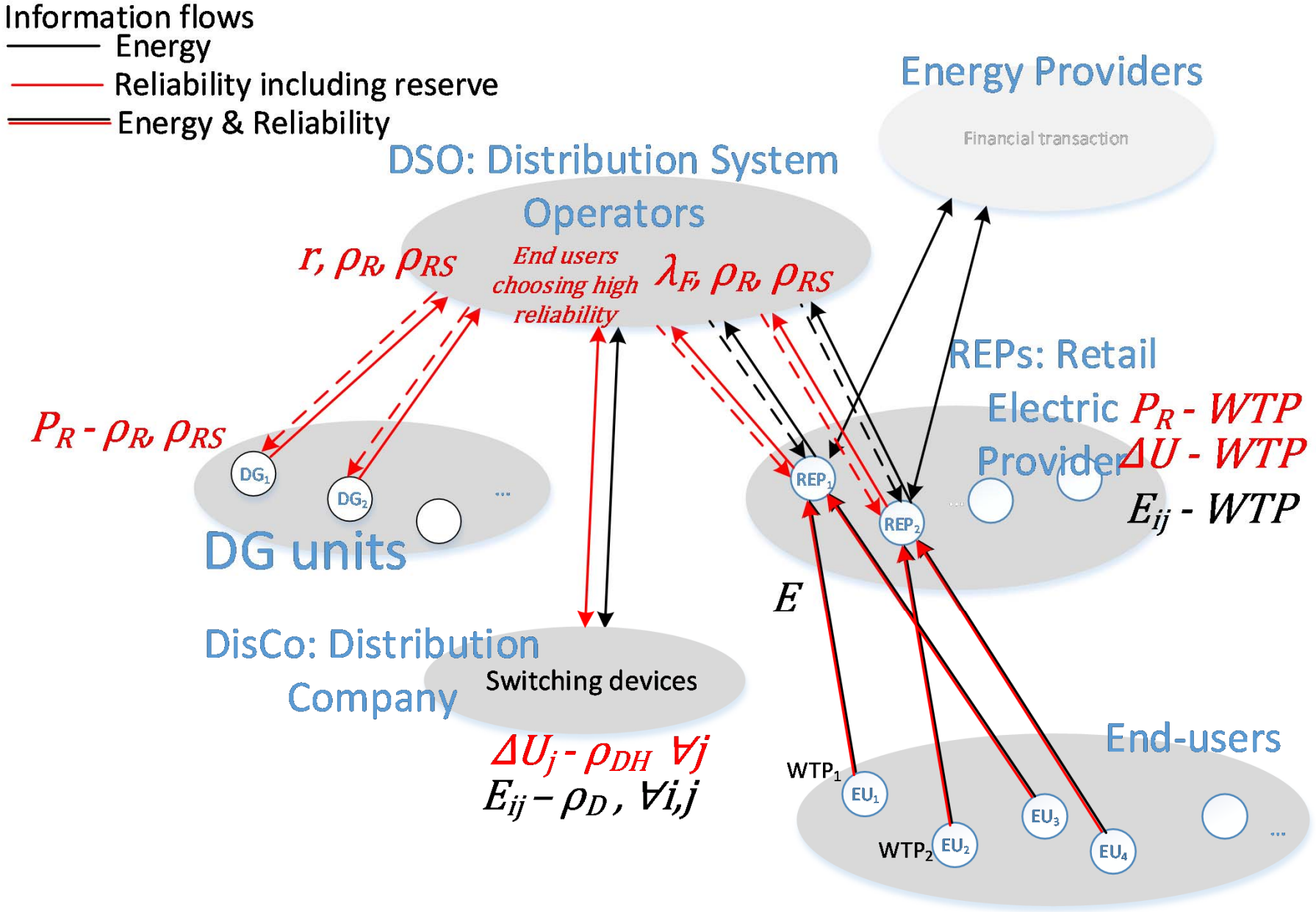
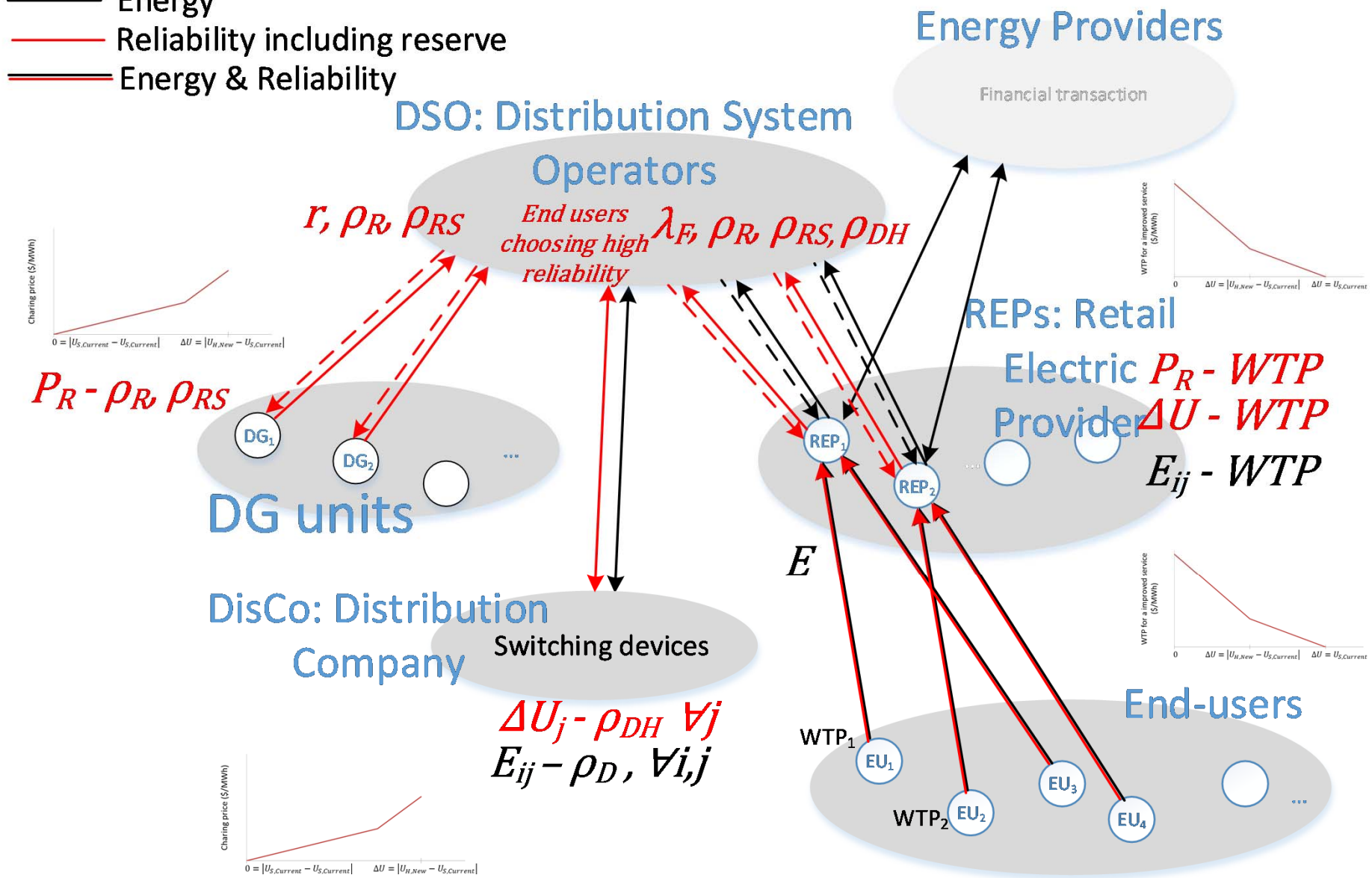
Differentiated reliable services

- Reliability = Service/Product
  - Delivery service with higher reliability level.
  - Resilience service
- Available Technologies for Enhancing Reliability
  - Advanced communication and control systems
  - Network reconfiguration by switching devices, (such as circuit breaker, recloser, sectionalizing switch or normally closed switch, tie switch or normally open switch)
  - Distributed Generation (DG)


Information flows
Energy
Reliability including reserve
Energy & Reliability
Energy Providers
Financial transaction
DSO: Distribution System Operators
r, ρ_R, ρ_{RS}
End users choosing high reliability
$\lambda_E, \rho_R, \rho_{RS}$
REPs: Retail Electric Provider
$P_R - WTP$
$\Delta U - WTP$
$E_{ij} - WTP$
$P_R - \rho_R, \rho_{RS}$
DG$_1$
DG$_2$
DG units
REP$_1$
REP$_2$
E
DisCo: Distribution Company
Switching devices
$\Delta U_j - \rho_{DH}$ $\forall j$
$E_{ij} - \rho_D$, $\forall i,j$
End-users
WTP$_1$
WTP$_2$
EU$_1$
EU$_2$
EU$_3$
EU$_4$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End users choosing high reliability
$\lambda_F, \rho_R, \rho_{RS}, \rho_{DH}$
Charing price ($/MWh)
$0 = |U_{S,Current} - U_{S,Current}|$
$\Delta U = |U_{H,New} - U_{S,Current}|$
WTP for a improved service ($/MWh)
REPs: Retail Electric Provider
$P_R - \rho_R, \rho_{RS}$
$P_R - WTP$
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DG_1
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WTP_1
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EU_1
EU_2
EU_3
EU_4

Information

- DG
  - Supply function of backup power
  - Maximize profit of selling backup power
- DisCo
  - Supply function of reliability service
  - Maximize no. customers receiving high reliability
- REP
  - Demand functions for backup power and delivery services
- DSO
  - Clear transaction based on the information from DG, DisCo, DSO

Communication setup for reliability

- DSO – DG-1: r, ρ_R , ρ_{RS}
- DG-1 – DSO: P_R, ρ_R , ρ_{RS}
- DSO – DG-2 : r, ρ_R , ρ_{RS}
- DG-2 – DSO : P_R, ρ_R , ρ_{RS}
- DSO – DisCo: EU, P_R , e_{EU}
- DisCo – DSO: U, ρ_{DH}
- DSO – REP-1: λ_F, ρ_R , ρ_{RS} , ρ_{DH}
- REP-1 – DSO: U, WTP(ρ_{DH}), P_R , WTP(ρ_R , ρ_{RS})
- DSO – REP-2 : λ_F, ρ_R , ρ_{RS} , ρ_{DH}
- REP-2 – DSO : U, WTP(ρ_{DH}), P_R , WTP(ρ_R , ρ_{RS})

Communication setup for reliability

- REP-1 – EU-1: λ_F
- EU-1 – REP-1: WTP_T
- REP-1 – EU-3: λ_F
- EU-3 – REP-1: WTP_T
- REP-2 – EU-2: λ_F
- EU-2 – REP-2: WTP_T
- REP-2 – EU-4: λ_F
- EU-4 – REP-2: WTP_T

DisCo – Maximize No. Customers Receiving High Reliability

- Install switches at the optimal locations cL^* where bring the level of service quality to meet the offered level U_H

$$\underset{cL}{\text{Max}} \quad N_H = \sum_{n=1}^{No.of\ LP} N_{H,n} \cdot t_{Qm,cL,n}$$

Number of customers who choose high reliability in load point, n

Where:

$$t_{Qm,cL,n} = \begin{cases} 1, & U_{Qm,cL,n} \le U_H \\ 0, & U_{Qm,cL,n} > U_H \end{cases}$$

$$U_{Qm,cL,n} = \sum_{E=1}^{No.of\ Events} \lambda_E r_E \left(1 - s_{m,cL,E,n}\right)$$ [1]

1. R. Billinton and R. Allan, Reliability Evaluation of Power Systems, New York: Plenum Press, 1996.

DisCo - Service Charge, $\rho_{DH,Qm}$

- Estimate from the DisCO's revenue $(R_{Exp})$for recovering the costs of upgrading system reliability

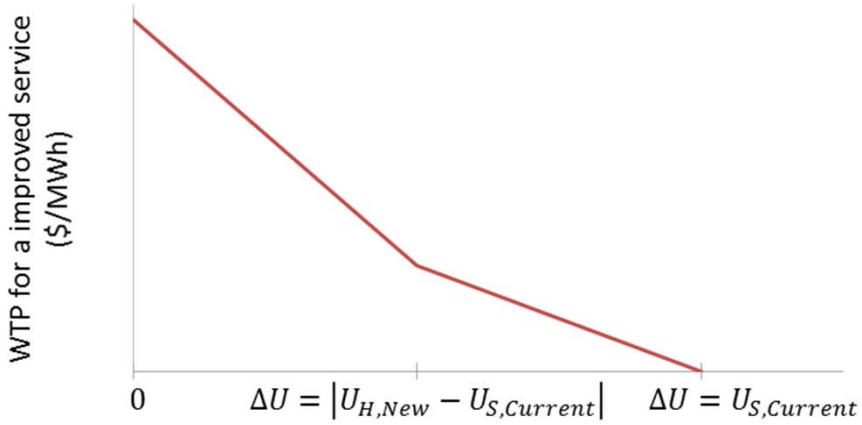
- Annualized capital and O&M cost:

$$m \cdot C_{Cap} + \sum_{k=1}^{yr} \frac{m \cdot C_{O\&M} - R_{Exp}}{(1 + r_d)^k} = 0$$

- Expected Revenue:

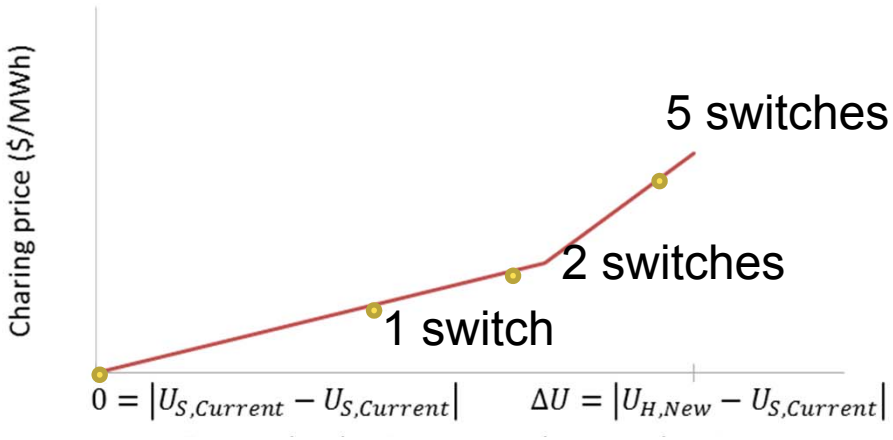
$$R_{Exp} = \rho_{DH,Qm_{cL*}} \sum_{n=1}^{No.of\ LP} \sum_{i=1}^{N_{H,n}} e_{EU,i,n}$$

REP



Incremental reduction in outage duration (hour/year)

DisCo



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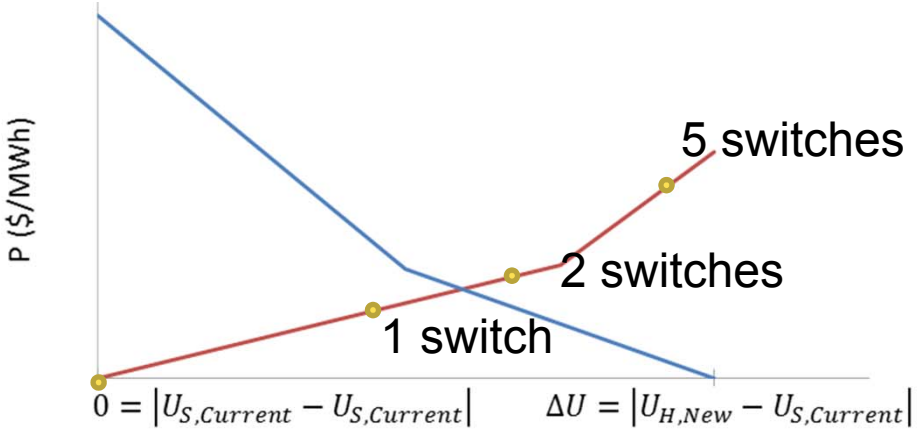
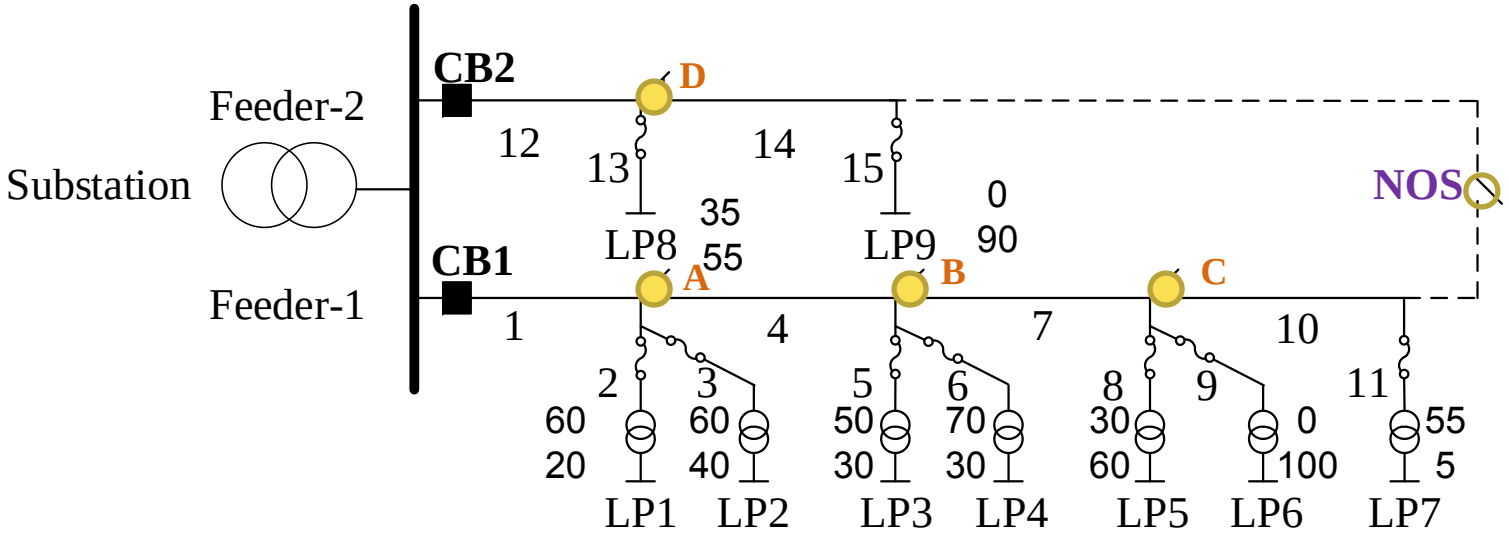


Incremental reduction in outage duration (hour/year)

Test system[1]

- Reliability standard including the extended outages:
  - 2.9 hours/year
- DisCo
  - 5 years of recovery period, 15% discount rate
  - Higher reliability: $U_{H,New} < 2$ hours/year, $\Delta U > 0.9$

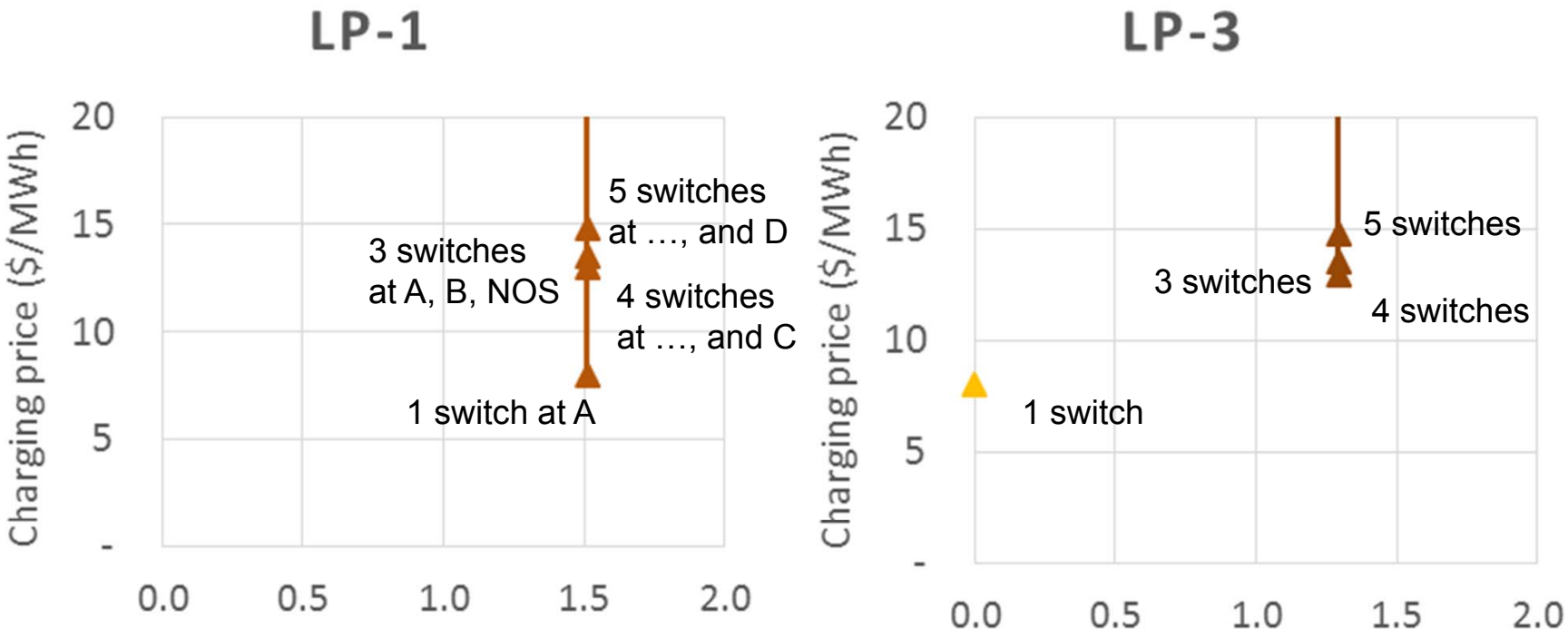


1. R. N. Allan, R. Billinton, I. Sjarief, L. Goel and K. S. So, "A Reliability Test System for Educational Purposes - Basic Distribution System Data and Results," *IEEE Transactions on Power Systems,* vol. 6, no. 2, pp. 813 - 820 , 1991.

DisCo's supply functions

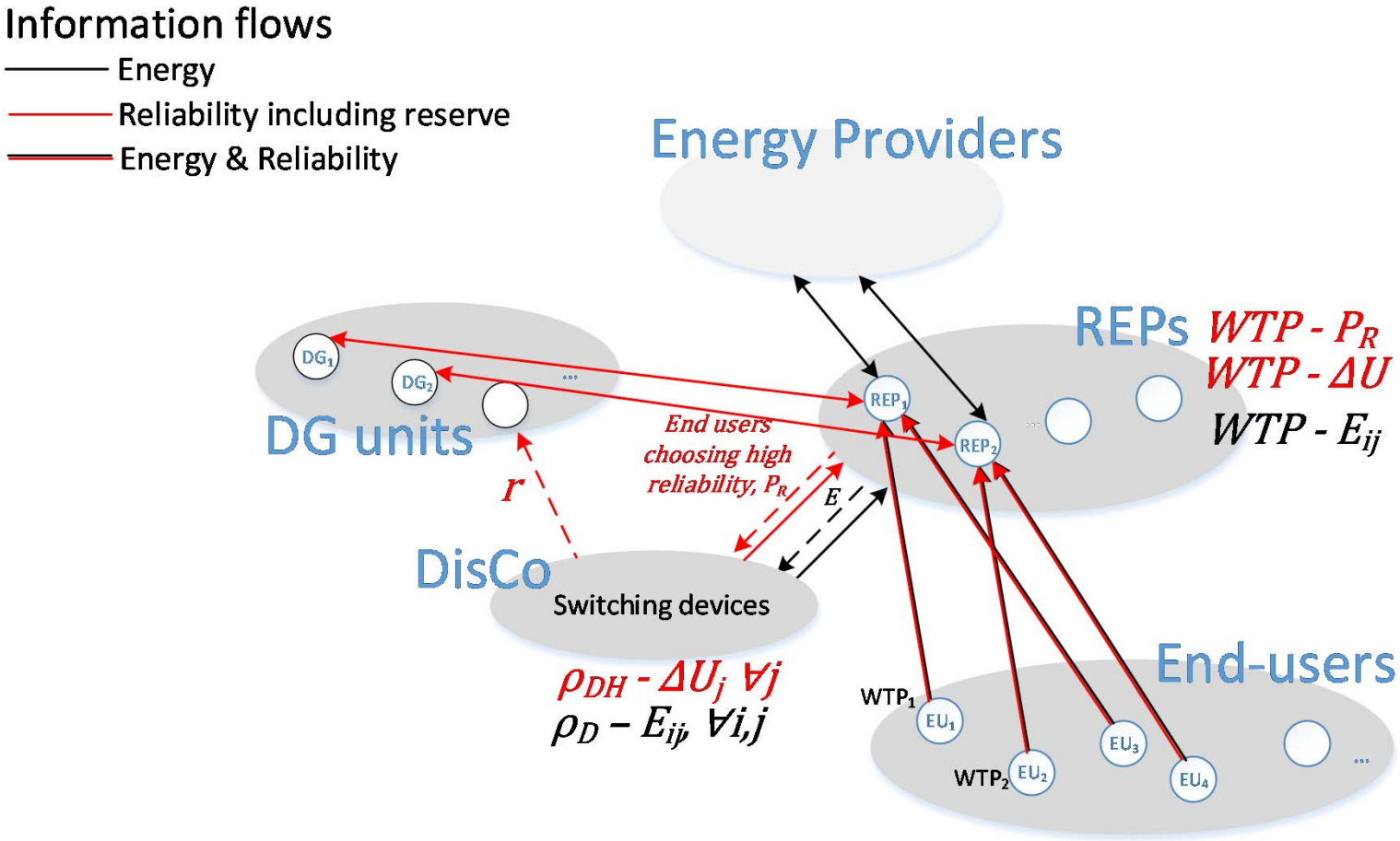
- DisCo's supply function of each load point

  $U \le 2$ hrs $\Delta U \ge 0.9$ hrs



Incremental reduction in annual outage duration comparatively to the current reliability level ΔU (hr)

No DSO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EU3
EU4