Center for Advanced Power Technologies
National Tsing Hua University, TAIWAN

國立清華大學 電機系
先進電源科技中心

演講公告

美國電力市場概論及工作實務分享

徐明雍 Ming

時間：2021年03月19日 13：30- 15：00

地點：新竹 國立清華大學 資電館 R104

美國電力市場概論
及工作實務
書報討論@清華大學電力組

U.S. Electricity Market Introduction
& Work Experiences
Seminar@NTHUEE Power Group

徐明雍 Ming

2021.3.19

綱要

1. 美國電業自由化主要法案及進程 (U.S. Power Market Deregulation)
2. 美國開放電力傳輸系統初期 (Day 1 Open Access to Transmission)
3. 電力市場設計主要元素 (Market design elements)
4. 電力市場的微經濟原則(Microeconomic principles to power market)
5. 電力市場之節點電價 (Nodal Pricing: Locational Marginal Price, LMP)
6. 金融傳輸權 (FTR - Financial Transmission Right)
7. 收斂/虛擬競標 (Convergence bidding / virtual bids)
8. 電力市場壟斷力之防範(Market Power Mitigation)

學、經歷

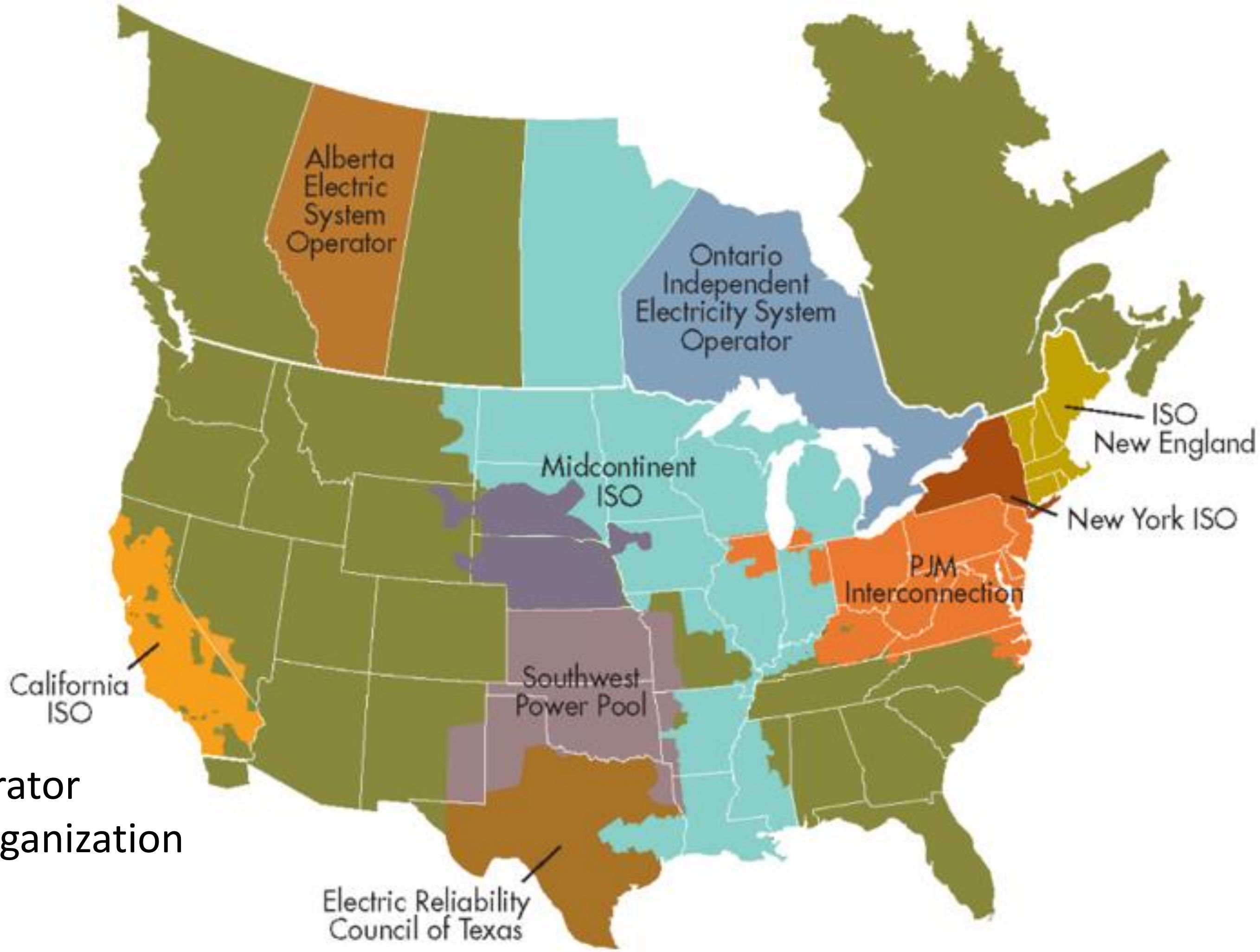
- 中山大學電機系82級 (NSYSU) @高雄 1993
- 北卡州立大學(NC State Univ.) @Raleigh, NC, 1998
- MAIN, Inc @Lombard (Chicago suburb), Illinois, 1998
- Midwest ISO (MISO) @Carmel, Indiana, 2004
- Paliza Consulting firm @Carmel, Indiana, 2005
- California ISO (CAISO), Dept. of Market Monitoring (DMM)@Folsom, CA, 2008

美國電業自由化(deregulation)主要時程

- 1996年FERC Order 888 法案
  - Deregulation of vertically integrated utilities 廠網分離
  - Open Access to Bulk Electric Power Transmission system 開放電力傳輸電網
  - High voltage(115KV, 138KV, 230KV, 345KV, 500KV, 765KV)高壓傳輸線路
- 1999年FERC Order 2000
  - Establish Wholesale Electricity Market 建立批發電力市場
- FERC (Federal Energy Regulatory Commission)

  能管會(聯邦能源管制委員會) 推動電業法
  - 採市場訊號來決定電力系統規劃
  - 促進新型能源產業技術發展

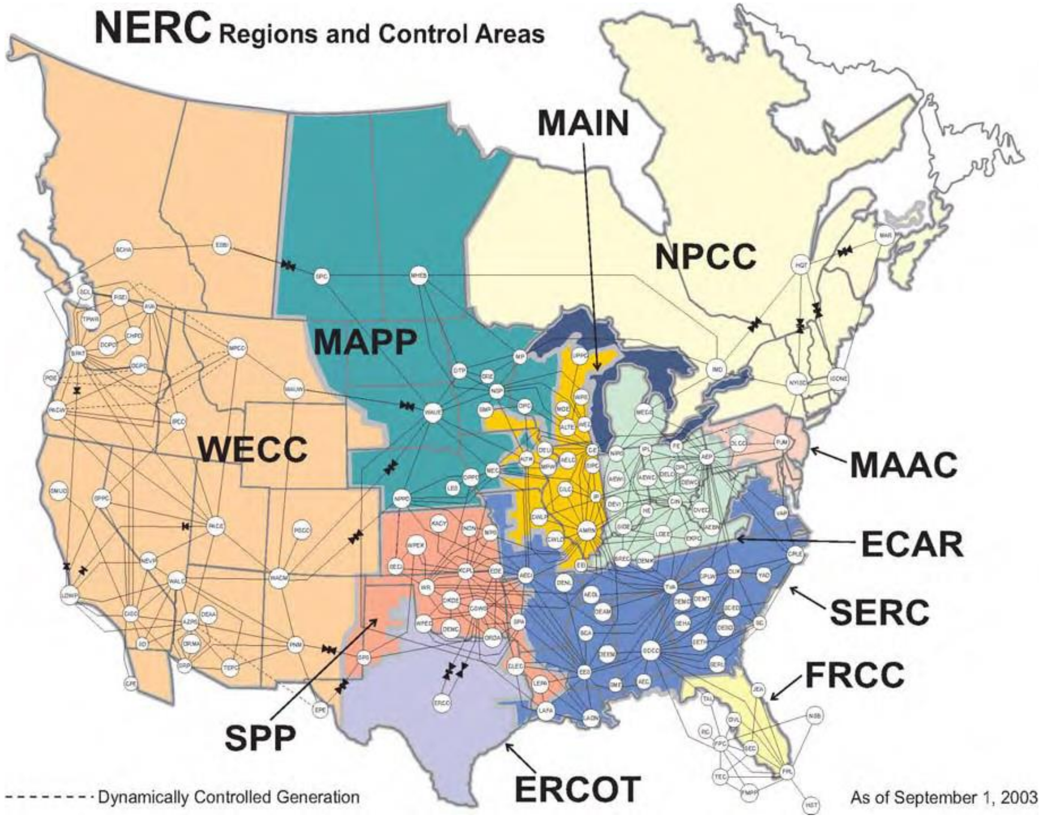
北美洲各區域電力市場(ISO/RTO)

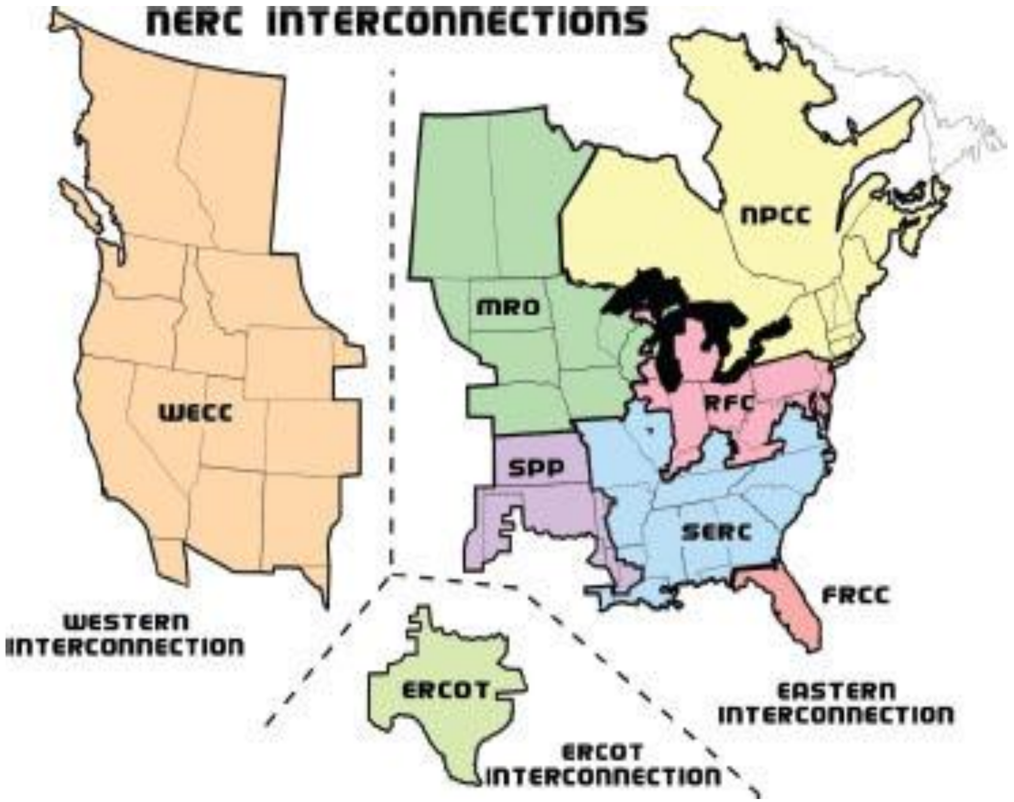


ISO: Independent System Operator
RTO: Regional Transmission Organization

Day1: NERC (North Electric Reliability Corp.) 北美電力可靠度監管機構

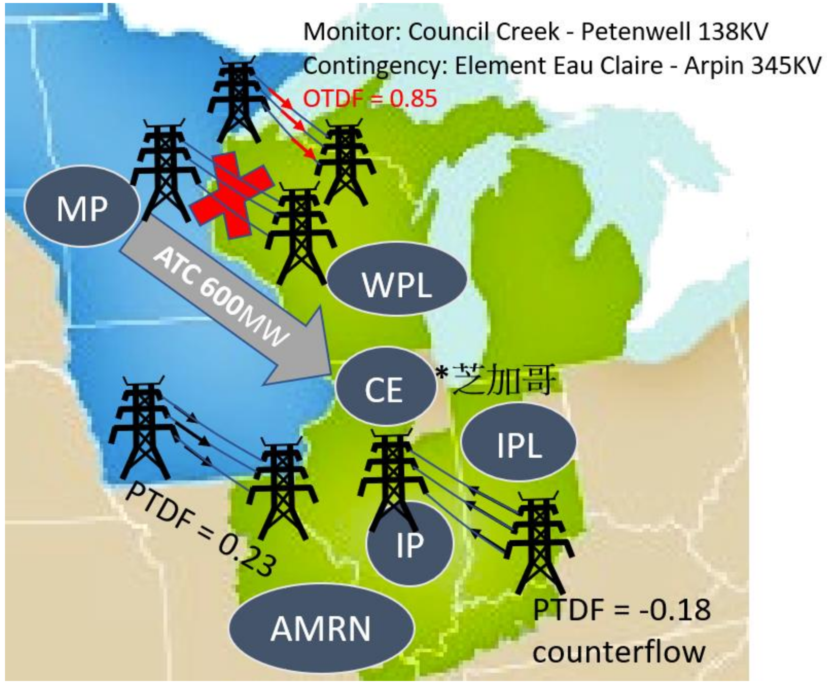
- 確保大電力傳輸容量的可靠性及充分性。





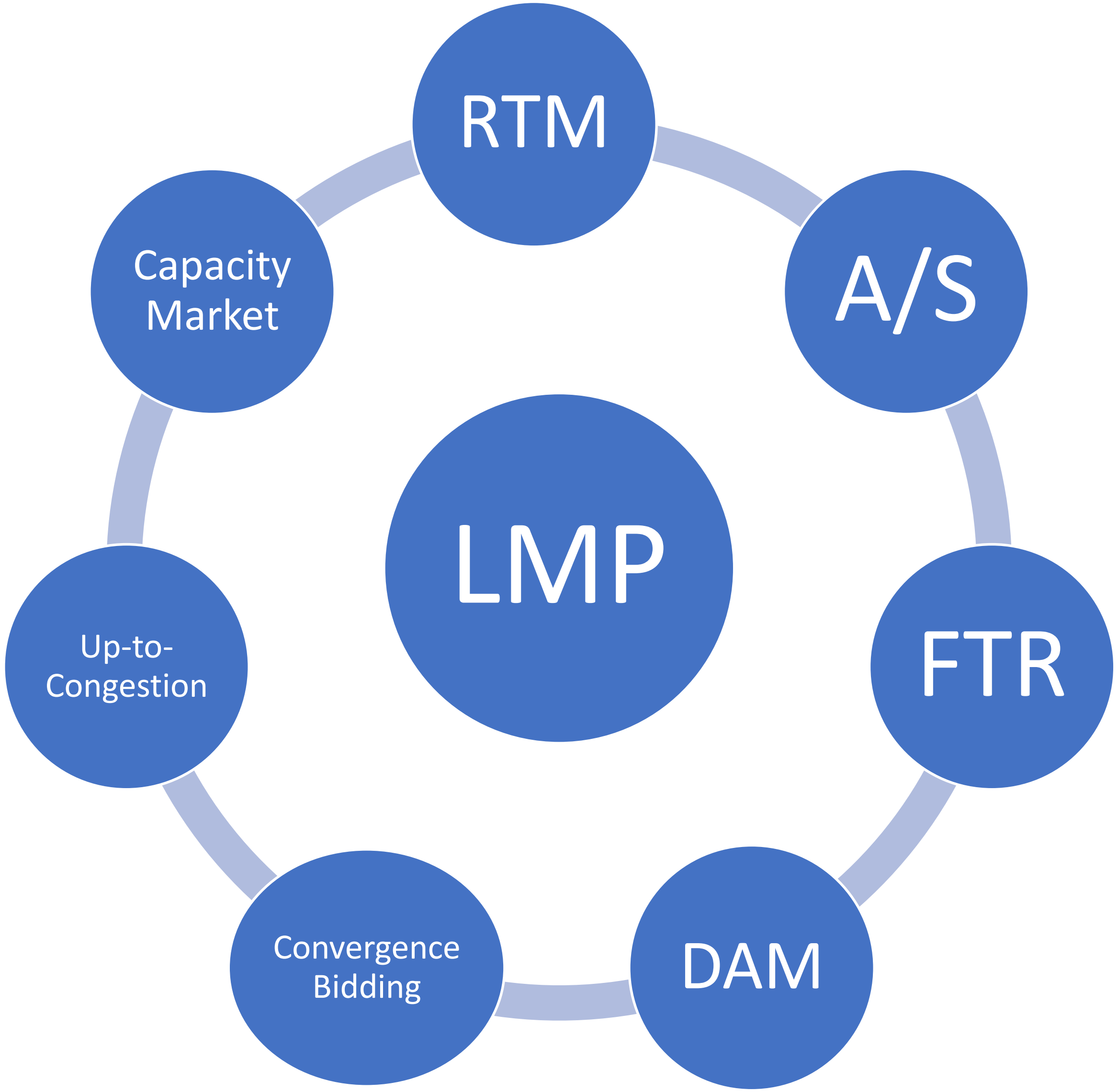
Day 1: After Deregulation Before the Market 初期開放傳輸電網，但未有電力市場

- **OASIS – Open Access Same-time Information System 公開同時資訊系統**
  - Transmission Service Request (TSR) 傳輸容量服務要求
- **ATC Calculation - Available Transfer Capacity可用的傳輸容量**
  - Powerflow-based 電力負載潮流計算
  - Limits picking (Thermal, Phase-angle, Voltage stability)
  - Posting of ATC to OASIS
- **TDF Calculation - Transfer Distribution Factor 傳輸流量分布係數計算**
  - PTDF/OTDF Power/Outage Transfer Distribution Factor
  - Flowgate 流量閘監控
- **Voltage Stability Analysis 電壓穩定度分析**
  - **VSAT Modal Analysis by PowerTech**
- Security Coordination 電網安全協調
  - TLR Transmission Loading Relief (Level 1, 2, 3)



Transmission Congestions
傳輸電網擁塞線路

Electricity Market Design
電力市場設計



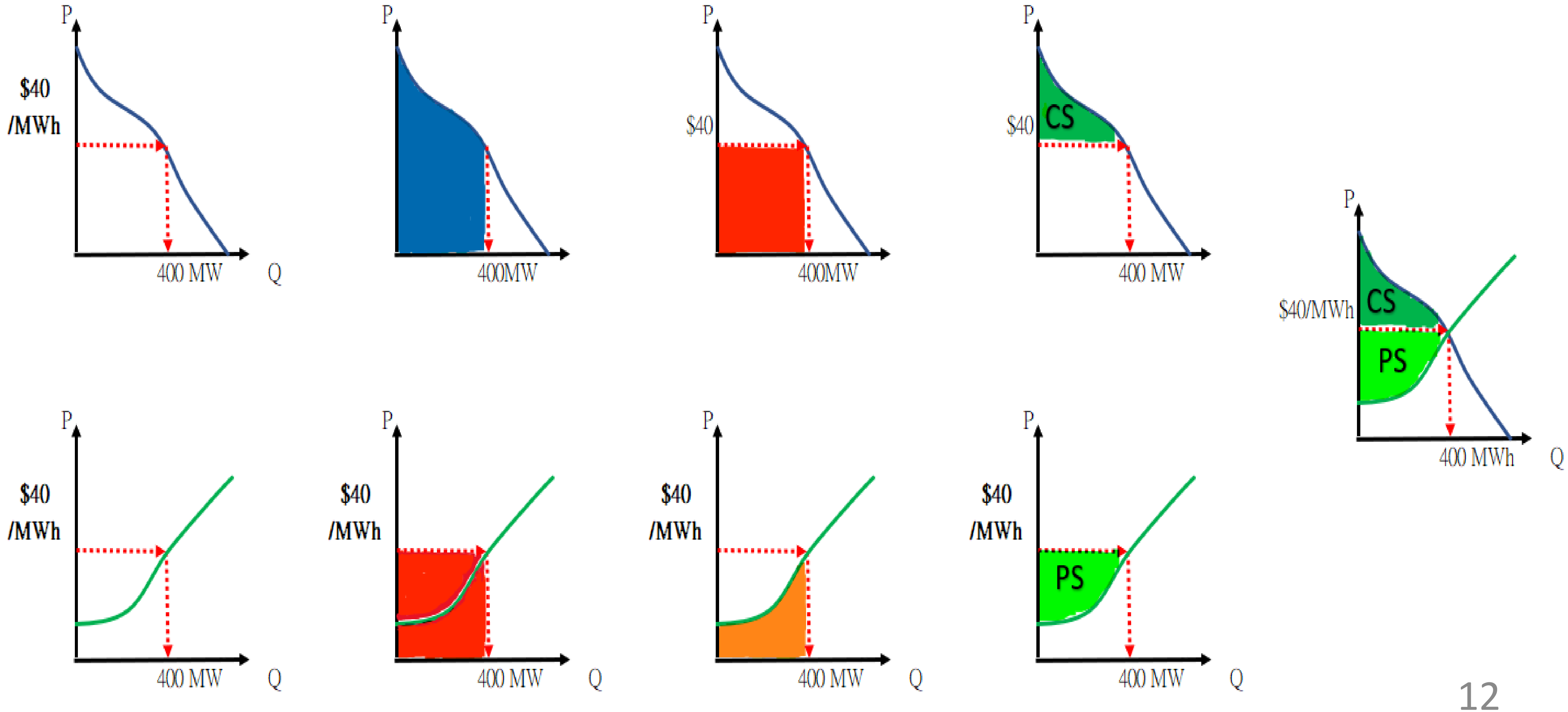
Microeconomic Principles for Electricity Market 電力市場微型經濟原則

- Measuring benefits to market participants (MP)
- Supply and Demand functions ⇔ Willingness To Pay

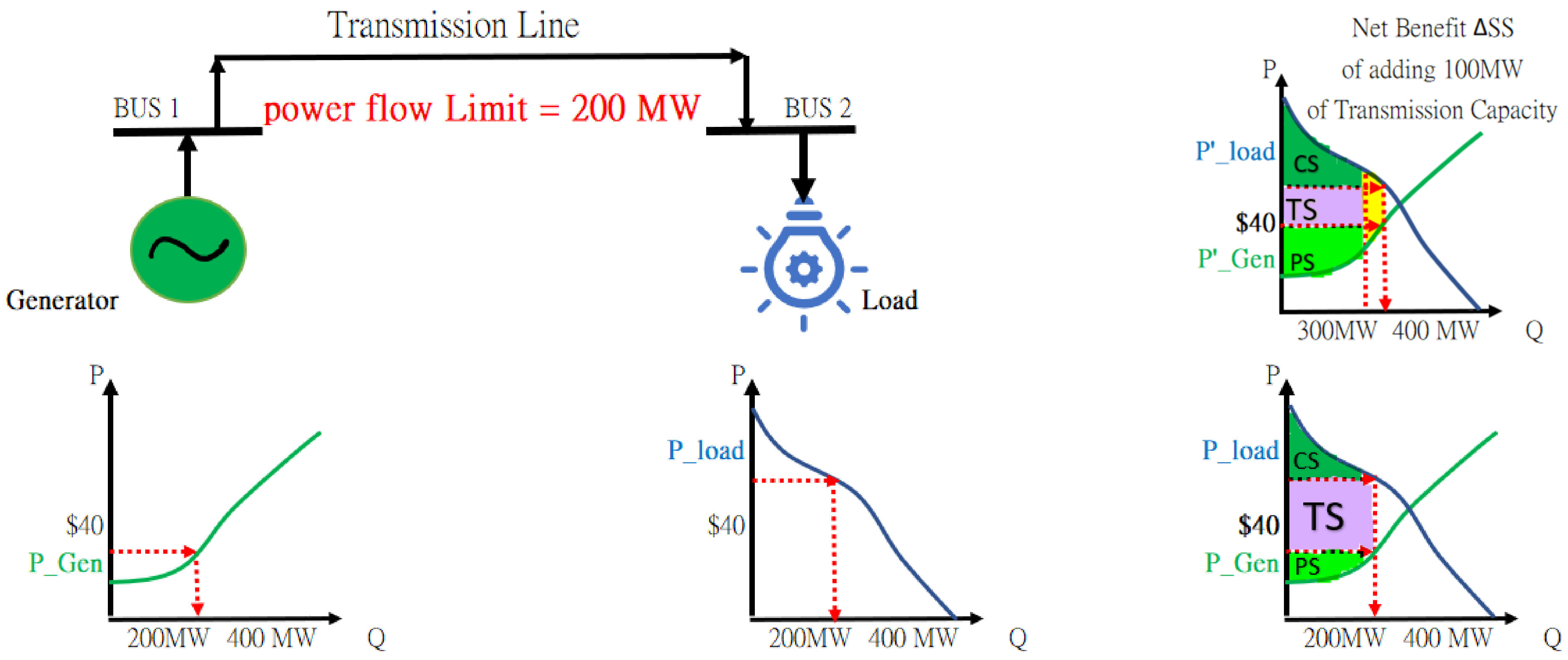
- **Key concept : economic Surplus 經濟剩餘**
    - CS: Consumer Surplus (Value of Electricity – bill) 消費者剩餘
    - PS: Producer Surplus (Profit = Revenue – cost) 生產者剩餘
    - TS: Transmission Surplus (Congestion Charge) 傳輸者剩餘
- Market Benefits = Social Surplus 社會剩餘(called Social Welfare)

    = CS + PS + TS

Social Surplus Calculation (no Transmission)
社會剩餘計算(不含傳輸線路限制)



Social Surplus Calculation: 包含傳輸線路限制



- \$P_gen = Marginal cost (supply Bus1)
- \$P_load = Marginal Value (demand Bus2)
- Transmission Owner receives (\$P_load - \$P_gen) = Congestion Revenue 擁塞費用

Market Power 市場壟斷力

- The ability to manipulate prices (操控價格) persistently to one's advantage, independently of the actions of others.
- Generating units (發電機組):

  The ability to raise prices above marginal cost by restricting

  generation output.
- May exercise market power because of:
  - Economic of scale 經濟規模
  - Transmission costs, constraints 傳輸線路擁塞限制
  - Flaw in market design 市場設計缺失

Market Power example: Monopoly 獨佔範例

- A generator total Production cost = $3 + 2Q + \frac{1}{2}Q^2$
  - ➢ Marginal Cost (邊際成本MC) = 2 + Q = Supply function
  - ➢ 得知可以影響電力市場電價 P
- Demand function: P ($/MWh) = 20 – 2Q

- Profit = Revenue – Cost

  $= (20 - 2Q) * Q - (3 + 2Q + \frac{1}{2}Q^2)$

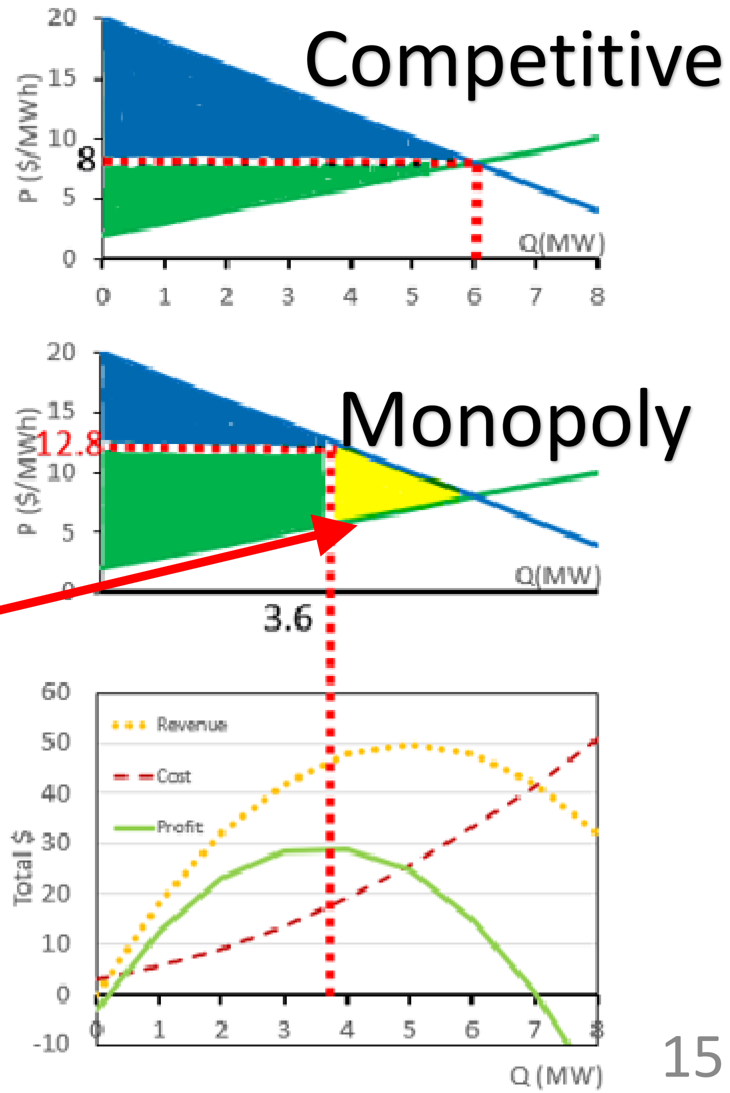
- Monopolist Solution

  dProfit/dQ = 0

  = dRevenue/dQ – dCost/dQ

  = MR - MC

Loss of market efficiency Due to market power



Game Theory 賽局理論

- Used to understand how markets evolve and operate
- Used in Auction Design and bidding strategies
- Nash equilibrium　納許平衡（非合作平衡）
  - A rational expectation equilibrium
  - No player can profitable deviate away
- Example Prisoner's Dilemma （囚犯困境）

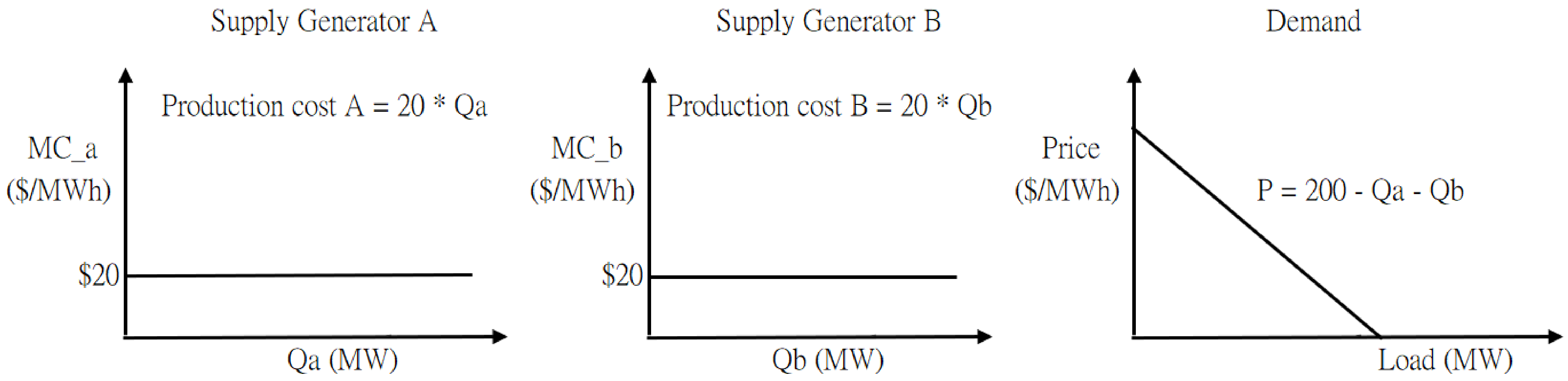
  two-players game (duopoly)

Duopoly 2人遊戲	甲 不認罪	甲 認罪
乙 不認罪	各判2年牢	甲: 1年 乙: 10年
乙 認罪	甲:10年 乙: 1年	各判5年

Oligopoly 寡頭壟斷

- 少數賣方所主導的市場，如電力市場
- Cournot Model 庫諾模型
  - Quantity as the strategic variable 產量為競爭手段
  - 利益最大化，即邊際收益(marginal profit) 等於邊際成本(marginal cost)
- Bertrand Model 柏氏模型
  - Price as the strategic variable 價格競爭為策略
  - Best bet to charge a price equal to its Marginal Cost 均衡結果等於邊際成本
  - Competitive commodity model!
- 形成市場壁壘，無法使新的競爭者進入市場。

Strategic Modeling Example 策略模擬



Cournot Quantity Equilibrium 古諾產量均衡

Profit ($) = P x Q - COST | Demand curve: P = 200 - Qa- Qb | COST = MC x Q

Qa \ Qb	50	52	54	56	59	60	63	64	66	68	70
50	4000 / 4000	3900 / 4056	3800 / 4104	3700 / 4144	3550 / 4189	3500 / 4200	3350 / 4221	3300 / **4224**	3200 / **4224**	3100 / 4216	3000 / 4200
52	4056 / 3900	3952 / 3952	3848 / 3996	3744 / 4032	3588 / 4071	3536 / 4080	3380 / 4095	3328 / **4096**	3224 / 4092	3120 / 4080	3016 / 4060
54	4104 / 3800	3996 / 3848	3888 / 3888	3780 / 3920	3618 / 3953	3564 / 3960	3402 / **3969**	3348 / **3968**	3240 / 3960	3132 / 3944	**3024** / 3920
56	4144 / 3700	4032 / 3744	3920 / 3780	3808 / 3808	3640 / 3835	3584 / 3840	3416 / **3843**	3360 / 3840	**3248** / 3828	**3136** / 3808	**3024** / 3780
59	4189 / 3550	4071 / 3588	3953 / 3618	3835 / 3640	3658 / 3658	3599 / **3660**	**3422** / 3654	**3363** / 3648	3245 / 3630	3127 / 3604	3009 / 3570
60	4200 / 3500	4080 / 3536	3960 / 3564	3840 / 3584	**3660** / 3599	**3600** / **3600**	3420	3360	3240	3120	3000
63	4221 / 3350	4095 / 3380	**3969** / 3402	**3843** / 3416	3654 / **3422**	3591 / 3420	340				
64	**4224** / 3300	**4096** / 3328	3968 / 3348	3840 / 3360	3648 / **3363**	3584 / 3360	339				
66	**4224** / 3200	4092 / 3224	3960 / 3240	3828 / **3248**	3630 / 3245	3564 / 3240	336				
68	4216 / 3100	4080 / 3120	3944 / 3132	3808 / **3136**	3604 / 3127	3536 / 3120	333				
70	4200 / 3000	4060 / 3016	3920 / **3024**	3780 / **3024**	3570 / 3009	3500 / 3000	329				
MC (Marginal Cost $/unit)	20										

Price = $80/MWh
Qa = 60MW
Qb = 60MW
Profit_a = $3600
Profit_b = $3600

Bernard Price equilibrium 柏氏價格均衡

Profit ($) = P x Q - COST | Demand: P = 200 - Qa- Qb | Supply COST = MC x Q

BIDa \ BIDb	$10	12	14	16	18	20	22	24	26	28
10	-950 / -950	-1800 / 0	-1800 / 0	-1800 / 0	-1800 / 0	-1800 / 0	-1800 / 0	-1800 / 0	-1800 / [illegible]	[illegible] / 0
12	0 / -1800	-752 / -752	-1440 / 0	-1440 / 0	-1440 / 0	-1440 / 0	-1440 / 0	-1440 / [illegible]	[illegible] / 0	-1440 / 0
14	0 / -1800	0 / -1440	-558 / -558	-1080 / 0	-1080 / 0	-1080 / 0	[illegible] / 0	[illegible] / 0	-1080 / 0	-1080 / 0
16	0 / -1800	0 / -1440	0 / -1080	-368 / -368	-720 / [illegible]	[illegible] / 0	-720 / 0	-720 / 0	-720 / 0	-720 / 0
18	0 / -1800	0 / -1440	0 / -1080	[illegible] / [illegible]	[illegible] / -182	-360 / 0	-360 / 0	-360 / 0	-360 / 0	-360 / 0
20	0 / -1800	0 / [illegible]	[illegible] / -1080	0 / -720	0 / -360	0 / 0	[illegible]	[illegible]	[illegible]	[illegible]
22	0 / [illegible]	[illegible] / -1440	0 / -1080	0 / -720	0 / -360	0 / 0	[illegible]	[illegible]	[illegible]	[illegible]
24	[illegible] / -1800	0 / -1440	0 / -1080	0 / -720	0 / -360	0 / 0	[illegible]	[illegible]	[illegible]	[illegible]
26	0 / -1800	0 / -1440	0 / -1080	0 / -720	0 / -360	0 / 0	[illegible]	[illegible]	[illegible]	[illegible]
28	0 / -1800	0 / -1440	0 / -1080	0 / -720	0 / -360	0 / 0	[illegible]	[illegible]	[illegible]	[illegible]
MC (Marginal Cost $/MWh)	20									

Competitive commodity model!

Price = $20/MWh
Qa = 90MW
Qb = 90MW
Profit_a = $0
Profit_b = $0

Opportunity Cost Example 機會成本

- Giving up an opportunity to earn revenue elsewhere is a Cost!
- A generating unit:

Cost \ Electricity Commodity	Energy	A/S : Operating Reserve
Capacity	400 MW	50 MW
Fixed Cost (capital and fixed O&M)	$16/h	
Variable Cost	$60/MWh	$10/MWh

- Anticipated market prices

Price \ Electricity Commodity	Energy	A/S: Operating Reserve
Market Price	$70/MWh	$25/MWh

- “Cost” of participating in each market (important for developing bids)

會計角度(full cost)	$76 = $16+$60	$26 = $16+$10
經濟家角度(Marginal Cost), ignored fixed cost	$75 = $60 + ($25-$10) opportunity cost	$20 = $10 + ($70-$60) oppo[illegible]

selling A/S

Take away point:
Marginal Cost 邊際成本

- Incremental cost (增量成本）for supplying additional unit quantity of product, ignoring the fixed cost

  每供給單位數量的產品，其所增加的生產成本, 不考慮固定成本

- 例如微軟office光碟片 ，每多賣一片 光碟片 其邊際供給成本
- Wind power發一度電的邊際供給成本 = 0
- 尖峰負載機組(Peaker, Combustion Turbine CT), 燃油屬性，MCP高
- 只要市場價格P大於average variable cost 平均變動成本，供應商就會願意生產提供，多少有賺，不然就會賣一個賠一個!
- 消費者：買一杯咖啡，第二杯半價＝＞邊際效益/好處utility下降

Electricity Market Clearing with co-optimization of A/S
電能暨輔助服務市場出清

- To minimize the total ***bid-based*** production cost 最低競標發電成本
- Equivalent to social surplus/welfare maximization
- Subject to
  1. Energy balance constraint 電力供給與用電負載需求之平衡
  2. System-wide reserve constraints 系統備載容量要求
  3. Local reserve constraints 區域備載容量要求
  4. Transmission constraints 傳輸線路容量限制
  5. Resource level constraints 發電機組特性及限制

Market Clearing Results 電力市場出清結果

- Desired unit commitments & dispatch schedules
  發電機組的排程及每小時發電量(百萬瓦MW出力)
- Nodal energy prices
  節點電價
- Desired reserve schedules
  發電機組需提供的輔助服務備載容量及排程
- Reserve market-clearing prices
  輔助服務市場備載容量的市場價格

Market Clearing Procedures 電力市場出清程序

SCUC – Security Constrained Unit Commitment安全機組排程

Unit On/Off status	LR/MIP problem

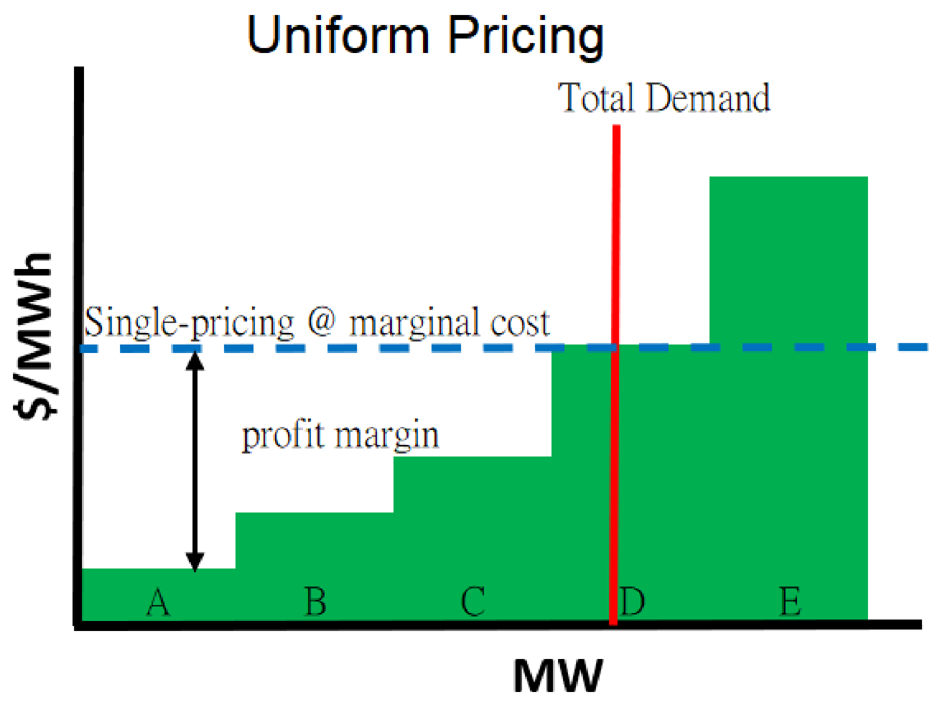
SCED – Security Constrained Economic Dispatch安全經濟調度

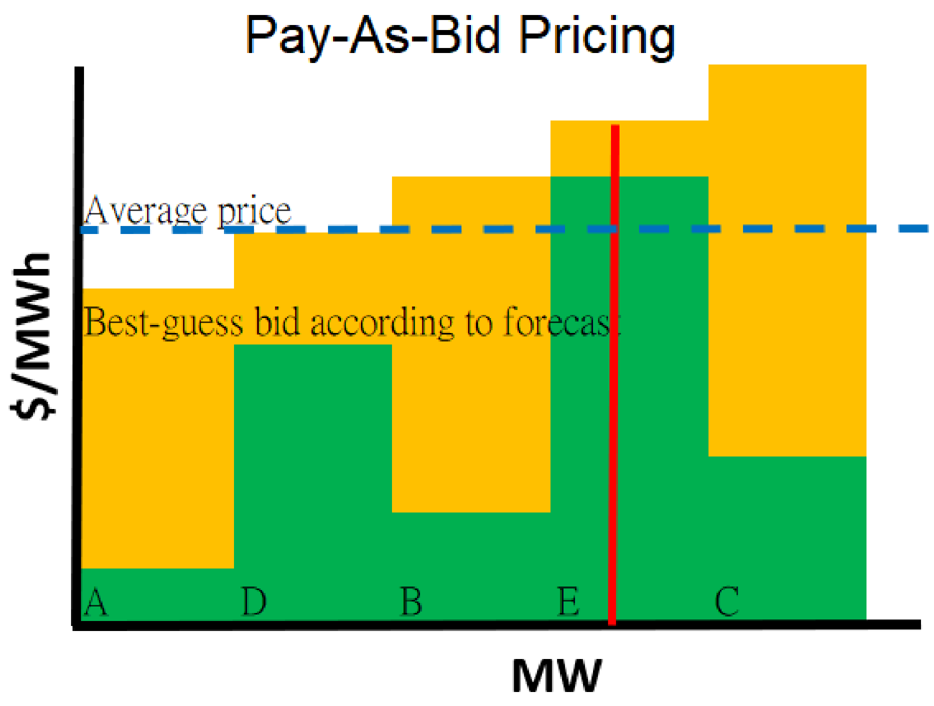
Generating output	Optimal power flow

RUC – Residual Unit Commitment 剩餘(系統穩定性)機組排程

Non-market process for reliability of system operation	Mandatory participation of certain units to ensure reliability

Uniform Pricing(單一定價) vs Pay-As-Bid (差別訂價)





Nodal Pricing: Locational Marginal Price (LMP) 節點電價: 區域邊際價錢

- 包含三個價格成份所組成

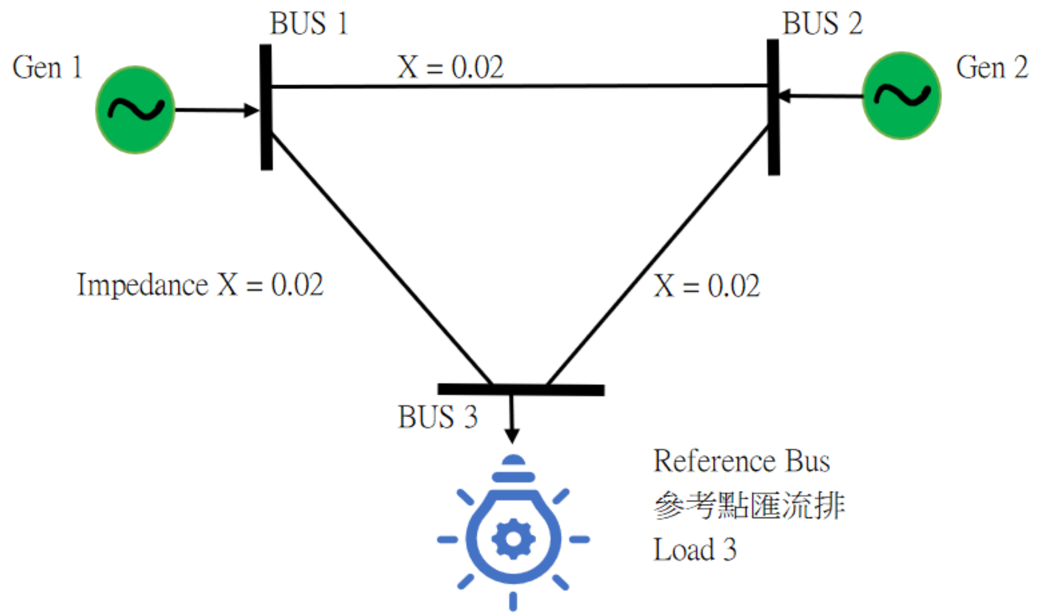
$$LMP = LMP_{energy} + LMP_{congestion} + LMP_{loss}$$

1. System Marginal energy price Component 邊際系統能源價錢
2. Marginal Congestion Component 邊際線路擁塞價錢
3. Marginal Loss Component 邊際線路損耗價錢

意義: 在每個節點/匯流排(node/bus)，若要增加*下一個*百萬瓦(1MW)單位***負載需求***，系統所需要的增量發電成本(incremental production cost)。

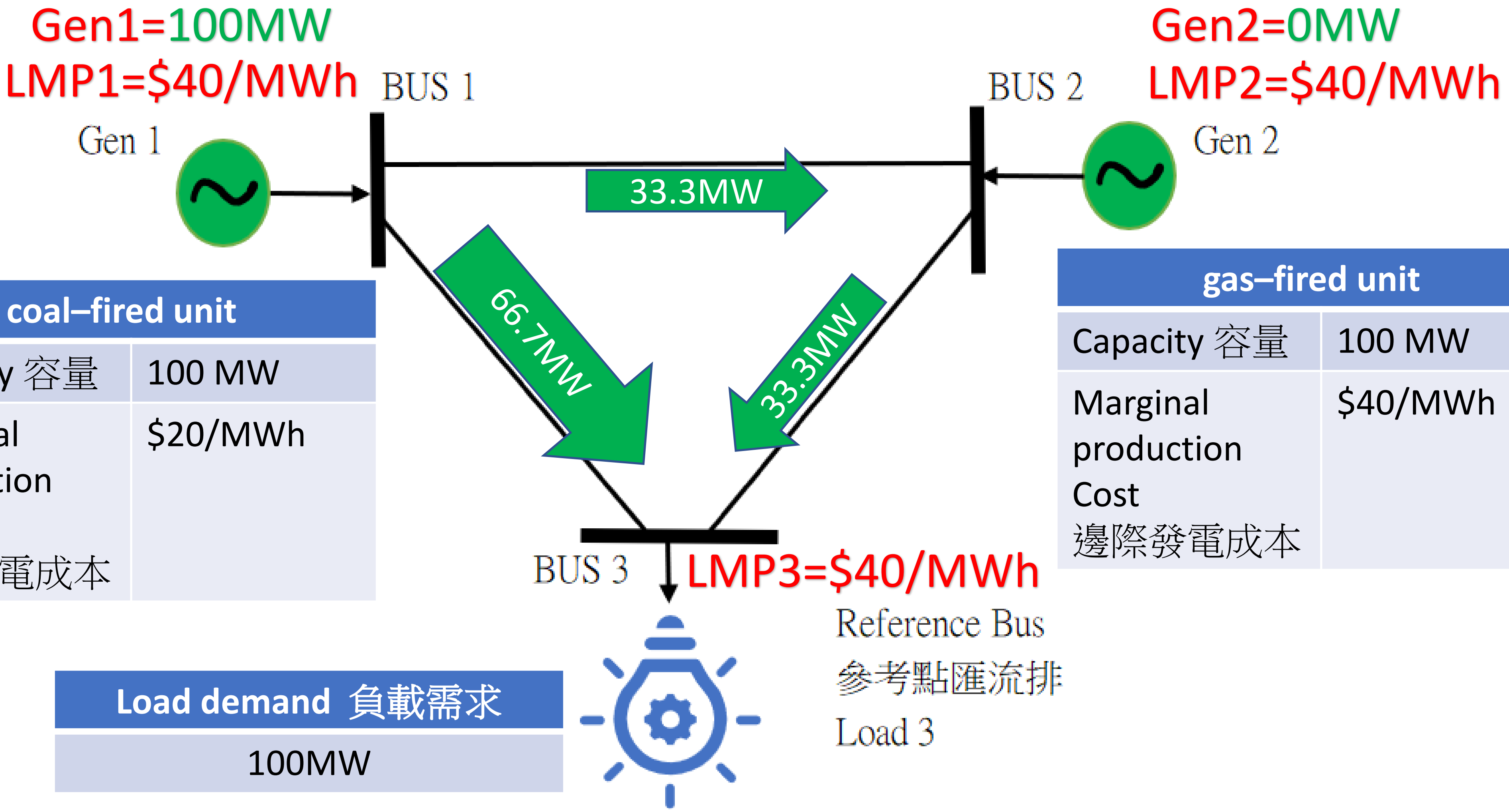
GSF: Generator Shift Factor 發電流量偏移係數

- 定義: 能源機組發電1MW注入電網一端 (source源頭)，同時在另一端(sink終點, 通常又稱reference bus 參考節點匯流排)流出供負載使用1MW，其電流在各傳輸線路的流向分佈比例的線性係數。
- Three-Bus Example



GSF	Line 1 - 2	Line 2 - 3	Line 1 - 3
Gen 1	1/3	1/3	2/3
Gen 2	-1/3	2/3	1/3
Load 3 (ref.)	0	0	0

3-匯流排節點電價計算範例-(非擁塞電網)
Three-Bus LMP Example – (Unconstrained)

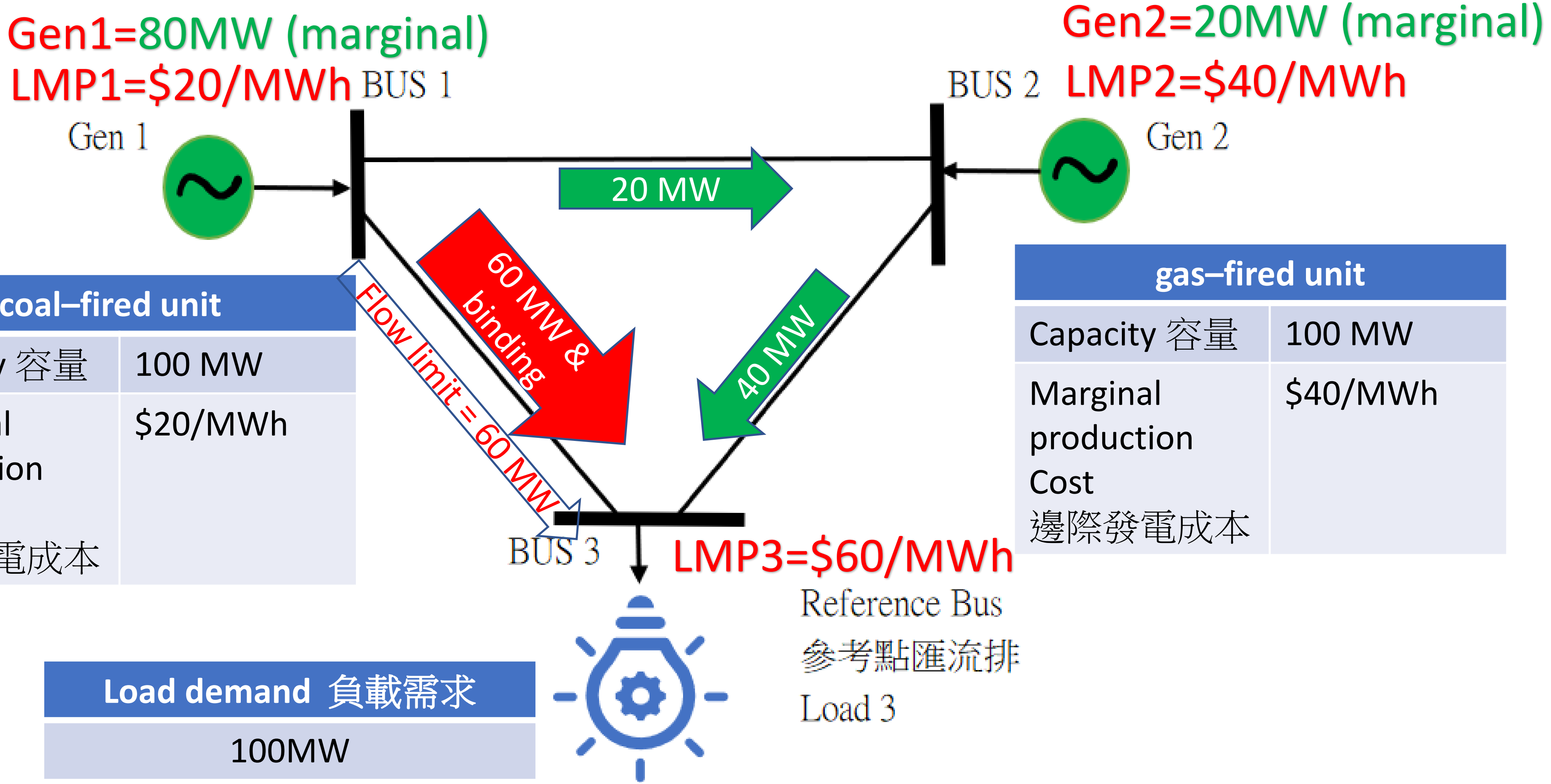


coal–fired unit	
Capacity 容量	100 MW
Marginal production Cost 邊際發電成本	$20/MWh

gas–fired unit	
Capacity 容量	100 MW
Marginal production Cost 邊際發電成本	$40/MWh

Load demand 負載需求
100MW

3-匯流排節點電價計算範例 (擁塞電網)
Three-Bus LMP Example (constrained)



coal–fired unit	
Capacity 容量	100 MW
Marginal production Cost 邊際發電成本	$20/MWh

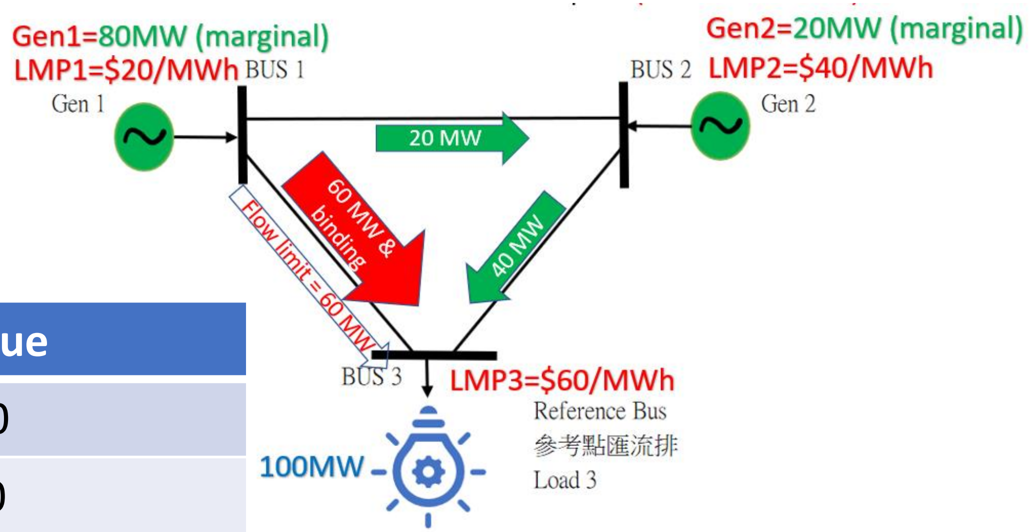
gas–fired unit	
Capacity 容量	100 MW
Marginal production Cost 邊際發電成本	$40/MWh

Load demand 負載需求
100MW

Electricity Market Settlement & Congestion Charges
電力市場結算&傳輸線路擁塞收費

- Method 1: $\sum \ (LMP_{cc}Sink \ - LMP_{cc}Source) * Flow$
  - Line1-2 $ = ($40 - $20) * 20MW = $400
  - Line1-3 $ = ($60 - $20) * 60MW = $2,400
  - Line2-3 $ = ($60 - $40) * 40MW = $800

  Total Congestion charges= $3,600



- Method 2: Gen Revenue – Load Payment

發電機組	出力 百萬瓦	Price	Revenue
Gen 1	80 MW	$20	$1,600
Gen 2	20 MW	$40	$ 800
負載用戶	用量	Price	Payment
Load 3	100MW	$60	$6,000

ISO/RTO 市場淨收	$3,600 (擁塞收費)

- Transmission Surplus (TS)

Three-Bus LMP Example – Problem Formulation 線性規劃問題

Objectitve

Minmize Electricity Market Production Cost f(x)

MIN f(Q) =20*Qgen1 + 40*Qgen2

Subject to:

Meet load demand:

Qgen1 + Qgen2 = 100MW

Generation <= capacity:

Qgen1 <= 100MW

Qgen2 <= 100MW

Line flow <= Limit

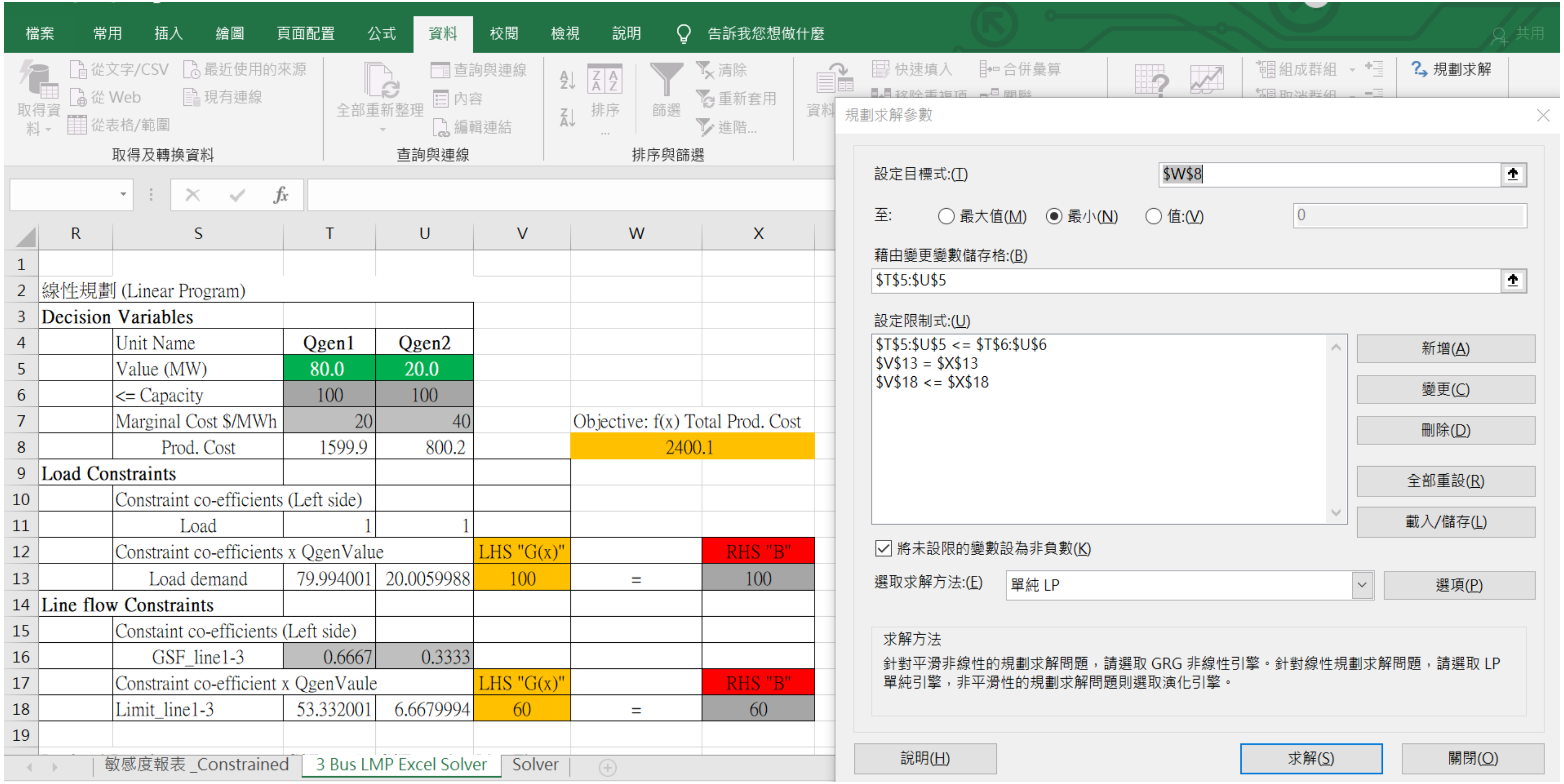
Qgen1 * 2/3 + Qgen2 * 1/3 <= 60MW

Non-negativity:

Qgen1 >=0

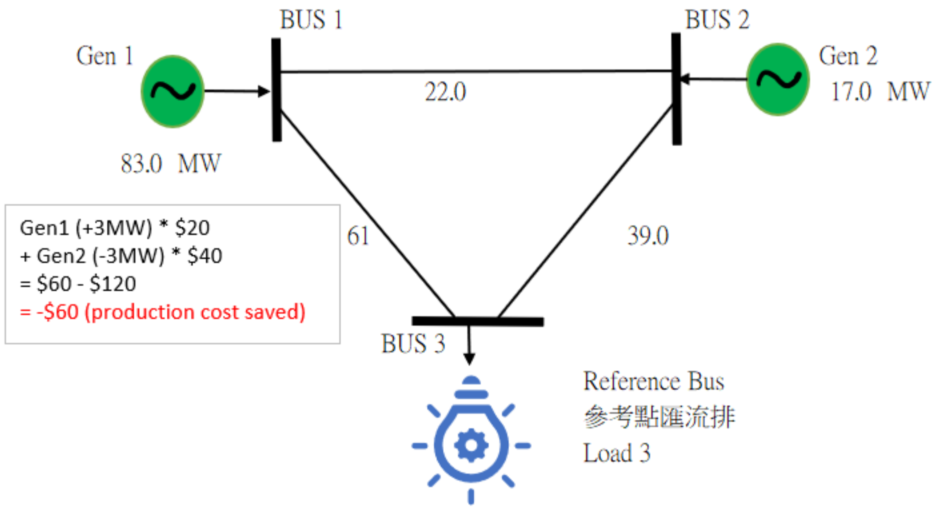
Qgen2 >=0

Three-Bus LMP Example – Excel Solver (規劃求解)

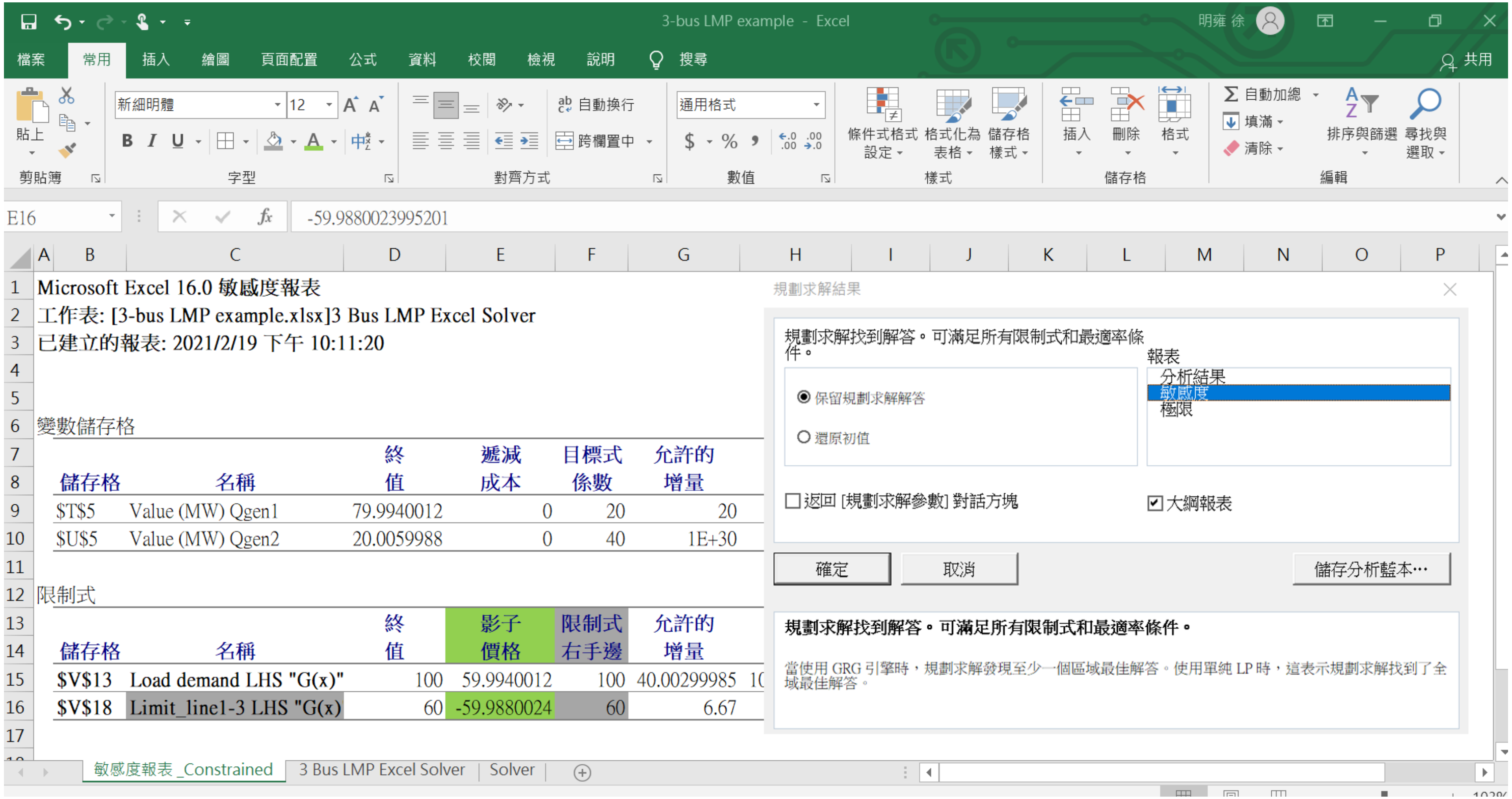


Shadow Price 影子價格

- 在最佳化問題中，當限制條件放寬一個單位之後，新的最佳解決方案的價值變化。
- 在3-Bus constrained network example, 放寬傳輸線1-3的流量限制1MW 為61MW, 而解得此Line1-3的影子價格為 -$60/MWh
- 意義為總電力生產成本 (total production cost)，因線路流量限制的放寬1MW，而降低了$60的成本 (因為可從較便宜的燃煤機組來多發電，燃氣機組少發點來供應負載需求)



Shadow Price 影子價格 -
Excel Solver (規劃求解) 敏感度報表


Microsoft Excel 16.0 敏感度報表
工作表: [3-bus LMP example.xlsx]3 Bus LMP Excel Solver
已建立的報表: 2021/2/19 下午 10:11:20

變數儲存格

儲存格	名稱	終值	遞減成本	目標式係數	允許的增量
T5	Value (MW) Qgen1	79.9940012	0	20	20
U5	Value (MW) Qgen2	20.0059988	0	40	1E+30

限制式

儲存格	名稱	終值	影子價格	限制式右手邊	允許的增量
V13	Load demand LHS "G(x)"	100	59.9940012	100	40.00299985
V18	Limit_line1-3 LHS "G(x)	60	-59.9880024	60	6.67

節點電價的實際運算

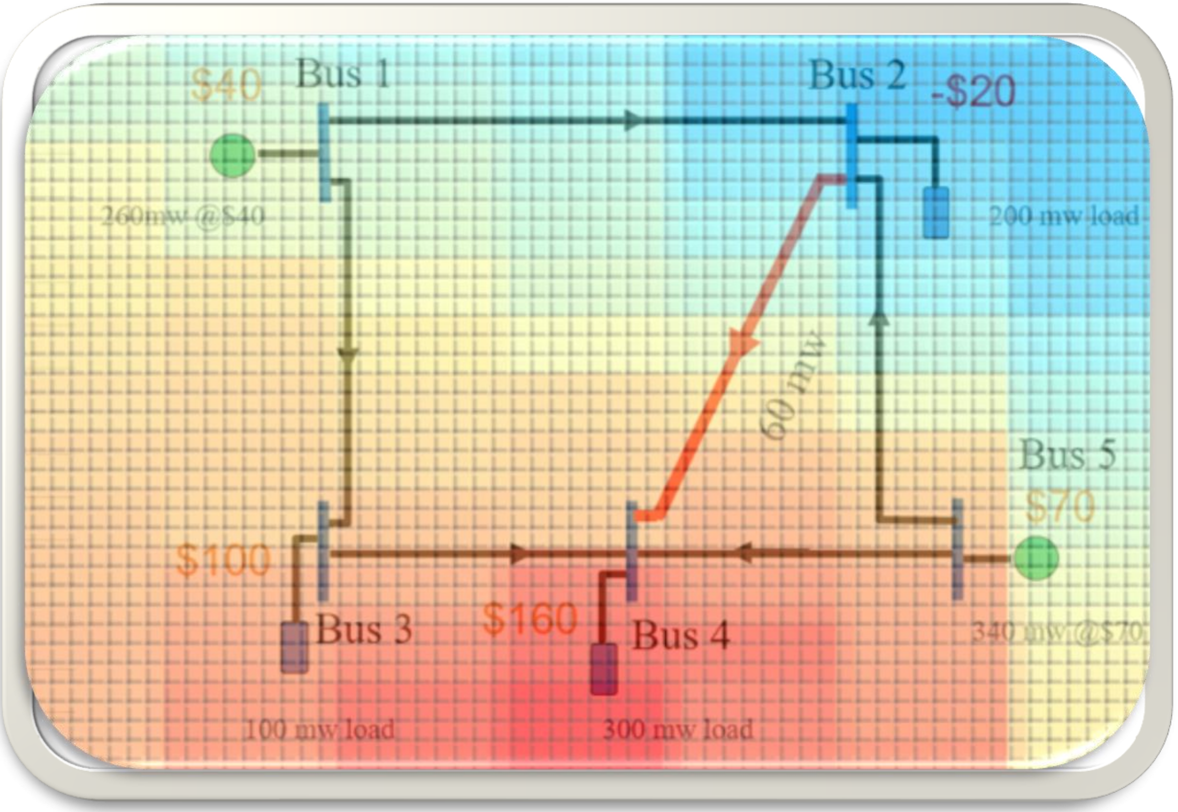
- 不考慮線路損耗 line losses ignored
- LMP_energy = LMP_reference Bus = LMP_bus3 = $60/MWh
- Shadow Price_constrained Line 1-3 = -$60/MWh
- GSF (DC Power flow $\Delta \underline{P} = \underline{B'}\ \Delta\ \underline{\theta}$)

Location	LMP	LMP_ energy	LMP_ congestion	Shadow Price Line1-3	GSF
LMP_bus1	$20		-$40	-$60/MW	2/3
LMP_bus2	$40	$60/MWh	-$20		1/3
LMP_bus3	$60		0		0

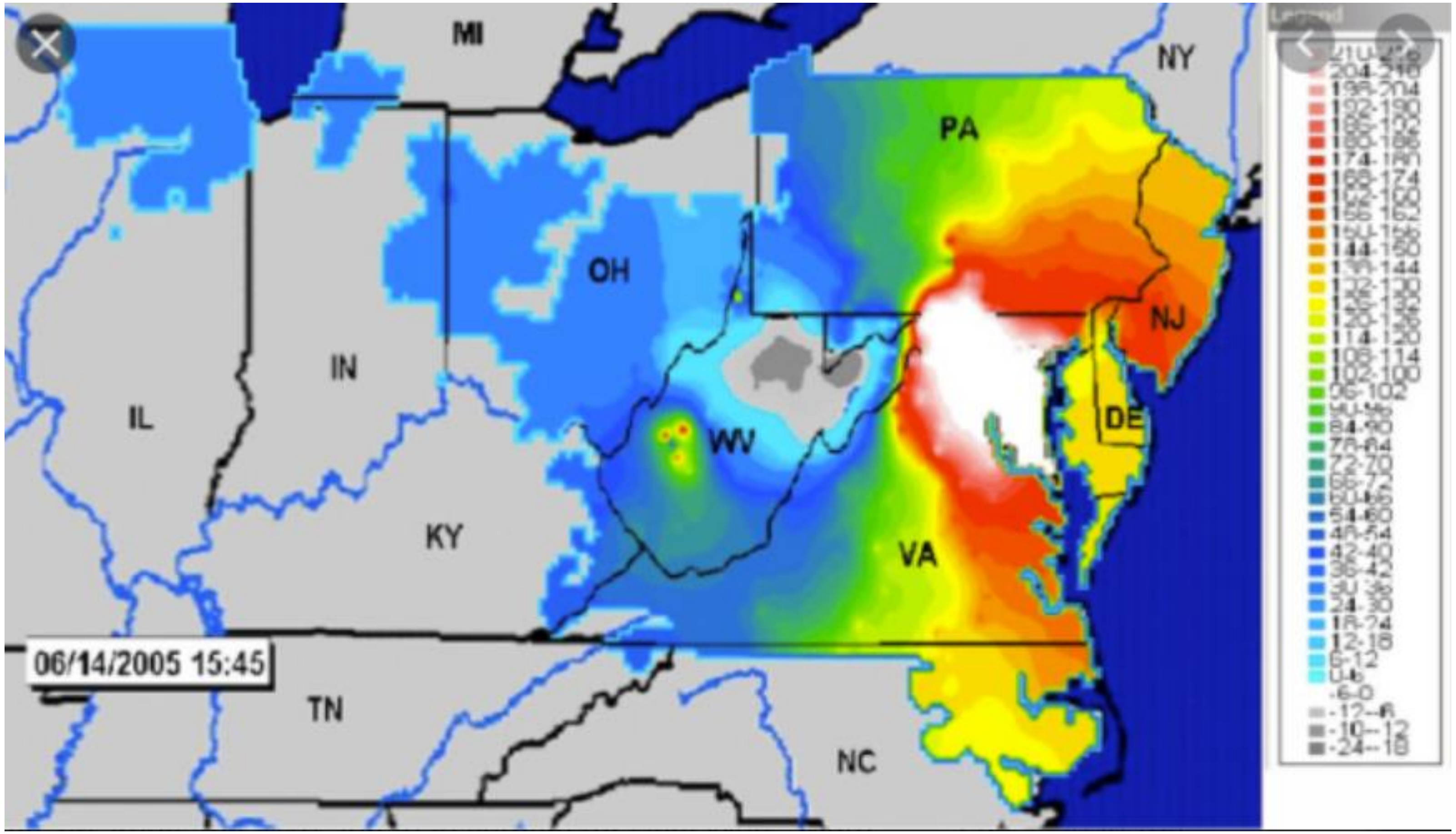
Negative LMP 負值的節點電價

- 可能嗎?
- 意義為何?

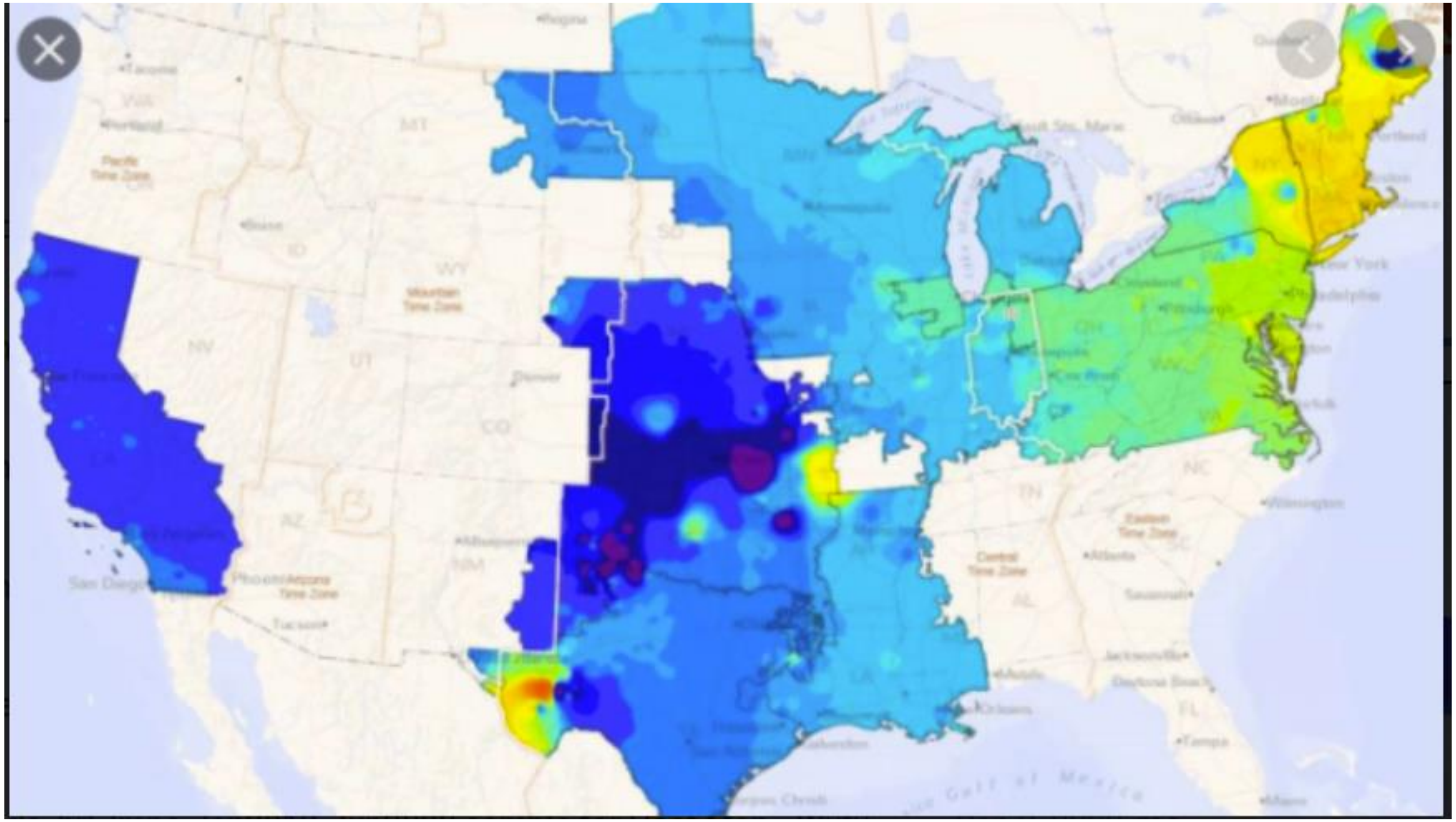
Locatn.	LMP	LMP_e	LMP_c	SP_L2-4	GSF
LMP1	$40		-$60		0.18
LMP2	-$20		-$120	-$330	0.36
LMP3	$100	$100	0		0
LMP4	$160		$60		-0.18
LMP5	$70		-$30		0.09



PJM 電力市場節點電價熱流圖(heat map)



美國主要電力市場-節點電價輪廓圖 (contour map)



Two Settlement System 雙結算市場

- Day-ahead Market (DAM) 日前市場and Real-time Market (RTM)即時市場

- DAM settlement is based on the schedule hourly energy quantity and day-ahead hourly prices
- RTM settlement on the actual hourly energy ***deviations from the day-ahead schedules,*** priced at real-time LMP *日前市場的偏移量來結算*

- Benefits:
  - Enhancing robust and competitive market 強化穩定競爭的市場
  - Providing additional ***price certainty*** to market participants (MP) 電價確定性

Two Settlement System雙結算市場 – 範例

- Load Serving Entity (LSE) 電力/零售公司: DAM Load < RTM Load

Market Type	DA Demand	Market Price	Payment
Day-ahead Market	100 MW	$20/MWh	$2,000
Real-Time Market	105 MW	$45/MWh	**$225**
		Total Charge	$2,225

- Generator / IPP 發電廠/發電公司: DAM Generation > RTM Generatn

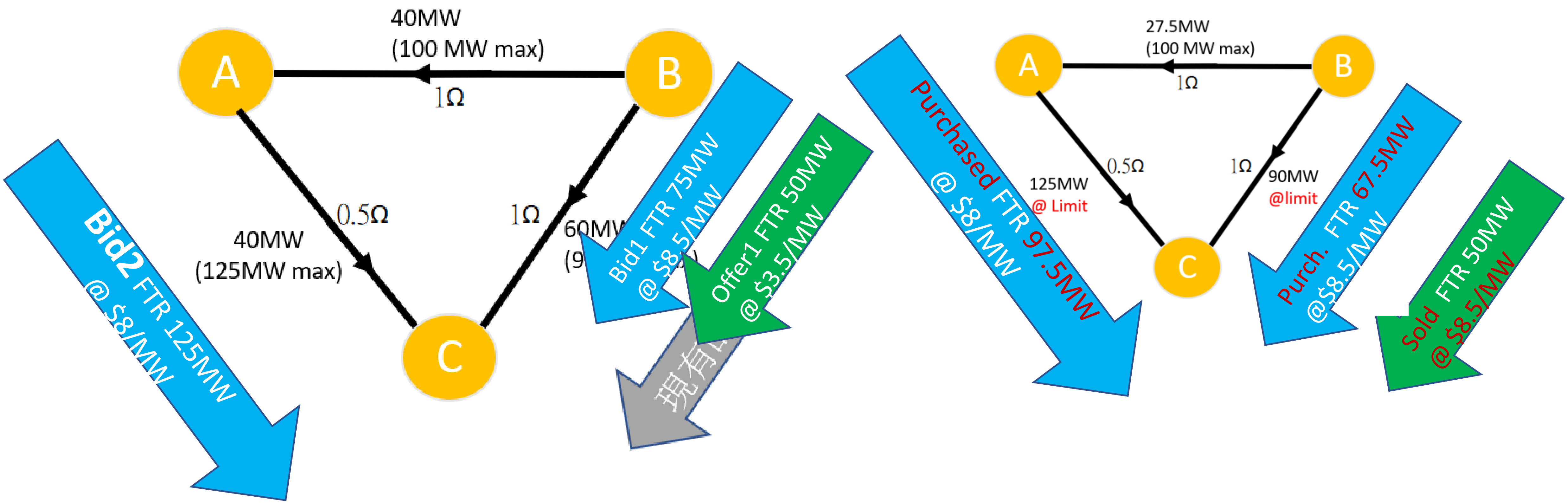
Market Type	DA Generation	Market Price	Revenue
Day-ahead Market	200 MW	$20/MWh	$4,000
Real-Time Market	190 MW	$35/MWh	**-$350 (payment)**
		Total Revenue	$3,650

Financial Transmission Right (FTR) 金融性傳輸權

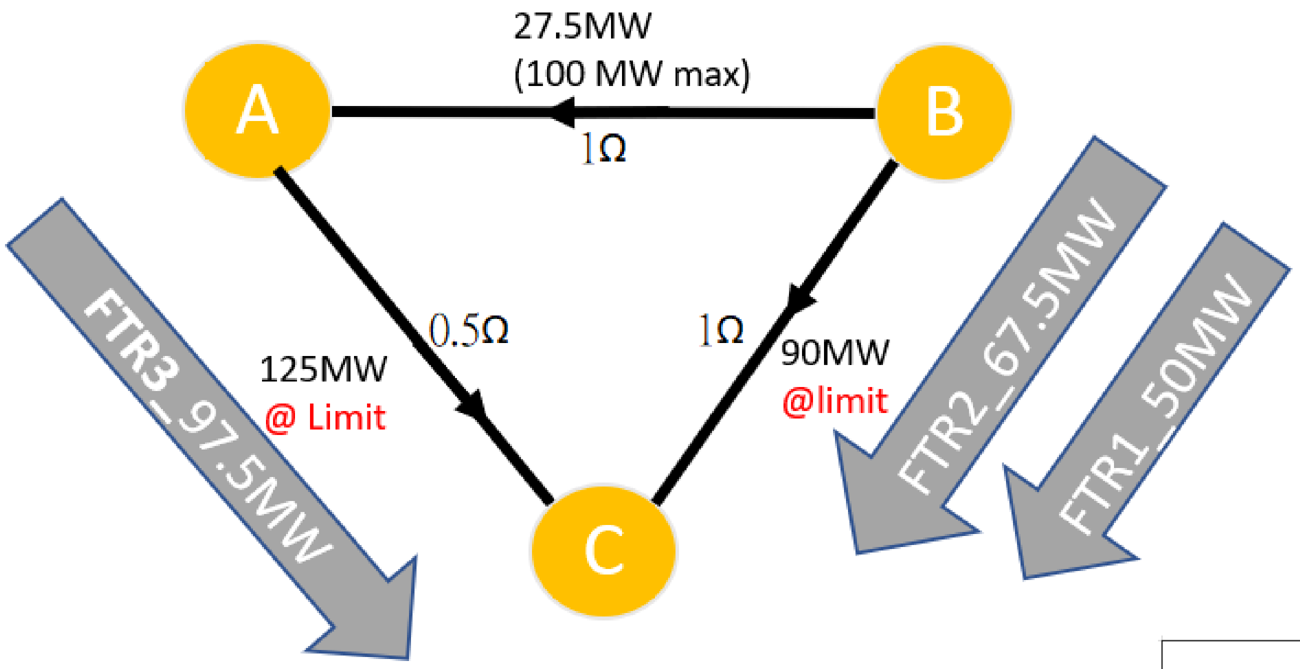
- Also called Congestion Revenue Right (CRR) 又稱擁塞收費權
- 目的 : Hedge Congestion Cost 線路擁塞避險商品
- 定義 :電力流量MW，源頭端(Source)，接收端(Sink)，時段(Period)

- 種類 : Obligation 義務權 / Option 選擇權
- 需要者: IPP/LSE 保障其財務financial positions的需求。
- 取得來源: FTR Auction Market process (yearly, monthly)

FTR Auction (yearly / monthly) Example
金融傳輸權(年度/每月)拍賣範例



FTR Offer/Bid Auction Example using the Excel Solver (規劃求解)



Objective MAX f(x) Auction Revenue

MAX 8*Qbid3A-C + 8.5Qbid2B-C - 3.5*Qoffer1C-B

Subject to:

Bid/Offer Capacity

Bid3A-C < = 125MW

Bid2B-C <= 75MW

Offer1C-B <=50MW

Line flow <= Limit	Offer1C-B	Bid2B-C	Bid3A-C	existingFTR100B-C
TDF_AB	0.4	-0.4	0.2	-0.4
TDF_AC	-0.4	0.4	0.8	0.4
TDF_BC	-0.6	0.6	0.2	0.6

-125MW' <= Line A-C <= 125MW

-90MW' <= Line B-C<=90 MW

-100MW' <= Line A-B <=100MW

	Qoffer1C-B	Qbid2B-C	Qbid3A-C	FTRb-c
FTR clearing MW	50	67.5	97.5	100
ShadowP_A-B	0			
ShadowP_A-C	7.75			
ShadowP_B-C	9			
Auction Clearing Price	-8.5	8.5	8	
Settlement	-425	573.75	780	

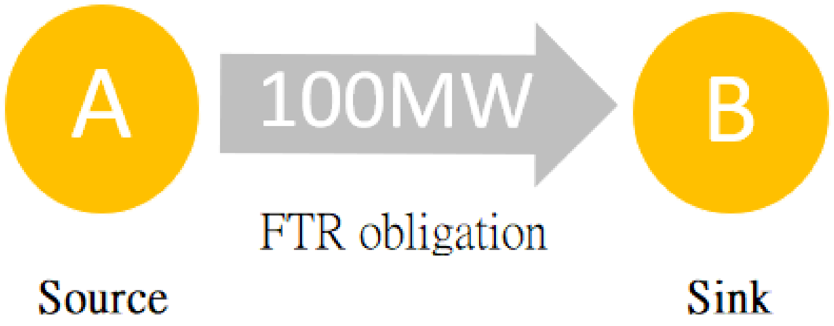
Objective MAX
1178.75

Excess Auction Revenue
928.75

FTR Valuation & Hedge Example
金融傳輸權價值&避險範例

- For an FTR with the following characteristics:
  - 100 MW from Source A to Sink B
- The value of the FTR obligation is calculated as:
  - $= (LMP_B\_congestion – LMP_A\_congestion) \times FTR\ MW$
  - $= (\$15 - \$\ 5) \times 100$
  - $= \$\ 1,000$

LMP	$27/MWh
LMP_energy	$20
LMP_congestion	$5
LMP_losses	$2



LMP	$39/MWh
LMP_energy	$20
LMP_congestion	$15
LMP_losses	$4

FTR Payoff Example 金融傳輸權收益範例

LMP (Gen node)	$30/MWh
Marginal Energy cost	$35
Marginal Congestion cost	-$6
Marginal Loss cost	$1

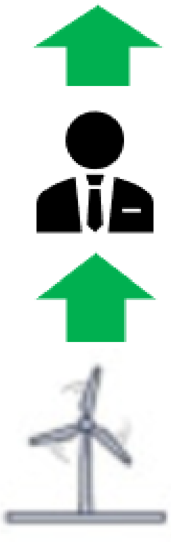
$38/MWh	LMP (load node)
$35	Marginal Energy cost
$1	Marginal Congestion cost
$2	Marginal Loss cost

FTR obligation

Customer sells power
@ $30/MWh LMP
to ISO market

Customer

Customer pays
$28/MWh PPA price
to wind farm



FTR Payoff to Customer	
FTR payoff	[$1 – (-$6)] * 100MW = $700
FTR cost	$5/MWh * 100MWh =$500
Net FTR payoff	$700 - $500 =$200

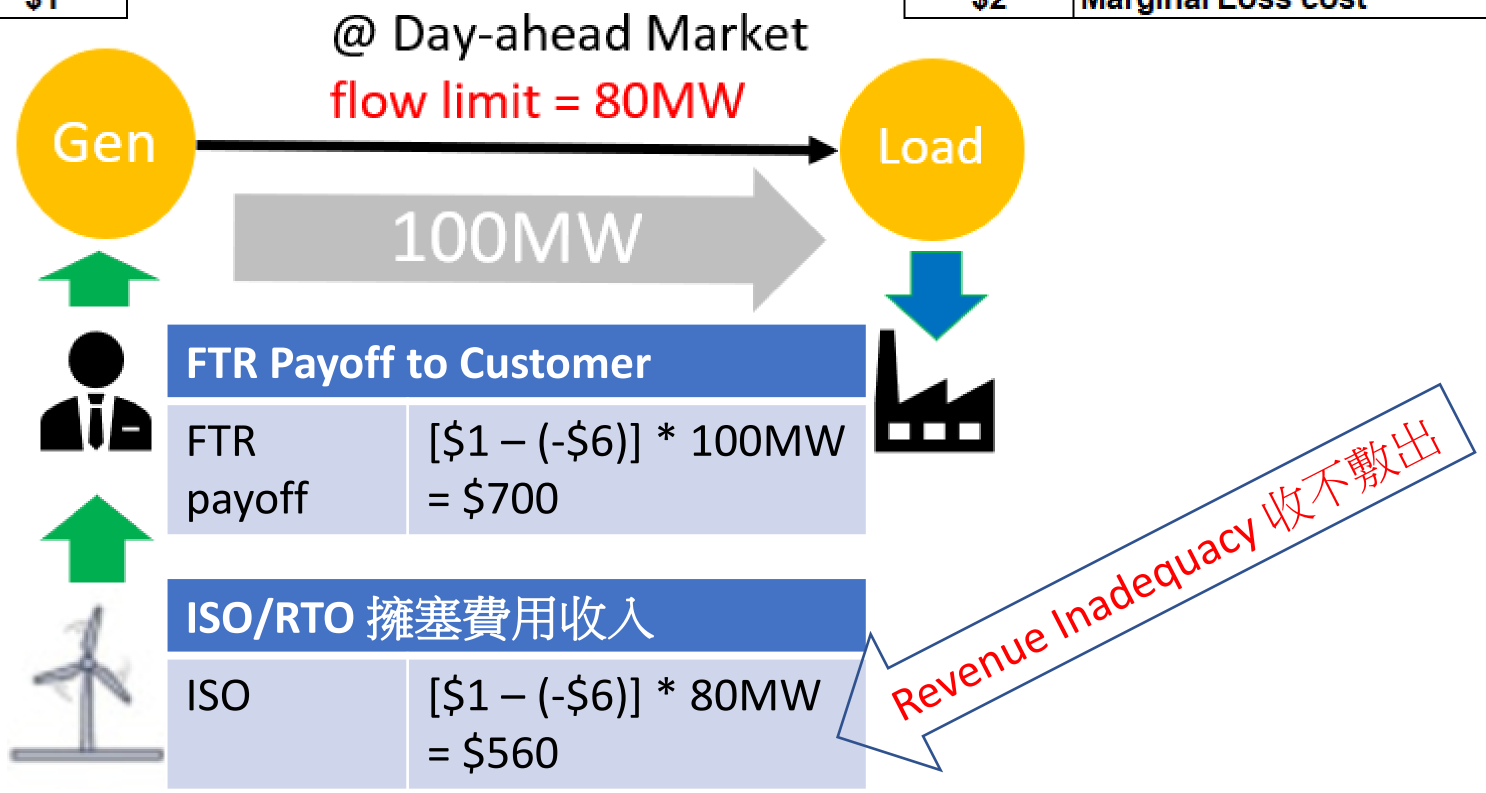
100 MW
Demand

Customer buys power
@ $38/MWh LMP
from ISO market

FTR Revenue Inadequacy 收支不足

LMP (Gen node)	$30/MWh
Marginal Energy cost	$35
Marginal Congestion cost	-$6
Marginal Loss cost	$1

$38/MWh	LMP (load node)
$35	Marginal Energy cost
$1	Marginal Congestion cost
$2	Marginal Loss cost



FTR Take-away Points
金融傳輸權要點

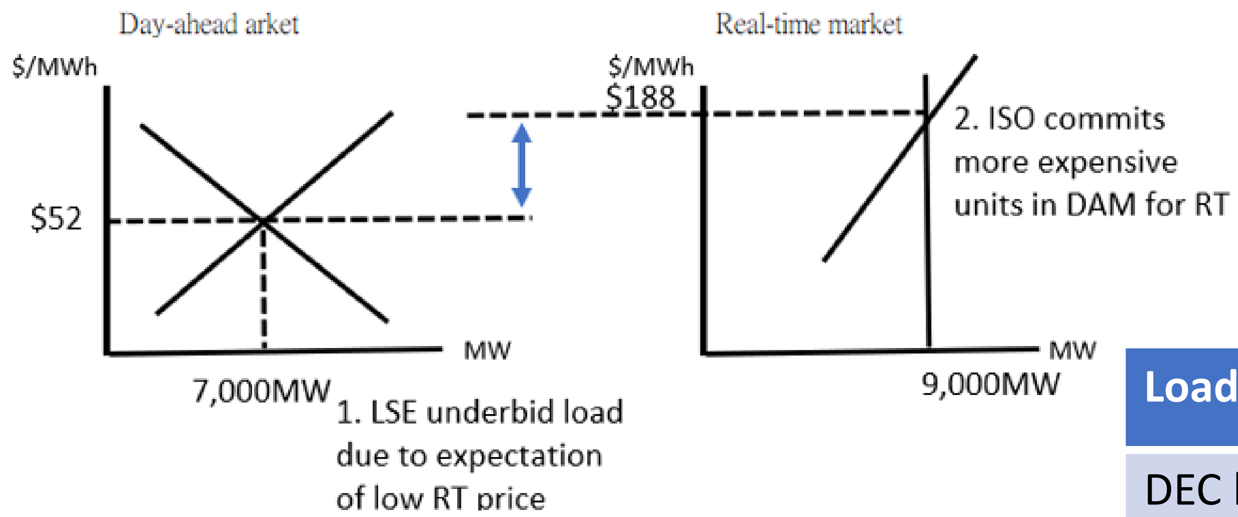
- Receive revenue streams in Day-ahead market
- Hedge congestion cost only只對擁塞部分避險
- Does not hedge against transmission loss charges
- Have financial risks (有風險) for holder of obligation (義務權) FTR in being charged when congestion flow is in the *opposite* direction: LMPcc_source > LMPcc_sink,

Value of obligation FTR = (MCCsink – MCCsource) is negative, i.e., paying for the counterflow

Convergence Bidding 收斂（電價）競標

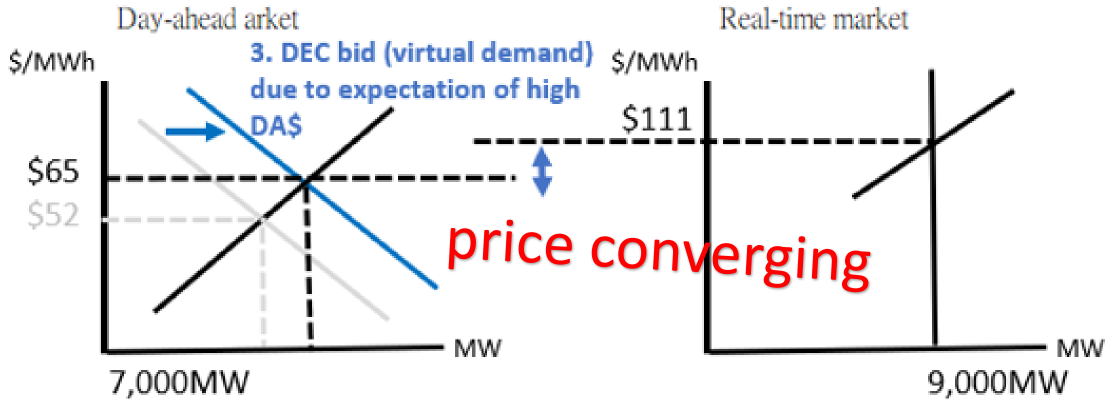
- 又稱Virtual bidding 虛擬競標
- 種類
  - INC bid (virtual supply offer 虛擬發電供應)
  - DEC bid (virtual load demand bid 虛擬負載需求)
- 目的
  - 避險節點電價變動
  - 收斂日前市場(DAM)和即時市場(RTM)的節點電價差異，提高電價穩定
  - 促進發電供應&負載需求在日前市場的參與及清算，提高市場效率及穩定運轉
  - 減低市場壟斷行為
- 性質
  - Expectation and arbitrage the expected price difference 市場期待&賺取價差
  - Virtual awards paid or charged the day-ahead LMP
  - fully liquidated (完全釋出清算) at the real-time LMP

Convergence Bidding example 收斂競標範例



Load purchase cost = 7,000MW * $52 + 2,000MW * $188 = $740,000

Load cost saved	$740,000 -$677,000 = $63,000
DEC bid profit	($111 - $65) * 50MW = $2,300



Load purchase cost = 7,000MW * $65 + 2,000MW * $111 = $677,000

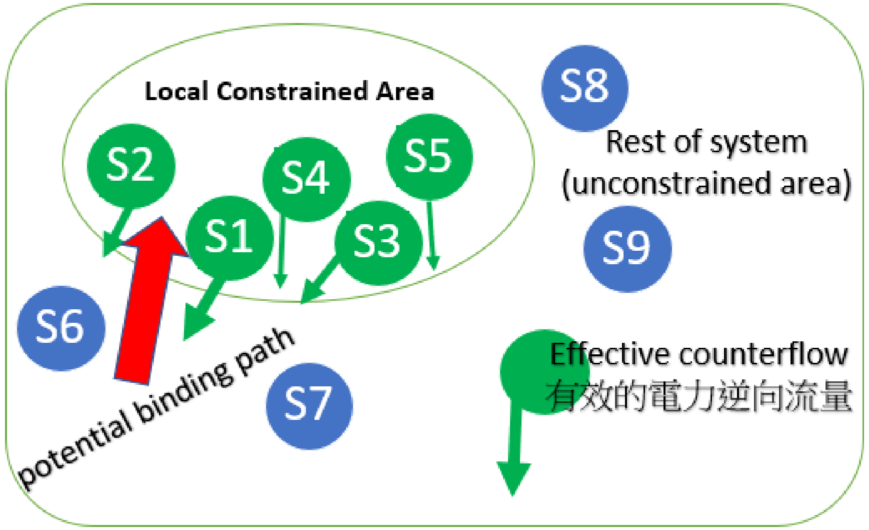
Measurement of Market Competitiveness 評估市場競爭性

- Structure-based 結構性
  - Concentration of supply
  - Residual Supply Index RSI　供給剩餘係數
  - $RSI = \frac{Total\ Supply - Largest\ Supplier's\ supply}{Total\ Demand}$
  - The pivotal supplier test 關鍵供應者測試
    - 若RSI <1 被視為關鍵供應者
    - 則市場可能不具競爭性，因為供應者扮演關鍵腳色來滿足市場需求，而可能提高價錢
- Conduct-and-Impact-based 行為影響性
  - Bid price impact on market price
  - Explicit assessment
- Market Power Mitigation 市場壟斷力防範

Total demand	**100MW**
Total supply	120MW
One supplier	30MW
RSI	0.9 = (120-30)/100

Competitive Path Assessment (CPA)
傳輸線路對市場競爭影響性評估

- Test *Only on potential Binding Constraints*
- Use RSI Index
  - to determine if there is competitive (effective) supply of counter-flow逆向電力流量.
- Three Pivotal Suppliers Test
  - Remove effective supply of up to three largest net suppliers for each binding constraint.



- If RSI ≥ 1 then Path is competitive, otherwise it is uncompetitive
- Pass tested competitive / uncompetitive designations to LMPM process for potential mitigation

RSI Calculation for Path Competitiveness example
傳輸線路影響市場競爭性之剩餘供給指數計算範例

	Effective CounterFlow (MW x GSF) 有效逆向電力流量		Effective CounterFlow (MW x GSF) 有效逆向電力流量	
	Dispatched 已調度	Resource Capacity 機組容量	Dispatched 已調度	Resource Capacity 機組容量
Gen. Suppllier 1	50	100	50	100
Gen. Suppllier 2	60	100	60	100
Gen. Supplier 3	70	100	70	100
Other Suppliers	220	**320**	220	**500**
Total	**400**	620	**400**	800
Congested Path Line Flow (MW)	1000		1000	
RSI_3-Pivotal Supplier 供給剩餘係數_去除3大供應者	(Totla Supply Capacity - 3 Largetst Capacity) / (Demand of Effective Counterflow 有效逆向電力流量需求)		(Totla Supply Capacity - 3 Largetst Capacity) / (Demand of Effective Counterflow 有效逆向電力流量需求)	
	=(620-100-100-100) / 400 =320/400 =0.75		=(800-100-100-100) / 400 =500/400 =1.25	
Path Competitiveness	un-ompetitive (擁塞線路影響市場競爭)		competitive (擁塞線路不影響市場競爭)	

CAISO Non-competitive Paths RSI example
影響加州電力市場競爭性(擁塞)線路的RSI實例

Table 1. Summary of RSI Results – Average RSI , Non-Competitive Paths (April-December, 2009)

		Cong.	Avg.	IFM ------------------------->				RTM ------------------------->			
Row#	CONSTRAINT_NAME	Hour	Flow	RSI0	RSI1	RSI2	RSI3	RSI0	RSI1	RSI2	RSI3
1	24074_LA FRESA_230_24065_HINSON _230_BR_1_1	431	601	5.12	2.70	2.54	2.42	1.16	0.27	0.14	0.12
2	VICTVL_BG	365	2,508	1.15	.92	.84	.79	1.02	0.79	0.72	0.67
3	LOSBANOSNORTH_BG	327	2,027	1.48	1.04	.98	.95	1.10	0.88	0.86	0.84
4	24082_LCIENEGA_230_24074_LA FRESA_230_BR_1_1	269	699	6.72	.16	.16	.16	1.36	0.18	0.18	0.18
5	SCE_PCT_IMP_BG	218	6,577	1.59	1.42	1.35	1.31	1.01	0.96	0.91	0.89

Default Energy Bid (DEB)預設電能競標值

- Purpose: 主要是在有市場壟斷的可能情況下，透過DEB 壟斷防範系統 (market power mitigation)，以呈現出真正市場競爭下的結果，也就是market Clearing at or near Marginal Cost not bid submitted
- Incremental Energy Cost curve
- Must provide to ISO/RTO master file
- Variable Cost Option 變動成本
  - Thermal Unit: Average Heat rate curve (BTU/KWh) 平均發電熱能須量
  - Non-thermal: Incremental Cost Curve ($/MWh)
- 再加上10% adder + Variable Energy Opportunity Cost if applicable

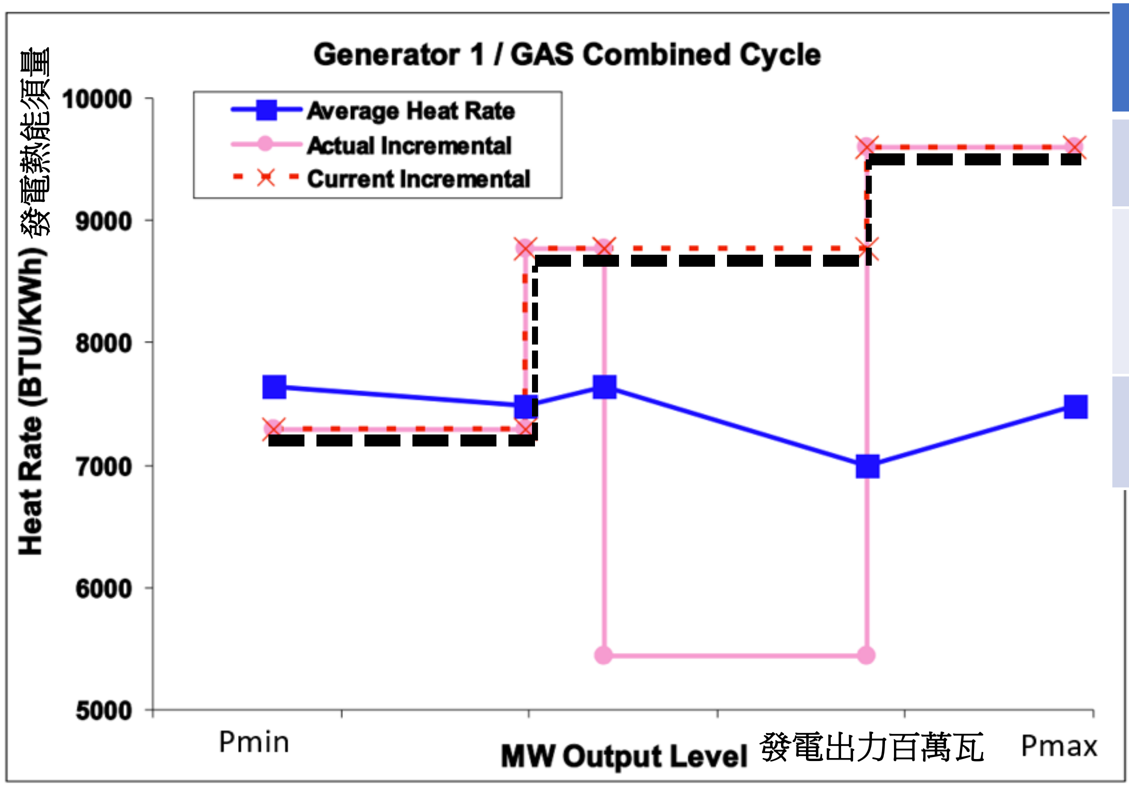
Default Energy Bid Example –
預設電能競標值計算範例 (燃氣複循環機組CCGT)

- Incremental Heat Rate(發電熱能須量)segment: 8,700 Btu/KWh (=8.7MMBtu/MWh)
- Natural gas price: $5/MMBtu
- O&M Cost: $3.3/MWh
- DEB Calculation for the segment

=(8.7 MMBtu * $5 + $3.3)* 110%

= $51.48/MWh

- Monotonically non-decreasing

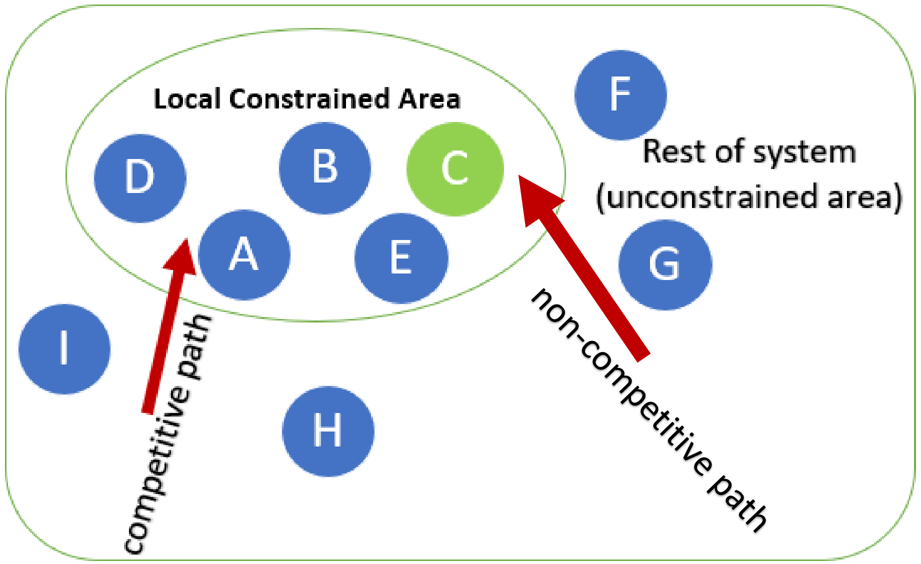


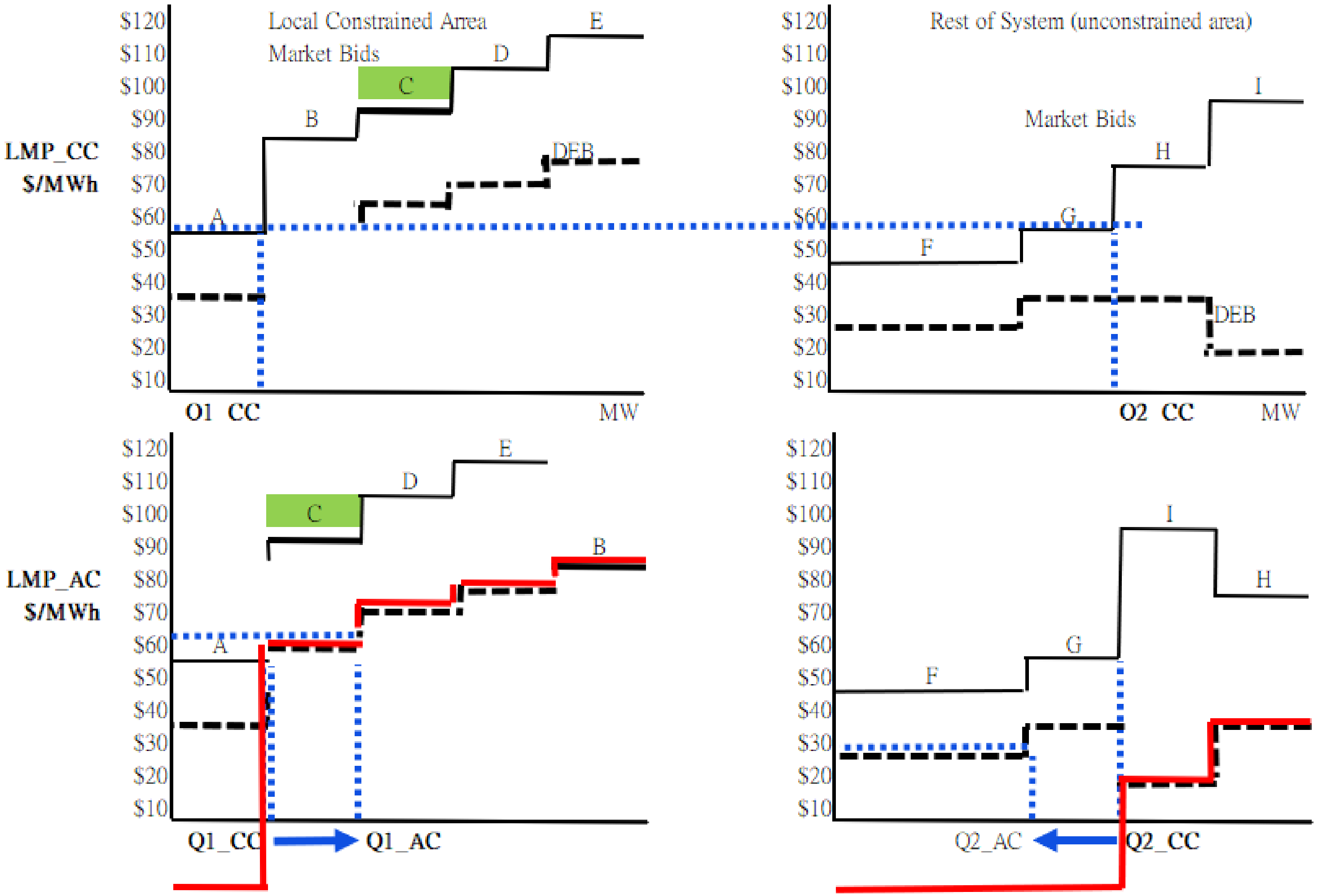
DEB $/MWh
$55.3
$51.4
$43.2

Local Market Power Mitigation (LMPM)
區域市場壟斷力防範

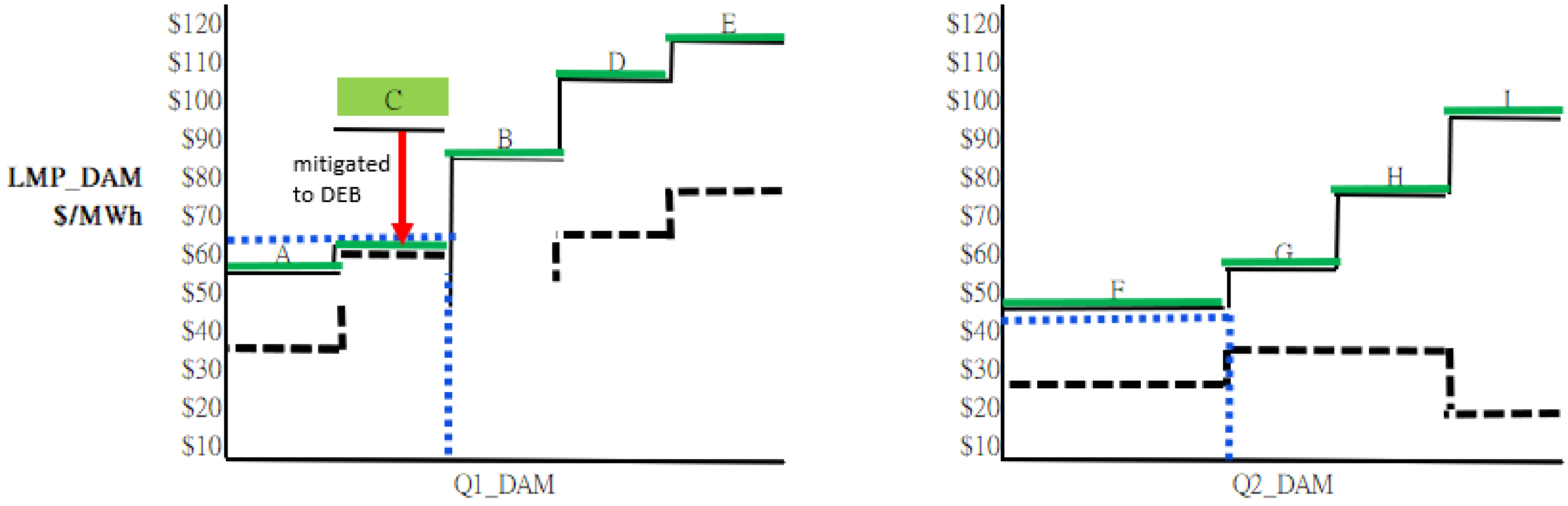
- Structural-based Process
  - Day-ahead market (DAM) run with Only Competitive Constraints enforced (CC run)
  - Day-ahead market run with All Constraints including non-competitive paths enforced (AC run) using DEB for bids above CC run schedule
- Triggering Criteria
  - Units that are dispatched UP in AC run to relieve non-competitive constraints are mitigated to DEBs
  - Bids not dispatched up in AC run keep original market bid for final Day-ahead market run
- Ex Ante Mitigation

Local Market Power Mitigation Example
區域市場壟斷防範範例





Final Mitigated Bids Passed to DAM Run
壟斷防範修正過的發電機組競標曲線



參考資料

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- ERCOT 2019 State of Market Report

謝謝您的聆聽，和意見想法！