Generator Cycling due to High Penetrations of Wind Power
系统接入高比例风电时的发电机组周期运行

erc electricity research centre

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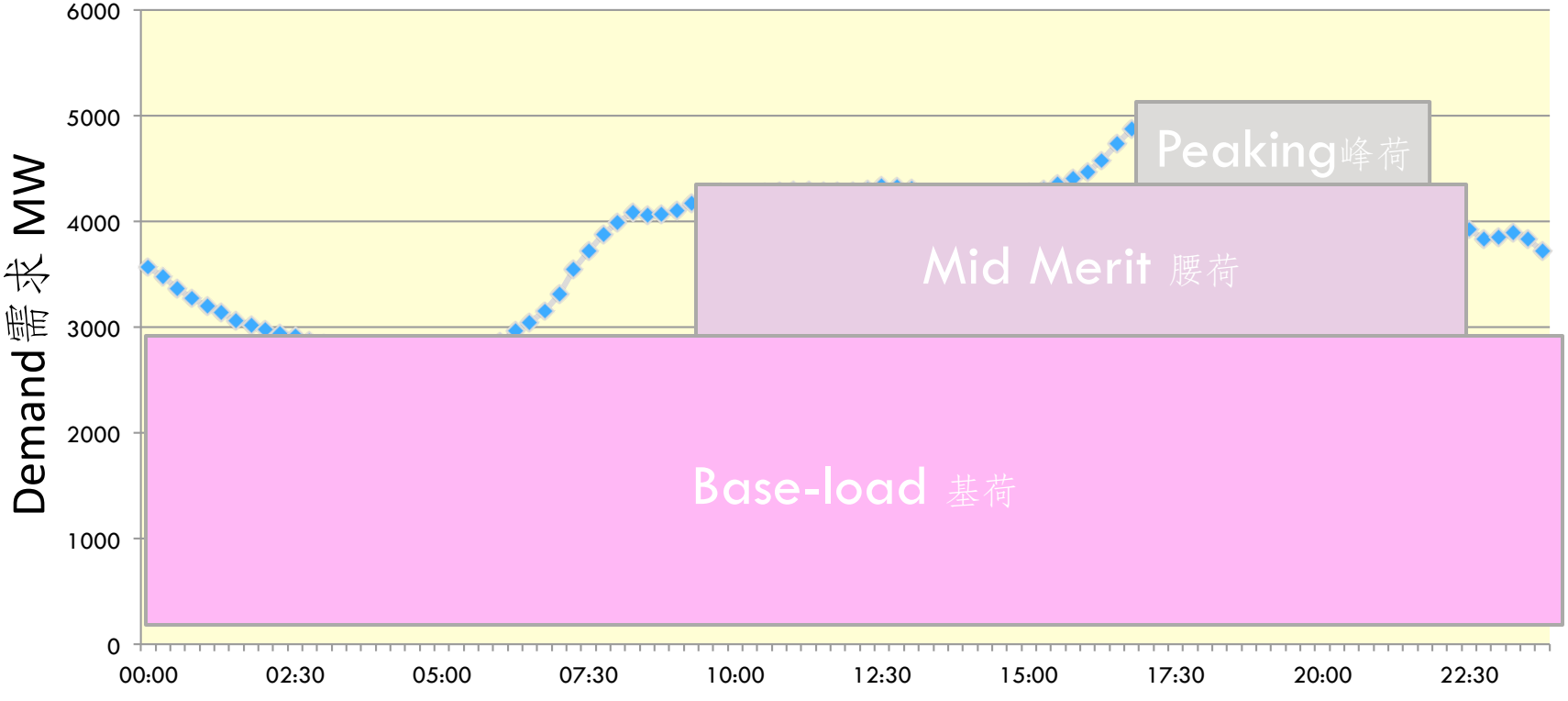
Generator Cycling 发电机组周期运行

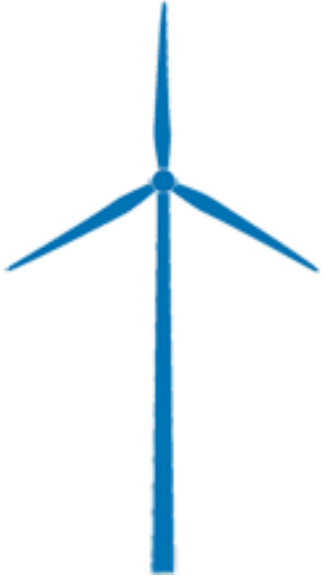
Cycling is the operation of electricity generating units at varying load levels, low load levels or in a start/stop manner.

周期运行是发电机组在负荷波动、低负荷或启停模式下的一种运行方式。

What is Cycling?什么是周期运行?

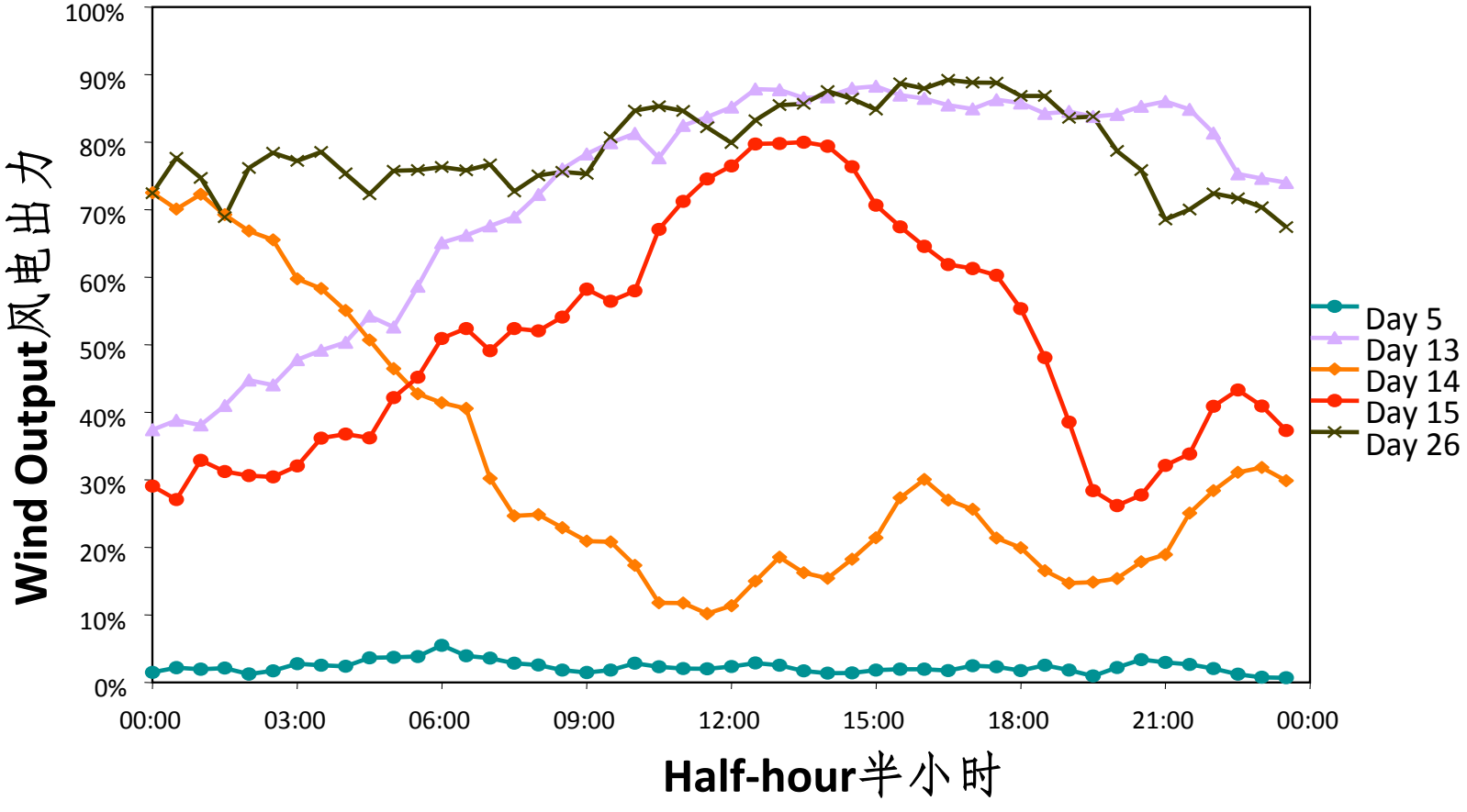


Wind and Cycling 风电与周期运行



Wind Power风电

Wind Variability风电的波动性



Effects of Cycling 周期运行的影响

Costs Associated with Cycling 相关费用

O&M Costs 运行维护费用

Capital Expenditure 固定资产折旧

Income Losses 收入损失

Fuel Costs 燃料费用

Environmental Costs 环境成本

Difficulties Determining Cycling Costs
确定费用的一些难点

- Impairment can take several years to manifest itself.

损失要几年后才会体现

- Every component is affected.

每个元件都受影响

- Normal base-load results in damage to components.

正常基荷状态下的元件损害

Magnitude of Cycling Costs 费用水平

- "It is estimated that cycling costs can range from $300 to $500,000 per single on-off cycle, depending on the type of unit."

不同类型的机组周期运行费用大不相同，每次启停的费用从300美元到50万美元不等。

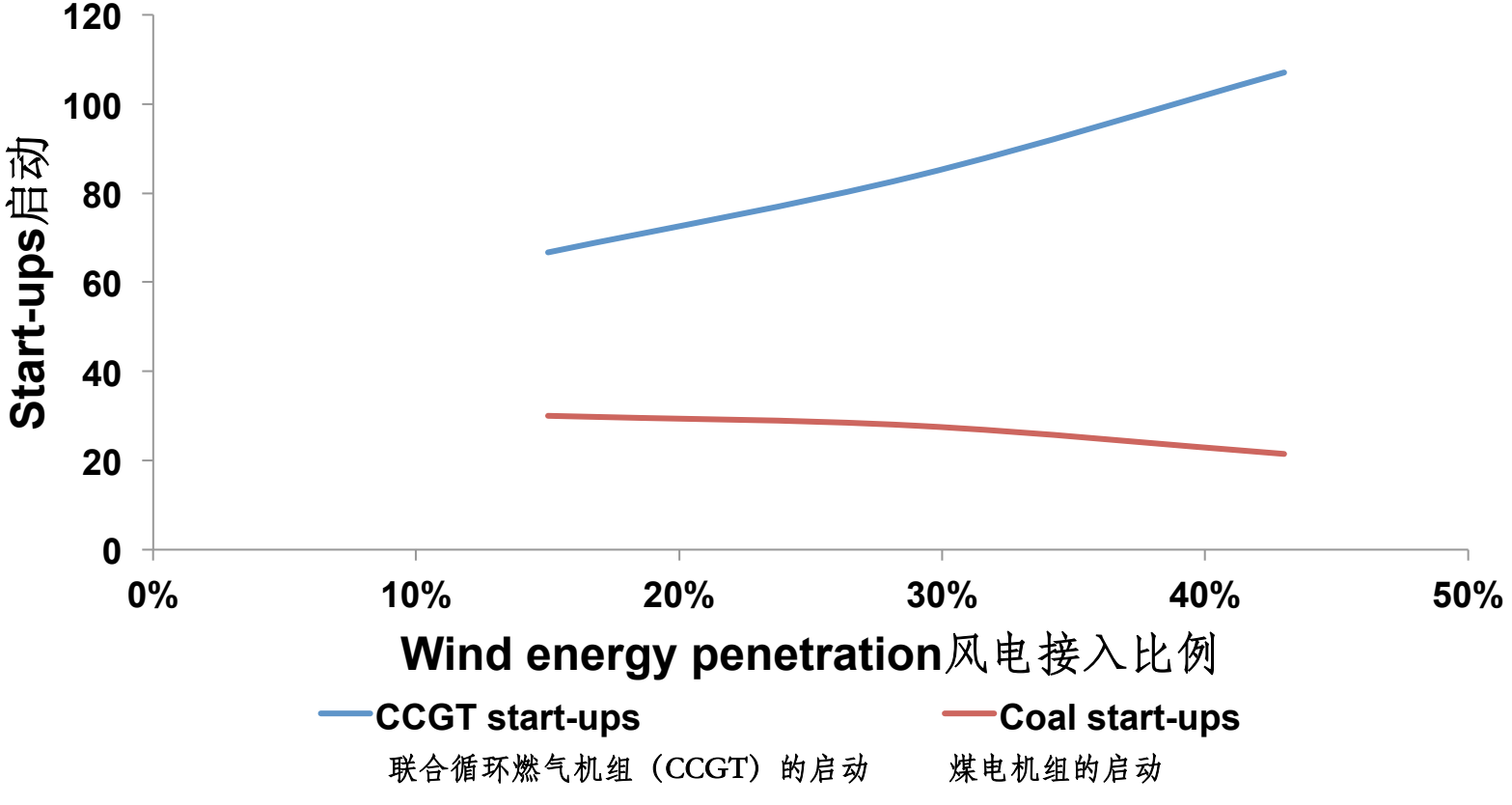
Lefton, S., Besuner, P., 2001. Power plant cycling operations and unbundling their effect on plant heat rate(电厂周期运行和解除其对电站热耗率的影响). *APTECH Technical Paper TP134, Available: http://www.aptecheng.com*

Detailed study results 研究成果

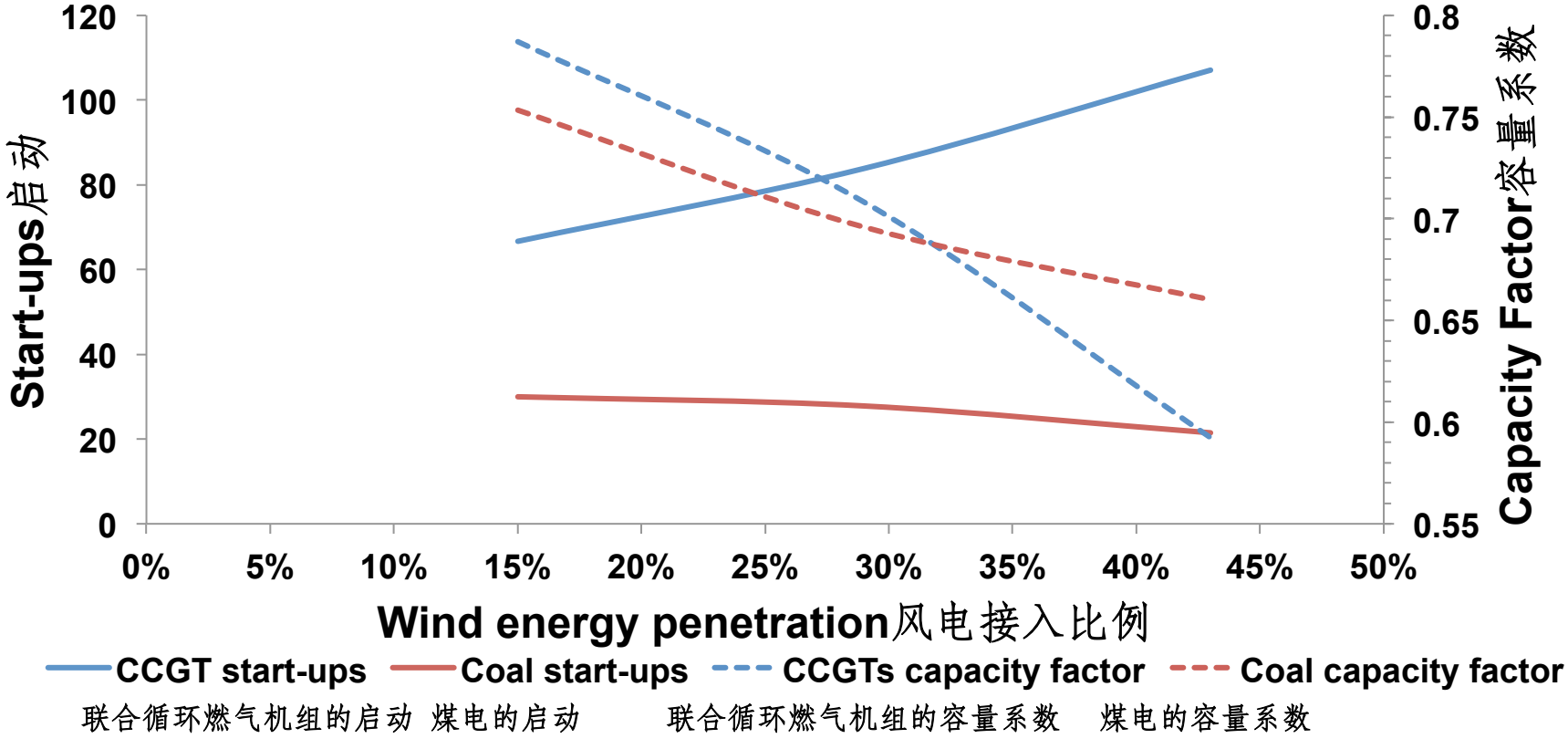
- Troy, N. "Generator Cycling due to High Penetrations of Wind Power", PhD Thesis, University College Dublin, Ireland, 2011.
- Troy, N., Denny, E. and O'Malley, M.J. "Base load cycling on a system with significant wind penetration", *IEEE Transactions on Power Systems*, Vol. 25, pp. 1088 - 1097, 2010.
- Troy, N., Flynn, D. and O'Malley, M.J., "Multi-mode Operation of Combined-Cycle Gas Turbines with Increasing Wind Penetration", *IEEE Transactions on Power Systems*, in press, 2011.
- Troy, N., Flynn, D., Milligan, M. and O'Malley, M.J., "Unit commitment with Dynamic Cycling cotss", *IEEE Transactions on Power Systems*, in review,2011.

- 《风电高比例接入时的机组周期运行》（博士论文）, 作者Troy N., 爱尔兰都柏林学院大学, 2011年。
- 《接入大量风电系统中的基荷周期运行》，作者Troy N., Denny, E. 和 O'Malley, M.J., 《IEEE 电力系统汇刊》录入（第25卷, 1088－1097页），2010年。
- 《风电接入比例的提高与联合循环燃气机组的多模式运行》，作者Troy, N., Flynn, D. 和 O'Malley, M.J.，《IEEE 电力系统汇刊》录入（审核中），2011年。
- 《动态周期运行下的机组优化组合》，作者Troy, N., Flynn, D., Milligan, M. 和 O'Malley, M.J.,《IEEE 电力系统汇刊》录入（复核中），2011年。

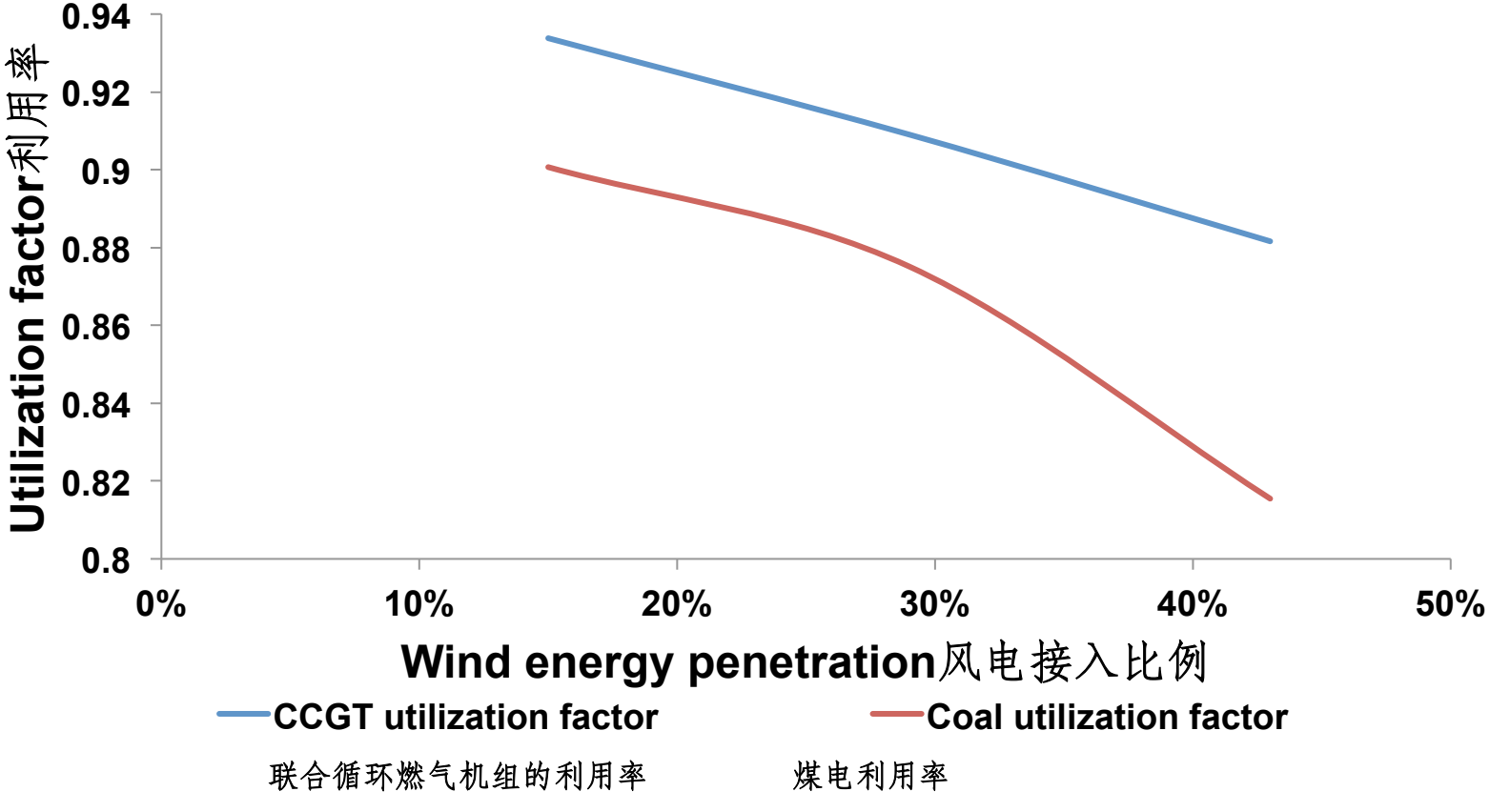
Impact of increasing wind energy penetrations on base-load start-ups风电接入比例提高对基荷启动的影响



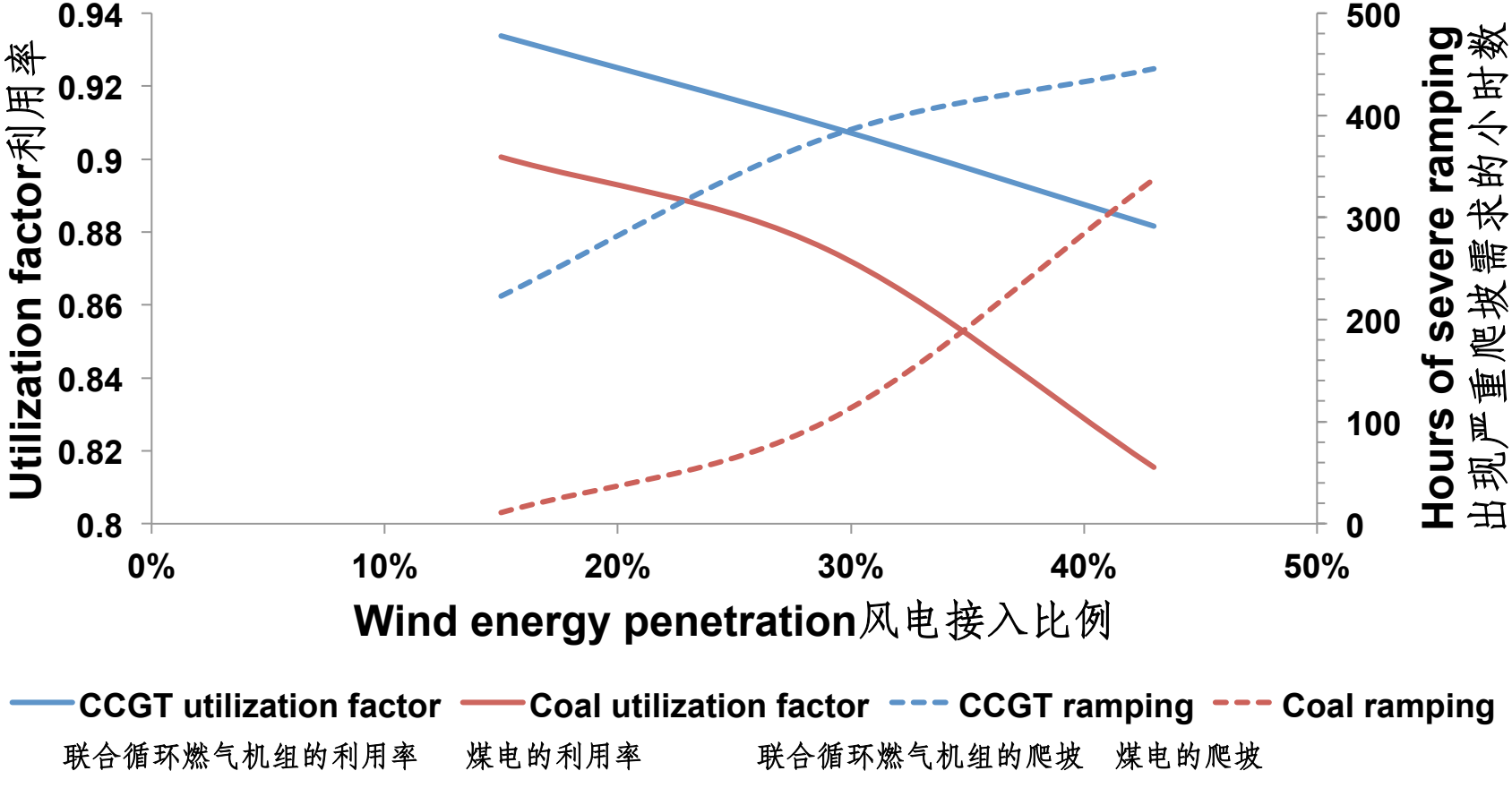
Impact of increasing wind energy penetrations on base-load start-ups and capacity factors风电接入比例提高对基荷启动和容量系数的影响



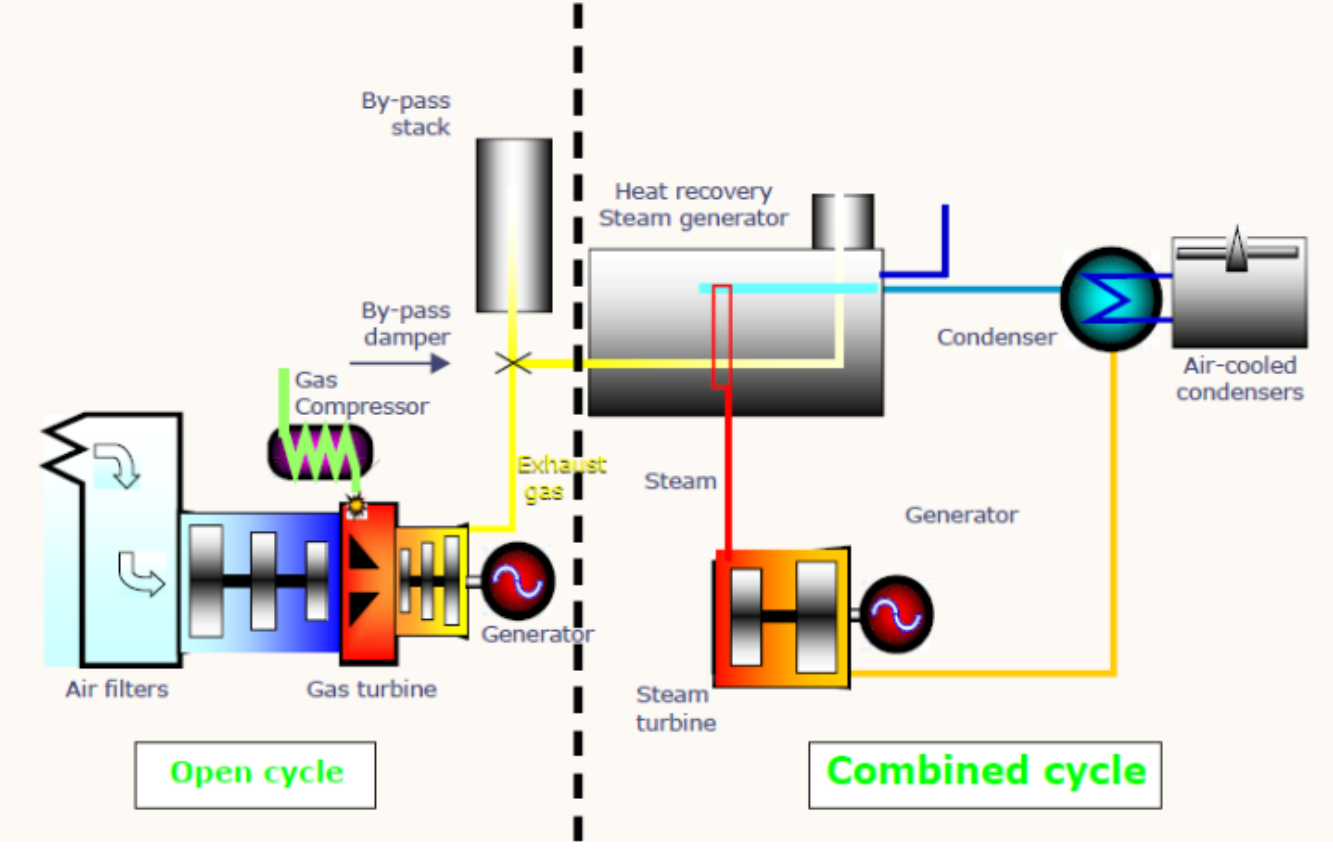
Impact of increasing wind energy penetrations on base-load utilization factor风电接入比例提高对基荷机组利用率的影响



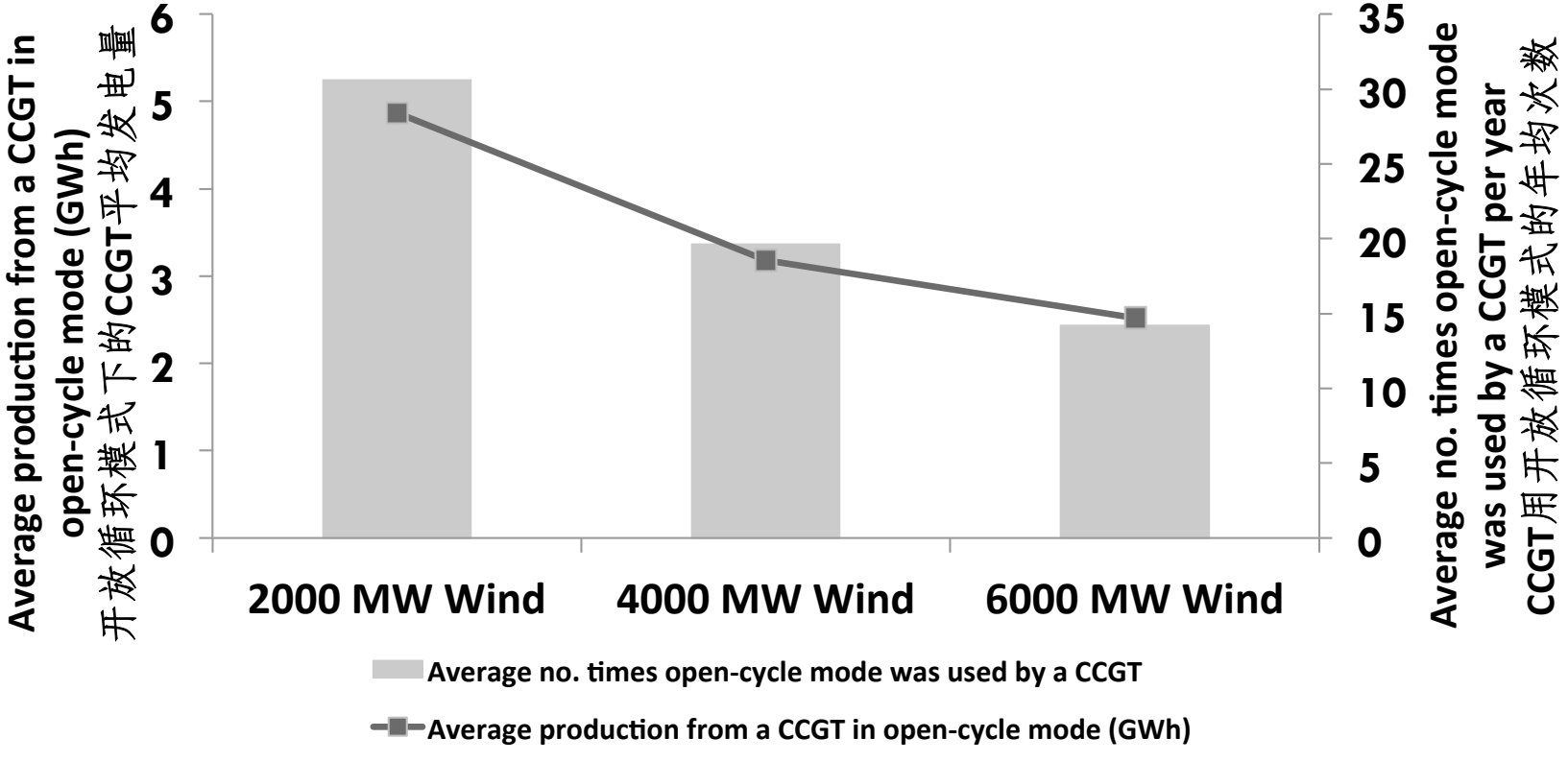
Impact of increasing wind energy penetrations on base-load utilization factor and ramping风电接入比例提高对基荷机组利用率和爬坡的影响



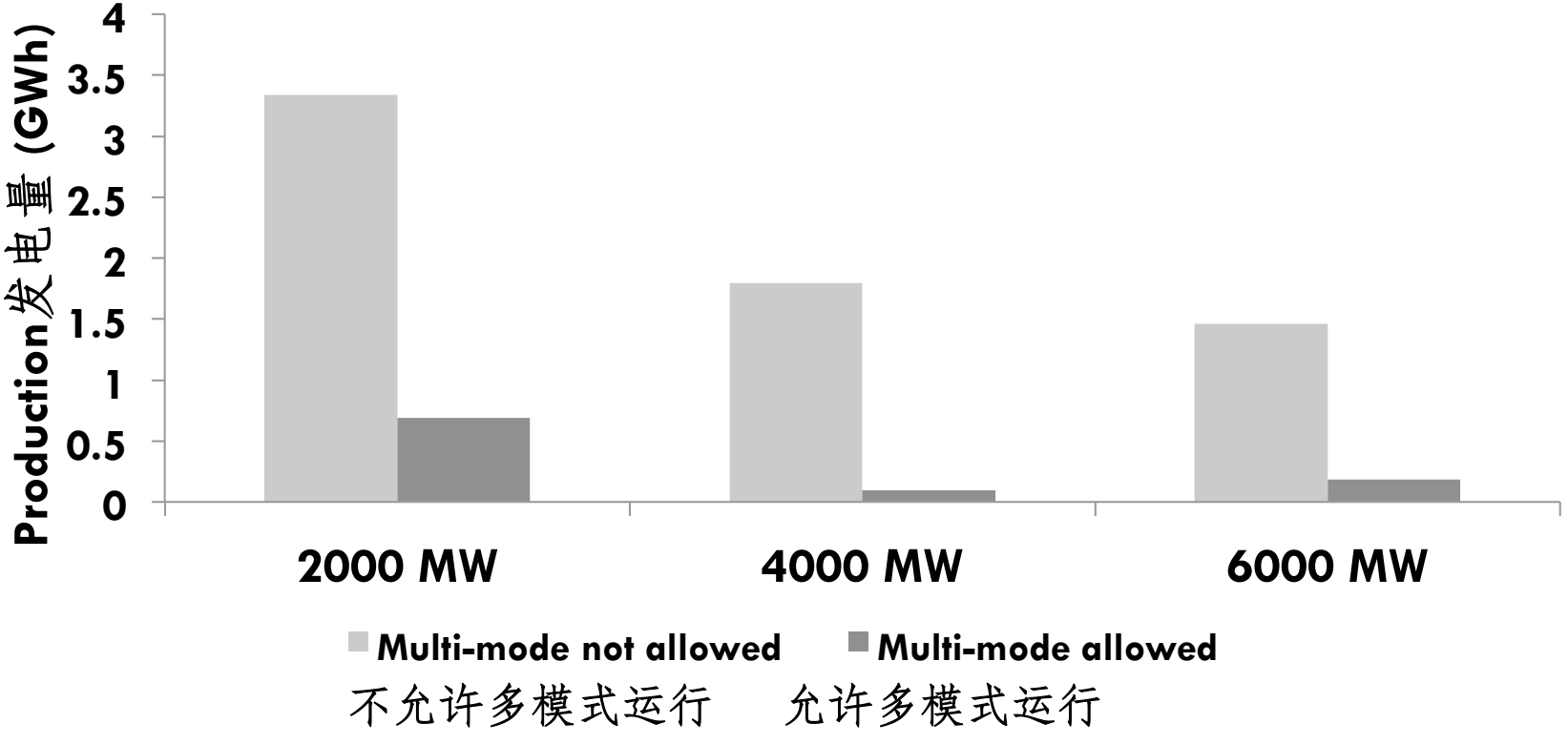
Multi-mode Operation of Combined-Cycle Gas Turbines
联合循环燃气机组的多模式运行



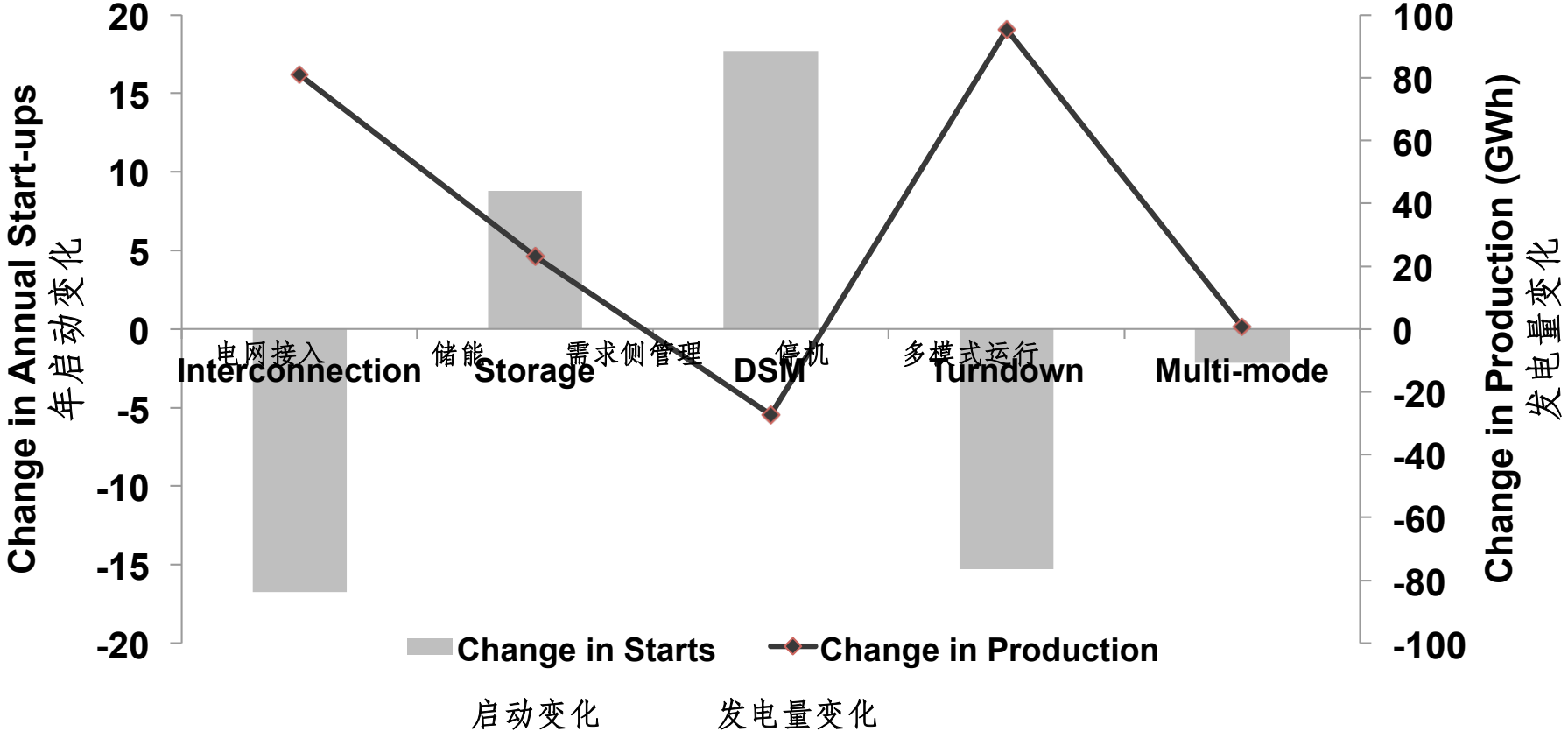
Utilization of Multi-mode Function with Increasing Wind Penetration风电接入比例提高对多模式利用率的影响



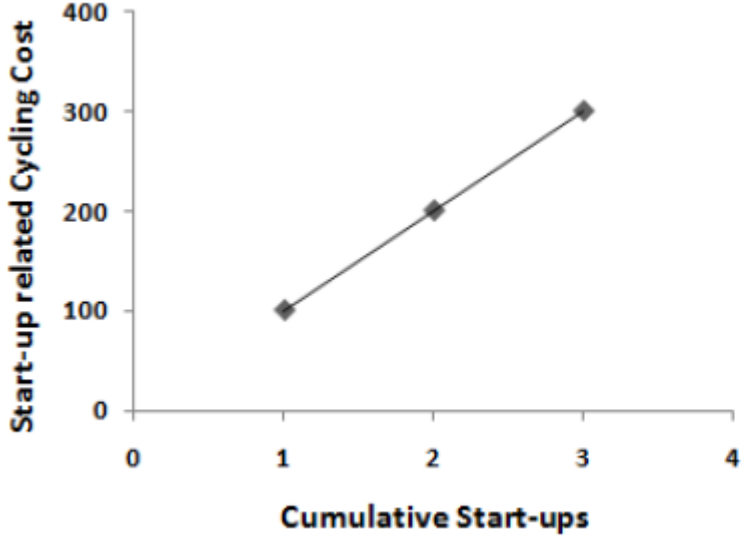
Production from Peaking Units with Increasing Wind Penetration提高风电接入比例对调峰机组发电量的影响



Comparisons of different sources of flexibility
比较多种灵活资源

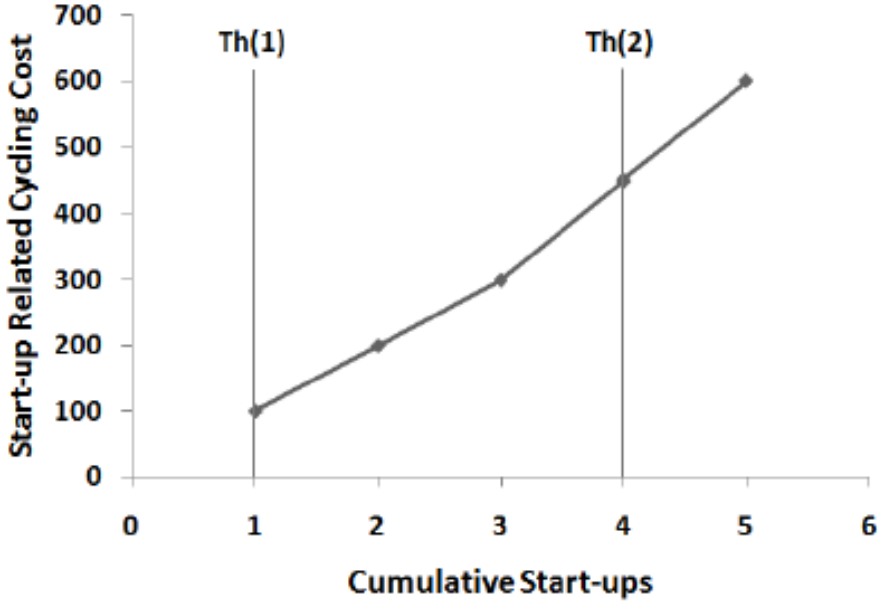


Dynamic Start-up Costs : Linear
动态启动成本：线性



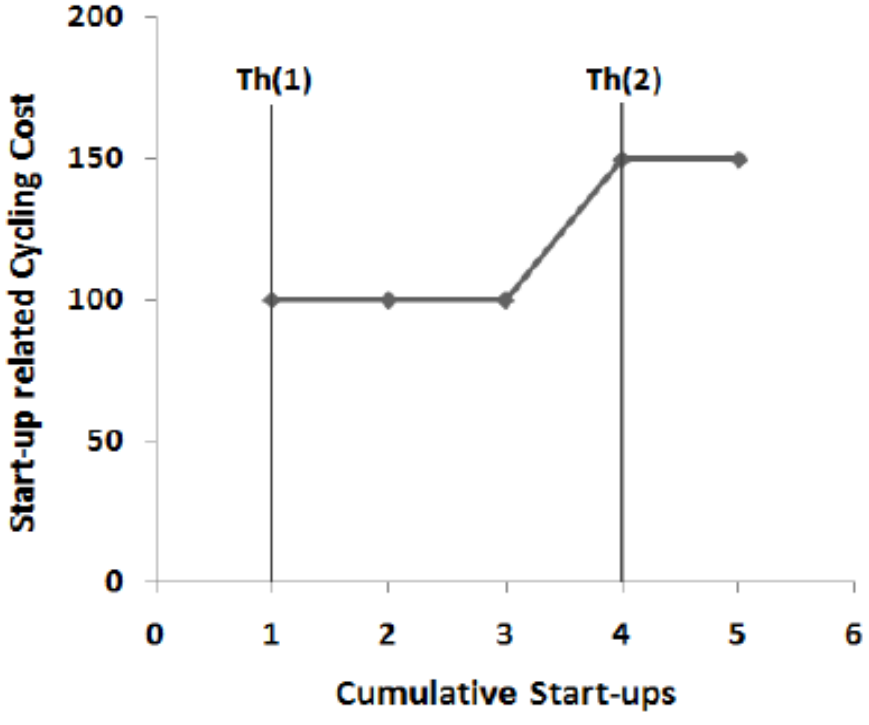
Time, t	s(t)	$N_S(t)$	$C_S(t)$
1	0	0	0
2	1	1	100
3	0	1	0
4	0	1	0
5	1	2	200
6	0	2	0
7	0	2	0
8	1	3	300
9	0	3	0

Dynamic Start-up Costs : Piece-wise Linear
动态启动成本：分段线性



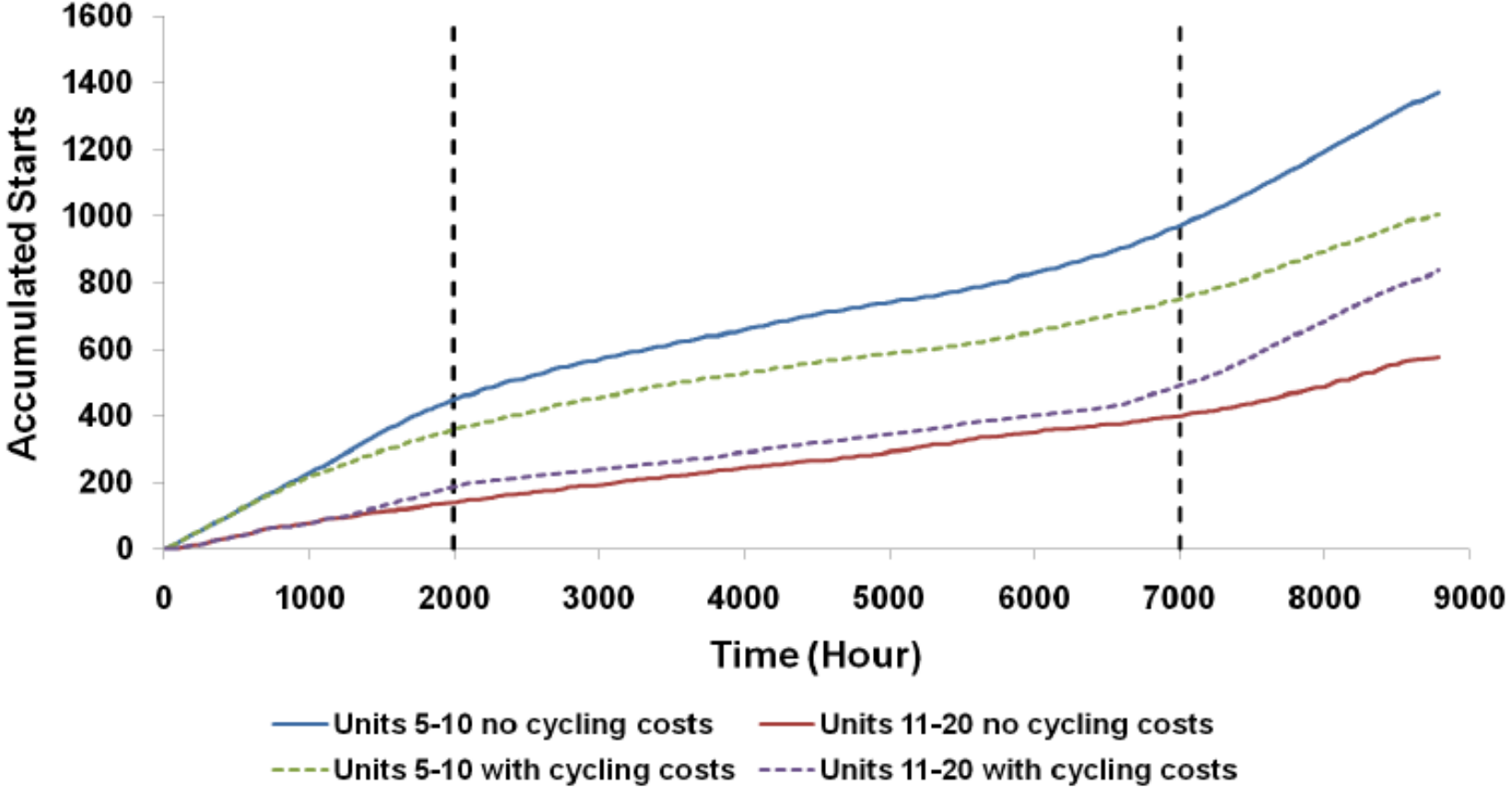
Time, t	s(t)	N_S (t, 1)	N_S (t, 2)	C_S (t)
1	0	0	0	0
2	1	1	0	100
3	0	1	0	0
4	0	1	0	0
5	1	2	0	200
6	0	2	0	0
7	0	2	0	0
8	1	3	0	300
9	0	3	0	0
10	0	3	0	0
11	1	4	1	450
12	0	4	1	0
13	0	4	1	0
14	1	5	2	600
15	0	5	2	0

Dynamic Start-up Costs : Step
动态启动成本：梯级递增



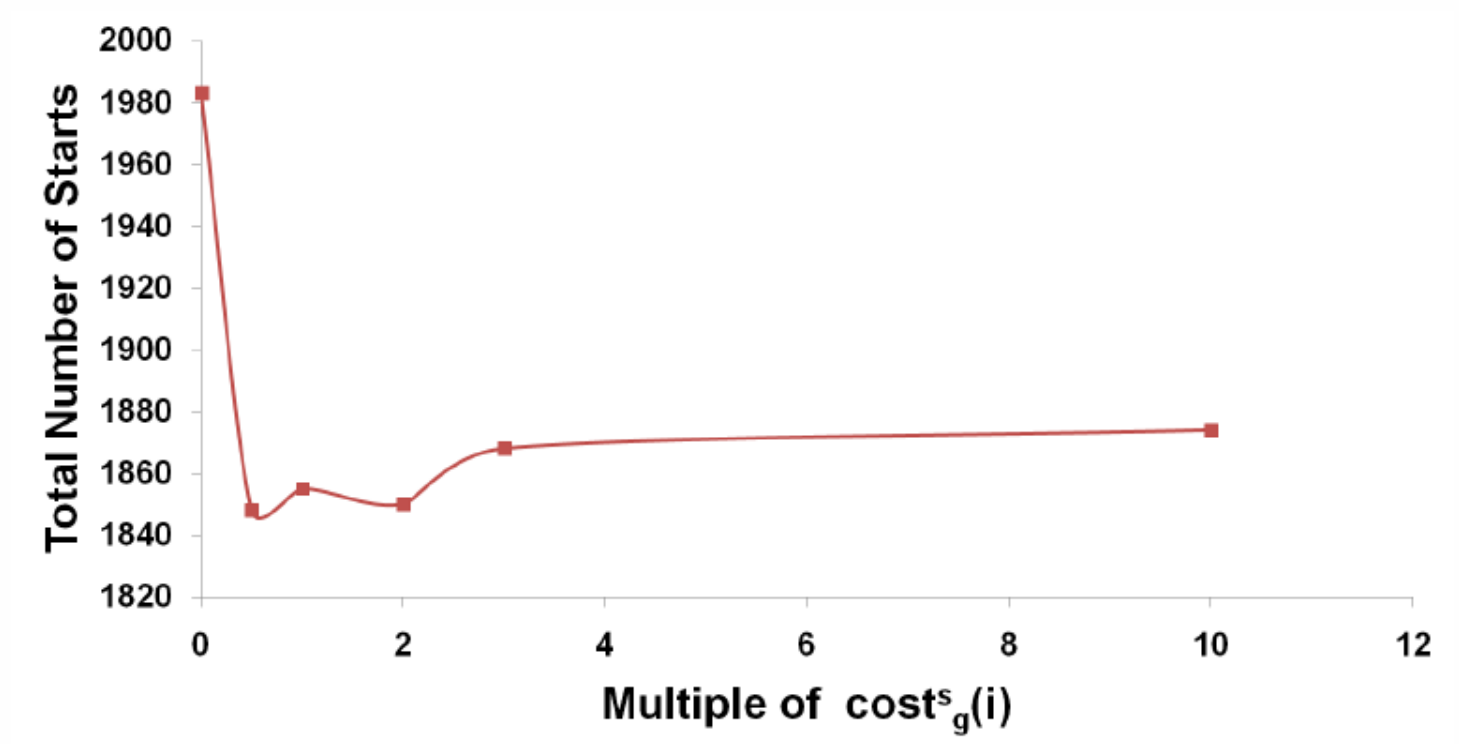
Time, t	$s_g(t)$	$N_g^S(t, 1)$	$N_g^S(t, 2)$	$C_g^S(t)$
1	0	0	-3	0
2	1	1	-2	100
3	0	1	-2	0
4	0	1	-2	0
5	1	2	-1	100
6	0	2	-1	0
7	0	2	-1	0
8	1	3	0	100
9	0	3	0	0
10	0	3	0	0
11	1	4	1	150
12	0	4	1	0
13	0	4	1	0
14	1	5	2	150
15	0	5	2	0

Impact of Dynamic Cycling Costs
动态周期运行成本的影响

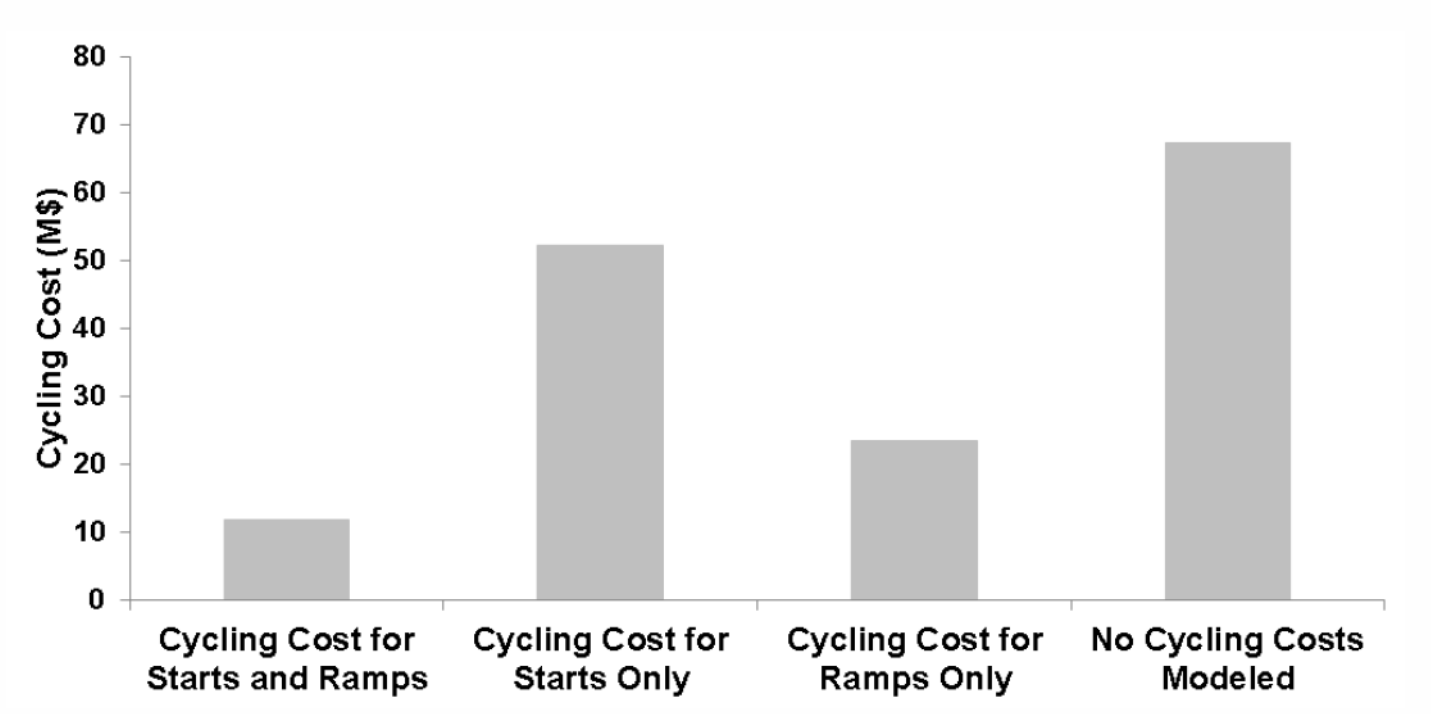


A large amount of cycling will just be unavoidable no matter how high costs get

不管成本多高，大量周期运行是难以回避的



If you don‘t model the costs – the answer is not optimal
如果不用模型进行成本计算，就不能得出优化方案



Cycling costs (that would have been incurred) shown for various scenarios不同情景下的周期运行成本

Model the cycling costs!
运用模型计算周期运行成本

Total system costs shown for various scenarios
不同情景下的系统总成本

Reading list相关资料和文献

- Balling, L., Hofmann, D., 2007. Fast cycling towards bigger profits. *Modern power systems*, [Online] Available: http://www.modernpowersystems.com.
- Brown, T. B., 1994. Assessing the effect of thermal transients on the life of boiler plant. *In: Proc. of International Conference on Life Management of Power Plants*. pp. 137-143.
- Energy-Tech, 2004. Cycling of Combined-Cycle Plants, [Online] Available: http://www.energy-tech.com.
- EPRI, 2001a. Correlating cycle duty with cost at fossil fuel power plants. *EPRI, Palo Alto, CA. 1004010*.
- EPRI, 2001b. Damage to power plants due to cycling. *EPRI, Palo Alto, CA. 1001507*.
- EPRI, 2002. Determining the cost of cycling and varied load operations: Methodology. *EPRI, Palo Alto, CA. 1004412*.
- Lefton, S., 2004. Profitable operation requires knowing how much it costs to cycle your unit. *Combined Cycle Journal,* [Online] Available: http://www.combinedcyclejournal.com/.
- Lefton, S., 2011. Power plant asset management Presented at UWIG Spring Workshop, Kansas City, [Online] Available: http://www.uwig.org/kcworkshop/Lefton-KCWork.pdf.

Reading list continued相关资料和文献

- Lefton, S., Besuner, P., 2006. The cost of cycling coal fired power plants. *Coal Power Magazine*, pp. 16-20.
- Lefton, S., Besuner, P., Agan, D., 2006. The real cost of on/off cycling. *Modern power systems,* [Online] Available: http://www.modernpowersystems.com.
- Lefton, S., Besuner, P., Grimsrud, G., 1995. Managing utility power plant assets to economically optimize power plant cycling costs, life, and reliability. *In: Proc. of 4th IEEE Conference on Control Applications*. pp. 195-208.
- Lefton, S., Besuner, P., Grimsrud, G., 1997. Cycling fossil fired units proves costly business. *Electric Light and Power* 75 (7).
- Lefton, S., Besuner, P., Grimsrud, P., Bissel, A., Norman, G., 1998. Optimizing power plant cycling operations while reducing generating plant damage and costs at the Irish Electricity Supply Board, Aptech Engineering Service Technical Report (TP123), [Online] Available: http://forgoodpower.com/technical papers.html.
- Starr, F., 2003. Background to the design of HRSG systems and implications for CCGT plant cycling. *Operation Maintenance and Materials Issues* 2 (1).
- Xcel Energy, 2010. Integrating Wind Cost of Cycling Analysis for Harrington Station Unit 3 [Online] Available: http://www.blankslatecommunications.com/Images/Aptech-HarringtonStation.pdf.
- K. D. Le, R. R. Jackups, J. Feinstein, H. Thompson, H. M. Wolf, E. C. Stein, A. D. Gorski, and J. S. Griffith, "Operational aspects of generation cycling," IEEE Trans. Power Syst., vol. 5, no. 4, pp. 1194–1203, Nov. 1990.


Thank
You!!