Energy
Market
Company

Spring Washer Effect

A Market Clearing Engine Study of the NEMS

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About the Author

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Lu Feiyu joined Energy Market Company, the market operator for the National Electricity Market of Singapore, as a Market Analyst in March 2002. His primary responsibilities are the daily operation of the market and review of its outcome, dissemination of market information and in-house application development. Feiyu is also one of the company’s pioneers in conducting local and international training and educational forums about the market clearing engine, specifically its formulations, pricing methodology and system enhancements. He is actively involved in enhancing the market system by identifying gaps between business processes and the market system, suggesting improvements and preparing and performing user acceptance tests. He also contributes to the market rule change process through technical reviews of the proposed changes.

Feiyu holds a Master of Engineering degree in Electrical and Electronic Engineering from Nanyang Technological University (Singapore).

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1.0 Introduction

Since the NEMS began operation on 1 January 2003, nodal price separation has been observed quite a few times. Nodal price separation is when the price difference between two adjacent nodes is well above the normal range[1] that is incurred from transmission loss. In most of these cases, the spring washer effect was the cause of the pricing anomaly.

This paper explores the spring washer effect in detail and discusses its relationship with nodal prices.

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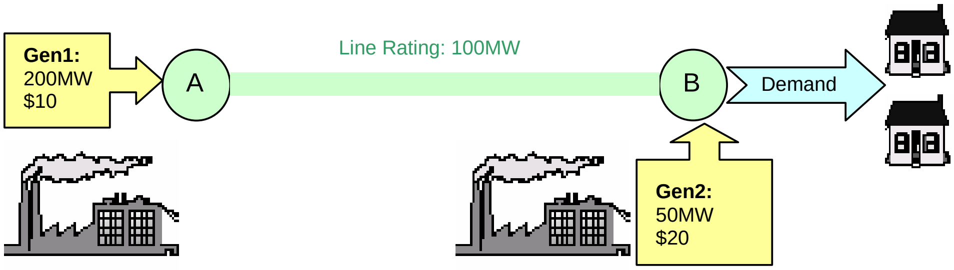
[1] Based on historical records, the normal price difference between two adjacent nodes is normally well below 3%.

2.0 Background

The spring washer effect is a result of the transmission constraint. Hence, some basic knowledge of transmission lines and their constraints is fundamental to help our understanding.

Any transmission equipment, such as an overhead line or an underground cable, has a certain limit to its capacity. This is defined by its physical capabilities, such as its thermal endurance. If operated over this limit, the transmission equipment has the risk of overheating (also referred to as overloading) and being damaged. To avoid this situation, generation units may be dispatched out of merit order.

For example, suppose we have a two-node system:



- Node A is an injection node, with 200MW of generation connected to it via Gen1, which is offering energy at $10/MWh into the market.
- Node B is a mixed node (both injection and withdrawal), where a 50MW generator and a load are linked. Gen2 is offering energy at $20/MWh.
- The transmission line between these two nodes has a maximum capacity of 100MW.
- Transmission loss is ignored to make the case simple.

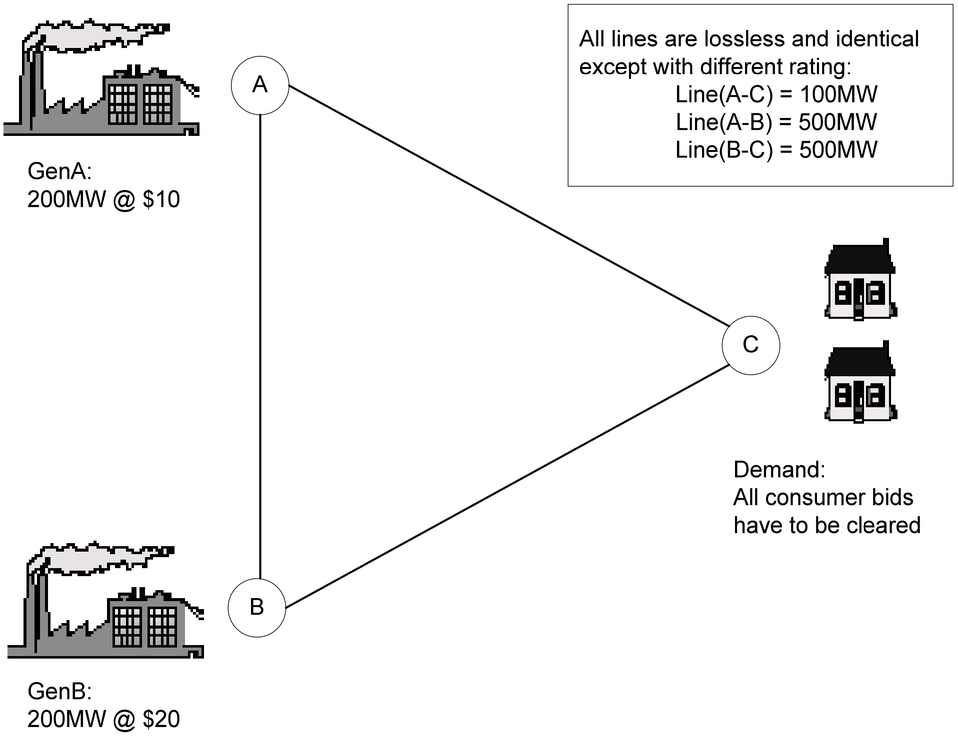
When the demand is less than 100MW, the nodal price for both A and B nodes is $10/MWh and is cleared from the marginal set Gen1. However, if the demand increases above 100MW, the transmission line becomes bound (at its maximum capacity). The price at node A remains at $10/MWh, but the price at node B is now $20/MWh, because any more demand increment will have to come from Gen2. In this situation, there are two marginal sets, one at each side of the constrained line.

The nodal prices in this example come from the generation offers, despite the presence of a transmission constraint. This is due to the spur configuration of the transmission grid used in the example. However, the majority of the transmission grid in the Singapore power system is meshed and has many loops. When a transmission constraint happens within a loop, the spring washer effect occurs.

3.0 Spring Washer Effect

To study the spring washer effect in further depth, a three-node model is used. Both A and B are injection nodes, each of which is linked with a 200MW generator. Generator A is offering energy at $10/MWh, while Generator B is offering energy at $20/MWh. Node C is a withdrawal node. All of the demand must be cleared, unless there is no feasible solution.

The transmission line between node A and B has a maximum rating of 500MW[2], which is effectively infinite in this particular case. The line between node B and C has the same rating. The line between A and C, however, is a weak link and can only transmit up to 100MW. This circuit is most vulnerable to binding constraint and will be the source of the spring washer effect.



The above model was constructed in a linear programming (LP) problem and the CPLEX Linear Optimizer 7.0 solver was used to solve the problem. The NEMS market clearing engine (MCE) uses exactly the same solver and thus the result of the solver would be comparable to that of the MCE.

The demand at node C varies so that we can observe the spring washer effect. The result of the analysis is summarised in the table:

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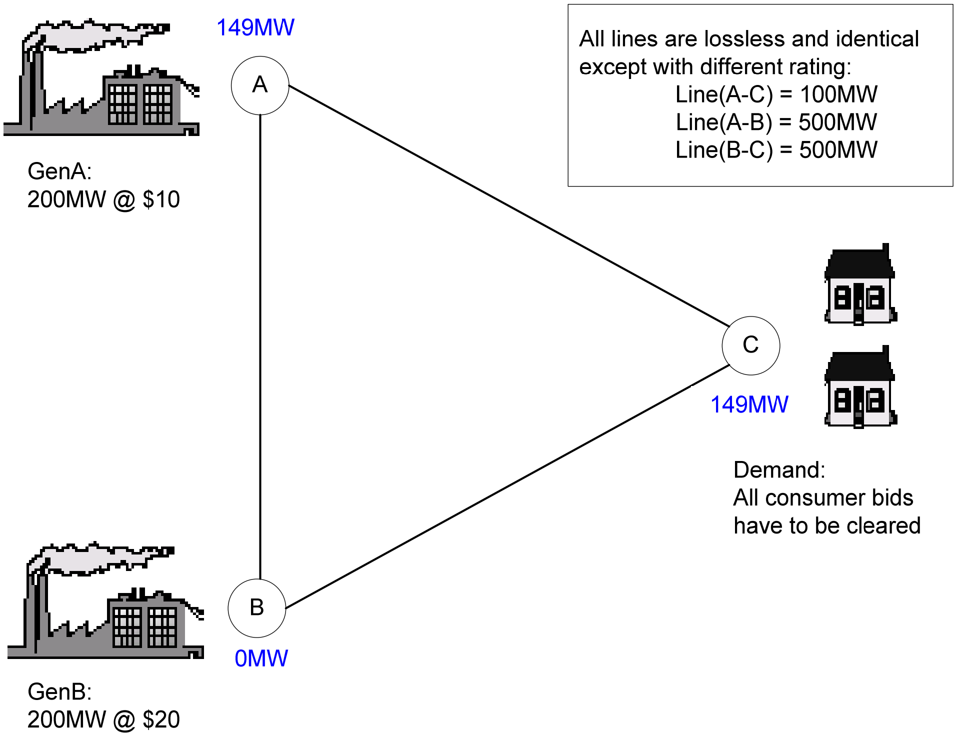
[2] To make the case simpler, reactive power is not considered. Hence, the rating is expressed in terms of MW instead of MVA.

Demand (MW)	Price at Node C	Price at Node A	Price at Node B
(0, 150)	$10.00	$10.00	$10.00
(150, 250)	$30.00	$10.00	$20.00
(250, 400)	No feasible solution	$10.00	$20.00

3.1 Demand < 150MW

When the demand is less than 150MW, the transmission system is free of congestion. Hence, the dispatch is based on merit order. All of the demand is met by the cheapest generation offer from GenA. For example, when the demand is 149MW, the dispatch results are as follows:



3.2 Demand > 150MW

When the demand reaches 150MW, the line A–C becomes binding. Law of physics proportionally assigns the generation from GenA to line A–C and line A–B at the fixed ratio of 2:1. Hence, with 150MW generation from GenA, 100MW flows to line A–C, which causes it to hit its maximum rating.

Now assume that the demand increases by another 1MW. The line A–C is already at its upper limit, so instead of increasing the generation at GenA, which would then violate the transmission limit, GenB is dispatched 1MW instead. The same law of physics sends 1/3MW to line B–A and sends 2/3MW to line B–C. The flow on line B–A will be relayed to line A–C so as to reach the consumer at node C. Hence the flow on line A–C now is:

$$150 * (2/3) + 1 * (1/3) = 100.33\text{MW}$$

This violates the 100MW rating of line A–C by 0.33MW.

Two-thirds of GenA generation flows onto the constrained circuit. So we can back off GenA by 0.33 / (2/3) = 0.5MW and add this to GenB. Now the flow on line A–C is:

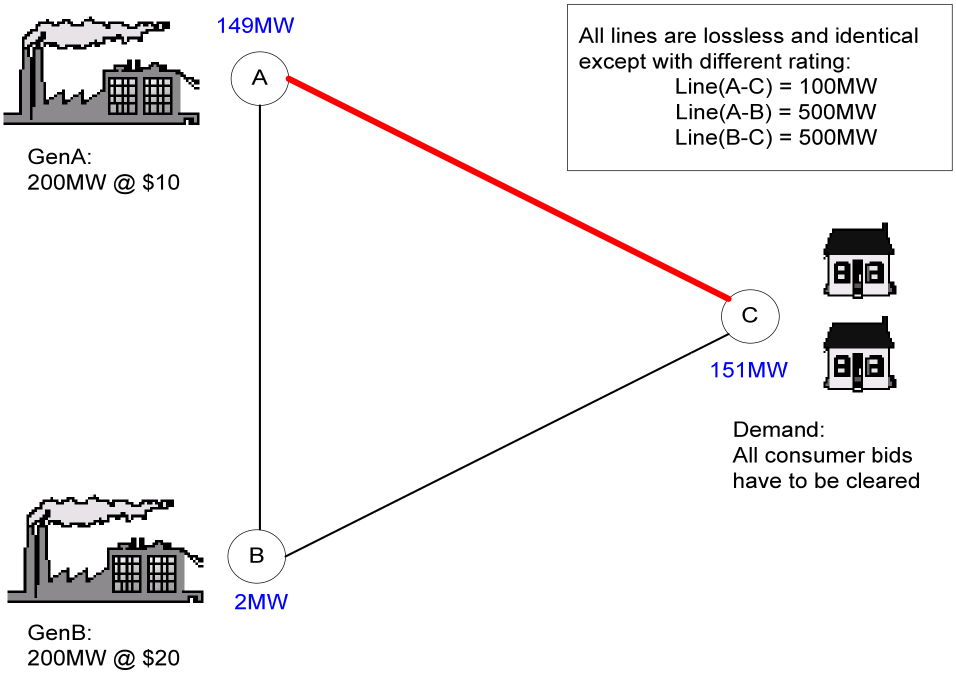
$$149.5 * (2/3) + 1.5 * (1/3) = 100.17\text{MW}$$

This still violates the upper limit of line A–C by 0.17MW. So we back off GenA by 0.17 / (2/3) = 0.25MW and add this to GenB. The violation on the constrained circuit is then reduced to 0.08MW. This process continues until there is no violation on line A–C, i.e., when GenA has backed off 1MW and GenB outputs 2MW.

Therefore, the cost of the additional MW at node C is:

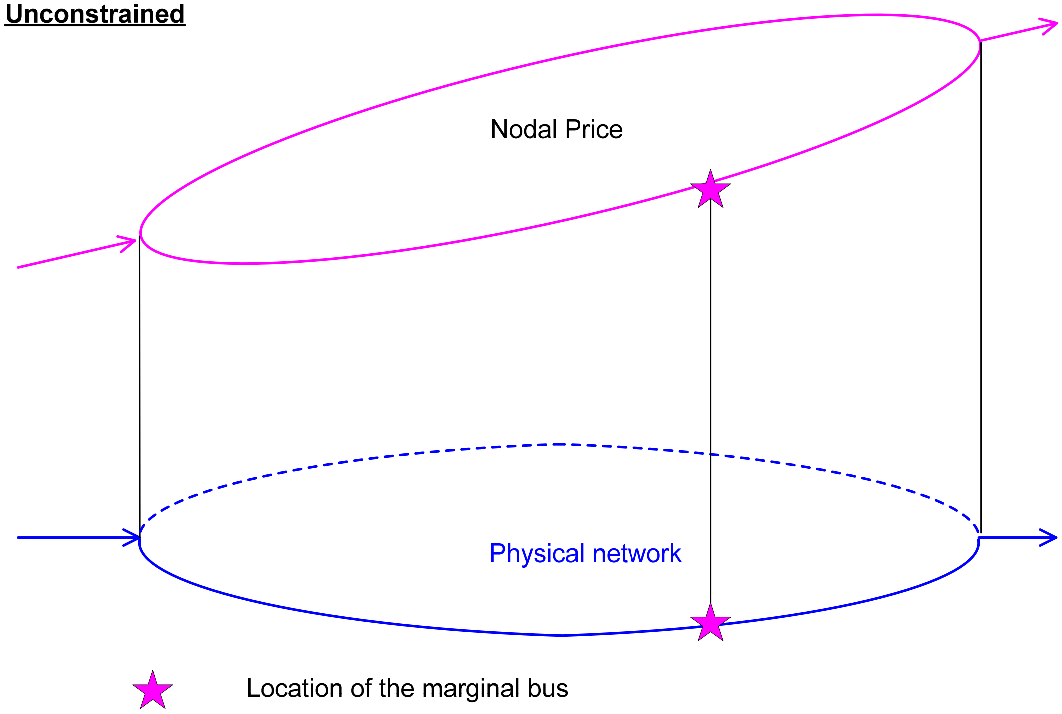
$$\$20 * 2 - \$10 * 1 = \$30/\text{MWh}$$

That is, the price at node C is now $30/MWh, which is neither the original marginal set price of $10/MWh, nor the price of the new marginal set of $20/MWh. This nodal price has been bumped up by the congestion cost.



This is referred to as Spring Washer Effect. Graphically[3], if there is no transmission constraint in the loop, the prices follow the marginal losses as shown in the figure. The prices rise in the direction of the power flow.

<u>Unconstrained</u>



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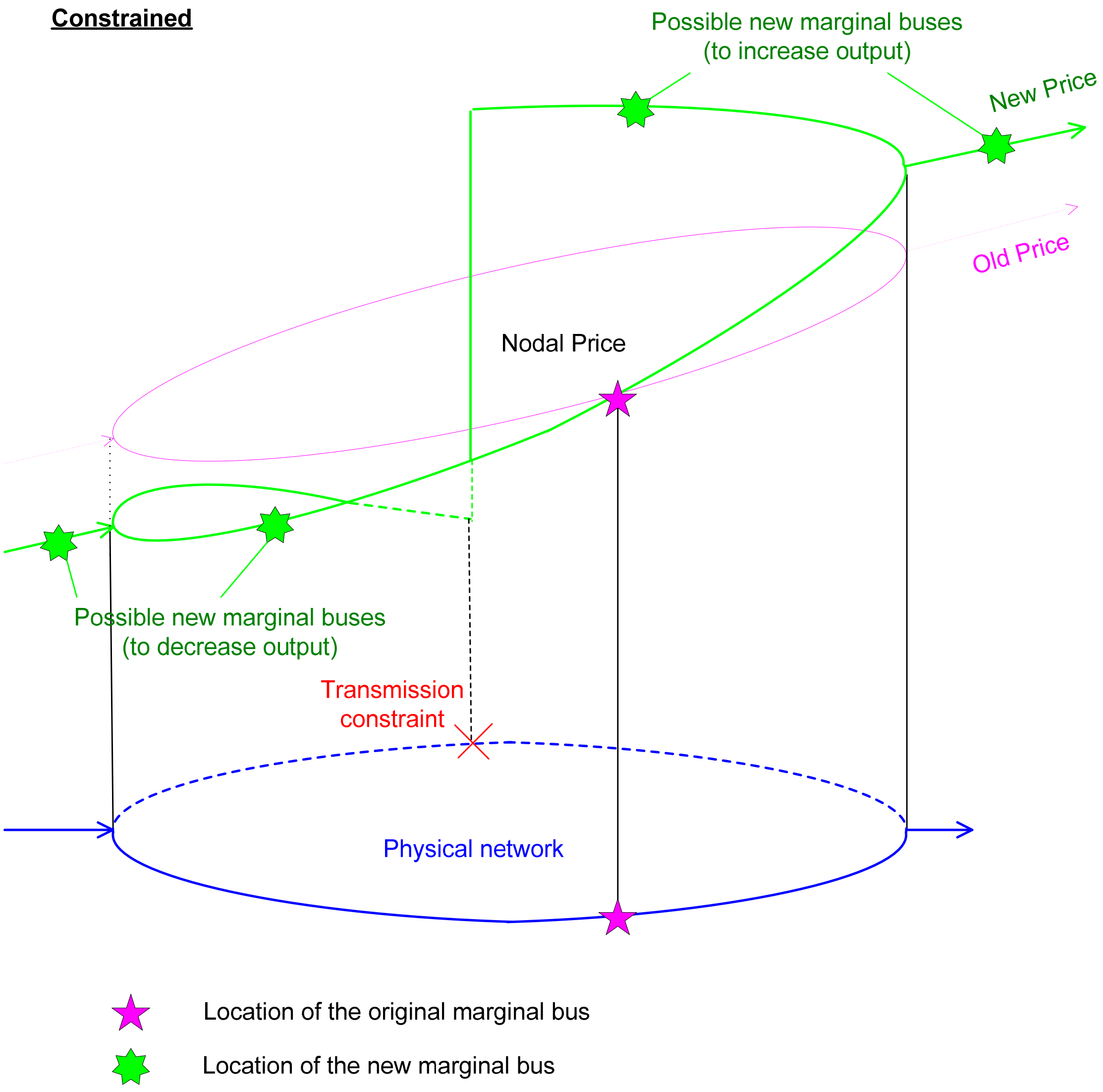
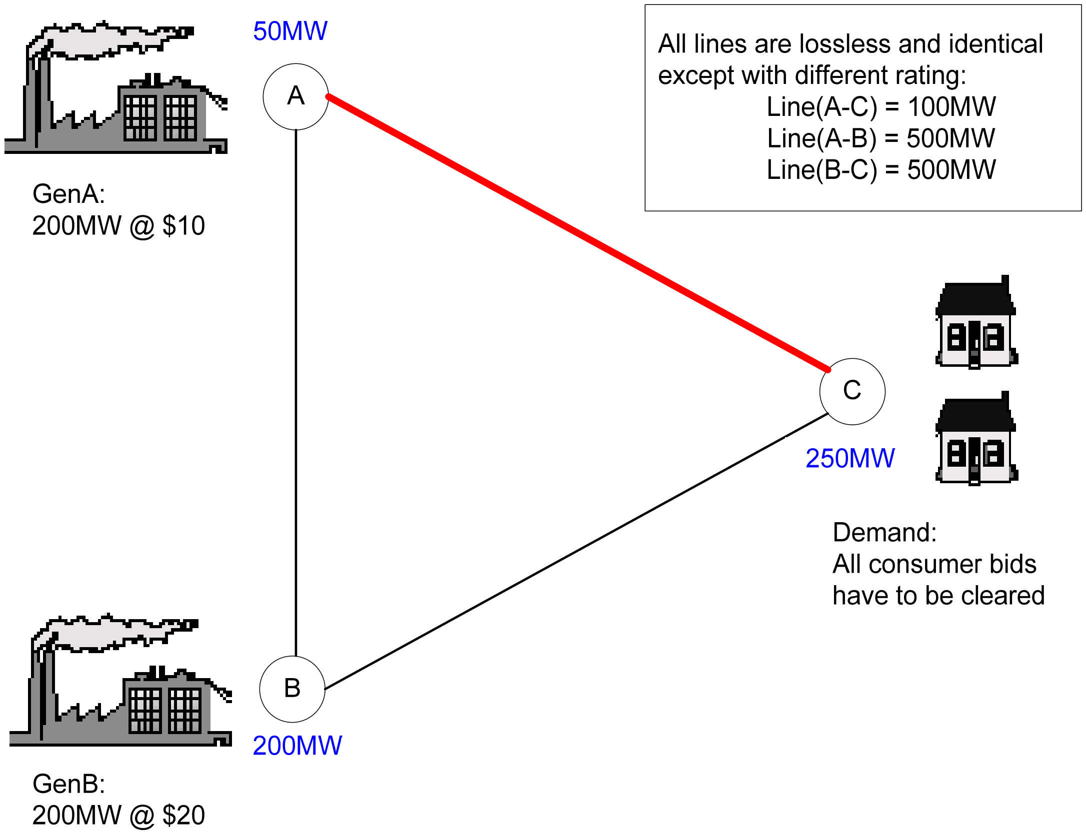
[3] The graphs are borrowed from Transpower's discussion paper *A Simple Guide to Nodal Pricing*.

If there is a constraint within the loop, the effect known as spring washer occurs as shown in the figure. This shows how prices spiral around the loop with a gap occurring across the constrained circuit. Some prices will be less than the old (unconstrained) case while others will be higher. Under such conditions, prices at each node are driven largely by the transmission constraint.



3.3 Demand > 250MW

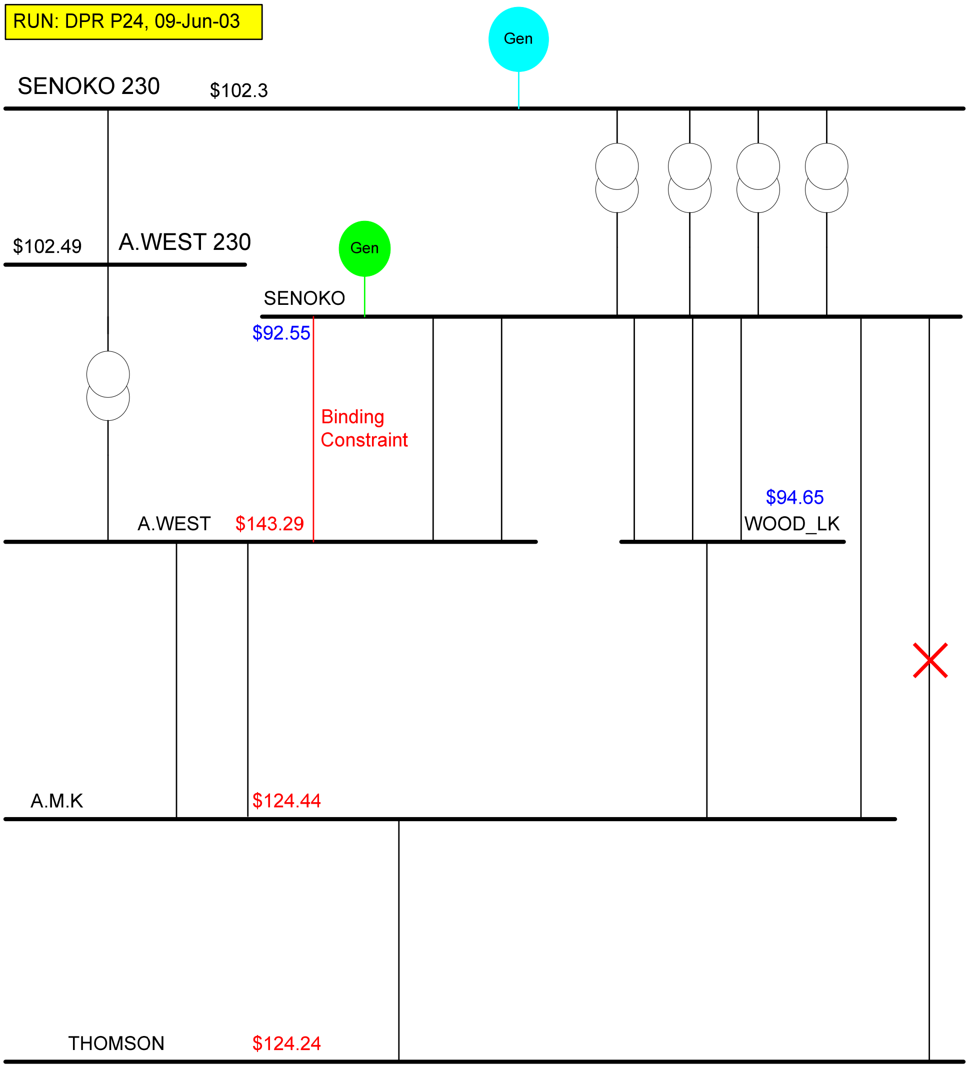
When the demand reaches 250MW, GenB is fully dispatched of its 200MW capacity and GenA is cleared 50MW. In fact, GenA could not be dispatched any more due to the binding constraint on line A–C. As a result, any increment in demand beyond 250MW can no longer find a feasible solution.



4.0 Case Study

A number of instances of spring washer effect have been observed since the market began. An instance that occurred in the real-time dispatch run for Period 24 on 9 June 2003 will be used in this case study.

Due to the unplanned outage of transmission line LINE66:SENOKO:THOMSON at 08:13 on 9 June 2003 and an increase of system demand in Period 24, the transmission line LINE66 : A.WEST : SENOKO 1 reached 100% of its maximum effective capacity, as highlighted (in red) in the diagram below. Since there is generation upstream of this binding line which could be dispatched less so as to alleviate the congestion the spring washer effect occurred, with higher prices (highlighted in red) present at the receiving end of the binding line and lower prices (highlighted in blue) at the sending end of the line. The spring washer effect spread within the vicinity and the prices returned to normal gradually.



In order to meet the demand in THOMSON with the SENOKO–THOMSON line out of service, more flows should be directed to A.M.K. through either the SENOKO230–A.WEST or SENOKO230–SENOKO branches, while the flows on the SENOKO–A.WEST line remain unchanged. In order to achieve this objective, the generation at SENOKO must be backed off so that more flow can be driven down the SENOKO230–SENOKO path, which enables more flow on the SENOKO230–A.WEST path at the same time. Given this compromise, the energy deficit violation is avoided.

As a result of this transmission constraint, two marginal generators (highlighted in green and blue) exist in the system. The green generating unit is the marginal set upstream of the binding line with its generation cleared down to the $92 offer block. The blue generating unit is the marginal set for the rest of the system, with its offer price set at $102.

No rerun was required in this case because price separation was unavoidable in order to obtain the best feasible solution under the current network configuration. However, the physical system did not experience the transmission constraint because the Power System Operator (PSO) practiced load transfer.

5.0 Conclusion

The spring washer effect occurs when there is a constrained circuit in the transmission loop. The nodal price at the sending end of the binding line is depressed, while the price at the receiving end is pushed up. This is a natural result of economic forces striving to achieve the optimal dispatch within a constrained transmission system.

6.0 Recommendation

Most of the occurrences of spring washer effect that have been observed to date have been caused by insufficient up to date information of the grid configuration. As in the 9 June 2003 case that we explored, although the PSO conducted physical load transfer at the distribution level, the MCE could not recognise these changes, because it only monitored the transmission level.

A system enhancement of the Dynamic LPF (load participation factor) was released into the production system on 20 May 2004. This made it possible for the physical load transfer exercised by the PSO to be captured by the MCE in the real-time dispatch. Since then, occurrences of the spring washer effect have been greatly decreased.

Glossary

LP, linear programming
A simultaneous solution method based on solving algebraic equations.

LPF, load participation factor
The percentage factor used by the market clearing engine to distribute the system forecast to individual consumption nodes.

MCE, market clearing engine
The software used in the NEMS to discover dispatch schedules and prices.

NEMS, National Electricity Market of Singapore
The Singapore electricity market.

PSO, Power System Operator
The system operator of Singapore’s power grid.