System Level Value of Power System Reserve Optimization in Singapore and South Korea

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1.0 Abstract:

One of the fundamental roles of a system operator is to maintain frequency in a narrow band around 50 Hz or 60 Hz. This is accomplished by constantly balancing generation and load. In pool based markets like South Korea and Singapore, majority of the balancing task is carried out through energy market dispatch. However, the market based dispatch alone does not ensure that appropriate resources are available to balance the generation and load. Consequently, the system operator must schedule enough operational reserves to cover unexpected events and variability.

Historically, in many markets around the world, the characteristics of operational reserves have been based on the capabilities of conventional steam generation units, not on the fundamental needs of the power system. Given the inflexibility of steam generators, the operational reserves have tended to be “spinning”, so as not to compromise on the reliability of the system. But the advent of technologies with capability of instant start and fast ramp-up has made possible the concept of rapidly despatchable, non-spinning reserves which assure equal reliability. Markets are increasingly viewing this option as it brings about a reduction in system operating and wholesale electricity costs.

In this paper, we will present the results of a recent study which analyzed the technical feasibility of non-spinning vs. spinning reserves in a European power system. We will apply the learning to demonstrate the value of increasing amount of non-spinning reserves in pool based electricity markets of South Korea and Singapore. The value analysis for both the markets will be based on merit-order dispatch and technical characteristics of typical spinning-reserve providers. The results for South Korea and Singapore will include, technical feasibility of non-spinning reserves, potential fuel savings due to increasing amount of non-spinning reserves, and impact on electricity wholesale price.
2.0 The need for reserves

The demand for, and generation of, electricity must be kept in constant balance in order to maintain the stability of an electricity system and to meet reliability standards that are set by the Grid Code. The system operator has to schedule enough capacity to meet the forecast load during each time interval of the day while trying to ensure economical dispatch based on a merit order.

However, because of unforeseen circumstances, there is always the risk of either too much or too little capacity being scheduled and committed, resulting in operative challenges during the day. Imbalance between forecast and actual situation can arise due to three main reasons:

1. Unplanned outages of power plants or and transmission lines
2. Electricity generation or demand (load) deviating from the forecast
3. Intermittent renewable generation output deviating from forecast.

To tackle the potential imbalances, the system operator must schedule sufficient “operating reserves” to deploy over short timescales, from seconds through to a few hours, depending on the challenge at hand.

2.1 Functions and types of reserve capacity

Reserve capacity serves two main functions in a power system:

• To stabilize power grids by providing frequency control when demand and generation do not meet.
• To provide emergency reserves for maintaining system stability after contingencies, such as a trip or failure in the existing power plant or transmission lines.

The practice till recently has been to ensure that power plants that provide this continuous, up-and-down frequency regulation are kept in operation, i.e. “spinning”, to adjust their load and maintain the delicate balance between demand and supply. “Spinning reserve” needs to be provided by generating plants that are on line and synchronized to the grid, as they need to increase their output immediately in response to the system operator’s request. While remaining in spinning mode however, they operate at lower efficiency consuming more fuel per unit of
power and incur higher maintenance costs as well. The graph below (Figure 1) illustrates the reality of sharp reduction in efficiency when a typical CCGT plant is operated at less than full load, so as to provide the reserve capacity.

![Figure 1: Efficiency Vs Plant load of CCGT plant](image)

Non-spinning reserves, on the other hand, refer to generating capacity that are not connected to the system but have the characteristics of being brought online rapidly within the stipulated response time. The advantage of such plants is that they are in stand-by mode most of the time and hence do not incur fuel or maintenance costs for an extensive period. Hydro plants and gas plants based on aero-derivate gas turbines or large combustion engines are capable of providing such non-spinning reserves.

### 2.2 Reserve classes and the response time of reserves:

The reserves are classified as primary, secondary and tertiary reserves:

The reserve capacity requirement in the system is determined by taking into account,

- expected magnitude and duration of the imbalance
- possible mutual dependency of imbalances
- imbalance gradients

Different grid codes in various markets stipulate the response time for frequency control, as Figure 2 illustrates.
The primary reserve has to respond to frequency signals, typically, within 5-10 seconds and ramp up to its full output in 30-60 seconds. Primary reserves aim at stabilizing the system frequency by compensating imbalances by means of appropriate reserves.

The purpose of the secondary reserve is to relieve the primary reserve so that it can return to its normal condition. The secondary reserve is controlled online by the system operator and must be capable of responding in 30-60 seconds depending on the power system. The secondary reserve typically has 5-10 minutes to ramp up to its full output, thereby fully relieving the primary reserve.
The tertiary reserve has the task of relieving the secondary reserve for the next contingency. The operation mode is manual and it typically needs to respond in 10-15 minutes.

Given the stipulation of instant response, primary reserve has to be necessarily of ‘spinning’ type and is usually provided by baseload, coal-powered or combined cycle gas turbine plants. For secondary reserves, historically, the choice was between “spinning reserves” or “hydro” plants that could start and ramp up within the stipulated response time. Tertiary reserve has been provided by hydro plants as well as by open-cycle gas turbines.

Today, large internal combustion engines (ICE), with the following design characteristics, widen the choice available to the system operator for secondary and tertiary reserve requirement.

- High efficiency (over 46%)
- Modular plant design ensures high efficiency at all plant loads
- 30 seconds to start and 2-5 minutes to reach full load
- 1 minute to stop
- Any number of starts/stops – with no maintenance impact

The above special characteristics of internal combustion engines make possible a new and more efficient way of providing reserves.

Let’s consider an example of a traditional method where reserve capacity is provided by a 400 MW combined cycle gas turbine (CCGT) plant, whose electrical efficiency at full load is 55%.

A synchronized plant can provide operating reserves only by running on part load and while doing so will run at a much lower efficiency (48% in this example).

Since efficient generating units will be part-loaded to provide the operating reserve, a plant (say, a 200MW CCGT with an efficiency of 51%) with higher marginal cost will need to be brought on the system to supply energy.

So, the system with traditional method of providing operating reserves will operate with an average electrical efficient way of 51%.

In the new way of working, with fast-starting generating units on stand-by, there will be no need to run the efficient CCGT plant on part-load. It can be run at its optimal load (corresponding to
efficiency of 55%), as the operator will feel secure with the comfort of having fast start-up plants that can be deployed instantly for reserve capacity.

The comparison between the ‘traditional’ way and the ‘new way’ is illustrated in Figure 3

Studies in different markets have shown that use of such internal combustion engines as stand-by reserve to replace spinning reserve results in overall high savings in cost at the system level, with no compromise whatsoever on the reliability or stability. We will discuss some of the studies below.
3.0 Study on European system.

A large study on the frequency stability capabilities of non-spinning, fast-ramping plants (based on combustion engines) performed by DNV GL (former KEMA) in 2012 showed that

- There was no visible negative effect of the decreasing inertia in the system as this is compensated by high enough ramp rates.
- Adding fast ramping generators to the power system increased the primary response (FCR) of the system which led to better frequency stability.

To obtain more insight on the impact of general reserve requirements, and to determine the possible contribution of a flexible reserve product in frequency control a second study was made by DNV GL in 2014.

The focus was on the Central European power system as expected in 2020 and the model was validated against actual generation in 2012 as reported by a.o. ENTSO-E. The Dutch power system was modeled in detail and the other European countries were represented using aggregated generation mixes. Several generation scenarios (high wind, high coal, high Photo Voltaic) were analysed for the Dutch power system, in order to get generally applicable results for systems with different generation compositions.

In the technical analyses the following variations on frequency restoration reserves were introduced:

- Amount of frequency restoration reserves in MW
- Ratio of spinning and non-spinning capacity as balancing product;
- Preparation period (fixed 30s for non-spinning and fixed 0s for spinning)
- Ramping period (for spinning reserves);
- Pro-rata or merit order reserve activation schemes.

For the technical simulations the aim was to get a set of technical requirements for a frequency containment reserve product.
The study showed that entire secondary reserves can be met by non-spinning, fast-response generators without jeopardizing the power system response.

The DNV GL 2014 study also assessed the cost impact of using non-spinning, fast-response generators in the European system. The analysis was based on a PLEXOS model co-optimizing the generation of electricity and reserve (FRR) requirements, taking power plant constraints (e.g. ramp rates, minimum up time, etc.) into account, resulting in the least-cost solution for generating electricity while having sufficient reserve capacity available. The contribution of flexible generators to frequency control was investigated by adding fast reserve generators to the Dutch power system under different scenarios.

In the modeling exercise, the following parameters (Figure 4) were considered for the reserve generators:

![Figure 4: Fast reserve generator characteristics](image)

The following specifications were assumed in the calculations, for ‘spinning’ and ‘non-spinning’ reserves (Figure 5).

<table>
<thead>
<tr>
<th>Type</th>
<th>Capacity</th>
<th>Preparation period</th>
<th>Ramping period</th>
<th>Full activation time</th>
<th>Minimum off-time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinning</td>
<td>case specific</td>
<td>n.a.</td>
<td>46s/225s/450s/867s/900s</td>
<td>46s/225s/450s/867s/900s</td>
<td>n.a.</td>
</tr>
<tr>
<td>Non-spinning</td>
<td>case specific</td>
<td>30s</td>
<td>91s</td>
<td>121s</td>
<td>300s</td>
</tr>
</tbody>
</table>

![Figure 5: Specifications of spinning & non spinning reserves](image)
The study found that operational expenditure (OpEx) clearly reduced on the national level when fast-response generators provided the reserve. The reduction in total national level OpEx was up to 0.7%, but when viewed on the basis of the additional OpEx requirement for providing reserves, the reduction was up to 58%. The (up) reserve provision from the fast reserve generators allowed coal-fired and gas-fired power plants to be switched off, lowering generation and OPEX.

As the fast-response generators can bring about a reduction in system operating cost while meeting the requirement of response time and reliability standards, The DNV GL report recommends that fast-response generators should be encouraged to participate in the reserve market.

4.0 S. Korea: Reduction of electricity price by replacing spinning reserves with stand-by (non-spinning) reserves.

The conclusions from the European study will be equally valid in other markets. To confirm this proposition, we examined the impact of replacing 1500 to 1970 MW of spinning reserve in S. Korea, with same amount of fast reacting stand-by reserves based on internal combustion engine technology. The central idea was that when such quick-starting stand-by reserves are allowed, the lower operating cost plants can be operated at full capacity and better efficiency, while the more expensive plants can be shut down each hour.

The study assumed that secondary reserve capacity will be maintained at approximately 2% of the total system capacity. For determining the price level, KPX ideal merit order curve was used. (Figure 6) The merit order curve, in turn, was based on short-run marginal cost (SRMC) of plants. To calculate the system level costs and potential savings for the future years, merit orders of future years needed to take into account the new plants that will come on stream for the years 2013-2020. (Figure 7)
Considering the additional capacity expected in the system, merit order curves were adjusted accordingly. For example, by adding 2800MW of new nuclear capacity, merit order curve moves to right when there is 2800 MW of cheap (10 WON/KWh) available and reduces the need to dispatch more expensive plants. (Figures 8 and 9)

It is assumed that the newly created plants would be more efficient. To account for fuel price uncertainty, an annual 3 % increase in fuel costs (in real terms) was factored in.

Actual hourly load data was used as basis of the study (2012 load curve). Load data for 2013-2020 were created by assuming a steady 3.4 % annual demand growth and no changes in load profile. Amount of secondary reserve in the system was set as 1500 MW for years 2012-2013.
From 2014 onwards, the secondary reserve was fixed as 2% of peak load. The ideal merit order curves, for the years 2012-2020, then looks as in Figure 10

![Merit order curves - KPX ideal](image)

**Figure 10: Merit order curve 2012-2020**

### 4.1 Impact of standby reserves

By allowing standby reserves to provide 1500 MW - 1900 MW of secondary reserves, it was seen that dispatched plants could be run at full load, and the more expensive and less efficient plants could be shut down.

When 1500 MW - 1900 MW of the most expensive plants can be shut down, the System Marginal Price (SMP) will drop, since now more efficient plants will set the SMP for the total fleet.

To calculate the nation level saving potential of 1500 MW -1900 MW stand-by reserves, the following process was followed:

First, for the traditional way (with spinning secondary reserves), the hourly system cost was arrived at by adding the hourly cost of demand met by coal and nuclear plants and the demand met by the other plants. The SMP considered was the one corresponding to the full demand (including reserve) on the merit order curve, subject to a cap (66.4 Won/KWh) for the units.
dispatched by the coal and nuclear plants. The system cost was calculated thus for every hour of the year and aggregated to get the annual, national level cost.

Next, for the ‘new’ way, the same exercise was repeated, but with SMP corresponding to the demand, without spinning reserves, on the same merit order curve. The national level cost was again arrived at, by aggregating the hourly costs in meeting the respective demand.

The difference in system costs between the ‘traditional’ way with spinning reserves and the ‘new’ way with stand-by reserves could then be calculated.

The methodology is explained in Figure 11 below.

![Figure 11: Methodology of calculating system level costs](image-url)
4.2 Results of study:
It was observed that adding 1500 -1900 MW of stand-by reserves into system would provide savings of 5478 billion won (5.0 bn USD) during 2013-2020 or 1.5% of system costs. The SMP would come down by the same 1.5% on average.

<table>
<thead>
<tr>
<th></th>
<th>Total annual cost KPX Ideal</th>
<th>Cumulative cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>KPX ideal</td>
<td>33219</td>
<td>36624</td>
</tr>
<tr>
<td>KPX ideal + Stand by</td>
<td>32742</td>
<td>36014</td>
</tr>
<tr>
<td>Difference %</td>
<td>-1.4%</td>
<td>-1.7%</td>
</tr>
</tbody>
</table>

Figure 12: Result table

4.3 Net benefit over 10-year period
Assuming investment cost of MUSD 1200 to set up 1500 MW of stand-by reserves based on internal combustion engines, the fixed costs to meet the 8 % IRR is 179 MUSD per annum and operating cost of plant ranges from 105 MUSD in the first year of operation to 137 MUSD in the tenth year of operation. The savings accrued by stand-by reserves are still considerably higher than the costs.
Thus, by enabling less expensive baseload plants to run at higher load factor and set the SMP for a longer period, fast-response standby reserves provide high national-level savings in electricity price.

5.0 **The National Electricity Market of Singapore (NEMS)**

The NEMS is designed to promote the efficient supply of competitively-priced electricity in an open and transparent manner in a real-time trading pool.

Natural gas generates most of Singapore's electricity and fuels almost 85% percent of Singapore's electricity generation. Nearly 95% of the plant mix for electricity generation is based on CCGTs. Singapore needs regulation and spinning reserves to ensure the reliable supply of electricity to consumers and the secure operation of the power system. Generators keep CCGTs on line at lower load to ramp up to meet peak demand as well as to provide the ‘reserve’ margin.

Singapore has high cycling load of approx 2000 MWe per day, due to variable pattern i.e. power consumption drops significantly during the night and off-peak hours, though the demand during peak hours continues to be high. The cyclical generation pattern is evident from the typical daily load curve of Singapore (**Figure 14**). The high cyclicality also results in lower average load factor and overall efficiency (**Figure 15**).

![Figure 14: Daily load curve-Singapore (Jan6, 2014) and Figure 15: Gross efficiency & Load factor for Generation](image-url)
In Singapore, most of the primary, secondary and contingency reserve is provided by existing CCGTs. These plants are running on part load and therefore act as “spinning reserve”, capable of responding to contingency situations by increasing their output rapidly.

To establish the value of non-spinning, fast-response response plants in the system in a future year (2020), two scenarios were compared, assuming the current growth levels in power demand as well as some addition in solar energy plants.

1: New investments are made in CCGTs and all power plants in the system provide spinning reserves (historical system)

2: New investments between now and 2020 are made in reserve & peaking power plants, and thereby the system will reduce its spinning reserve by 700MW (proposed system)

In the first scenario, the cost of spinning reserves will continue to increase due to lower average, operating efficiency of the CCGTs.

The second scenario envisages addition of secondary and contingency reserve capacity, provided by flexible generation, which would be non-spinning i.e. on stand-by using internal combustion gas engines, burning no fuel and generating no emissions, waiting for a system operator’s activation signal before starting and synchronizing to the grid in just 30 seconds. Furthermore, the primary reserve could be relieved faster than the present requirement, i.e. in 2-5 minutes instead of 10.

By using fast and flexible plants (such as those powered by modern gas engines) for secondary and contingency reserve, some of the older, inefficient CCGTs, that provide the service now, could be stopped, and the others could be loaded to maximum load (allowing only for primary reserve), releasing additional base load power. This would increase the electrical efficiency of all CCGT plants and, as the most expensive generators would be stopped, it would lower the electricity price since the most expensive marginal units are shut down.

If, say, 700 MW of spinning reserves are replaced with same amount of stand-by reserves, then the last 700 MW from the merit order can be shut-down. As in the pool based market such as Singapore, the last required MW sets the price for all generation, the saving is big, especially during the trading intervals when there is need to turn on the oil boilers.
When stand-by reserves are actually requisitioned to balance the system, the overall impact on generation cost is quite minor, but the savings are huge, as idling cost of reserves can be avoided.

Based on simplistic assumptions, it can be seen from table below (Figure 16) that replacing 700 MW of spinning reserves with stand-by reserves will provide annual fuel cost savings of approximately S$ 278 million in 2020.

<table>
<thead>
<tr>
<th>Technical impact</th>
<th>Replacing 700MW CCGT capacity in 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total CCGT capacity participating in providing reserves</td>
<td>MW 7700</td>
</tr>
<tr>
<td>Required reserves</td>
<td>MW 700</td>
</tr>
<tr>
<td>Reserves share of total CCGT</td>
<td>% 10.4%</td>
</tr>
<tr>
<td>Improvement in CCGT’s efficiency relative to present efficiency, when increasing output by 10.4%</td>
<td>% 2.9%</td>
</tr>
<tr>
<td>Fuel consumed (historical system)**</td>
<td>TWh 117.1</td>
</tr>
<tr>
<td>Fuel consumed (proposed system)</td>
<td>TWh 113.7</td>
</tr>
<tr>
<td>Reduction in fuel consumption</td>
<td>TWh 3.4</td>
</tr>
<tr>
<td></td>
<td>% 2.9%</td>
</tr>
</tbody>
</table>

**Figure 16: Technical calculation – impact of stand-by reserves**
* GT Pro software for HD CCGTs
**Based on present thermal efficiency of 45%
*** Based on improvement in thermal efficiency, by 2.9% or 45 x 1.029 = 46.3%

<table>
<thead>
<tr>
<th>Financial Impact</th>
<th>Replacing 700MW CCGT capacity in 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel price</td>
<td>S$/GJ 23</td>
</tr>
<tr>
<td></td>
<td>S$/MWh 82.8</td>
</tr>
<tr>
<td>Fuel cost historical dispatch (historical dispatch)</td>
<td>MS$ 9,692</td>
</tr>
<tr>
<td>Fuel cost, optimized dispatch</td>
<td>MS$ 9,414</td>
</tr>
<tr>
<td>Fuel cost savings</td>
<td>MS$ 278</td>
</tr>
</tbody>
</table>

**Figure 17: Financial calculation – impact of Stand by reserves**

The fuel cost savings, through improved efficiency, will eventually lead to reduction in system marginal pricing at national level, as we have seen in the Korean case study.

The above calculations have been done based on broad assumptions, but they do help in identifying clear opportunities and possibilities of improving the overall efficiency of the system.
6.0 Market mechanism for non-spinning reserves:

Historically, in many markets, the reserve requirement—both regulation and emergency—has been met by spinning reserves, i.e. with plants that are kept running and connected to the grid. In NEMS, for instance, as CCGTs as well as the Oil fired steam power plants cannot be started up and ramped up in time to meet the reserve code requirement, the only way these plants could do so was by staying on line at lower load, and providing margin for spinning reserve. While the intent of grid code was to spell out the response time, the grid code also specifies that power plant needs to be online to provide these reserves, which is a legacy requirement arising out of limitation in flexibility of Thermal Power Plants / CCGTs technology.

Increasingly, markets are being redesigned to permit the participation of non-spinning reserves.

Electric Reliability Council of Texas (ERCOT) which, in the past, used to divide contingency reserves into spinning (responsive reserves) and non-spin reserves has dispensed with this practice. To meet the requirement of NERC BAL-002-1 Disturbance Control Standard (DCS), ERCOT specifies “that the contingency reserve (CR) must be fully deliverable within 10 minutes so that frequency can be restored to the pre-disturbance level within 15 minutes”. The only qualification now is the response time and this permits non-spinning reserves from plants based on aero-derivate gas turbine and internal combustion engine to bid in this market.

In the NEM in Australia, AEMO’s specification for ancillary services calls for ‘delayed raise” product with a response capability of 5 minutes and opens up the market for participation by non-spinning plants. A recent study done by Wartsila on the NEM market shows that plants based on internal combustion engines could lower the price of “Raise 5 minute product” by 34%.

7.0 Recommendation:
Markets in S.Korea and Singapore will stand to gain considerably by encouraging the participation of non-spinning generators in providing secondary and tertiary reserves. The national level savings will be high (as illustrated), without compromising on the reliability and stability of the system. The thrust on renewable energy in the future and the resulting variability in generation will make it even more necessary to increase the reserve margin in the system. Fast-response generating plants will provide much-needed flexibility.
8.0 References:

1. Frequency restoration product specifications and the role of fast reserve generators. -A report prepared for Wartsila Finland Oy by DNV GL Energy, KEMA, Nederland B.V- May 2014. (Figures 4 and 5 on Page 10 have also been sourced from this report)

2. Appendix to report “Private Capacity Addition for Reserve Adding Resolution” prepared by Korea Society of Resources Economics, May 2013. (Figures 6 to 13 have also been sourced from this report)

3. Load curve for Jan 8, 2014 (Figure 14) was sourced from Daily load report of Energy Market Company, Singapore.

4. Load factor data and efficiency data (Figure 15) for Singapore were sourced from website of Electricity Management Authority of Singapore (http://www.ema.gov.sg/media/files/facts_and_figures/2012.03/TPS4.pdf) and (http://www.ema.gov.sg/media/files/facts_and_figures/2012.03/TPS5.pdf)

5. Concept paper on “Future Ancillary Services” brought out by Electricity Reliability Council of Texas. (Draft version, Sep 2013)