Enabling major national savings through a new approach to system security

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A healthy reserve capacity is essential to avoid power system blackouts. In South Korea, low investments together with an increasing demand have resulted in the reserve margin falling to very low levels, thus jeopardising system security.

Currently, the thermal power plant fleet is kept on part load to provide spinning reserve of about 4 GW. But there is a more efficient, economic and sustainable way of handling a substantial part of this reserve (2.5 GW) by using highly flexible fast starting power plants.

Installed base

Conventional thermal and nuclear power plants dominate electricity generation in South Korea. Coal fired power plants account for a little above 40 per cent of the generation, followed by nuclear with approximately 34 per cent. Natural gas accounts for some 19 per cent and oil just around two per cent. The generation share as of 2010 is illustrated in Figure 1.

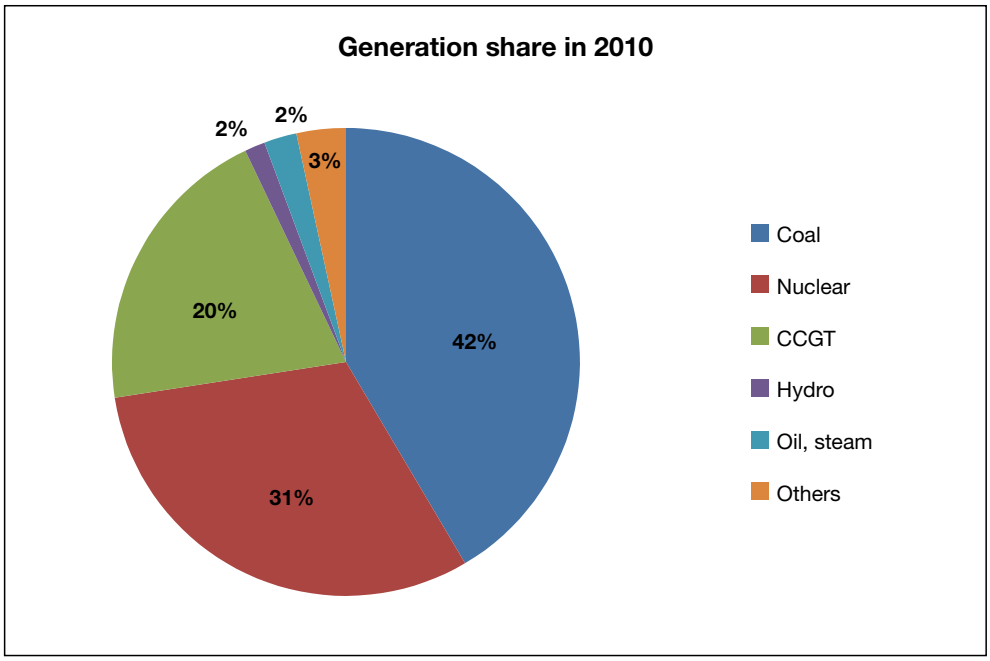

Figure 1. Generation share in South Korea 2010 (based on produced GWh).

Electricity generation capacity in 2009 was about 80 GW and is expected to reach 88 GW by 2017. Nuclear energy will power most of this expansion in line with the government's policy to improve energy security by reducing fuel imports.

Market structure

Korea Electric Power Company (KEPCO), the national utility that is majority-owned by the government, has sole responsibility for transmission and distribution and accounts for most of the country's generating capacity. In 2010, the company had generating assets with an installed capacity of 74.6 GW. The rest is from independent power producers, which account for about 10% of the installed capacity. The 2010 overall capacity division by technology is illustrated in Figure 2.

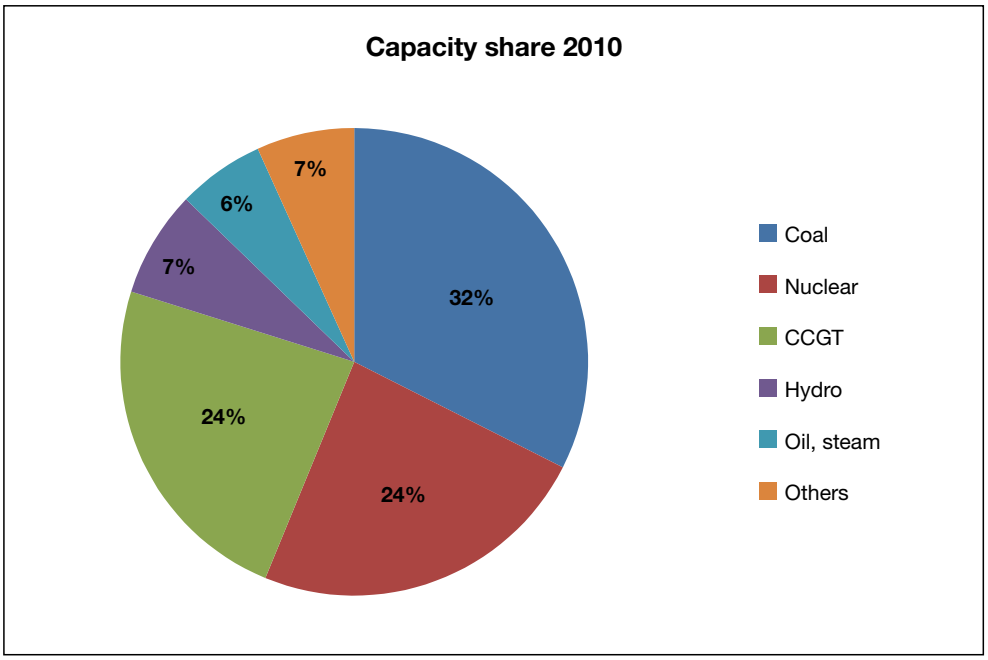

Figure 2. Capacity share in South Korea 2010 (based on installed GW).

As part of the electricity sector reform in 2001, KEPCO's generating assets were spun-off into six wholly-owned subsidiary generating companies (Gencos): Korea Hydro & Nuclear Power Co. (KHNP); Korea East-West Power Co. (EWP); Korea Midland Power Co. (KOMIPO); Korea South-East Power Co.(KOSEP); Korea Southern Power Co. (KOSPO); and Korea Western Power Co. (KOWEPO).

At the same time, the Korea Electric Power Exchange (KPX) was established to serve as the system operator and to coordinate the wholesale electric power market. KPX regulates the cost-based bidding-pool market, and determines prices for energy sold between generators and the KEPCO grid.

KEPCO is the main retailer and apart from large industrial consumers, is the sole purchaser of electricity from the pool.

Since 2004, regional districts have been allowed to bypass KEPCO and the power pool by buying power directly from the IPPs.

Market challenges

Despite the restructuring, the market has not incentivised sufficient investments in new power generation. The Korean electricity market provides system marginal price (SMP[1]) for each hour, which should stimulate new investments if the supply side is scarce. However, there are two main reasons why the market has not delivered adequate investments in the past years. Firstly, even though the SMP has increased, the Gencos cannot receive the full SMP for their existing assets. Secondly, the retail prices are regulated and the current level of retail tariffs is below the SMP. These market limitations are reducing the investment incentives of the Gencos, and on the other hand have run KEPCO into debt, since the cash flow from the retail market is not covering the costs of electricity procurement.

Inadequate investments in new capacity and simultaneously increasing electricity demand have caused the reserve margins to fall just 5-7% over peak

1 Gencos and IPPs bid their available capacity to the market for each hour, a day ahead. KPX then calculates the cost for each power plant and dispatches plants according to plant efficiency and fuel cost. This means that nuclear and coal fired plants are dispatched ahead of more efficient gas fired combined cycle plants because of high gas prices. The last plant to be dispatched sets the SMP for that hour, and each dispatched plant receives the SMP.

demand instead of the more typical 13-15%. This reserve margin development has increased the risk of blackouts, but according to the current investment scenarios the situation will ease by 2015 at the earliest, or as late as 2018.

Reserves in power systems

All power systems require a certain reserve capacity, but the requirements in terms of size and dispatch speed differ considerably. The reserve requirements are defined in the Grid Code prepared by the Transmission System Operator (TSO), who is also responsible for maintaining system stability.

Reserve capacity for normal balancing service in any power system traditionally requires that the regulating power plants operate at part load. In part load operation, the plant efficiency is lower than at full output, and of course less power is produced as well. Hence, providing such a service comes at a cost.

More specifically, reserve capacity serves two main functions in a power system which are typically defined as follows:

- To stabilise power grids by providing frequency control when demand and production do not meet. The power plants that produce this continuous up and down frequency regulation must be in operation, i.e. “spinning”, and adjust their load to maintain the delicate balance between demand and supply.
- To provide emergency reserve for maintaining system stability after contingencies, such as a trip or failure in the existing power plant or transmission lines. Emergency reserve can be divided into three subcategories – primary, secondary and tertiary. The response time for each is categorised by the country’s grid codes.

Figure 3 illustrates the reaction time requirements and the utilisation of the different reserves in South Korea after an emergency situation.

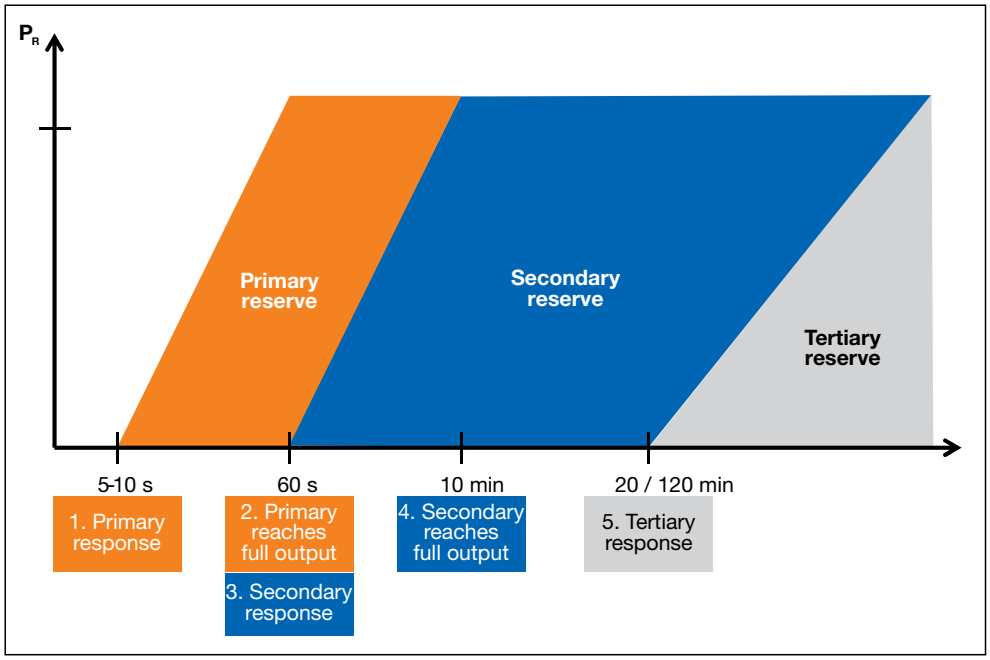

Figure 3. Reserve response time requirements and utilisation in South Korea.

Primary reserve

When an emergency situation occurs, e.g. a plant trips, the inertia of the system maintains system stability during the first few seconds. The primary reserve then automatically responds to the frequency deviation in the system. As soon as the frequency falls below a set limit, this reserve starts to ramp up without any dispatcher involvement.

The primary reserve has to be spinning since the required response time is typically 5-10 seconds and the reserve has 30-60 seconds to ramp up to its full output. In South Korea these time limits are 5-10 seconds and 60 seconds, respectively.

The minimum size of this reserve capacity is typically equal to the biggest generating unit in the power system, or sometimes the largest grid connection contingency, so that if the largest unit trips, the spinning reserve kicks-in before the system collapses.

Secondary reserve

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. In South Korea, this time limit is 60 seconds. The secondary reserve typically has 5-10 minutes to ramp up to its full output, thereby fully relieving the primary reserve. This time interval is 10 minutes in South Korea.

In South Korea the secondary reserve is currently provided by spinning thermal units, operating on part load, since the non-spinning reservoir hydro capacity is very limited. Typically, the amount of secondary reserve has to cover the full primary reserve and is typically ~ 2% of the total generation capacity connected to the grid. Due to the considerable seasonal variations in South Korea, the required size of both the second and tertiary reserves varies on an annual basis. Table 1 presents this setup.

In South Korea the amount of spinning reserve serving primary reserve purposes is 1.5 GW, and secondary reserve purposes 1-1.5 GW depending on the season.

Tertiary reserve

The tertiary reserve has the task of relieving the secondary reserve for the next contingency. It is normally non-spinning and the operation mode is manual. The reserve is usually activated by phone, and it typically needs to respond in 10-15 minutes. In South Korea the response time is 20 minutes during peak season and 120 minutes off-season. However, due to the critical capacity situation in South Korea in the summer, much of the tertiary reserve is in operation, providing spinning reserve and energy to the system.

Tertiary reserve is traditionally non-spinning capacity, typically large simple cycle gas turbines. During the period for which this reserve is procured, in most markets it should under no circumstances participate in the energy markets, i.e. it is only to be used in case of a system fault or contingency. Again, the necessary capacity has to do with the largest single contingency, i.e. the largest system unit, and with the replacement of the full secondary reserve; the minimum provision is typically around 2-3% of total grid capacity.

When there is a trip in the system, the primary reserve is automatically activated first by the frequency dip. The primary reserve is released when the secondary reserve is activated and takes over the load from the primary reserve and so on.

Table 1 presents a summary of the requirements for the reserves in South Korea.

	Spinning/ non-spinning	Time frame		Amount	
		Peak season (Jan, Feb, Jun, Jul, Aug and Dec)	Other months	Peak season (Jan, Feb, Jun, Jul, Aug and Dec)	Other months
Primary	**Spinning**	1 minute		1500 MW	
Secondary	**Spinning**	10 minutes		1500 MW	1000 MW
Tertiary	**Non-spinning**	20 minutes	120 minutes	1000 MW	1500 MW

Table 1. Summary of the requirements for the reserves in South Korea.

Technological challenge

Thermal plants typically offer high efficiency by using high pressure superheated steam in the process. Starting and stopping power plants with such steam cycles is always a major undertaking, a process requiring modest heat-up rates and time. Starting such a power plant in less than 1 hour exposes the technology to high thermal stresses and causes wear and tear. The starting time for coal fired power plants is around 4 hours in hot stand-by conditions, and 1-1.5 hours for gas turbine combined cycles.

It is obvious that such thermal plants cannot provide any off-line services to the system stability which requires 5 seconds to 15 minutes start-up times. As a consequence, both primary and secondary reserves need to be on-line i.e. “spinning”. However, running thermal power plants on partial load considerably reduces their efficiency, hence increasing the fuel consumption and emissions. In the case of South Korea, 2.5-3 GW of such ramp-up capacity is continuously kept available.

The question is: is there a more optimal way of operating the power system assets, and still provide the necessary stability services?

Smart Power Generation

Smart Power Generation (SPG) offers three simultaneous features that are valuable in this context:

- High efficiency – between 45 and 50% net plant on site. In a typical multi-unit installation the efficiency remains the same over the wide load range of 3-100%
- Operational flexibility – fast starting, stopping, ramping, without impact on the maintenance schedule
- Fuel flexibility – natural gas, LNG, biogases, fuel oil (HFO, LFO) and liquid biofuels

Smart Power Generation offers a new way to stabilise power systems. Capable of starting and synchronising to the grid in a mere 45 seconds, and ramping up to full load in 5 minutes, it can provide a secondary reserve function from stand-still, with no fuel cost and emissions. This service is available immediately again, with no downtime. For instance, some 200 MW size range Smart Power Generation plants in the USA start 3 to 10 times a day, balancing the wind power.

In Figure 4, a comparison of start-up and loading times for different power generation technologies is displayed.

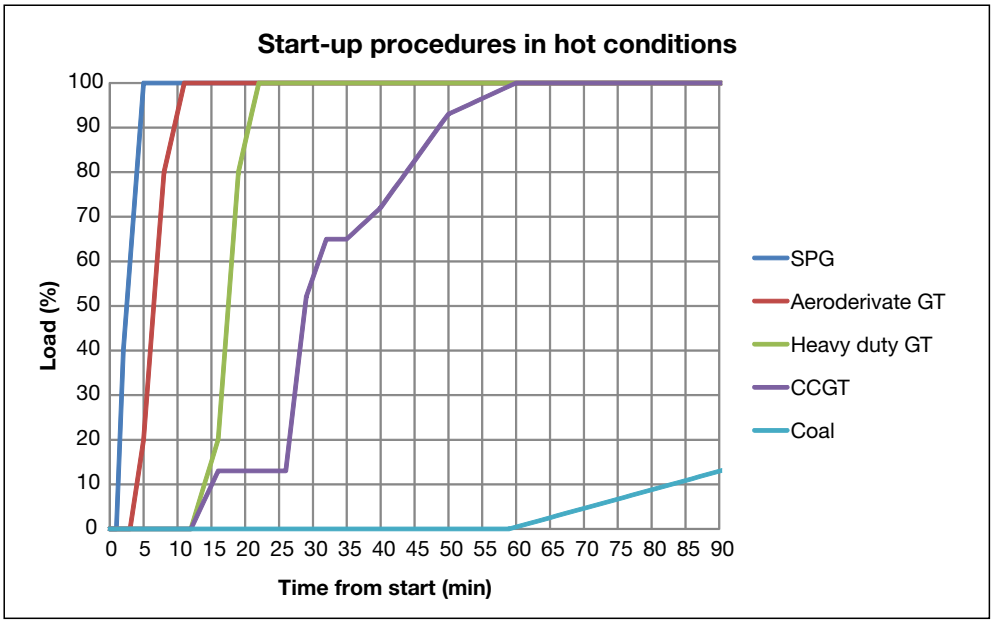

Figure 4. Start-up procedures in hot conditions.

Smart Power Generation is a proven technology based on modern computerised combustion engines. Plant sizes typically range from 20 MW to 600 MW which is the optimum size range for system optimisation.

Optimising the South Korean power system with Smart Power Generation

In South Korea, most of the primary and secondary reserve is provided by existing combined cycle gas turbine plants. These plants are running on part load and are therefore able to increase their output rapidly. The amount of secondary reserve is 1-1.5 GW. As the required response time is 1 minute, today all this capacity is spinning. The Grid Code also clearly stipulates that it should be.

The secondary reserve capacity could be provided by Smart Power Generation, which would be non-spinning i.e. on stand-by, burning no fuel and generating no emissions, waiting for a system operator's activation signal and then starting and synchronising to the grid in just 45 seconds. The main change is that the secondary reserve would not need to be spinning anymore. Furthermore, the primary reserve could be relieved 50% faster than the present requirement, in 5 minutes instead of 10. This would naturally reduce the vulnerability of the system.

By using Smart Power Generation for secondary reserve, some of the older, inefficient combined cycles that currently provide the service could be stopped, and the rest could be run on full or nearly full load, providing additional base load power or serving as primary reserve. This would increase the electrical efficiency of all CCGT plants AND it would lower the electricity price as the most expensive generators would be stopped[2].

[2] KPX calculates the fuel cost for each power plant and dispatches according to efficiency and fuel cost. The last plant to be dispatched sets the SMP for that hour.

The amount of tertiary reserve is also 1-1.5 GW (depending on the season) and the required response time is 10-120 minutes. Although it is stipulated that this capacity can be non-spinning, spinning units are used at the moment due to a lack of suitable non-spinning capacity. Smart Power Generation could also provide this service most efficiently, much better than the old steam power plants that typically end their lifecycles in this function.

National savings

Freeing up the CCGT capacity that is currently kept for emergency reserve, and stopping the older CCGT's through the use of Smart Power Generation could deliver significant system level savings.

How could the savings be evaluated?
In South Korea's power system CCGTs are the main reserve providers. Let us make the safe assumption that the reserve provision is distributed evenly within the CCGT fleet. That means that the CCGTs are running on part load in order to provide reserves. The CCGT capacity is about 20 GW and if all the CCGTs participated in providing 2.5 GW of reserves (secondary and tertiary) it would mean that all the CCGT plants would need to run with 12.5% lower output to provide reserves. If those CCGTs would not need to operate on part load anymore and reserves could be provided by non-spinning units, there is an impact on the total efficiency of the system. Increasing the CCGT output by 12.5% has an impact on the CCGT's efficiency which is 2.5-3% (i.e. 1.3-1.5 per cent units for a typical CCGT which has 48-55% efficiency). The relation between output and relative efficiency can be seen in figure 5.

1. Increase output by 12.5%
2. Impact on efficiency 2.5%

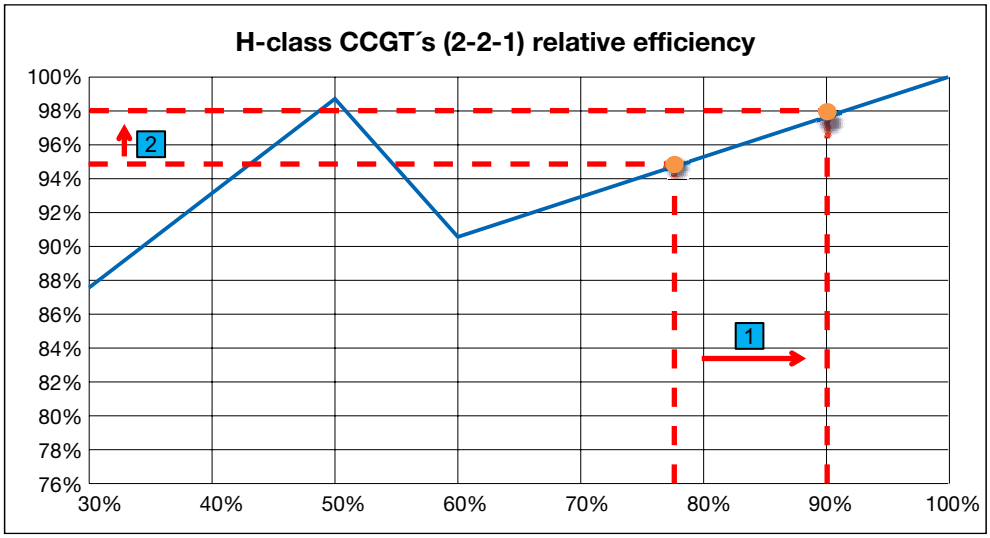

Figure 5. H-Class CCGTs (2-2-1 configuration) relative efficiency[3]

Even during the low load period of the year, replacing spinning reserves with Smart Power Generation would yield considerable savings. With the total secondary or tertiary reserves at 1.5 GW, i.e. 7.5% of total CCGT capacity, Smart Power Generation would enable an increase in the electrical efficiency of each CCGT plant by 0.7-1.0% per cent units.

[3] According to the available data, some of the CCGT fleet capacity is currently not in use. However, the starting point for this calculation does not affect the results, since the relation between output and relative efficiency is almost linear.

The technical impact of introducing 2.5 GW, 1.5 GW or 1 GW of flexible Smart Power Generation capacity is described in detail in Table 2 below.

Technical impact		Replacing 2500MW reserves	Replacing 1500MW reserves	Replacing 1000MW reserves
Total CCGT capacity providing reserves	MW	20 000	20 000	20 000
Required reserves	MW	2500	1500	1000
Reserves share of total CCGT capacity (each CCGT could increase its output by this much if they were not required to provide reserves)	%	12.5	7.5	5.0
Impact on each CCGT's efficiency when increasing output by above row%	**%**	**2.5**	**1.5**	**1.0**
Fuel consumed (South Korea historical 2010)	TWh	189.0	189.0	189.0
Fuel consumed (optimised)	TWh	184.3	186.2	187.1
Reduction in fuel consumption	**TWh**	**4.7**	**2.8**	**1.9**
	%	**2.5**	**1.5**	**1.0**

Table 2. Technical calculation

Replacing 2.5 GW of CCGT reserves with flexible Smart Power Generation will provide annual fuel cost savings of $269 million (at 2010 gas prices) and the cost of the investment can be paid back in 6.3 years. The detailed economical impact of replacing the CCGT reserve capacity with Smart Power Generation units is shown in Table 3.

Financial impact		Replacing 2500 MW reserves	Replacing 1500MW reserves	Replacing 1000MW reserves
Fuel price	USD/GJ	15.8	15.8	15.8
	USD/MWh	56.88	56.88	56.88
Fuel cost historical dispatch (Calculated from South Korea historical 2010) historical dispatch)	MUSD	10 750.3	10 750.3	10 750.3
Fuel cost, optimised dispatch	MUSD	10 482.6	10 589.1	10 643.8
Fuel cost savings	MUSD	268.8	161.3	107.5
SPG capacity needed	MW	2500	1500	1000
Investment cost	MUSD/MW	0.675	0.675	0.675
Total investment cost	MUSD	1688	1013	675
Savings per year	**MUSD**	**269**	**161**	**108**
Simplified payback time	**years**	**6.3**	**6.3**	**6.3**

Table 3. Financial calculation

Conclusion

With the increasing risk of power shortages prior to the commissioning of new CCGT and nuclear power plants, South Korea needs to consider installing reserve capacity that can be brought on stream quickly. Smart Power Generation provides a viable alternative and the deficit could be removed in 1.5 years.

The addition of these flexible gas fired power plants will not only fill a potential power gap but will also allow the entire system to operate more efficiently and economically by providing system reserve capacity with higher efficiency and lower costs, even after the new, large base load capacity comes online.

To allow the use of Smart Power Generation as secondary reserve, the grid code would have to be modified to allow the secondary reserve to be non-spinning.

Summary of benefits of the Smart Power Generation solution for South Korea:

- A quick remedy for the acute capacity deficit – delivery of 3 GW within 1.5 years
- Annual savings of $269 million over the years to come. This annual saving remains the same in the future if spinning CCGT units are used for reserves.
- Reduced import of LNG – up to 2.5% per year
- Lower wholesale electricity price
- Reduced CO_2 emissions
- Improved system stability due to faster replacement of primary reserves – 5 minutes instead of 10

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DBAC428448 / 09.2012 / Bock's Office