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Operational flexibility with Wärtsilä 50SG

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In Asia, the power system is going through major structural changes. More capacity is needed, ageing power generation may have to be closed and renewable generation is being integrated. These are challenges to the fundamental task of power systems: to match production with demand.

Smart Power Generation based on gas engines is a proven solution for these new challenges. Modern gas engines employ a series of techniques and features that offer superior single-cycle efficiency combined with fast loading and un-loading capability.

The paper will show real cases of gas engine synchronisation readiness from standstill in 30 seconds with potential for non-spinning Secondary Reserve, very fast power increase reaching 100% power from standstill in only 5 minutes, fast Primary Frequency Control reserve and Secondary Frequency Control within a power window of 70%.

The fast reaction capability is required especially in grids where the inertia constant is decreasing. This happens when renewable generation units are connected to the system indirectly through a converter or a frequency drive and is thus not contributing to system inertia.

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Power System Challenges

The power system balance must be maintained continuously to match power supply and demand. Traditionally, this is fairly easy and you can rely on historical statistics and demand prognosis to ramp up and down your generation. In case of disturbances you arrange reserves, primary and secondary that can be activated in order to maintain security of supply.
Even in a conventional power system with a limited amount of intermittent renewable generation like wind and solar, the daily cycling of generation can be significant.

For instance, in the Jawa-Bali power system this balance is mostly achieved by cycling the existing coal and other thermal power plants between full load and partial load operation to match power demand during 24-hour daily cycle. In September 2011, on average 1.8GW of coal power was ramped down every night, while gas, diesel, and MFO –fired generation capacity continued to operate throughout the low-demand night time. In this case, agile, efficient and flexible gas based generation would improve the overall system efficiency by avoiding inefficient partial load operation of base load power plants [1].

In Thailand the daily load curve is characterized by three distinctive load peaks within the 24 hour cycle. To respond to these peaks, about 6 GW of intermediate and peaking power capacity is dispatched daily. Given the average annual growth in peak demand of 4.2%1, by 2030 about 14GW of intermediate and peaking power capacity is needed for daily load following duties. There are no new domestic peaking hydro plants in planning after 2017 [2].

Fast, efficient and flexible generation, the first technology that comes to mind is hydro, however if there are no possibilities to extend the hydro installed base, the second best option is (reciprocating) combustion engine based gas generation, by some utilities nowadays even called “gas hydro”.

In 2013 the Turkish generation capacity was more than 60 GW, where the hydro capacity is on a significant level at a rate of 34 % [3]. Even though Turkey has this high share of hydro, the transmission system operator, TEIAS, is utilizing gas engines for balancing the continuous heavy industry related fluctuations of ± 1,5 GW.

The issue of frequency stability will be discussed in the next chapter, after that the engine performance will be described and followed by some case studies.

Frequency Stability Contribution with Combustion Engines

The introduction of renewable energy sources is advancing rapidly, and some countries are targeting 50% of their electrical energy need from renewable power by 2020 [4]. While the environmental benefits of these sources are obvious, the intermittency and unpredictability of their power output may pose a challenge for grid frequency stability. This is further exaggerated by the fact that renewable sources do not always contribute to *stability services* and *system inertia*, while they are replacing power plants that were contributing to those services. With high penetration levels the vulnerability of the system may increase during disturbances such as sudden loss of production.

The low variable costs of wind and solar powered generation and the political incentives for priority of dispatch provide means to displace conventional generation in the power systems. This can lower the system resiliency to disturbances in two ways.

The first effect originates from the fact that currently renewable power generation units may not be required to contribute to system stability services nor to system inertia. The first originates from the simple condition that the eventual reserve provision and response of renewable generation is at least to some degree subject to the natural variability and unpredictability of their respective power source. Thus they are many times not currently required to participate in system services in form of primary and secondary reserve provision. In addition to the above mentioned there is also a desire to use renewable generation to its full extent.

The second effect comes from the way many of the renewable generation units are connected to the power system. Many modern renewable generation units are connected to the system indirectly. That is through converter or a frequency drive and is thus not contributing to system inertia.

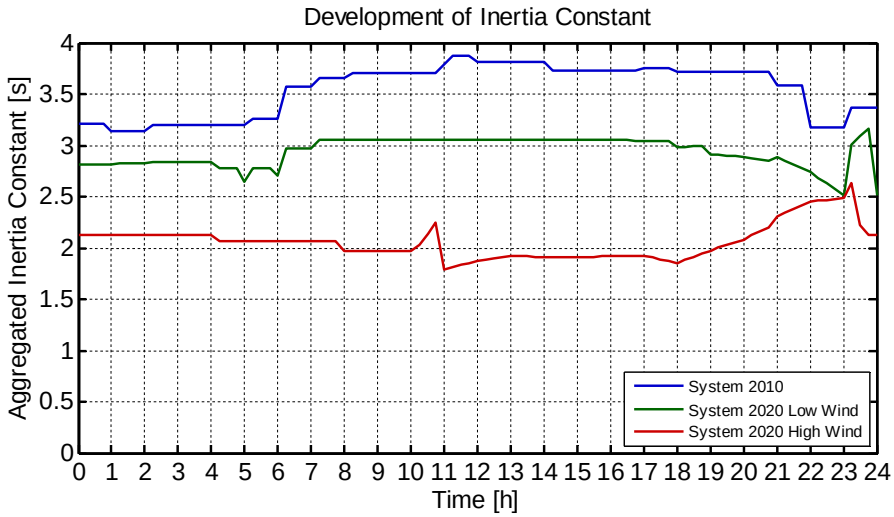

Figure 1: Example of the development of Inertia constant of one European country current situation and forecasted situation in year 2020 high and low wind situation renewable energy production not contributing to system inertia. [5]

This loss of inertia through the displacement effect, may lead to a higher rate of change of frequency and eventually to a lower absolute frequency drop in case of system disturbances. This have spurred TSOs (Transmission System Operators) to evaluate a request to renewable generation units to provide so called "synthetic" inertia, where indirectly connected renewable generation units would mimic the inertia response of conventional generation technologies.[6]

The decreased inertia and the potential for reduced availability of system services with increasing wind generation may lead to a greater requirement to ramp conventional generation units up and down, not only due to the natural variation of their power source particularly if rising demand coincides with falling wind generation. But, also indirectly through the above mentioned displacement effect.

Combustion engines are very suitable for system balancing services, to compensate for both the natural variability of renewable generation and for the indirect effect of decreased system stiffness and reduced availability of system services.

A large study on the frequency stability capabilities of combustion engines performed by KEMA [7] have showed that for compensating the reduced system stiffness, combustion engines' natural ability to provide a high loading capability helps power systems to enhance system performance, furthering the introduction of more sustainable power generation capacity without endangering system performance.

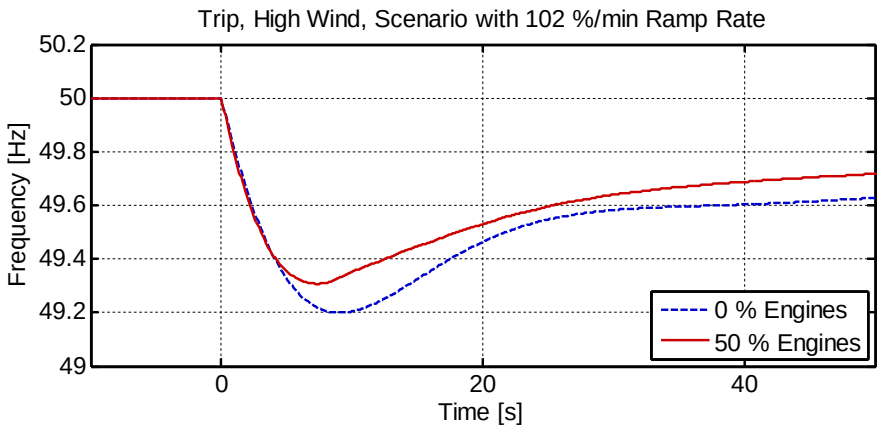

Figure 2: Primary reserve frequency plot for a 2020 High wind scenario in a European country, where the blue line is business as usual and the red line when 50% of the conventional generation except that nuclear and CHP is replaced with combustion engines [7].

The combustion engines' quick start and rapid loading capability further makes system services like secondary control (upwards) available from stand-by condition. The possibility for having rapid secondary power replacement from combustion engines from stand-still in case of production shortfall enhances overall system performance capability. This capability compensates for the potential lack of rapid response service capability from other conventional plants, particularly if they would be forced to cease running due to high availability of renewable power production output.

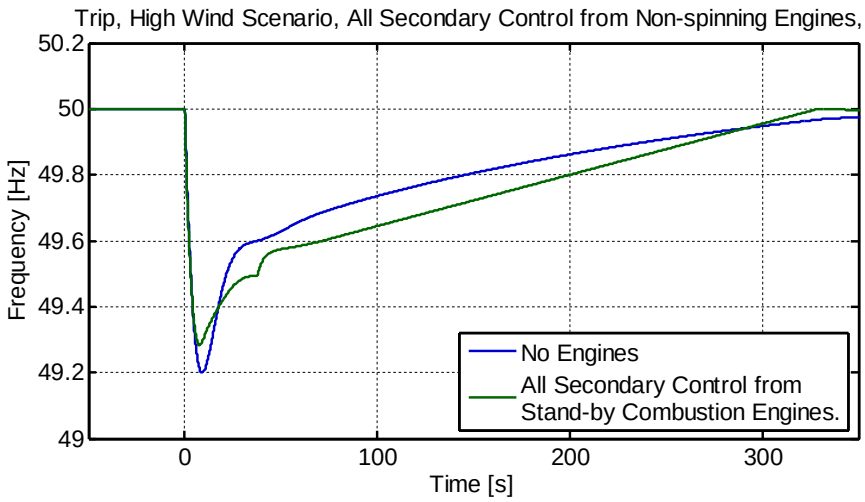

Figure 3: Secondary reserve frequency plot for a 2020 High wind scenario in a European country, where the blue line is business as usual and the green line when all secondary control response comes from stand-by generation [7].

Gas engine performance

The Wärtsilä 50SG is a four-stroke, spark-ignited gas engine that works according to the lean-burn process. The engine runs at 500 or 514 rpm for 50 or 60 Hz applications, and produces 18,810 and 19,260 kW of mechanical power respectively. This represents electrical power outputs of 18,320 kW and 18,760 kW respectively, at which the Wärtsilä 18V50SG engine is the world´s largest reciprocating gas engine and has the highest simple cycle efficiency of all prime movers.

In addition to high efficiency and power, a key benefit of the Wärtsilä 50SG, as with all Wärtsilä engines, is that each engine can be either individually started or all engines started simultaneously, ramped up and down, and stopped according to need, without any impact on the maintenance schedule.

This is useful for peak applications, or in markets where there is a significant amount of renewable generation being integrated in the grid – it can start to produce electricity within one and a half minute and reach full power in five minutes in the event of a sudden drop in e.g. wind capacity. The engines can also be stopped in one minute and reloaded in just six minutes, something that is not possible with other combustion technologies. In a multi-engine plant the engine generator sets can be started, stopped and controlled individually, part of the plant can be running at the required load point, while part of it is kept as reserve capacity. All engines in a multi engine power plant can also be started simultaneously, if so desired.

Compared to gas turbines, the performance of the engine is also less sensitive to ambient conditions. There is only a small decrease in efficiency or power output at higher ambient temperatures.

Cylinder configuration	18 cylinders in V
Engine speed	500 rpm for 50 Hz / 514 rpm for 60 Hz
Generating set output (electrical, pf = 0.8)	18 320 / 18 760 kW
Available energy for steam turbine driven generator	10 % of generating set output
Output in combined cycle mode (electrical)	20 150 / 20 640 kW
Length engine / generating set	12.5 / 18.8 m
Weight engine / generating set	285 / 365 tons
Emission levels, Nox from engine	TA-Luft, ½TA-Luft, IED 2010 lower levels with SCR

Figure 4. Wärtsilä 50SG technical data

The below graphs show the start, loading and stop performance. The time required for starting an engine from standstill depends on the cooling water temperature, the graphs below are for an engine preheated to 70°C cooling water temperature and the engine starts to produce electricity within 90 s and reach full power in 5 minutes.

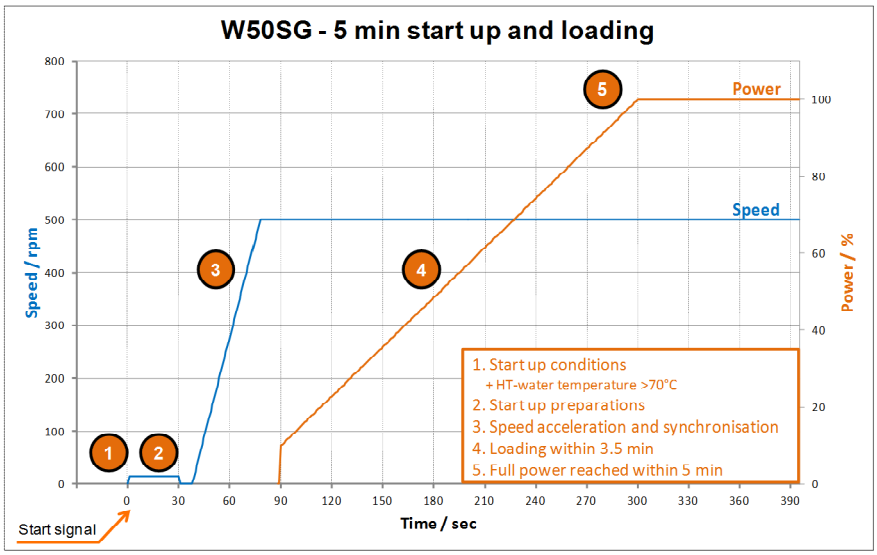

Figure 5:. Wärtsilä 50SG start up and loading of a preheated engine

The maximum ramp up rate for an engine which has achieved nominal operating conditions is 400 kW/s i.e. 130 % per minute, corresponding to 24 MW/minute/engine. The maximum ramp down rate is 900 kW/s i.e. 300 % per minute.

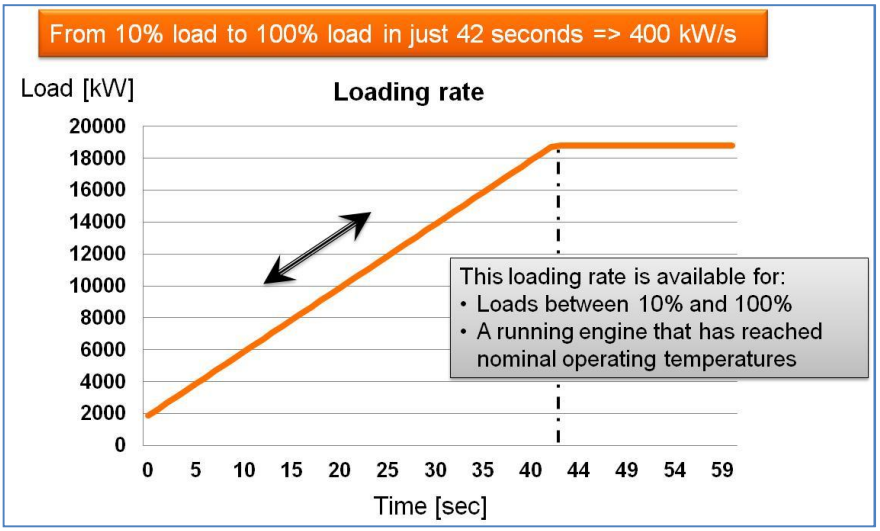

Figure 6: Loading rate of one Wärtsilä 18V50SG generating unit is 400 kW/s.

A typical unloading sequence when stopping the engine is shown in the graph below. The engine is ready to restart six minutes after the stop signal as no cooling down is required. There is no minimum time requirement to operate the engine once it has started meaning the engine can be started and stopped as many times per day as required.

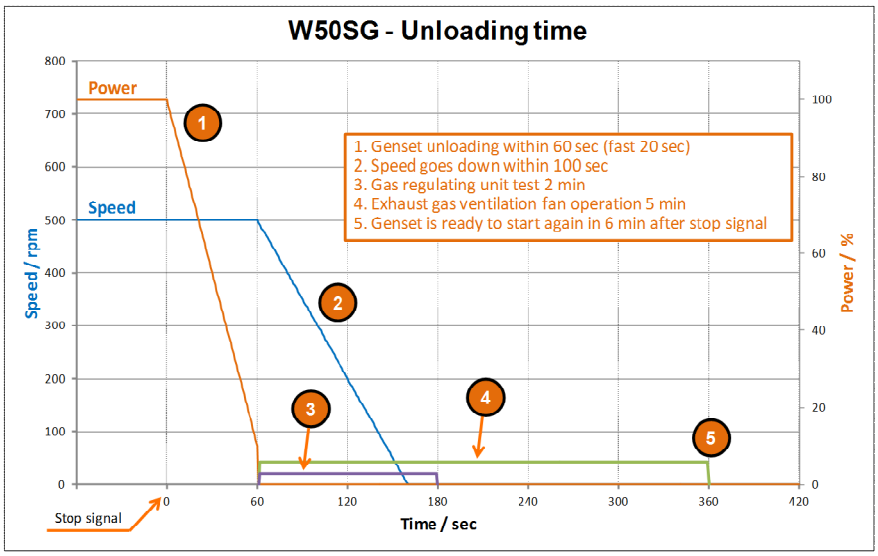

Figure 7: Unloading of one Wärtsilä 18V50SG generating unit.

A Wärtsilä 50SG power plant delivers power rapidly when needed. As an example a power increase from 77% power to 100% power can be achieved within four seconds.

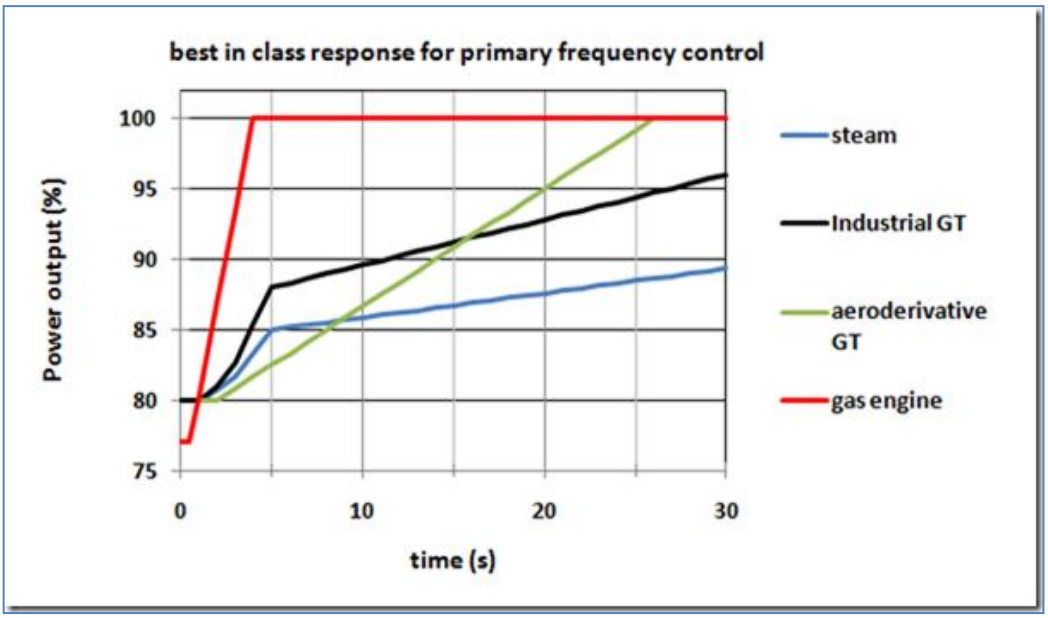

Figure 8. Wärtsilä 50SG power increase capability comparison from 77% to 100% power [8].

A 440 MW simple cycle power plant consists of 24 engines of the Wärtsilä 18V50SG. When closing the cycle by adding heat recovery boilers and a steam turbine the power plant output increases to 480 MW. The combined cycle plant can also be built as a Wärtsilä Dry Flexicycle. It integrates the engine cooling system to the steam turbine condenser, and all the cooling in the power plant is done by radiators. This way the water consumption of the power plant remains at as low level as with air cooled condensers (ACC), but by placing the radiators on the roof of the building, the required footprint is cut down by almost 15% compared to the use of ACC's and by almost 10% compared to cooling towers.

The loading rate of a power plant in operation with Wärtsilä 18V50SG generating units is remarkable. A 440 MW simple cycle power plant or a 480 MW combined cycle plant, both consisting of 24 units of the Wärtsilä 18V50SG engine, has a loading rate capability up & down of 576 MW/minute as all units can be loaded and unloaded simultaneously and the loading rate of one Wärtsilä 18V50SG engine is 24 MW/minute.

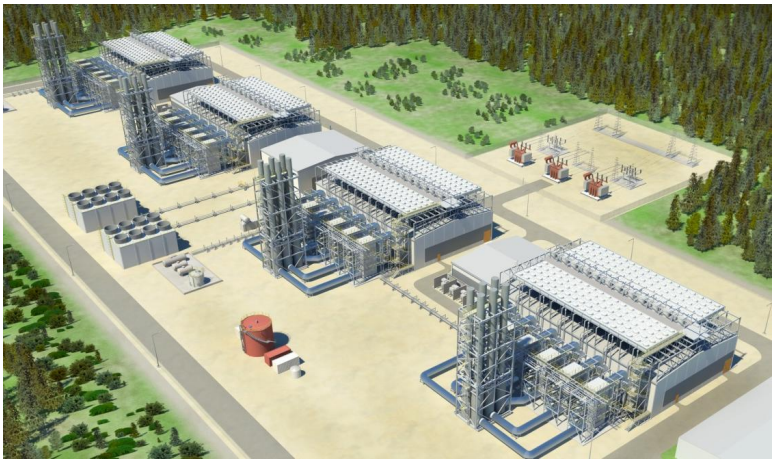

Figure 9: Example of a 480 MW combined cycle power plant with 24 generating units of Wärtsilä 18V50SG, one heat recovery boiler per engine and on steam turbine.

Power plants based on multiple engines have many advantages. For example, since operators need run only as many engines as are required, they offer flexible power output with high plant efficiency. Operators can also carry out maintenance without shutting down the entire plant. Wärtsilä gas power plants meet current and future requirements for overall cost of ownership with extremely high simple and high combined cycle efficiency. They are also designed for easy maintenance and many hours of maintenance-free operation. With the introduction of its most powerful gas engine Wärtsilä can offer a solution to complete the existing power systems by dispatchable dynamic capacity and capability to ensure a sustainable, reliable and affordable power system. The solution is the Wärtsilä 50SG.

Gas engine performance case studies

As discussed in the first chapter rapid ramping in order to meet the daily cycles are needed, in Turkey these ramping services are provided by Primary reserves, which can be seen as contingency reserves for loss of production. The Secondary reserves, primarily used for releasing Primary reserves are in Turkey also used for balancing.

Primary reserve, Primary Frequency Control

The minimum size of the primary reserve capacity is typically equal to the biggest generating unit in the power system, or sometimes the largest grid connection contingency. If the largest unit trips, the inertia in the system will slow down the frequency dip until the spinning reserve is automatically activated. The primary reserve requirement of the Turkish power system is actually smaller than the largest unit and has further decreased from 770 MW to 300 MW, owing to the European ENTSO-E interconnection from 2012 onwards.

In Turkey, the TSO TEIAS define that the power generation units should meet the primary reserve regulation setpoint within 30 seconds, typically tested with a 10% step test. An initial reaction of the generating unit should be seen within 2 seconds. Since the ENTSO-E interconnection, the typical plant primary reserve is 1%.

Wärtsilä commissioned in February 2011 a 52,4 MW gas power plant for Harput Tekstil to the city of Gediz, fairly close to Izmir in Turkey. The HG Enerji power plant consists of 6 generating sets based on the 20 cylinder reciprocating gas engines of the type W20V34SG. In Figure 2 results from the Primary Frequency Control testing with 10% reserve (0,873 MW of the generating set output of 8,73 MWe) can be seen. The initial reaction of 2 seconds is met as well as reaching the new setpoint well in advance of the required maximum 30 seconds. The generating set operation is very stable as can be seen, even though the sample rate for the measurements is 100 ms.

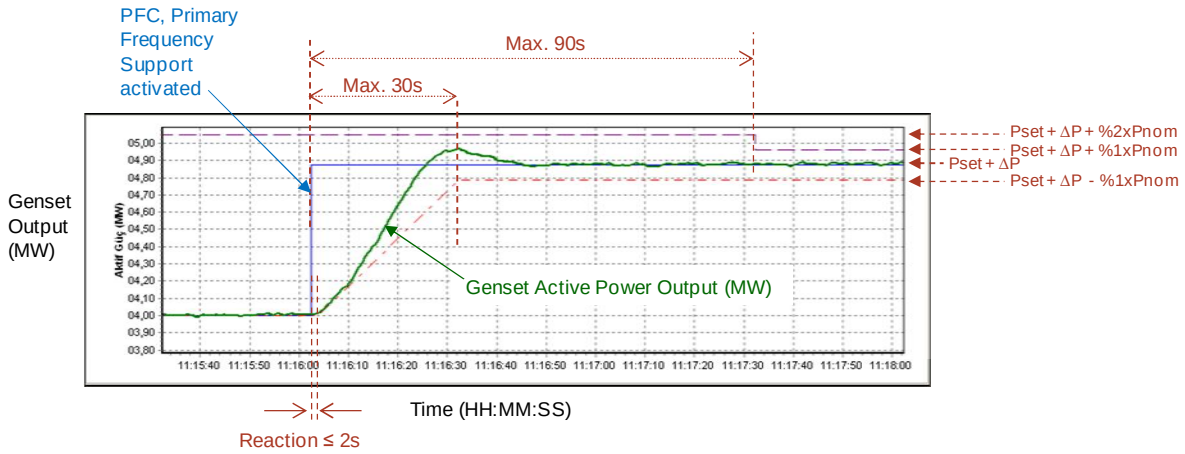

Figure 10: Primary Frequency Control 10% validation at HG Enerji Power Plant in Turkey

TEIAS requires testing of Primary Frequency Control support on both under- and over-frequency operation and the clear results of rapid action and very stable operation of the generating set can be seen in Figure 11.

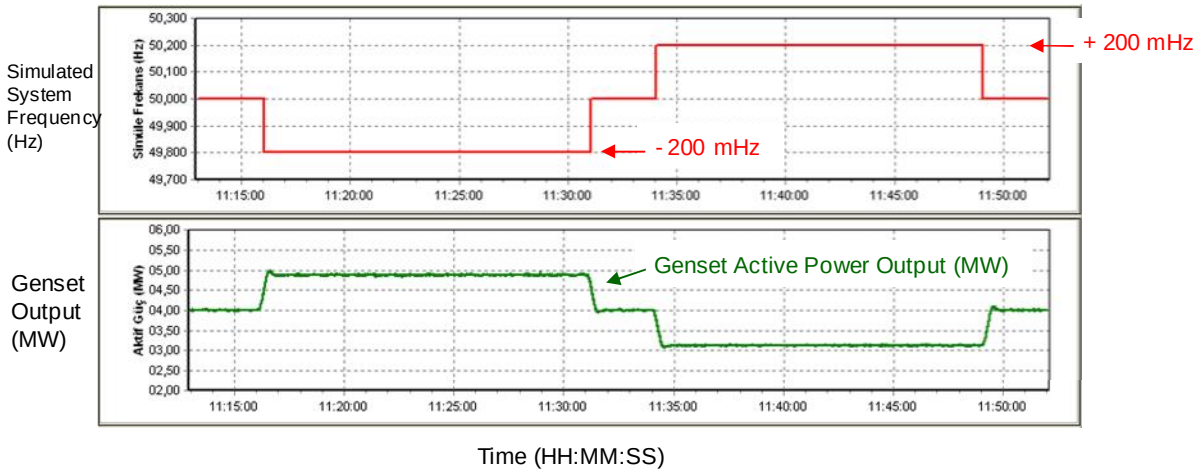

Figure 11: Generating Unit active power control response test to simulated system frequency steps

(-200 mHz - 0 - +200 mHz) at HG Enerji Power Plant in Turkey

20 % Primary Frequency Control Operation

As discussed earlier, the typical plant primary reserve in Turkey is 1%, but the performance is tested with a 10% step test. At a 7x18V50SG, 130 MW Power Plant in Turkey, successful operation of secondary frequency operation has been conducted since 2012, similar to the case presented in Figure 4. In addition to the secondary frequency control operation, the plant started to operate with the full 10% of primary frequency control in the autumn of 2013. In December 2013, the customer approached Wärtsilä to evaluate the possibilities to start to operate with 20% primary frequency control, requesting for a faster ramp rate allowing to reach 3,7 MW within 30 seconds on a unit level.

Updated ramp rates were provided to the customer and the official 20% primary frequency control tests were conducted in January 2014. From February onwards the customer has been able to operate with the 20% primary frequency control in addition to the secondary control which in a way can be seen more as a balancing operation. This case is a perfect example of full utilisation of one of the three corners of the Smart Power Generation, the Operational Flexibility, which have been further enhanced for this customer and their operation.

Secondary reserve

In Turkey the secondary reserve is currently provided in two different ways [3]. Part of this reserve capacity is provided with hydro power, which is a fast form of regulating power. However, the hydro power allocated for reserve capacity cannot be used for power generation, meaning that some additional thermal generation has to make up for the corresponding amount of hydro reserve. Secondly, gas-fired power plants are utilised for providing secondary reserves [9].

Typically, the amount of secondary reserve has to cover the full primary reserve and is typically ~ 2 % of total generation capacity connected to the grid. In Turkey, the secondary reserve requirement is currently considerably smaller at 770 MW [3].

Gas engines with very rapid response and fast control provides a perfect match for grid stability and secondary reserve operation. Figure 12 shows a real case from a 130 MW, 7x18V50SG Power Plant in Turkey. In this Power Plant SCADA screenshot (WOIS, Wärtsilä Operator's Interface System), the plant setpoint signal provided to the power plant over a RTU (Remote Terminal Unit) from the TEIAS Grid Control centre is showed with black trend pen colour. The Power Plant total active power output is showed with red trend pen colour. As can be seen the power plant is following the Grid setpoint immediately and exactly. This, even to the point that it is difficult to distinguish the difference between the control signal from the grid and the plant output following. The two trend pens are more or less on top of each other.

As highlighted in Figure 12, a reserve balancing need from 21 to 127 MW is provided within 37 minutes with some up/down balancing in between. This Power Plant can provide up/down regulation of a remarkable 48 MW / minute.

Currently, the vast majority of the 770 MW secondary reserve requirements are provided with Wärtsilä gas engines.

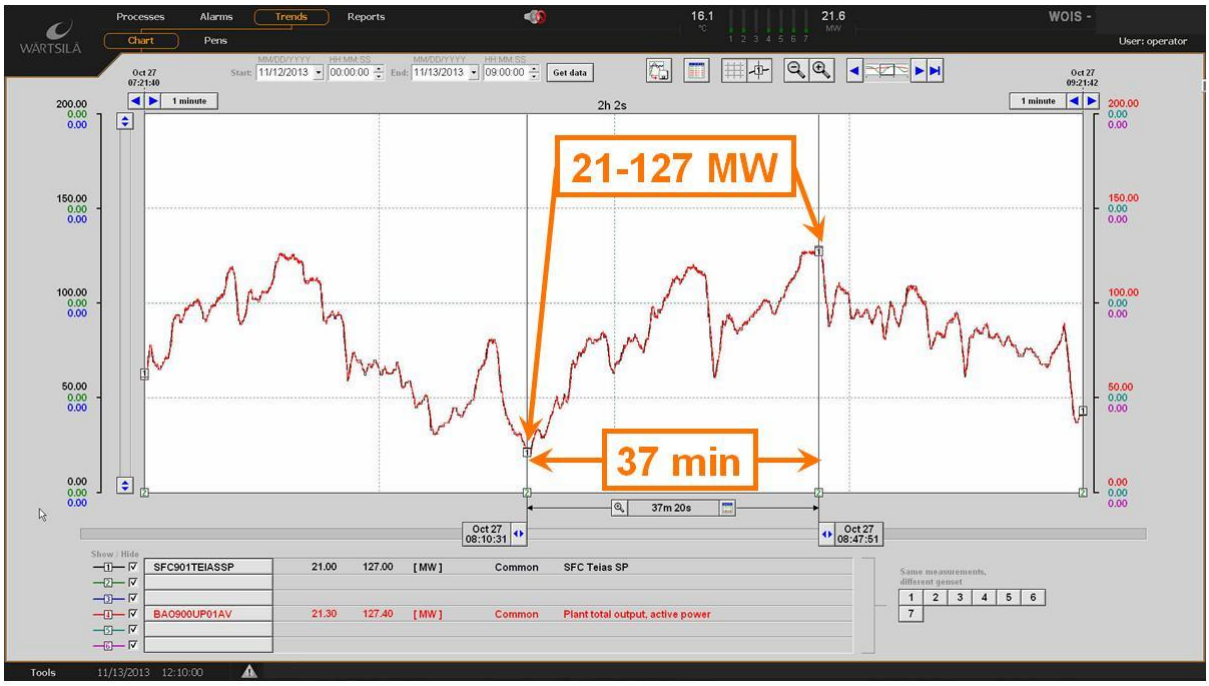

Figure 12: Secondary Reserve, Grid Balancing operation with a 130 MW, 7x18V50SG Power Plant in Turkey. The black pen is the Grid control setpoint, the red pen is the Power Plant output with immediate and exact following.

Conclusions

Smart power generation with flexible power plants based on multiple, fast-reacting, modular units in parallel have many advantages. Such power plants have proven to share low costs with high fuel efficiency and excellent reliability. They can run on the best buffer fuel available i.e. hydrocarbon gas under pressure in pipelines and storage systems. Easy and quick extension of the installed generating capacity make smart power generators suitable as a solution in uncertain demand situations. They can assist slower power plants in case fast ramping up of electricity production is needed.

Internal combustion engines (ICEs) are a promising technology for supporting wind and solar energy. Comparing different sources of flexibility for power systems, gas-fired ICE power plants are very mature technology and cost-competitive to OCGTs (Open Cycle Gas Turbines). Growth in ICE plants actually exceeds that of turbine-based technologies. The key asset of internal combustion engine-based generation is fast starting and ramping capability. Quick reaction time is key to follow the output of wind and solar as closely as possible. The part-loading efficiency penalty at 30 per cent load is zero for combustion engines and about 32 per cent for turbine-based plants. Furthermore, one of the advantages is fuel compatibility. Combustion engines provide additional fuel security, because they can operate on any liquid or gaseous fuel, including biofuels [10].

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