Electricity network balancing for renewable energy integration

The planned massive introduction of renewable energy sources creates challenges for the frequency and voltage stability of electrical networks. This is especially true for smaller systems, and a combustion engine synchronous generating set with the option of having a synchronous condenser operational mode makes sense.

The introduction of wind and solar power is already a challenge for the interconnected systems in Europe and elsewhere, but represents a substantial complication for smaller synchronous systems, such as islands. Both wind and solar based energy sources located in a limited area can show relatively large and fast variations in output. Therefore, a proper dimensioning of active and reactive power balancing is essential.

The evolving generation mix
Many smaller power systems, such as those on islands, have traditionally relied on a limited number of feasible generation technologies. These options include combustion engines, steam or gas turbines, small-scale hydro, or a direct connection to the mainland. However, this situation is rapidly changing. The rapid development of renewable generation based mainly on
wind and solar radiation provides new opportunities, while even more futuristic power generation based on tidal flows or wave energy is gradually emerging. For many larger systems, a critical share of generation from variable sources has not been reached yet. But for smaller systems, a critical situation can occur rapidly due to their limited size.

**Integration of renewable generation**

Traditionally, system stability via the controlling of active and reactive power has relied on the characteristics and availability of conventional power generators. In cases where a substantial fraction of the power generation is derived from renewable sources, there is often insufficient dispatchable and controllable traditional generating capacity. Renewable generation cannot fully be dispatched in the traditional sense, and in many cases doesn’t contribute to system reserves, system inertia and voltage control. Consequently, a major challenge in the integration of renewable energy sources is to reliably balance the generation and load.

In future power systems with a high degree of renewable power generation, conventional power plants will at least partly be displaced in order to make space for the output from indirectly coupled renewable generation. Thus, the relative contribution of conventional generation to the system will be reduced and less conventional units will be available for balancing and for providing system inertia. Consequently, fluctuations and forecast errors from variable generation may introduce imbalances between generation and load, leading to issues with operational control. For example, greater rates of frequency change and deeper frequency excursions may be observed during system contingencies. In addition, the generation may have less time to react, and higher output ramping capabilities could be needed in order to keep the power system stable.

It is estimated that if variable renewable generation in a power system increases above a critical system specific fraction, the following integration challenges may arise:

1. Frequency regulation primary and secondary reserves have to be additionally allocated into the system.
2. The rotating inertia of synchronous systems is severely reduced and not constant. Therefore, the dynamic stability of the grid frequency during disturbances may be compromised.
3. Voltage control and the short circuit current may be insufficient as a consequence of replacing synchronously coupled generation with indirectly coupled generation.

In contrast to the larger interconnected systems, smaller power systems in particular may not enjoy the same array of integration possibilities. The larger systems can at least partly rely on the connection to a large diverse generation mix, reserve sharing, multiple supply connections, and an existing fuel supply or storage infrastructure.

**System stability services from variable renewable generation**

In principle, renewable generation with its inherently variable output, can provide some similar system services to those of conventional generation, such as active and reactive power control within certain boundaries, depending on equipment ratings, technology and the presence of the primary energy source. This control will generally lead to a reduced output from those renewable resources, since a certain amount of power may have to be kept in reserve. This will most likely be counterproductive as renewable energy, which needs no fuel, tends to have very low marginal costs and their full utilisation is generally the preferable choice.

**Operational flexibility**

As discussed, an increased penetration of renewable generation will inherently lead to a more variable and intermittent dispatch of fuel-based generation, as shown in Figure 1. Fuel-based generation must be able to quickly reduce its output and shut down so as to make room for renewable generation. It must also be able to quickly start and load in order to make up for any shortfalls, either through forecast errors or sudden reductions in variable generation output. Therefore, the ability of a generator to accept frequent starts and stops will be essential. Combustion engine technology is very suitable for this. One can make an easy analogy to modern cars where, for reasons of emissions reduction and fuel efficiency, the engine stops every time the car halts. Modern combustion engine
Fig. 1 – An illustration of a future smaller power system having a significant share of renewable generation.

Fig. 2 – Starting and loading in less than 5 minutes a 46.7 MW gas combustion engine plant with 5 x Wärtsilä 20V34SG engine.

Fig. 3 – The expression 24/7 may no longer signify around the clock operation for conventional generation but rather 24 hours with seven starts and stops.
technology driving generators do the same, depending on the need for output. This ability saves fuel, reduces wear and lowers emissions, as running idle is not necessary.

A pre-heated modern combustion engine can start and be ready to synchronize in < 30 seconds, can go to full load in 2-5 minutes, unload to no load in 30-60 seconds, and thereafter can immediately take load again. If the generating set has to be shut down it can be restarted within 5 minutes.

These unique capabilities enable cascading operation of a multiple unit power plant, where the operational efficiency can be kept close to optimal under virtually all loading conditions. Cascading operation means that the generating units are started and stopped according to the need of the load or upon dispatch request.

Another operational flexibility aspect is the power-output ramping capability of generation. High ramping capability and accurate power output control capability are essential in order to compensate sudden fluctuations in variable generation output, short-term forecast errors and, in the case of high penetration of indirectly coupled generation, to compensate for the effects of decreased system inertia.

A decrease in the relative amount of natural inertia from conventional generation and load in the system, will require faster response from the generators and higher ramping capability in order to arrest the frequency dip or rise to safe values.\(^7\)

Combustion engines with electromagnetically controlled gas admission valves, have an inherently high ramping capability, as well as a fast reacting and accurate power control system. Figure 4 illustrates the response of combustion engine-driven generators to frequency deviations. The measurement is taken from a combustion engine-driven plant in Turkey, operating in primary frequency control and having 10% of its nominal power output as primary reserve. The orange line is system frequency and the black line is active power. The combustion engines react rapidly to deviations in system frequency, and assist in driving the grid frequency back to the desired range.

**The synchronous generator**

The reactive power supply of directly coupled synchronous generators is, in many ways, the foundation of any power system’s voltage control, both continuously and dynamically. A synchronous condenser is by definition a synchronous machine connected to the grid without active load. The technology has many features that are desirable for the integration of indirectly coupled variable renewable generation, especially for smaller systems.\(^8\)

An option for reactive power generation, where there is no need for active power from a generating set, is to de-couple the prime mover from the generator and let the generator run by itself connected to the grid. The generator can then provide valuable system services, such as inertia, short circuit support and voltage control, without generating active power. Active power can be provided by renewable energy sources in this case. The disconnected engine at standstill serves only as a back-up power provider. No fuel is wasted and no unnecessary CO\(_2\) is emitted in this case. In case back-up power is needed, the engine can be rapidly started and connected with the spinning generator. Although such an integrated solution is not in itself a new concept, the motivation for using it may now be different because of the rapid introduction of renewable generation.

The operational area and application restrictions may be slightly different for different generator designs. Figure 5 shows the general principles of the synchronous condenser mode of a generator. The orange line illustrates the synchronous condenser mode reactive capability.

The adjustment of voltage via reactive power is done in the same way as for any synchronous generator. Increasing the excitation, i.e. creating a stronger magnetic field, results in providing reactive power to the system, while decreasing the excitation means withdrawing reactive power.

A synchronous condenser generating unit with a combustion engine as...
the prime mover consists of the same main components as an ordinary generating set. In order to enable the synchronous condenser mode and the switchover between operational modes, only a special controllable clutch between the generator and the engine is needed, along with the corresponding control units. A modern combustion engine generating set is shown in Figure 6.

**Clutch**

The clutch is engaged during engine start-up, and can be disengaged when the generating set has been accelerated up to nominal speed and the generator has been synchronized with the grid. Re-engaging, in case active power is needed, is done only when the rotating speeds of the engine and generator are again the same.

As soon as the generator is disengaged from the engine, the engine can be shut down and the generators can continue operating as a condenser. Again, whenever active power is required, the engine is started and accelerated up to the speed representing system frequency, which allows the clutch to be engaged. After this the generating set is ready for power production.

**Benefits of synchronous condenser operation**

An integrated “hybrid” synchronous condenser generating installation has
the following interesting features with respect to a further integration of variable indirectly coupled renewable generation:

1. The voltage can be adjusted at the connection point with the grid, even while the prime mover is shutdown or in stand-by mode.

2. The energy stored in the spinning rotor of the synchronous machine can help in stabilizing a power system during disturbances, load fluctuations, or as a result of the variability of renewable generation output, even when no active power is needed.

3. A synchronous machine can, irrespective of whether it is running in generator or condenser mode, produce a high amount of reactive power for a short period of time in response to a system fault. This can be valuable for assisting system stability by supporting the system voltage during and after a disturbance.

4. A synchronous machine is an internal voltage source, this means that unlike with a capacitor/reactor bank or SVC, the value of the reactive power from a synchronous condenser can be continuously adjusted, even with reduced system voltage.

**CONCLUSION**

For integrating variable, indirectly connected renewable generation, the flexibility of conventional generation is clearly a key aspect. Smart Power Generation using combustion engines has many of the needed features and capabilities. As discussed above, these capabilities can be even further enhanced with an integrated synchronous condenser operation mode.

**REFERENCES:**


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**Fig. 7 – Features of a flexible generation unit.**

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<td><strong>1) FAST START</strong></td>
<td>• Ready to synchronize in 30 s</td>
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<td><strong>2) HIGH LOAD</strong></td>
<td>• Very high simple cycle efficiency</td>
<td>• Multi-unit -&gt; high firm capacity</td>
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<tr>
<td><strong>3) VARIABLE LOAD</strong></td>
<td>• Part load efficiency unaffected by unit cascading</td>
<td>• Very high ramping capacity</td>
<td>• 10 % low load capacity</td>
<td>• No EOH for shutdown or restart</td>
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<td><strong>4) FAST UNLOADING/STOP</strong></td>
<td>• Sequential shutdown/ mode change of units</td>
<td>• &lt; 1 min to no load</td>
<td>• &lt; 5 min restart capacity</td>
<td>• No EOH for cycling or restart</td>
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<tr>
<td><strong>5) CONDENSER LOAD</strong></td>
<td>• Voltage control or VAR support even at unit shutdown</td>
<td>• System inertia support</td>
<td>• System short circuit current support</td>
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