Virtual Synchronous Generators

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***Abstract* — In electricity grids the frequency of the voltage is stabilized by a combination of the rotational inertia (rotating mass) of synchronous power generators in the grid and a control algorithm acting on the rotational speed of a number of major synchronous power generators. When in future small non-synchronous generation units replace a significant part of the synchronous power generation capacity, the total rotational inertia of the synchronous generators is decreased significantly. This causes large frequency variations that can end up in an unstable grid. A way to stabilize the grid frequency is to add virtual rotational inertia to the distributed generators. A virtual inertia can be attained for any generator by adding a short-term energy storage to it, combined with a suitable control mechanism for its power electronics converter. In this way a generator can behave like a "Virtual Synchronous Generator" (VSG) during short time intervals, and contribute to stabilization of the grid frequency.**

***Index Terms*-- Distributed generation, distributed energy resources, microgrids, synchronous generators.**

I. Introduction

THE A growing share of Renewable Energy Resources (RES) and Distributed Energy Resources (DER) in the electricity generation mix of the EU forces these new sources to adapt itself to a whole new situation in the electricity network [1]. The character of all small RES and DER up to now was just a following nature. In future electricity networks this will not satisfy anymore, new sets of demands are necessary to secure safety and stability.

When many small non-synchronous generation units replace a significant part of the synchronous power generation capacity, the total rotational inertia of the synchronous generators is decreased significantly. As a consequence the variation in the rotational speed of the synchronous generators due to changes in their net load will become much higher than at present. This causes large frequency variations that can end up in an unstable and unsecure grid. The key to preventing this situation to happen may be to let the local generators mimic, through its power electronic grid-coupling interface, the behavior of self-stabilizing synchronous generators. This paper introduces the VSYNC project, started in 2007 under the 6[th] EU-Research Framework program, in which the concept of a Virtual Synchronous Generator (VSG) technology is demonstrated [2].

This work was supported by the 6th EU-Research Framework program

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II. Electricity Grid Transition

In recent years Renewable Energy technologies such as wind power and electricity from solar PV have grown in the EU Member States at high rates (> 25%) although from a very small base. In several regions, such as Denmark, northern Germany and northern Spain, these technologies start to constitute a noticeable and even substantial part of electricity generation in the region. Apart from these intermittent renewable energy sources also demand-pattern driven electricity generation, such as CHP, constitute a growing part of the electricity generation mix.

This pattern is expected to continue and even to accelerate for several reasons. The EU has set a 22% target, including hydro, for the share of renewable energy sources in the electricity generation mix of 2010. Furthermore it has set a target of an 18% share of CHP in the electricity generation mix. This means that 30%-40% of electricity generation will come from RES or DER in 2010. EU Member States have translated these targets in policies supporting RES and DER. The trend towards more RES and DER is supported in some ways by the liberalization of electricity markets. As costs for DER-technologies come down and new technologies, like micro-CHP based on Stirling technology or fuel cells, are being developed, the economic advantages of DER-generation (quickly installable, less dependent or even independent on fuel prices) become more and more apparent. These micro-generation technologies provide also opportunities for new players in the energy markets.

Until recently the focus on grid-connected RES and DER generation equipment has been on connecting, rather than integrating ('fit and forget'). Main concerns were with voltage and current trip limits and synchronization to the grids frequency. As Table 1 [3] shows this approach works as DER penetration stays at a relative low level (<2% penetration). However, with growing levels of DER penetration the impact of it increases. As Europe is going to those higher DER levels pretty soon, power quality issues with impact on the local level will have to be resolved. To date DG interconnection systems to the Local Electric Power System are mainly concerned with Generation and Energy Conversion. At higher levels of DER penetration other aspects like System Control, Electrical Protection, Steady-State control and Ancillary Equipment services have to be more and more incorporated in the ICS [4].

TABLE 1: CHANGING GRID NATURE WITH INCREASING DER PENETRATION

% of Generation	$\leq$ 2%	$\leq$ 10%	$\leq$ 25%	100%
Grid Penetration Scenarios	I. Low -numbers and level of DER with relatively stiff grid connection	II. Moderate -level of DER with relatively soft grid connection	III. High -level of DER with capacity of grid less than the load demand	IV. DER operates part time as an island or micro -grid
DER Impact and its Role in the Grid	Very low, not significant to grid operation	Non critical, can affect distribution voltage near DG	Critical to power delivery and meeting demand	Primary power source for stand alone operation
Interconnection and Integration Objectives	Non interference, good citizen and compatible	Manage any local distribution impacts	Engage DER for system operations and control	Rely on DER for stability and regulation
Rules/Standard Operating Procedures	IEEE 1547 -2003 current practice radial feeders	Modified 1547, add network and penetration limits	New rules include operation and grid support requirement	Standalone rules that are system dependent
Main Concerns with -respect -to system dynamic grid impacts	- Voltage and current trip limits, - Response to faults - Synchronization	- Interfere with regulation, - Recovery times, - Islanding - Coordination.	- Availability - Regulation provided - Ramping response - Interactions of machine controls	- Availability - Load following - Voltage control - Normal and reserve capacity

......Transitions On - and Off -Grid......

III. VIRTUAL SYNCHRONOUS GENERATOR CONCEPT

A. VSG characteristics

The character of all small RES and DER up to now is of a “following nature”. This means that all the available power of the source is delivered to the electricity grid, irrespective of the voltage level or power flow in the grid. Mostly all new DER makes use of electronic power converter for the grid-coupling. The adaptation of an electronic converter to mimic the character of a Virtual Synchronous Generator for short periods, including inertia, may be a major improvement for the dynamic properties. With these types of VSG-converters, limitations on penetration levels can be removed. Because the system needs a small electrical storage, the first and most important step to intentionally islanding and true microgrid operation is also set.

The following characteristics can be implemented:

- Prevent electricity grid instability and blackouts due to large frequency variations caused by decentralized generation, and the subsequent social chaos.
- Retain safety in fault situations of an electricity grid with any given share of decentralized generation.
- Laydown a basis for intentionally islanding of low voltage area's with decentralized generation, in order to to keep functioning the social structures in these areas.

This gives low voltage areas with large amounts of DER the ability to operate inherently safe and maintain power quality. A beneficial point is that this new VSG technology even can let DER work autonomously for short during network failures.

B. VSG application

In electricity grids the frequency of the generated voltage is stabilized by a combination of the rotational inertia (rotating mass) of synchronous power generators in the grid and a control algorithm acting on the rotational speed of a number of major synchronous power generators. This works because the rotating masses of all synchronous generators are coupled electromechanically through their grid connections and as a consequence run at exactly the same electrical frequency. When in future decentralized non-synchronous generation units replace a significant part of the synchronous power generation capacity, the total rotational inertia of the synchronous generators is decreased significantly. As a consequence the variation in the rotational speed of the synchronous generators due to changes in their net load will become much higher than at present. This causes large electrical frequency variations that can end up in an unstable grid.

C. Virtual inertia

A way to stabilize the frequency of the synchronous generators is add virtual inertia to the distributed electricity generators. This principle has been investigated theoretically by a number of authors [6-8] for wind generation case where only the stored energy in the distributed resource is used, this is the rotational inertia of the wind generator. Here the existing power electronics converter is combined with a suitable control mechanism. For distributed electricity generators without some means of energy storage, e.g. photovoltaic systems and micro CHP, there is no virtual inertia [5]. However a virtual inertia can be attained for any distributed electricity generator by adding a short-term energy storage, combined with a suitable control mechanism for the power electronics converter, to the distributed generator, as depicted in Fig. 1. In this way distributed electricity generators can behave like "Virtual Synchronous Generators" during short time intervals, and contribute to stabilization of the grid frequency during large fluctuations in the net loads of the synchronous generators in the grid.

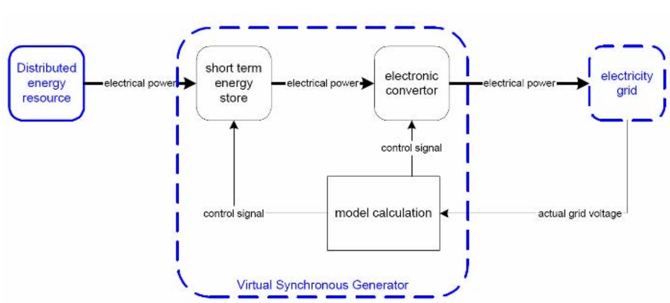

Fig. 1. VSG diagram

IV. VSYNC PROJECT

The idea of a virtual synchronous generator is about to be realized in a 6th EU-Research Framework as mixed research and demo project. The coordination is in the hands of ECN (NL), with other partners being T.U.Eindhoven (NL), T.U.Delft (NL), K.U.Leuven (B), U.P.Bucharest (Rom.), Labein (ES), 3E (B), Ufe (D), Electrica (Rom.) and Continuon (NL). The project started end of 2007 and will run for three years. Besides the required research and system development, two demos in existing grids are foreseen.

V. REFERENCES

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