



Virtual Synchronous Machines: The Future of Grid Integration

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This paper is aimed to present an insight into the challenges that the power transmission infrastructure faces in terms of stability and operability due to integration of renewable energy on a large scale. Furthermore, the available mitigation strategies are discussed and various stability measures are discussed in detail with reference to the published papers to list out a comprehensive analysis.

Keywords: Photovoltaic; renewable; grid-stability; synchronverters; virtual synchronous machines.

1. INTRODUCTION

Power Systems globally are undergoing a major shift from the predominant centralized generation using larger capacity thermal, nuclear or hydro power plants to a more distributed generation. New Renewable Energy sources including Photovoltaic Solar

Energy and Wind Power sources are being connected to the Grid. At the demand side, loads such as Electric Vehicles are being added to the system. The increased share of renewable energy is to reduce dependence on depleting conventional sources of power and increased use of non-polluting renewable resources.

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Countries like India have set ambitious goals of having 175 GW of clean energy capacity [1], including 100 GW solar and 60 GW of wind energy by 2022. China, also the largest energy consumer globally, is aiming to meet its 20% energy needs through renewable sources by 2030 [2]. European Union has aimed to meet 32% of its energy needs by 2030 [3] through renewable energy sources. As the share of renewable energy keeps on increasing globally, to study the impact of integrating such large capacity of distributed renewable energy sources on the grid becomes highly relevant.

The renewable sources of energy are mostly variable frequency AC, high frequency AC, or DC sources and hence there is a need of DC-AC converters (inverters) for these sources to be connected to the grid. The current philosophy being followed, in the control and integration of renewable energy generation, is to extract maximum power from the source (solar/wind) and provide to the grid [4,5,6]. The hidden savior in this approach are the synchronous generators that pitch in during the time of fluctuations and provide the grid with much needed stability, and power balance, which cannot be provided by renewable energy sources. Conventional synchronous generators, being coupled to steam or gas turbine, inherently have large mechanical inertia which ensure stability to the grid at the times of fluctuations. With the increased share of distributed generation and renewable energy, which lack rotational inertia (rotor) damping to power system, grids are more prone to system faults. In Conventional power plants, where synchronous Generators are utilized to generate Energy, rotating inertia offers stability to the system due to sudden changes in load. This kind of flexibility is inherently absent in the newer methods of generation, at least as per current philosophy wherein the sources are connected to provide 100% of the generated energy to the grid.

2. MATERIALS AND METHODS

The primary two methods that can offer to stabilize the grid in cases of large distributed generation share are:

1. To have quick start conventional generators available to pitch (running or standby state) in at the time of system instability.
2. To have the distributed generation systems mimic the responses provided by the conventional system, through various modifications to the inverters.

The first method is not further discussed in this paper due to the fact that in this approach the non-renewable infrastructure still needs to be in place and be in standby state thereby partially defeating the purpose of moving towards renewable, distributed sources of energy.

The second method is to mimic the stability characteristics of a synchronous generator thereby offering the system with the same level of stability and discussed further.

Inverters and controllers combined are herein referred to as synchronverter as in various papers [7,8] that were evaluated to prepare this review. Synchronverter may be defined as a virtual synchronous machine that generated response similar to a synchronous generator with a capacitor bank connected in parallel arrangement to the stator of the generator. The advantage that this type of arrangement enjoys is that it gives full autonomy to vary various system parameters at any stage of generation even while connected to the grid, this kind of flexibility is limited in case of conventional generators, this along with the fact that the conventional control algorithms and equipment can be used, as is, makes these synchronverters, the path forward.

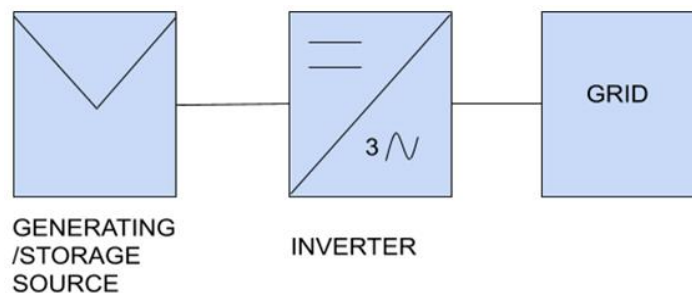


Fig. 1. Simplified VISMA model

The first mention of virtual synchronous machines was during the 9th International Conference on Electrical Power Quality and Utilization, 2007 at Barcelona [9]. Here the authors presented the VISMA or Virtual synchronous machine as a concept elaborating on how the same can be used to stabilize the grid in case of renewable integration along with decentralized generation. Broad components of VISMA are the energy storage/generating unit, generating direct current. This is connected to the direct voltage side of the inverter, the output of inverter is alternating current, thus the inverter is analogous to the synchronous generator in a conventional setup and the generating / storage unit is analogous to the driver i.e. the turbine in a conventional setup. It clear by now that the mechanical component of a VISMA only exists as a logical concept, however from grid point of view VISMA is as good as a synchronous generator the voltage supply circuit of VISMA inverter physically executes what the process computers of the machine mathematically compute. If the grid requires active power, a virtual torque on the virtual shaft has to be provided. The energy required for this is taken from the direct voltage system of the VISMA inverter, respectively supplied to the direct voltage system by the generation unit. If reactive power has to be supplied to the grid, then the process computer influences the value of the virtual excitation voltage. The capacitor of the VISMA in the intermediate circuit supplies the reactive current.

Virtual parameters can be modified and controlled remotely and, in a manner, similar to the conventional setup without requiring any additional communication infrastructure and thus no changes to the current setup. The VISMA model is a complete two-shaft model of electrically excited generator arrangement with all the static and dynamic properties of a

conventional arrangement. The basic functioning of VISMA is constituted of three different steps namely measuring the voltage at the point of connection of arrangement to the grid, measuring and feeding the current produced to the grid, dynamically in real time.

In the paper [9] an experimental set-up has been used to study the VISMA. The following are investigated through the same model, the conclusions are also listed:

1. Fundamental frequency characteristics and contribution of the damper with respect to flow to and from the grid, locally produced or caused by the grid,
2. Response of reactive power during a drop-in grid voltage and the transfer of power from the damper to the intermediate circuit of the VISMA.

Various Scenarios are run in the above-mentioned paper [9] to substantially prove that the concept of VISMA is a technically feasible concept to integrate renewable and decentralized sources to the grid.

3. RESULTS AND DISCUSSION

The more recent concept is that of synchronverters as was discussed during the beginning, VISMA differs from synchronverters as synchronverter do not depend on the tracking of reference currents or voltages, however the concept of using energy storage devices to generate and provide virtual inertia is the same as demonstrated from [10,11]. Moreover, VISMA's act like current sources whereas synchronverters act as voltage sources, power system infrastructure is inherently built to accommodate voltage sources rather than current sources and thus Synchronverters are preferred method of integration.

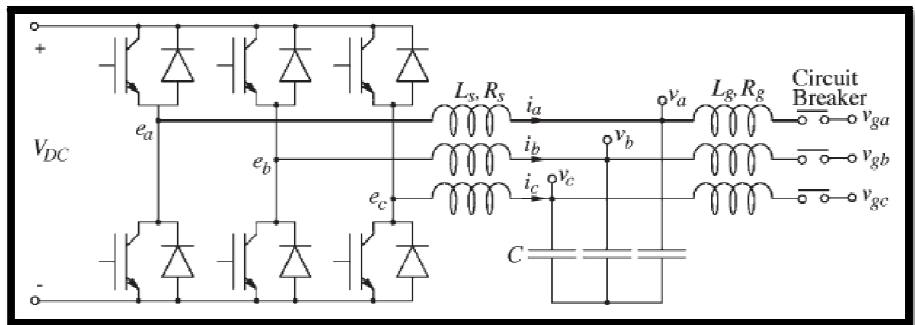


Fig. 2. Power part of a synchronverter — A three phase inverter, including LC filters

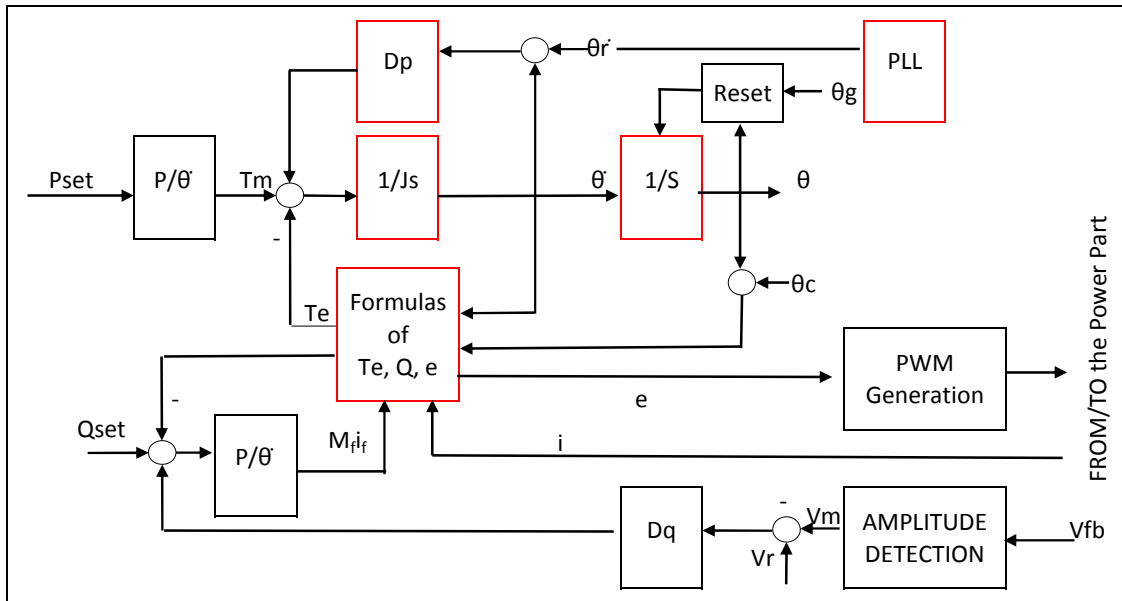


Fig. 3. Electronic part of a synchronverter model

The implementation of synchronverter (inverter) as shown in [7,12] is further elaborated and explained the synchronverter from the perspective of power and electronics. The power part of a synchronverter is studied through the model as shown in Fig. 2.

A simple inverter used to convert dc power into three-phase AC is shown in Fig. 2 which shows the power part, which is essentially same as a conventional power electronic converter. It includes three legs operated using Pulse Width Modulation and LC filters to reduce the voltage ripple caused by the switching. The part to the left of the capacitors along with the capacitors is the power part of the synchronverter, whereas the grid impedance and resistance is the part to the right of the capacitors.

Electronic part of synchronverter consists of the sensing, protection, and control circuits and hence the synchronverter is known as digital signal processor shown as a simplified model in Fig. 3.

The back emf e , that is calculated according to the mathematical model is fed to the PWM generation block, the generated pulses are then used to operate the semiconductors as shown in Fig. 2. The current generated from inductors are looked upon as the stator current I and fed to the mathematical model. The power part and

electronic part thus together constitute a Virtual synchronous machine.

It is worth noting here that the mechanical friction coefficient D_p plays the role of frequency droop coefficient, this is the equivalent of controlling the frequency by controlling the real power in a conventional power system. The D_p loop can regulate frequency/ θ of the converter arrangement and generate the phase angle θ for the back emf e .

In conventional systems the reactive power is controlled to control the voltage, here the reactive power is regulated to generate the field excitation current M_{fif} and a voltage droop control is introduced to control the voltage droop coefficient D_q . Hence a single controller can be used to control voltage, real power, reactive power and frequency. A dedicated PLL or synchronizing unit as shown in Fig. 3 is used to provide the grid information to the synchronverter. As mentioned earlier, the synchronverter finds usage in integration of wind power, solar power and other distributed generation sources. There are various iterations and modifications that can also be made like removal of PLL and synchronizing units. The basic arrangement of a synchronverter remains the same. Use of electronic logic gives us the flexibility to modify the parameters and generate flexibility resembling that of the conventional generators.

4. CONCLUSIONS

Various research papers are studied and reviewed to conclusively list as to how various methods can be used to overcome the major challenge of providing electrical grid with the stability that it enjoys currently due to the presence of large synchronous generators, in case of large renewable integration.

Highlights of various researches conclusively proving that distributed generation sources especially the renewable energy sources can not only be integrated to the grid seamlessly but also can be looked upon as the primary source of energy without any change to the physical infrastructure of the grid and without impacting the stability at the same time are suitably indicated.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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