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Effect of Virtual Synchronous Machine on DFIG based Wind turbine

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Abstract—*Distributed generators (DGs) like photovoltaic, wind turbine, and gas cogeneration systems have received more attention in recent years than ever before. Power inverters are frequently used to connect DGs to the grid. To keep up with the grid, inverters in DGs are typically controlled by a phase-locked loop (PLL). If the capacity of inverter based DGs continues to grow, the power system will be significantly impacted from a stability standpoint. A possible solution is the idea of the virtual synchronous machine (VSM), which controls inverters to behave like a real synchronous generator. During a short period of operation, the VSM can produce virtual inertia from energy storage, and a VSM can produce active power in the same manner as a synchronous generator. As synchronous generators (SGs), DFIG-based wind turbines (WTs) are required to replicate inertia response because of their widespread use in power systems. Therefore, investigating the impact of the Virtual Synchronous Machine on the DFIG-based wind turbine is important. A detailed two-machine system has been used to analyze the effect when VSM replace synchronous generator. This paper analyzes system behavior in an all-VSM grid. The role of the power system stabilizers in the all-VSM grid has been comprehensively evaluated. Analysis is further carried by integrating Doubly fed induction generator (DFIG) based wind turbines (WTs) in VSM to occupy a high penetration in power system. The analysis in this paper have been performed in MATLAB/SIMULINK environment.*

Keywords—*Virtual Synchronous Machine, Power System Stabilizer, Phase-Locked Loop, Doubly-fed Induction Generator, Wind Turbine, Distributed Generators, Synchronous Generators.*

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I. INTRODUCTION

The percentage of distributed generators (DGs) connected to the grid by inverters is in growing. The inverters used in DGs are generally controlled by the phase-locked Loop (PLL) to synchronize with the grid frequency and phase. Power systems may become unstable if the percentage of inverter type DGs becomes larger and larger because the inverter frequency only follows the frequency determined by other synchronous generators, which is detected by PLL. If the PLL loose the locked situation by the power system disturbance, the inverter has possibility to stop the operation due to over current of ac side or over voltage of dc side, and power shortage may be occurred. However, the inverters can be controlled to behave like a synchronous generator using concept of “Virtual Synchronous Machine (VSM)”. A simple VSM model is shown in Fig.1.

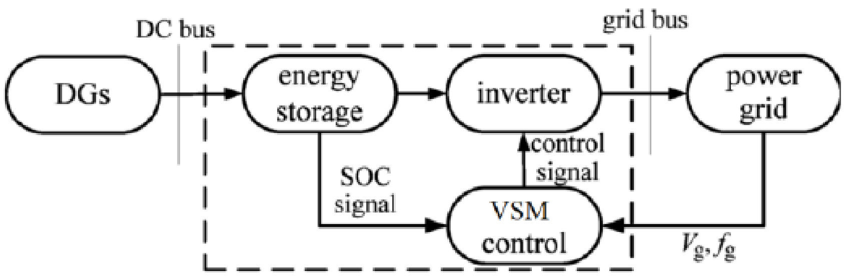

Fig. 1 VSM diagram

To inject or absorb power, the VSM control unit sends the appropriate control signal to the inverter by utilizing the grid voltage/frequency and storage device state of charge (SOC). The VSM controller directs the inverter to behave like a synchronous generator. Using VSMs can improve grid stability because they can use energy storage to provide virtual inertia that is comparable to the rotor's inertia of synchronous generators. Additionally, the inverter can continue operating in synchronization with other generations in the power system.
However, the inertia of synchronous generator may cause the oscillation of active and reactive power of the DG. The real synchronous generator mainly uses the power system stabilizer (PSS) to damp this oscillation. On the other hand, the power system is a variable and ambiguous nonlinear system, making it hard for the PSS to set the right control parameters. The VSM can handle the challenge of selecting the right control parameters. Virtual inertia can be generated using an algorithm and the swing equation because the VSM does not have a real rotor system. The equation, on the other hand, is nonlinear, making it challenging to select appropriate parameters. I n this paper effect of VSM on DFIG based WT when Synchronous generator is replaced by VSM is analyzed for following models.

- Integrating DG inside VSM
- Integrating DFIG based WT with VSM

II. METHODOLOGY

To analyze the effect of Virtual Synchronous machine on DFIG based Wind turbine considered following two models.

- Integrating DG inside VSM
- Integrating DFIG based WT with VSM

The analysis followed in this project are as follows: -
1. Comprehensive analysis on the impact of replacing SG with VSM and VSM_{PSS}, using a detailed two-machine system.
2. Comprehensive analysis of the LFO modes which exists in an all-VSM power system.
3. Evaluation of the role of PSS in an all-VSM power system.

It is noted that in this project, VSM topology uses a direct voltage-controlled approach, “dq-axis current injection” converter, which uses a “Swing-equation based inertial response”.

- *VSM*

Power generation is dominated by synchronous generators. Virtual synchronous machine combines a three-phase inverter with synchronous generator behavior through a control system, ensuring stable grid operation, damping, power compensation and voltage control.

- *The structure of proposed VSM*

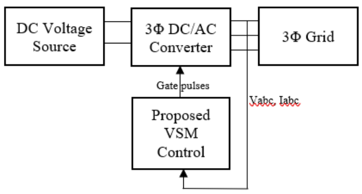

Fig 2: structure of proposed VSM control-based power system model

To enable RESs to behave like SGs, VSMs are proposed. Wind turbine applications are the basis for the VSM method used in this project. This VSM paradigm has the unique benefit of not requiring switching operations in all modes. In other words, grid connected operation, low-voltage ride-through and islanding. We can substitute any renewable energy source in place of the DC voltage source. As a result, the synchronous generator is replaced with a virtual synchronous machine system in two-machine and four-machine systems.

- *The proposed VSM control structure*

The usual dq frame current controllers are used in this. The three main components of the proposed control structure are outlined below:

- *1) Virtual governor*

The virtual governor’s primary functions are to maintain a nominal frequency f. Regulating f in proportion to current demand i_d (associated with the active power P) accomplishes this. The following equation provides a description of the governor dynamics:

$$i_d^* = k_t(f^* - f)\left(\frac{1}{1+\tau_s s}\right) + i_{d-set}$$

Where f* is the reference frequency, i_d* is the equivalent current set point, and i_{dset} is the reference active current. The PLL, which supplies f to the virtual governor, operates in both islanded and grid-connected modes, ensuring that f is well controlled in all modes of operation. A Maximum power point tracking (MPPT) algorithm can be used to calculate P_{set}, which determines $i_{d\text{-}set}$. The Virtual governor's droop gains and damping filter time constant, respectively, are kf and τf. The voltage VC is aligned in the dq frame by the PLL, so $V_{cq}= 0$ ($V_{cd} = |V_c|$).

- *2) Virtual AVR*

The virtual AVR's function is to adjust V_{cd} in accordance with the reactive power Q and the current demand dq. The virtual AVR arrangement is where V_d^*, i_q^* , Kv and τv address the reference voltage, reference reactive current, droop gains and damping filter time constant respectively. The virtual AVR effectively controls V_{cd} for every working mode (matrix associated and islanded) and guarantees quick issue current infusion during shortcoming.

$$i_q^* = -K_v(V_{cd}^* - V_{cd})(\frac{1}{1+\tau_v s})$$

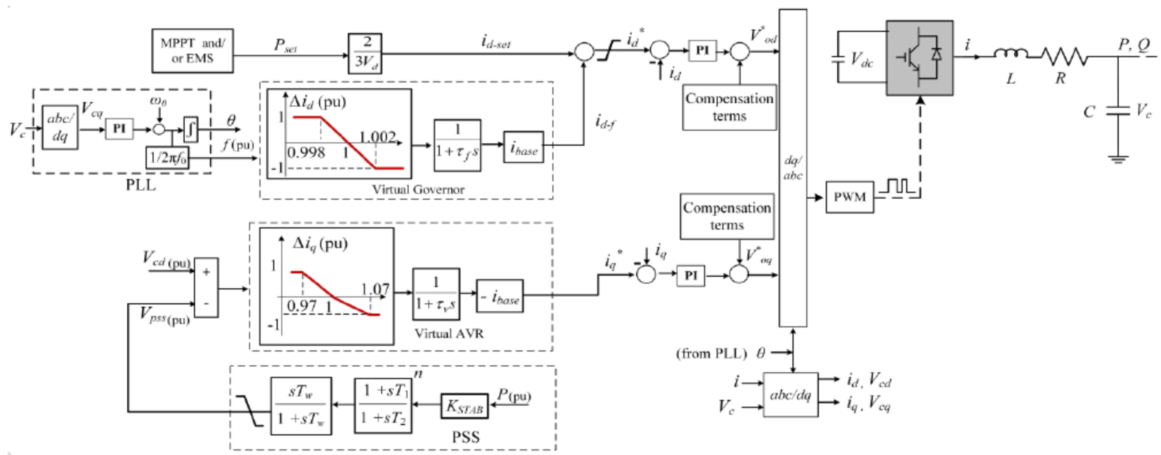

Fig 3. The controller block diagram

- *3) Power System Stabilizer*

The primary function of the PSS is to dampen LFOs, thereby enhancing power system stability. The P signal, which is a function of the difference in rotor angle $\Delta\delta$ between interconnected machines (for an inductive grid), is implemented here. This makes it possible to utilize a local variable (P) with sufficient information regarding remote signals (Δδ). The lead-lag filter, where n is the number of cascaded lead-lag filters, provides phase compensation for the damping signal. The signal washout block acts as a high-pass filter, removing steady state signals from VPSS and passing all signals in the frequency range of interest. The equation that represents the integration of PSS and virtual AVR is given by,

$$i_q^* = -K_v(V_d^* - (V_d - V_{pss}))(\frac{1}{1+\tau_v s})$$

Table I outlines the parameters of the system. The base rating of machine and network parameters are 1500 MVA. The transmission network and SG terminal both have nominal voltages of 230 kV and 13.8 KV, respectively.

Table I - System parameters

VSM		
Parameters	*Value*	
Current Loop PI control	Ki = 9e-3	Kp = 9e-4
tp,tf	0.005 s	1.3 s
Phase locked loop PI control	Ki = 0.05	Kp= 0.005
Filter impedance	L = 0.3 pu	R= 0.008 pu
Synchronous Generator		
Active power	1500 MVA	
Voltage (line to line)	13.8 KV	
Frequency	50 Hz	
Transformer		
Power	1500 MVA	
Frequency	50 Hz	
Primary / Secondary voltage	13.8 KV	230 KV

Rm, Lm	499.99 ohm	500 Henry
Transmission network		
Length	110 KM	
Fault duration	1.5 - 2 sec	

III. INTEGRATING DG IN VSM

The VSM control unit sends the appropriate control signal to the inverter to inject or absorb power by utilizing the grid voltage/frequency and state of charge of the storage device. The VSG controller directs the inverter to behave like a synchronous generator.

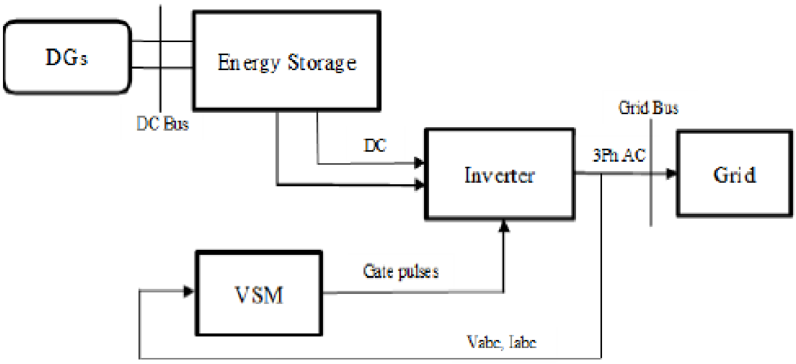

Fig 4. Block diagram for integrating DG in system

Using VSGs can improve grid stability because they can use energy storage to provide virtual inertia like synchronous generator rotor inertia, and the inverter can continue operating in synchronization with other generations in the power system. The swing equation and the Park's transformation serve as the foundation for the SSG control plan. Simulating the characteristics of a synchronous generator is all that this plan does. Be that as it may, it isn't required for inverters to emulate coordinated generator, impeccably. The DG's active and reactive power may fluctuate due to the synchronous generator's inertia. This oscillation is mostly dampened by the power system stabilizer (PSS) in the real synchronous generator.

A. System configurations considered:

Analysis is done for two bus system.

- VSM_{DG} and SG
- $VSM_{DG\text{-}PSS}$ and SG
- VSM_{DG} and SG_{PSS}
- All VSM

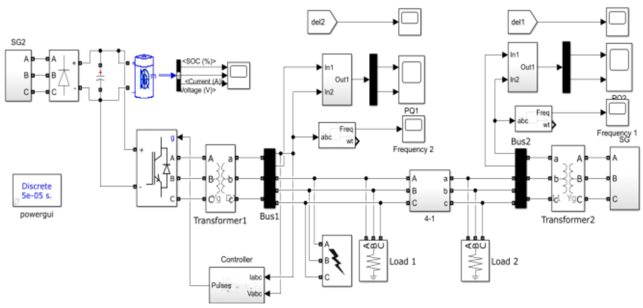

Fig 5. Simulation block diagram of VSM_{DG} and SG

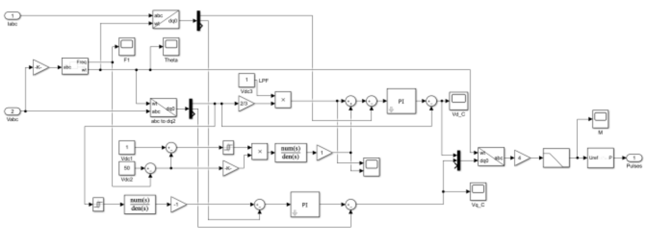

Fig 6. VSM Controller

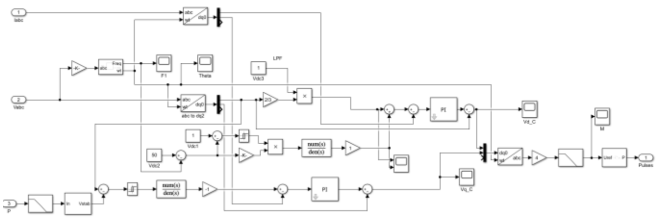

Fig 7. VSM Controller with PSS

B. Summary of Integrating DG with VSM

Removing DG, SGs completely from the system and designing the system only with VSM will reduce the fault clearing time from 2sec to 0.5sec. Simulation results are tabulated as follows,

Table II - Summary of Integrating DG with VSM

System Configuration	***P(pu)***	***Q(pu)***	***δ Degrees***	***Fault clearing time (s)***
VSM_{DG} and SG	0.5	-1	20	2
$VSM_{DG\text{-}PSS}$ and SG	0.5	-1	20	1.9
VSM_{DG} and SG_{PSS}	0.5	-1	20	1.9
All VSM	2	0	20	0.5

IV. INTEGRATING DFIG BASED WT WITH VSM

Wind power generation has grown in importance around the world as a response to public concerns about climate change and demands for sustainable development. As a result, the importance of power converter-interfaced wind turbines (WTs) has increased with grid penetration. Power systems will experience significant stability impacts from a high grid penetration of WTs.

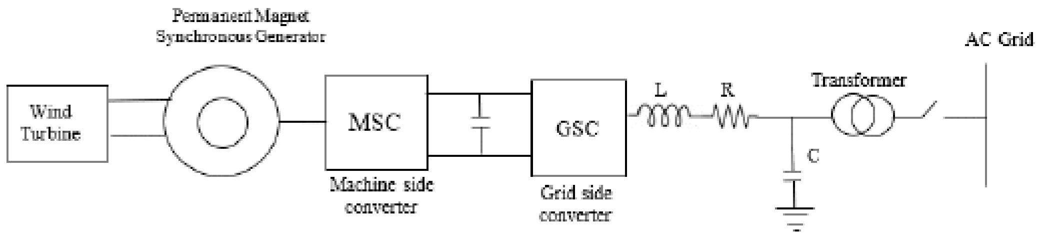

Fig 8. Block diagram for integrating DFIG based WT with VSM

- *System configurations considered:*

Analysis is done for two bus system.

1. DFIG and SG
2. DFIG and VSM
3. DFIG and VSM_{PSS}

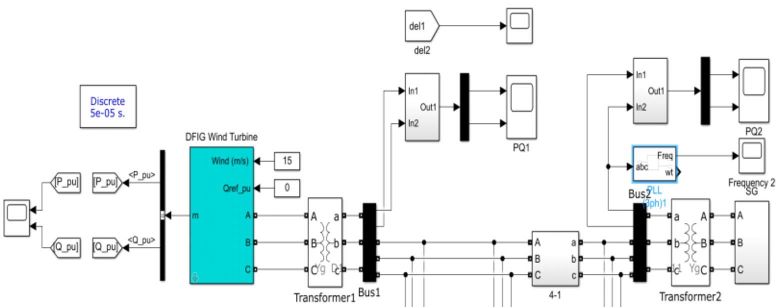

Fig 9. Simulation block diagram of DFIG and SG

- *Summary of Integrating DFIG based Wind Turbine with VSM:*

Removing SGs completely from the system and designing the system with DFIG, VSM and PSS will reduce the fault clearing time from 1.2sec to 0.5sec. Simulation results are tabulated as follows,

Table III - Summary of Integrating DFIG based Wind Turbine with VSM

System Configuration	***P(pu)***	***Q(pu)***	***δ Degrees***	***Fault clearing time (s)***
DFIG and SG	1	-1	20	1.2
DFIG and VSM	1	-2	20	1
DFIG and VSM_{PSS}	0.5	0.4	20	0.5

V. CONCLUSION

To resolve the problem of power grid instability in the presence of a high percentage of inverter based DGs, the VSM which is the concept of controlling an inverter to behave like a synchronous generator is studied. The overall effect of replacing SG with VSM is improved LFO mode damping. However, for satisfactory performance when connected to SGs, the VSM must be integrated with PSS. For various test scenarios, the VSMPSS's robustness was confirmed. The absence of inter-area oscillations and the well-damped LFO modes of an all-VSM system render the use of a PSS unnecessary. Therefore, it is essential to use VSMs to decouple the SGs from the grid to eliminate LFOs without the need for a PSS. The analysis findings may not hold true for all topologies and a poorly designed VSM due to the wide variety of VSM algorithms described in the literature. System behavior is similar for both symmetrical and unsymmetrical fault. The two-machine test bed accurately describes the dynamics of the participating generators, as demonstrated by the close correspondence between the transient and small-signal analyses, and it can be used to investigate LFOs in VSMs with various dynamics.

FUTURE SCOPE: Power quality is an important aspects of renewable energy integration such as voltage and frequency fluctuations which are caused by non-controllable variability of renewable energy resources. The intermittent nature of RESs due to changing weather conditions leads to voltage and frequency fluctuations at the interconnected power grid and harmonics, which are introduced by power electronics devices utilized in renewable energy generation. Power grids operate with RES can be very complicated. Several capacitors can be used to maintain steady-state power factor close to unity over the output range of generators. However, these generators do not have the ability to control reactive power. Hence, VSM based intelligence control strategy can be adopted for power quality improvement in realistic power system.

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