

Mitigation of Frequency Issues in Grid Connected Renewable Energy Sources

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Abstract—The increasing penetration of variable-speed wind turbines in the electricity grid will result in a reduction of the number of connected conventional power plants. This will require changes in the way the grid frequency is controlled. Like conventional generators, wind turbines have a significant amount of kinetic energy stored in the rotating mass of their blades. In case of variable-speed wind turbines, this energy will not contribute to the inertia of the grid as the rotational speed is decoupled from the grid frequency by a power electronic converter. Frequency stability is the ability of the power system to maintain steady frequency following a severe system upset resulting in significant imbalance between generation and load. As a low inertia system is integrated to the grid, the rate of change frequency (ROCOF) changes. This paper studies the rate of change of frequency for a grid integrated with renewable energy sources. The remedies such as Virtual Inertia is used to overcome the frequency stability issue. Simulation results of implementation of ROCOF relay, droop characteristics and virtual inertia are discussed in this paper.

Index Terms— Rate of Change in frequency (ROCOF), Droop characteristics, virtual inertia (VI), Renewable Energy sources.

I. INTRODUCTION

When the power system suffers from various disturbances, frequent short-term power imbalance is unavoidable, as a result, the grid frequency will deviate from its rated frequency (50/60 Hz), leading to significant frequency deviation or RoCoF and the power system diminished stability. In severe cases, this can frequently trigger under-frequency load shedding (UFLS), and other protective measures.

Renewable Energy Sources (RES) make the frequency events worse due to lack of rotating inertia. Commonly RES relate to the power grid as a current source and work in Maximum Power Point Tracking (MPPT) mode. Therefore, RES do not participate in grid frequency regulation. The inertia towards grid frequency control is contributed solely by conventional power plants. With the increase in RES, the mechanical inertia per unit operating electrical power is getting reduced and making the electrical grid less stable towards any frequency event. The large-scale integration of renewable power into the microgrid (MG) has caused a reduction in the inertia of the MG. As a result, variations in the load demand or weather dependent renewable penetration cause poor dynamic response in a low inertia MG with an increased dip in frequency from its nominal value and high rate of change of frequency. Thus, appropriate frequency control technique is needed to tackle this issue. To improve the dynamic response of MG and RoCoF characteristics, artificial or synthetic or virtual inertia (VI) is injected into the MG.

The VI control technique reintroduces the inertia property in a MG through a supplementary VI control loop and this addition of the control loop into the MG improves the frequency stability. ROCOF concept is described in section II. Wind turbine model is developed in section III. Section IV deals with RoCof relay implementation whereas virtual inertia concept is explained in section V. Microgrid model with VI control is covered in section VI. Results and conclusion is part of section VII and VIII respectively.

II. RATE OF CHANGE IN FREQUENCY

From a linearized model of power system frequency dynamics, the ROCOF, $d\Delta f/dt$ of the system can be calculated using equation 1.

$$\frac{d\Delta f}{dt} = \frac{f_o}{2HS_b}(\Delta P_m - \Delta P_{load}) \text{ ----- (1)}$$

f_o is the nominal frequency, H is the inertia constant, S_b is the rated apparent power, P_m is the input mechanical power, P_{load} is the electrical load in the system.

ROCOF is inversely proportional to the inertia constant of the system, H . Higher the inertia constant, lower is the ROCOF of the system and vice versa. The inertia constant of a power system is defined as the ratio of stored energy at a rated speed of rotor to the apparent power rating of the system. It can be calculated using equation 2.

$$H = \frac{\text{Stored energy at rated speed of rotor}}{\text{Apparent power rating}} = \frac{1}{2} \frac{J\omega^2}{S_b} \text{ -----(2)}$$

H is the inertia constant, J is the moment of inertia, ω is the speed of rotor, S_b is the rated apparent power of the system.

III. MODELLING OF WIND DG SYSTEM USING PMSG

To know the actual effect of inertia and the ways to mitigate the issue, it is required to know the detail model of a wind power system. Hence modelling of grid integration with Permanent Magnet Synchronous Generator is done. Block diagram is shown in Fig. 1. The Simulink model is shown in Fig 2. This system is studied for various operating conditions and drop in frequency is observed. Further ROCOF relay is modeled in Matlab/Simulink. Abruptly changing the load power at 1 sec, frequency dip is observed.

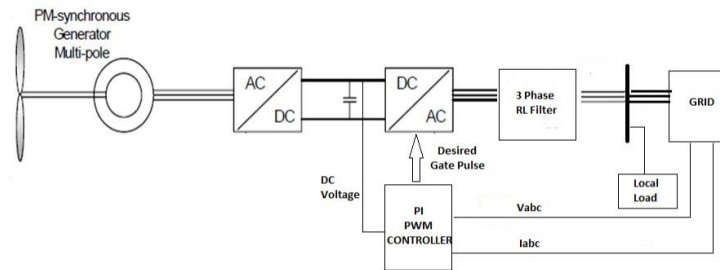


Fig 1 Block diagram of grid integrated wind generation system

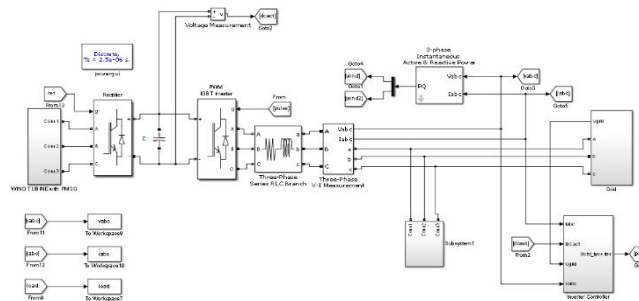


Fig.2 Simulink model of grid integrated wind generation system

IV. IMPLEMENTATION OF ROCOF RELAY AND DROOP CHARACTERISTICS

A conventional power plant contains droop characteristic inherently due to the presence of mechanical inertia. ROCOF relay is implemented (Fig. 3) and the change in frequency can be observed at 2.2sec, 4.2 sec and 7.1 sec as shown in Fig.4. The rate at which the frequency changes at 7.1 sec is -3Hz/s as shown in Fig. 5

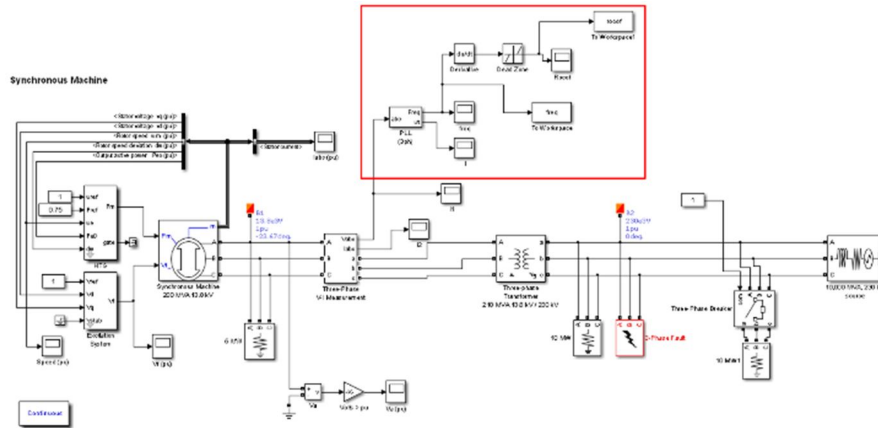


Fig 3. Implementation of ROCOF relay

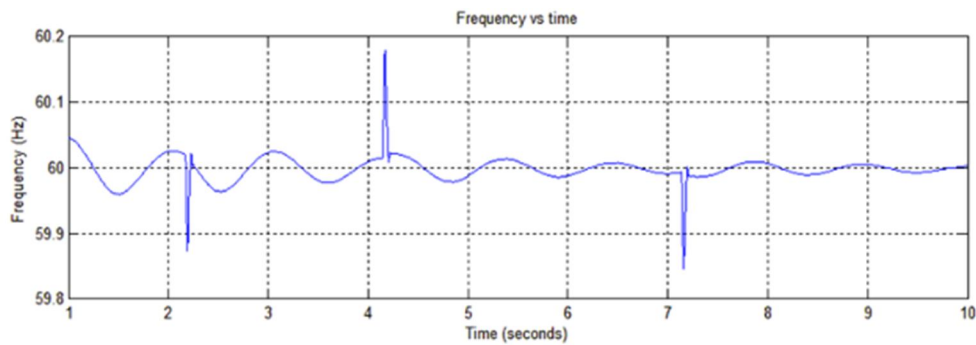


Fig 4. Change in Frequency at 2.2sec, 4.2sec,7.1 sec

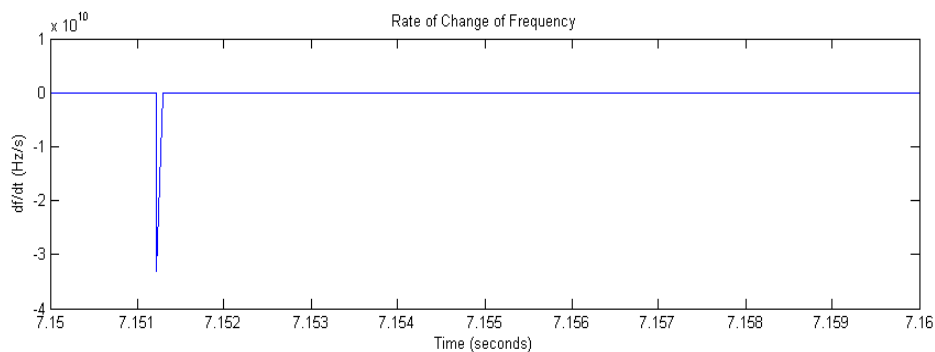


Fig. 5 Rate of change in frequency at 7.1sec

Whenever there is an imbalance between the generation and consumption in a power system, the generators cannot respond instantaneously to balance the system. The kinetic energy stored in the rotors is responsible for counteracting this imbalance through inertial response until the primary frequency control has been activated. As conventional generators are displaced by RESs, the inertial response also decreases. This leads to an increased rate-of-change-of-frequency (ROCOF), and a low frequency nadir (minimum frequency point) in a very short time. The primary frequency control cannot respond within the small-time frame (typically less than 10 s) to arrest the system frequency change. In systems with lower inertia, the frequency nadir is considerably lower along with a high ROCOF. Such situations can lead to tripping of frequency relays (causing under-frequency

load shedding (UFLS)) and, in the worst case, may lead to cascaded outages [1,2]. The solution to such scenarios is to add virtual inertia in the system.

V. VIRTUAL INERTIA

Increasing penetration of RES is making frequency issues worse due to lack of rotating inertia and hence the inherent capability of load sharing like conventional power plants [3]. RES can mimic the frequency droop characteristic of the synchronous machine [4] and can act like a Virtual Synchronous Generator (VSG) or Synchronverter. It helps RES to participate in frequency regulation.

To overcome such problem, one of the advanced arrangements is to emulate the behavior of conventional SG in power systems to enhance the system inertia, stability, and flexibility. It is known as a virtual synchronous generator (VSG) that mimics the activity of the prime movers, thus adding some inertia to the system control loop virtually and accordingly stabilizing the system frequency [5,6]. Where it can be established by using energy storage system (ESS) together with a power electronic inverter and a proper control mechanism [7].

The concept of VSG is based on reproduction the dynamic characteristics of a real SG by combining the concept of virtual rotor (i.e., emulating the inertia and damping properties of real SGs) as well as the concept of virtual primary and secondary control (i.e., emulating the primary and secondary frequency control loops of real SGs [7]. On the other hand, the SGs are considered the source of the dynamics in traditional power systems.

VI. DEVELOPMENT OF MICROGRID MODEL

Block diagram of microgrid is shown in Fig.6. Various power generation sources are integrated into MG for contributing power to a common load. The virtual synchronous generator model is presented in Fig.8

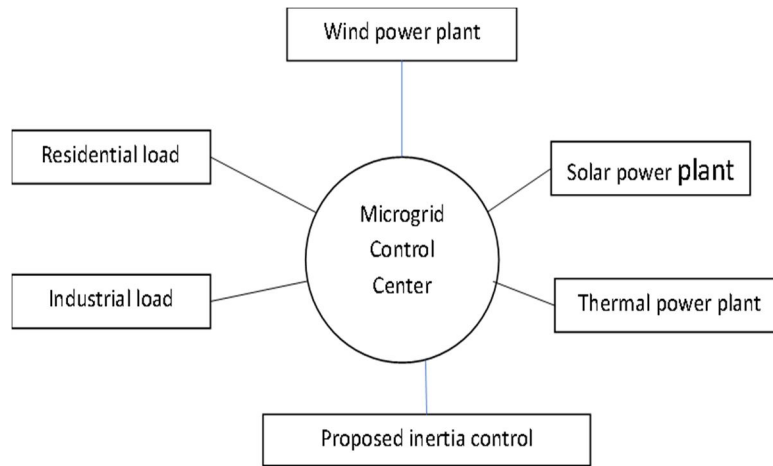


Fig. 6 Block diagram of microgrid

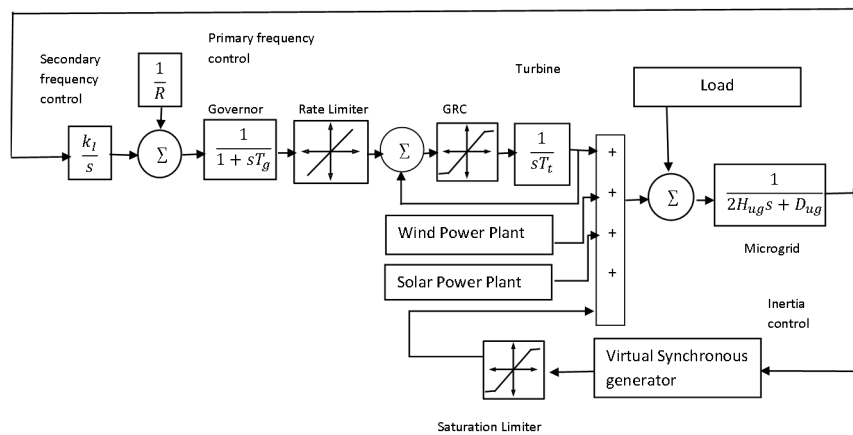


Fig. 7 Dynamic model of Microgrid with virtual inertia

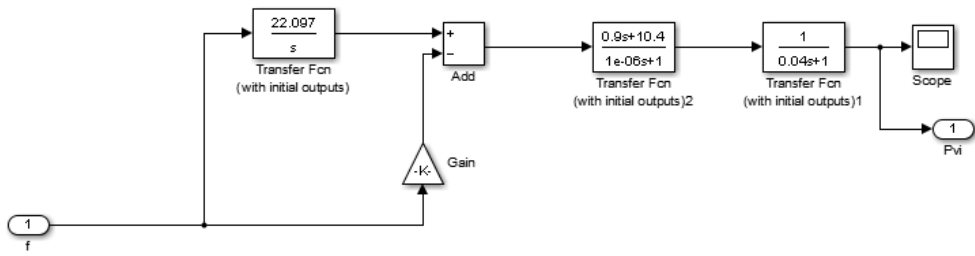


Fig. 8 Virtual Synchronous generator

VII. SIMULATION RESULTS AND DISCUSSIONS

Simulation parameters are presented in table 1.

TABLE 1. SIMULATION PARAMETERS

Parameters	Value
Hi	0.9
Di	10.4
Kp	3.4903
Ki	22.0968
Tin	0.04

The performance of islanded microgrid is tested by introducing sudden change in the load for a high inertia system and low inertia system, i.e. with and without renewable penetration. The change in frequency is observed with and without virtual synchronous generator. The frequency response of low inertia system without virtual inertia is shown in Fig 9. And with virtual inertia is shown in Fig.10

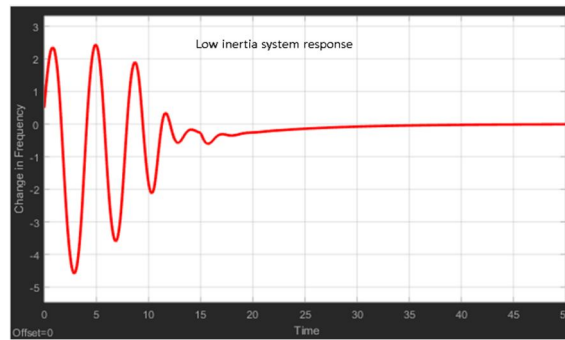


Fig. 9 Frequency response of low inertia system without virtual inertia

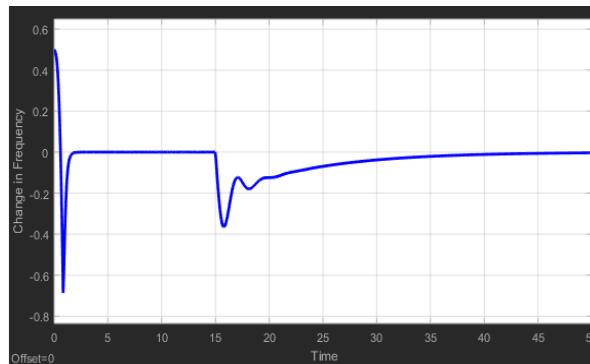


Fig. 10 Frequency response of low inertia system with virtual inertia

VIII. CONCLUSION

With increasing the penetration level of Renewable Energy Sources (RESs) into power electronics-based renewable power systems, the overall system inertia might be significantly reduced, increasing the susceptibility of the renewable power system to the system instability. Thus, maintaining the dynamic security of renewable power systems have become the main challenge for integration more RESs. Therefore, this paper studies and analysis the rate of change in frequency with penetration of renewable energy sources into the grid. It models the microgrid with virtual inertia and analyses the importance of adding virtual inertia into the grid.

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