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Research Paper

STABILITY ENHANCEMENT IN MICRO GRIDS USING VIRTUAL INERTIA CONTROLLER

M Sailaja[1]*, Seetha Chaithanya[2] and G Venkata Suresh Babu[3]

*Corresponding Author: M Sailaja ✉ sailaja.subbu1@gmail.com

The stability and operation aspects of converter-dominated Micro Grids (MGs), however, are faced by many challenges. Important among these, are: 1) the absence of physical inertia; 2) comparable size of power converters; 3) mutual interactions among generators; 4) islanding detection delays; and 5) large sudden disturbances associated with transition to islanded mode, grid restoration, and load power changes. Sources in the MGs use droop control to share power according to their capacity without any form of communication. In this paper a novel controller for inverters which makes the inverter to mimic the behavior of the synchronous generator, called the synchro converter is proposed. This introduces a virtual inertia in the system and improves the frequency response of MGs under transients involving large frequency deviations. During mode conversion, i.e., from grid connected mode to islanded mode or vice-versa, there is a mismatch in power generation and load demand mismatch. This causes instability in the system and leads to unwanted tripping of the MGs which further causes instability. The micro grid, which has two inverters and two synchronous generators, is simulated using Simulink/ MATLAB software to test the proposed control strategy.

Keywords: Distributed generation, Droop control, Frequency stability, Transient response

INTRODUCTION

Power Systems mainly consist of large generation plants supplying distant loads through the utility grids. In recent years, a number of factors have gradually led to changes in this structure. Small generators of some MW have already been dispersed throughout the transmission grid (DG). The new concept is the distribution of smaller units throughout the distribution system as near as possible to the consumer loads. The DGs have to change from passive appendage to primary energy supply, remaining connected to the grid under serious disturbances and offering ancillary services. Under this operation

[1] PG Student, Department of EEE (PS), SITS, Kadapa, AP, India.
[2] Assistant Professor, Department of EEE, SITS, Kadapa, AP, India.
[3] Associate Professor & HOD, Department of EEE, SITS, Kadapa, AP, India.

philosophy, DGs must support the grid from local disturbances, as central generation stations support high voltage systems in the transient period. This can be achieved through the control of the DGs electronic interface to the main grid and the energy storage plants. These controllable DGs (Storage devices are a main feature for proper functionality of the micro grid. They can be coupled to the micro grid through an electronic interface either as creative sources or combined with other micro sources, forming hybrid systems. Storage devices usage ensures the unified dynamic performance of the micro sources achieving power quality and the "plug and play" feature. Reliability and continuity of service is also promoted by controlling the power delivered by the storage device.

In other words, storage devices should provide, at any moment, the difference between the load demand and the available source power. This way, micro sources with slow dynamic response such as Fuel Cell Systems (FCS) or micro sources with uncertain prime mover, such as wind turbines, are prevented from stalling under fast or heavy load transients. The sizing, the incorporated controller and the response speed of a storage device highly depend on the micro grid configuration, the system requirements and the type of micro sources included. The main drawback of the storage device usage in real systems is that it increases the system cost. This especially applies for distribution grids. The droop equation combined with classical control can lead, under certain operational conditions, the micro grid to become unstable, while the stability enhancement for these cases needs sophisticated calculations. In addition, the non-linearity of the micro grid makes the implementation of fuzzy logic controllers at the DGs converters an attractive proposal. In case of planned islanding, the set points of DG of micro grid are adjusted (prior to islanding) to have a smooth transition. This results in minimum transients when the micro grid is moving from grid-connected mode to islanding mode. In case of unplanned islanding, the deviation in frequency and power swing depends on the supply-demand gap in the islanded network. It is possible to reduce the transient by using fast-acting converter interfaced DG units. A large variation in load/ source within a micro grid may lead to a transient stability problem when it is islanded, and the same disturbance may pose a small-signal stability problem when it is grid connected. This paper proposes a control technique for inverter-based DGs to improve the frequency response of micro grid in islanding in addition to power management. The micro grid under study is modeled using the power system toolbox of Simulink/MATLAB with synchronous generator and inverters. The effect of the proposed strategy on system inertia, frequency deviation, and its rate of change are analyzed for a system with DGs based on synchronous machine and inverter through simulation. The effect of adding inertia on frequency oscillations and transient response is also investigated in the present study.

INERTIA AND TRANSIENT RESPONSE OF MICROGRID

Rotational inertia is a measure of an object's resistance to changes in the rotational speed. The relation between power, angular speed, and inertia of a power system is given by

$$J\frac{d\omega}{dt} + D_e\omega_r = \frac{P_{mech} - P_e}{\omega_0}$$

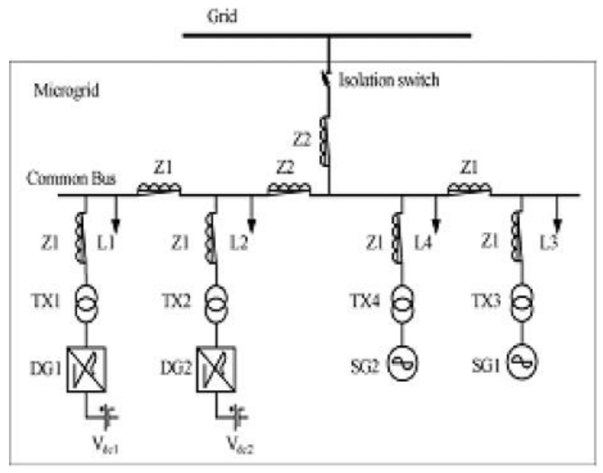
$$\frac{d\omega}{dt} = \frac{P_{mech} - P_e}{J\omega_0}.$$

The rate of change of speed and, hence, system frequency deviation is inversely proportional to inertia. Stiff power grids maintain frequency and voltage during disturbances owing to large inertia and fast field control of synchronous generators, respectively. Due to high inertia of rotors, synchronous generators store a large amount of kinetic energy. Whenever there is a load increase, the imbalance in mechanical and electrical power for a synchronous generator, leads to speed deceleration. Momentarily, the kinetic energy stored in the rotor will be utilized to compensate for this imbalance. Similarly, the field control of generators acts quickly to maintain system voltage during reactive power demand, such as induction motor starting or faults. Thus, power system frequency and voltage are regulated within a tight band. Inverters are static and do not have rotating masses, but it is possible to have infinite inertia when the inverter output phase angle is controlled to a constant value during power change. However, droop control and current limitation on inverter switches lead inverters to have less inertia. Such sources may not be able to regulate voltage and frequency during disturbances. Thus, micro grids with inverter-based sources may suffer from voltage and frequency instability.

MODIFIED DROOP CONTROL FOR IMPROVED TRANSIENT RESPONSE

The deviation in frequency in an isolated micro grid for disturbance in load depends on the supply-demand gap. As discussed in the earlier section, the disturbance, which is perceived as small in a grid-connected system, shall be large in an isolated system and may lead to tripping of the generator or load shedding. If adequate inertia is provided during the transient, it is possible to avoid unwanted triggering of CBs (under frequency and over frequency) whenever there is a disturbance in the islanded micro grids.

Figure 1: System Considered for Simulation



The control block to incorporate the modified droop control in an inverter is shown in Figure 2.

Thus inertia gets added virtually to the system by modifying the droop gain of the inverter. Since large disturbances take time to settle, k_1 is decreased at predefined time steps to slowly reduce the added inertia to zero, so that the frequency slowly reaches its steady-state value.

Figure 2: Block Diagram of Modified Droop Control

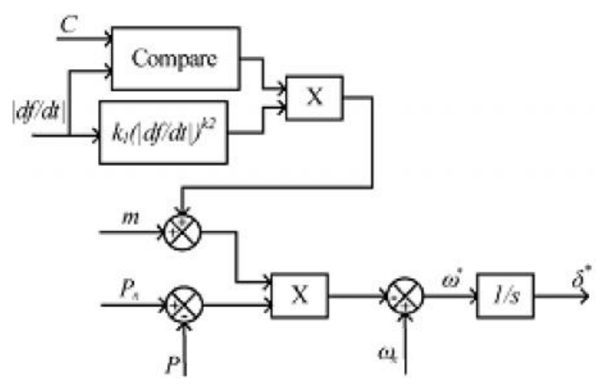
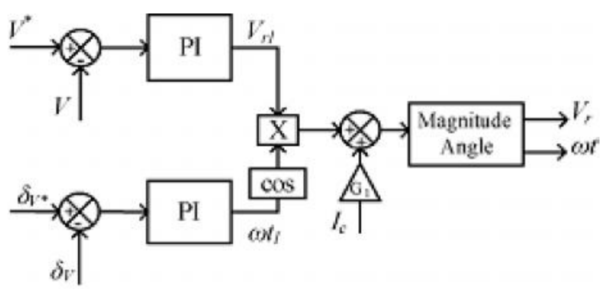


Figure 3: Voltage Magnitude and Phase Controller with Active Damping



Voltage magnitude and phase angle are regulated using an inner fast voltage-control loop which employs the Proportional-Integral (PI) controller. Capacitor current, with small gain, is fed back as shown in Figure 3 to provide damping. Finally, switching sequences for the inverter are generated from voltage magnitude and phase references using the Space Vector Pulse Width Modulation (SVPWM) technique. In this paper, the proposed technique is tested in three different scenarios when the micro grid is islanded (unintentional) from the main grid.

SYSTEM SIMULATION FOR TRANSIENT RESPONSE

In order to validate the proposed control strategy, a micro grid shown in Figure 2 is considered for simulation. The system consists of loads (L1 to L4) and DGs based with an inverter as the front

Figure 4: Frequency Profile with Inverter Using Traditional Droop Control

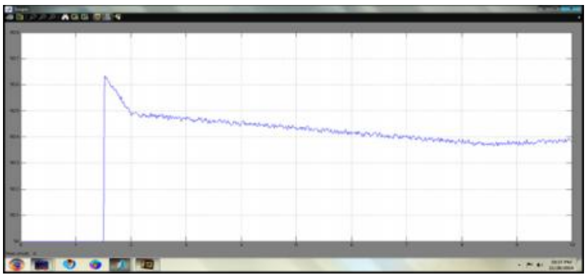


Figure 5: Frequency Profile with Inverter Using Modified Droop Control

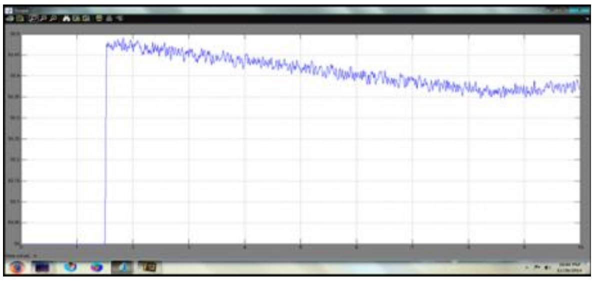


Figure 6: df/dt Profile with Inverter Using Traditional Droop Control

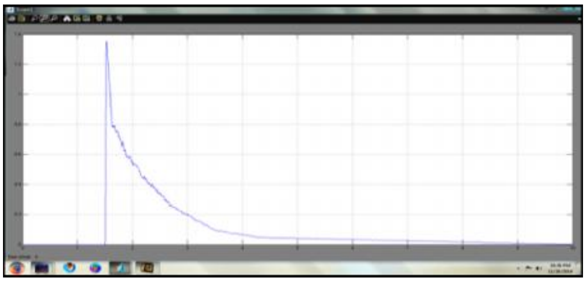


Figure 7: df/dt Profile with Inverter Using Modified Droop Control

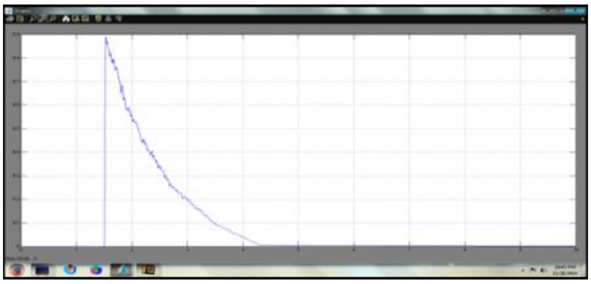


Figure 8: Load Sharing by SG1 Using Traditional Droop Control

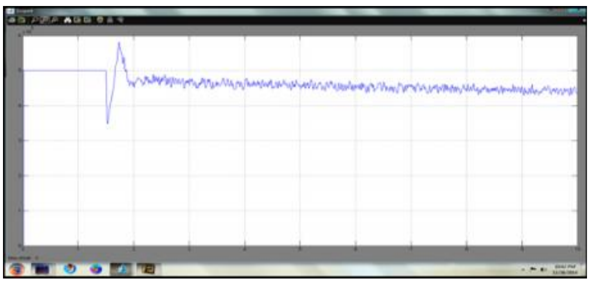


Figure 9: Load Sharing by SG1 Using Modified Droop Control

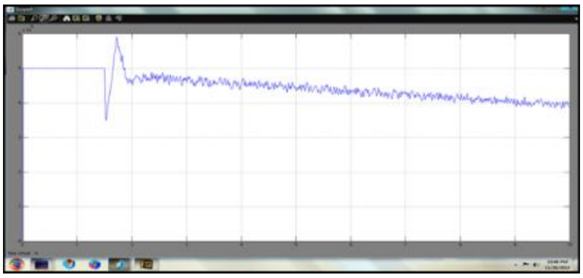


Figure 10: Load Sharing by SG2 Using Traditional Droop Control

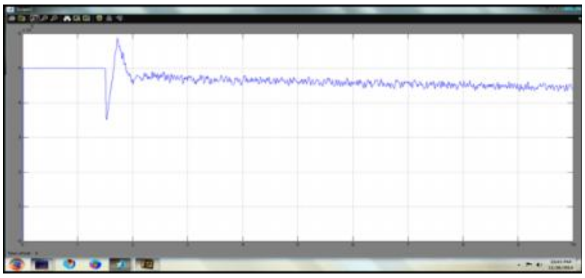


Figure 11: Load Sharing by SG2 Using Modified Droop Control

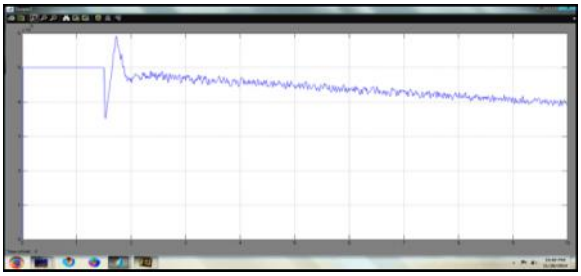


Figure 12: Load Sharing by Inverter DG1 Using Traditional Droop Control

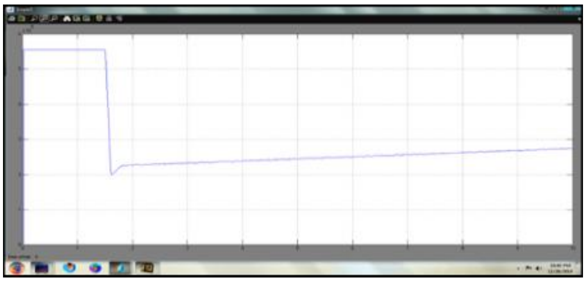


Figure 13: Load Sharing by Inverter DG1 Using Modified Droop Control

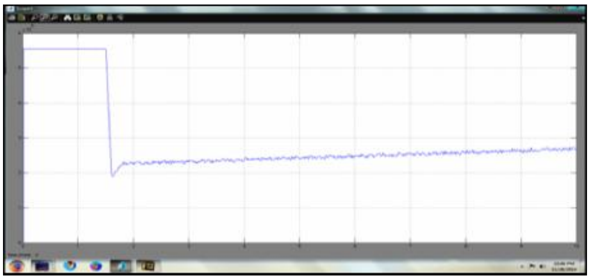


Figure 14: Load Sharing by Inverter DG2 Using Traditional Droop Control

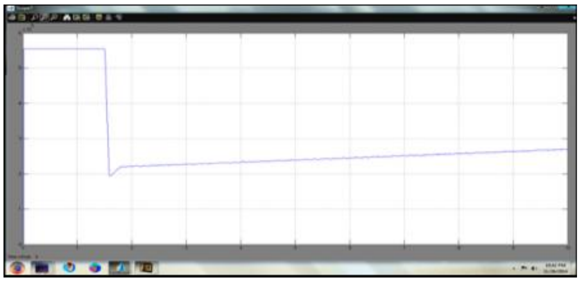


Figure 15: Load Sharing by Inverter DG2 Using Modified Droop Control

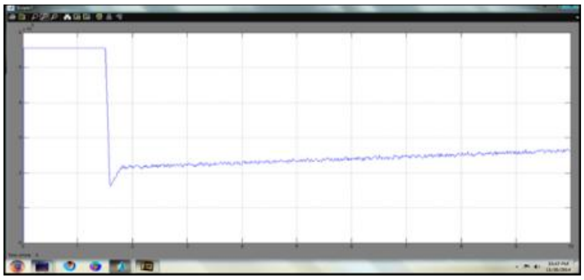


Figure 16: Current Profile of DG1

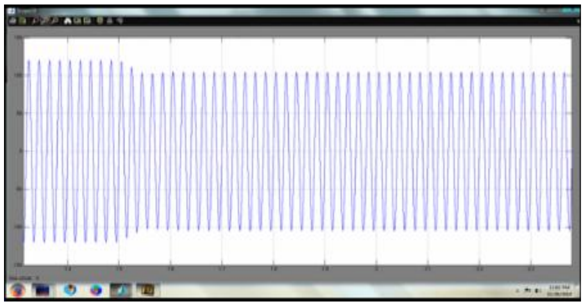


Figure 17: Current Profile of DG2

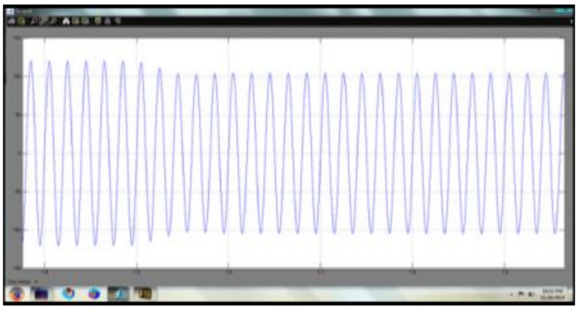


Figure 18: Current Profile of SG1

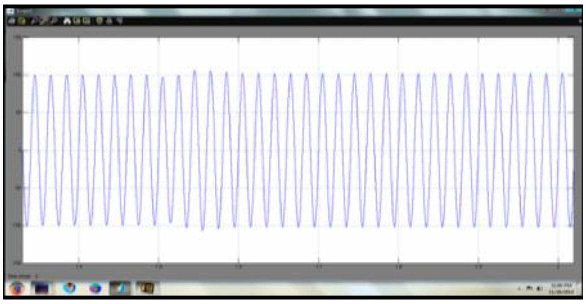


Figure 19: Current Profile of SG2

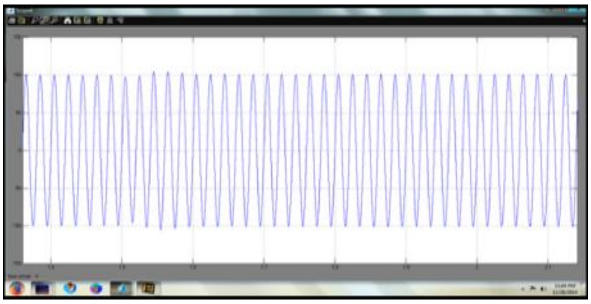


Figure 20: Frequency Profile with Inverter Using Traditional Droop Control

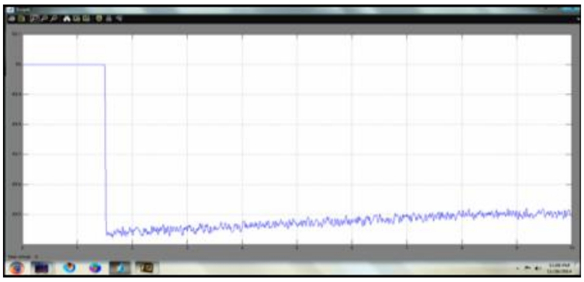


Figure 21: Frequency Profile with Inverter Using Modified Droop Control

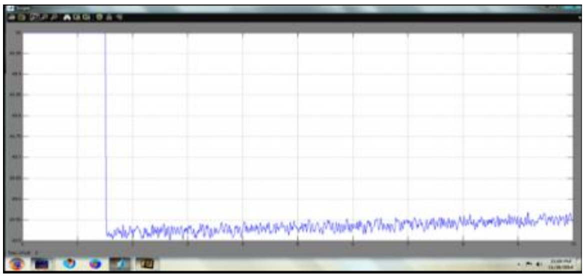


Figure 22: df/dt Profile with Inverter Using Traditional Droop Control

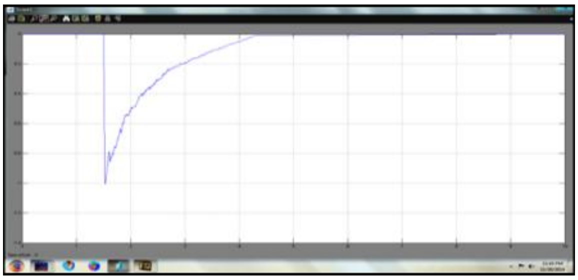


Figure 23: df/dt Profile with Inverter Using Modified Droop Control

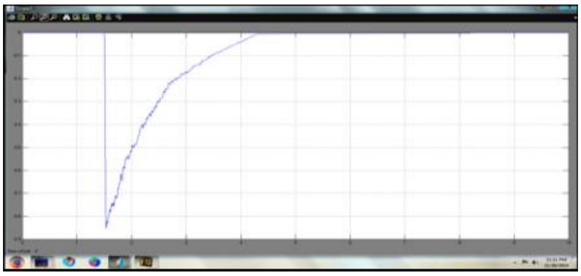


Figure 24: Load Sharing by SG1 Using Traditional Droop Control

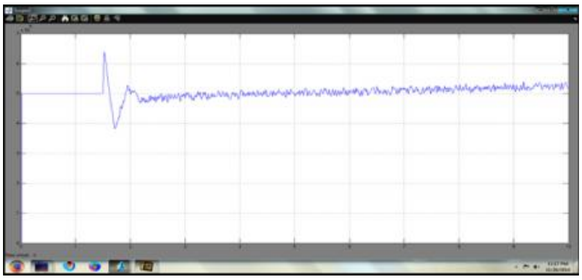


Figure 25: Load Sharing by SG1 Using Modified Droop Control

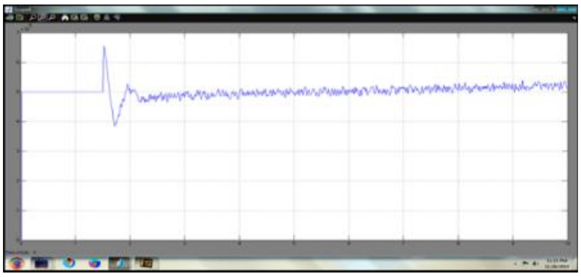


Figure 26: Load Sharing by SG2 Using Traditional Droop Control

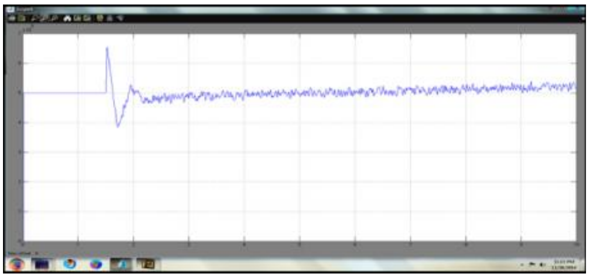


Figure 27: Load Sharing by SG2 Using Modified Droop Control

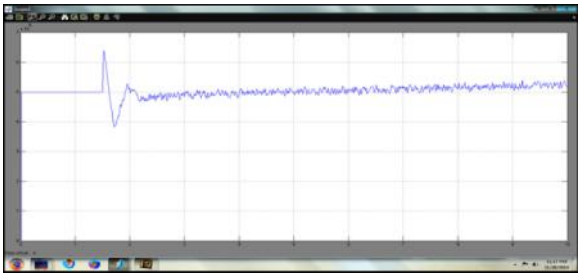


Figure 28: Load Sharing by Inverter DG1 Using Traditional Droop Control

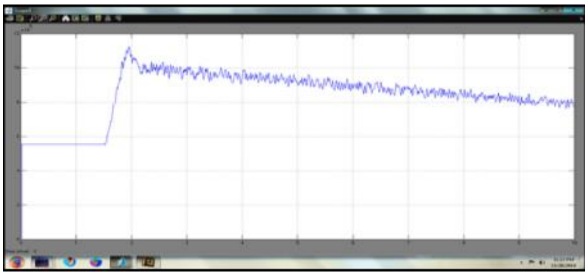


Figure 29: Load Sharing by Inverter DG1 Using Modified Droop Control

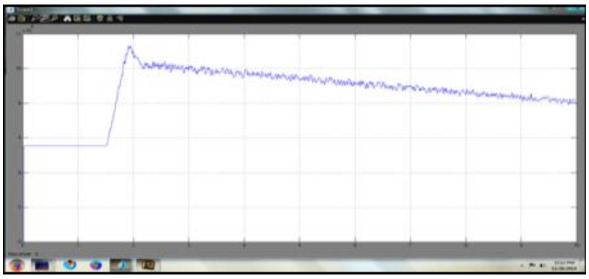


Figure 30: Load Sharing by Inverter DG2 Using Traditional Droop Control

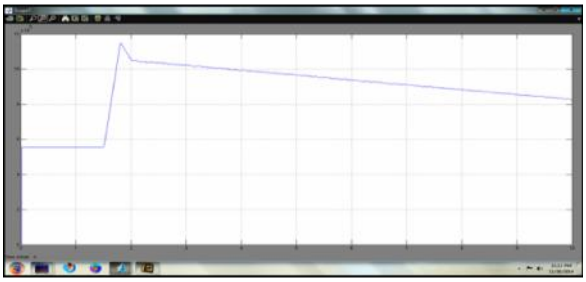


Figure 31: Load Sharing by Inverter DG2 Using Modified Droop Control

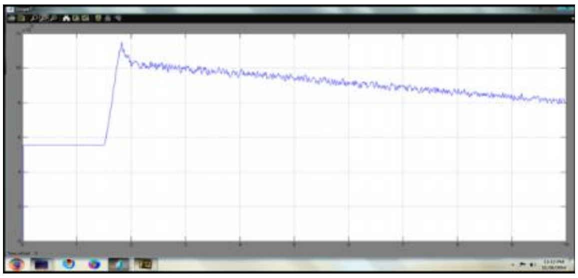


Figure 32: Frequency Profile with Inverter Using Traditional Droop Control

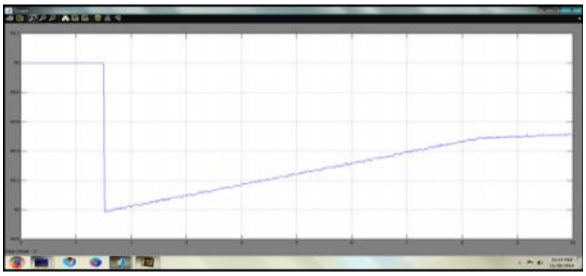


Figure 33: Frequency Profile with Inverter Using Modified Droop Control

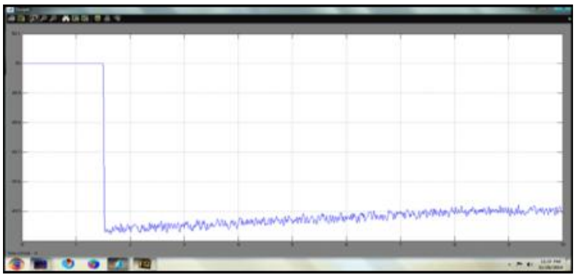


Figure 34: df/dt Profile with Inverter Using Traditional Droop Control

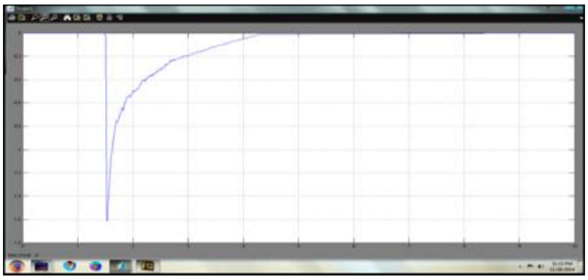


Figure 35: df/dt Profile with Inverter Using Modified Droop Control

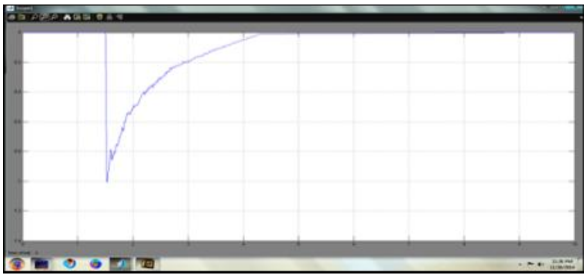


Figure 36: Load Sharing by SG1 Using Traditional Droop Control

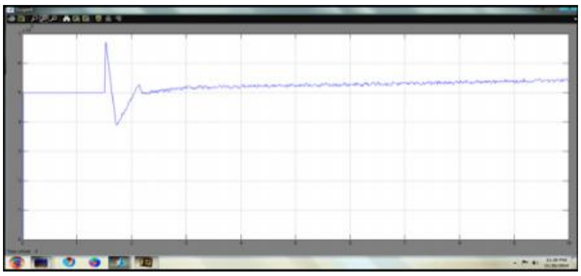


Figure 37: Load Sharing by SG1 Using Modified Droop Control

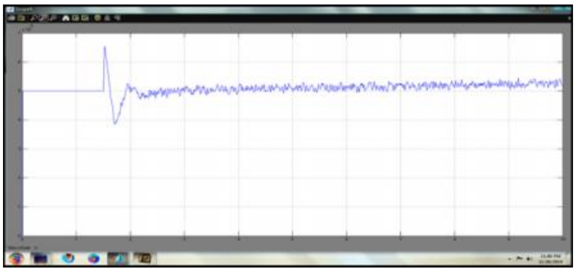


Figure 38: Load Sharing by SG2 Using Traditional Droop Control

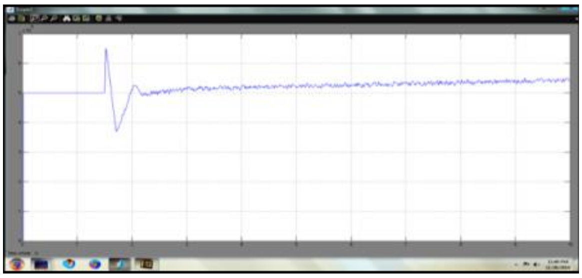


Figure 39: Load Sharing by SG2 Using Modified Droop Control

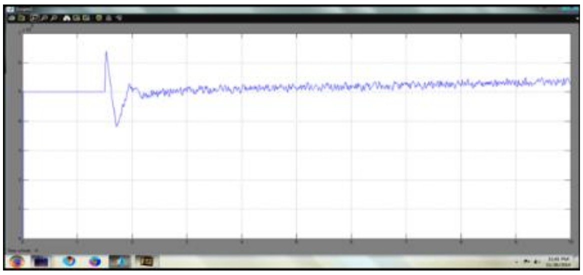


Figure 40: Load Sharing by Inverter DG1 Using Traditional Droop Control

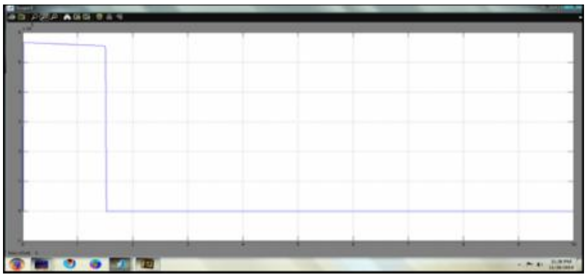


Figure 41: Load Sharing by Inverter DG1 Using Modified Droop Control

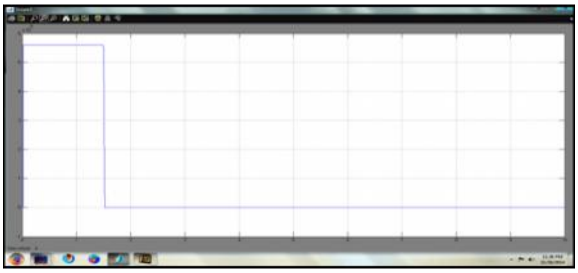


Figure 42: Load Sharing by Inverter DG2 Using Traditional Droop Control

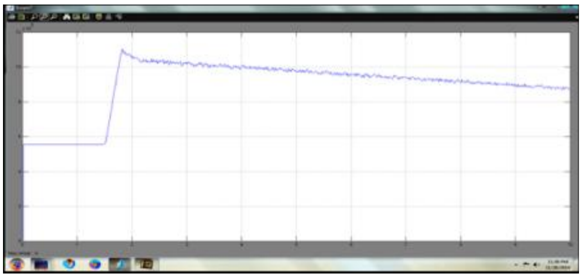
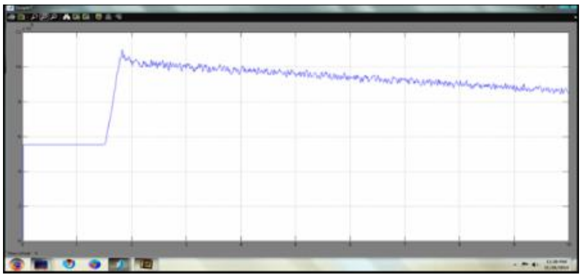


Figure 43: Load Sharing by Inverter DG2 Using Modified Droop Control



end (DG1, DG2) and conventional synchronous generators (SG1, SG2).

CONCLUSION

A new control technique to improve the transient response of grid connected inverters for MG application is proposed in this paper. A VSC based MG with loads, connected to distribution grid is considered and is simulated using MATLAB/SIMULINK software. The droop control technique is applied to inverter-based MGs. Simulation are carried to study the behavior of inverter during steady state and during mode conversion. Results show that employing droop control to inverters allows them to take the bulk of the power change transiently, at reduced frequency deviations. The inverter behaves like a synchronous generator by increasing or decreasing its real power output during mode conversion. The action of droop controller adds a virtual inertia in the system and increases the transient stability. The effect of rotor acceleration and deceleration for frequency stabilization in a synchronous generator is mimicked by the inverter. Thus it is possible to reduce unwanted triggering of sources out of synchronism and to reduce load shedding in an islanded MG. This approach can reduce the short-term storage requirements of a MG where frequency is a major constraint, thus reducing the cost. The control can be designed to ensure MG operation within prescribed frequency limits, also making sure that the inverter is not overloaded. Thus it can be concluded that droop control changes the static behavior of inverter into a dynamic one and improves the transient stability of the system.

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