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Modeling and Simulation of Inverter-Generator Interactions in Micro Grid

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ABSTRACT

Micro grids are the present trendy topic due to their role in the coordination of distributed-energy resources, decreasing transmission investments by including generation near to the load centers, and providing islanded operation during blackouts. Here, a micro grid with a mix of synchronous generators and inverter based distributed energy resources is considered. Three operating conditions have been simulated for micro grids in this paper namely inverter alone, generator alone and considering both inverter and generator. The inverter-generator interaction has been studied in detail in the present work.

Keywords: Micro grids, distributed energy resources, blackouts, grid connected, islanded, inverter control system.

1. INTRODUCTION

Micro grids offer numerous advantages to the grid and to end clients. Large portions of the new sorts of distributed energy resources are inverter based, for example photovoltaic (PV), wind, micro turbines and fuel cells. Inverters with energy storage enhance the new functions such as energy arbitrage and seamless islanding, which means uninterrupted power supply function. In any case, synchronous generators (SGs) are most widely recognized sort of DER for the most part in reinforcement power applications. It is normal that synchronous generators will assume a noteworthy part in micro grid establishments. Therefore, it is important to examine the performance of micro grids when they are worked with a mix of synchronous generators and inverter based distributed energy resources [1].

Majorly inverters can be operating in two modes, namely grid connected and grid forming. Voltage controlled inverters with energy storage can be operated in grid connected or islanded mode, and can operate with grid forming sources or in standalone mode. The need for moves between grid connected and islanded mode is eliminated. Elimination mode transition is helpful, as experience proposes that most issues happen amid mode moves.

Voltage controlled inverters show poor transient burden imparting to synchronous generators in islanded mode operation. Initially inverter tends to pick up majority of any load step [1]-[2]. This poor transient burden confines the inverter rating with respect to the biggest burden steps, increase weight on the inverter, and reduces battery life by subjecting the battery to bigger and more incessant burden steps. While transient load burden sharing issue could be moderated by selecting a vast inverter, but limitations on cost prove a hindrance to this. Cost limitations might drive the designer to pick the smallest inverter possible, but transient burden sharing turns into a critical concern in that case. Voltage controlled inverters can work in any mode but they can be more difficult to control during transients. This research examines the behaviour of voltage controlled inverters amid over-burdens and amid current restrictions when working in parallel with synchronous generators. Figure 1 presents the basic micro grid architecture.

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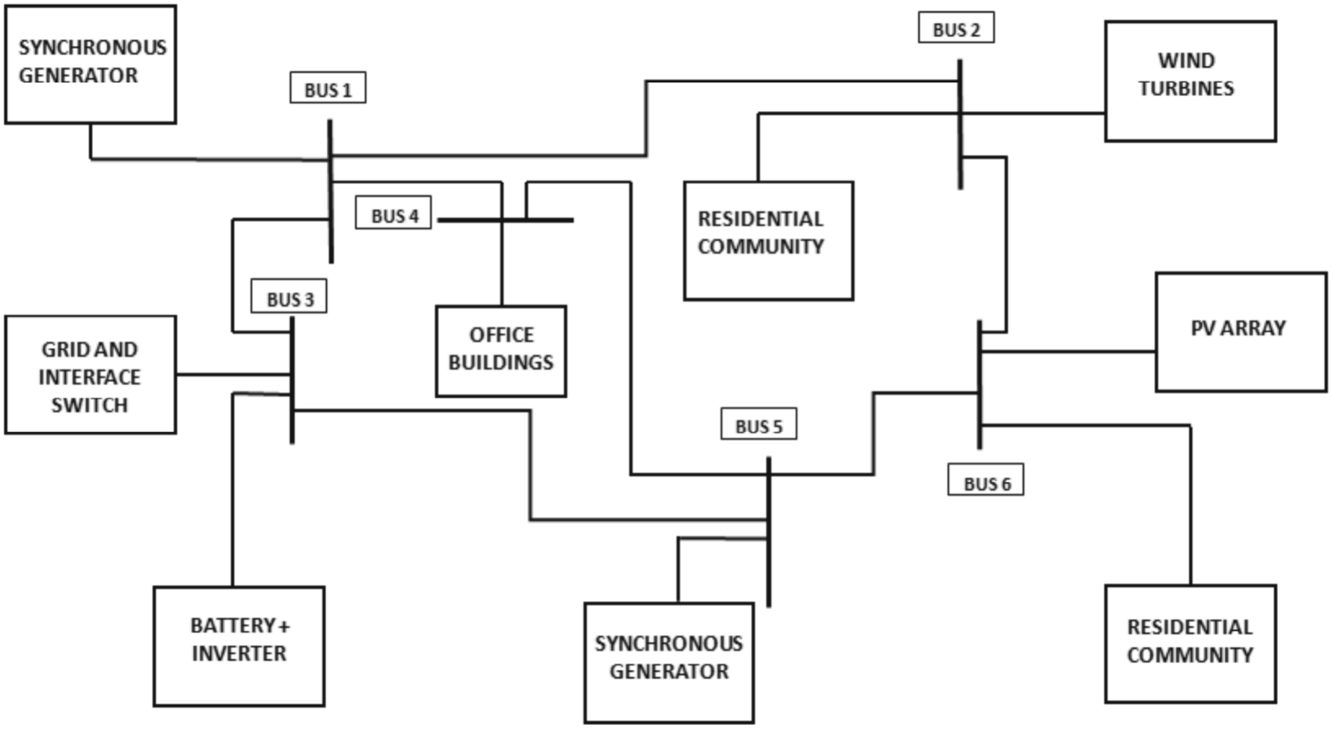
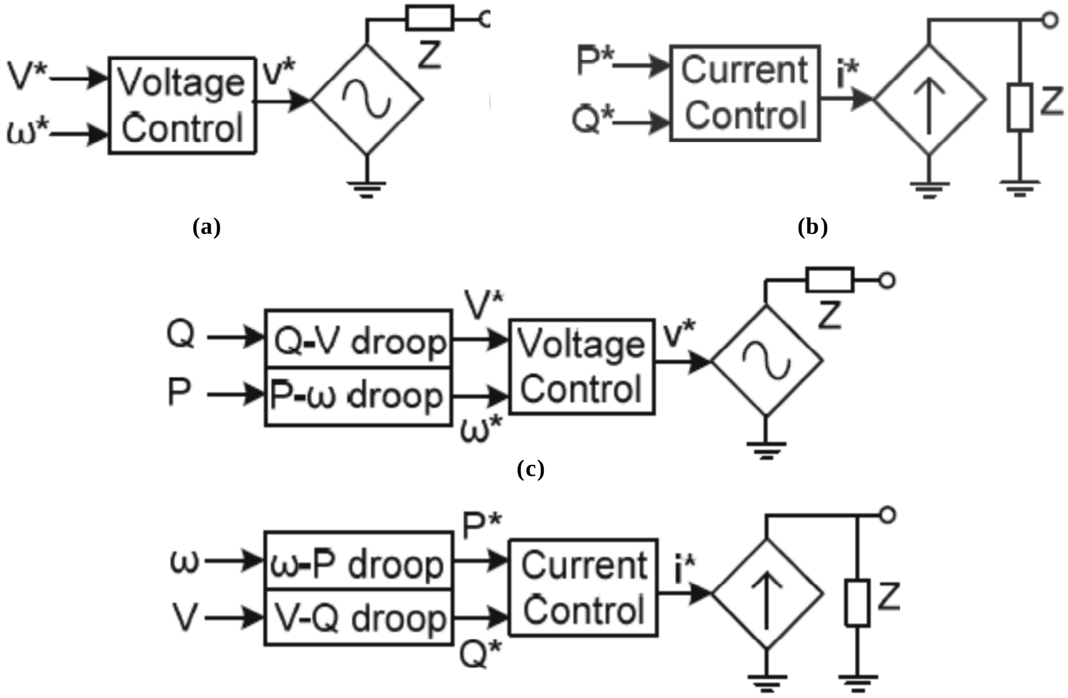


Figure 1: Basic Micro grid Architecture

2. INVERTER CONTROLS IN MICRO GRID

Basically inverter controls can be classified into four basic types as shown in Figure 2–Grid forming, Grid feeding, Grid supporting grid forming and Grid supporting grid feeding.

Grid forming control acts as a fixed voltage source, and this is not suitable for paralleling with other grid forming sources. Little variations in voltage and frequency references would bring the voltage sources to



(a) (b) (c) (d)

Figure 2: Basic inverter control types: (a) Grid Forming
(b) Grid Feeding (c) Grid supporting grid forming (d) Grid supporting grid feeding

fight against each other creating high circulating currents and leads to instability. Grid forming voltage sources are commonly connected in standalone applications, as they cannot be worked in parallel with the utility [3].

Grid feeding control acts as a fixed current source, and this control normally uses a phase locked loop to follow the grid voltage. This control is not suitable for micro grids without a grid forming source to direct the voltage and does not add to voltage and frequency control.

Grid supporting control supports the grid by adjusting the set points based on the grid condition. Grid supporting grid forming control is a generalised form of grid forming control that acts as a droop controlled voltage source, where the references are frequency and voltage based on measurement of active and reactive powers respectively.

Grid supporting grid feeding control is a generalised form of grid feeding control that acts as a droop controlled current source, where the references are active and reactive powers based on measurement of frequency and voltage respectively [1].The circuit diagram shown in Fig.3 represents the three phase three wire voltage source inverter with LC filter. The LC filter acts like a low pass filter to filter out the harmonics in switching. The space vector modulation technique is used to calculate the duty cycle. The space vector algorithm is used in this work [4].

Grid supporting grid feeding inverter control has been proposed for operation in micro grids, and has shown the real and reactive power sharing without commutations provided by the droop [5]. The voltage and frequency droop gain characteristics are presented in Fig.4.

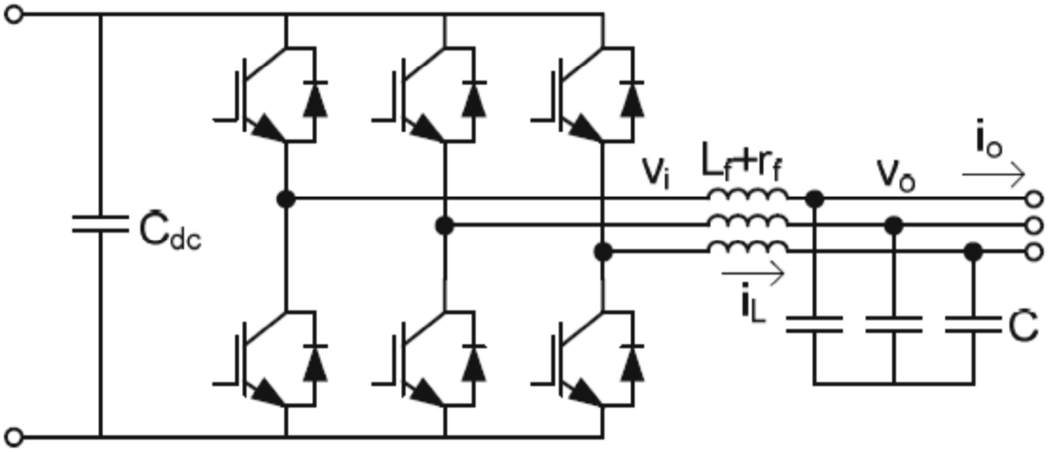


Figure 3: Simple inverter plant

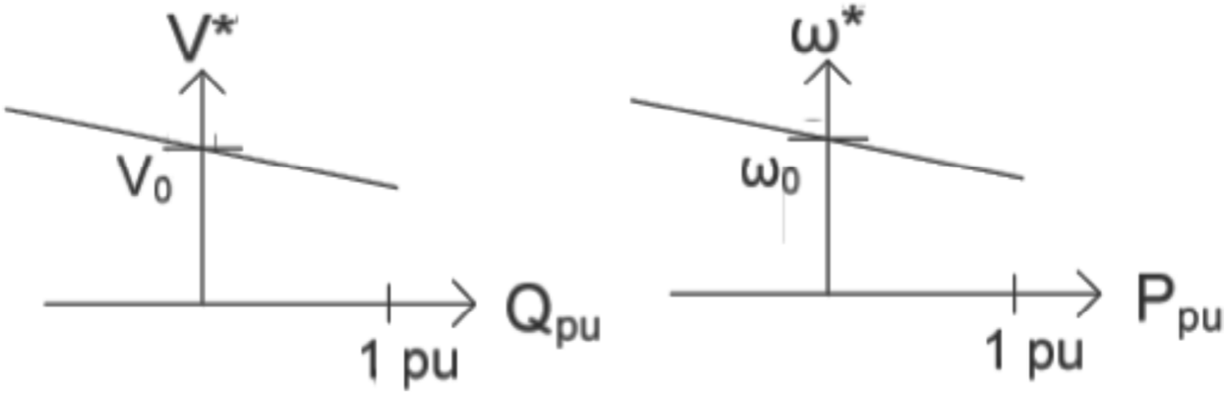


Figure 4: Voltage and Frequency drooping

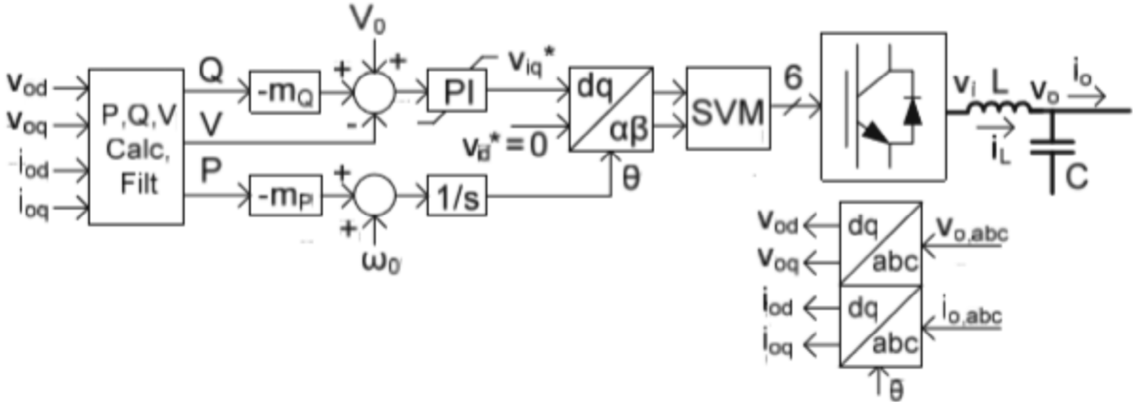


Figure 5: Inverter control simulation diagram

The main purpose of droop control is to give the stable real and reactive power share without communication. But for the required optimization of inverter controls i.e., adjusting set points to restore the frequency and voltage to rated values requires communication [6]. In this work only droop control is considered which provides the stable power sharing. The outline control of inverter with voltage and frequency droop is shown in Figure 5, where the frequency and voltage are the references.

The calculation of real and reactive power obtained from the frequency-active power and voltage-reactive power droop, is given by,

$$P = \frac{1}{m_p}(\omega_0 - \omega^*) \tag{1}$$

$$Q = \frac{1}{m_Q}(V_0 - V^*) \tag{2}$$

Where m_p is the active power droop gain, m_Q is the reactive power droop gain, ω_0 is the nominal frequency, ω^* is the frequency reference, V_0 is the nominal voltage and V^* is the voltage reference. The current control references are obtained from the real and reactive power calculations.

The absence of transient load power sharing between generator and inverters in voltage control mode can be comprehended by considering differences between the generators and inverters voltage and frequency control droops [7].

Here the inverter is rated at 11.1 kVA at 208V_{L-L}, 50 Hz and with diode bridge rectifier as input to the inverter, and is consists of three phase standard IGBT bridge. A load of 1.4 kVA is always connected to the system and an additional load of 10kVA is connected through a breaker. The 10 kVA load is connected at 0.5 s and is disconnected at 2.5 s. Also, grid is connected initially to this system and is disconnected before 0.5 s. Figure 6 provides the simulation result with considering inverter alone. Here it can observe that the voltage, active and reactive power of inverter is in per unit system, with load being the base quantity. The inverter controller parameters are given in table 1.

While considering simulation results to observe that the inverter behaviour is initially in transient state, settles instantaneously when the load is connected at 0.5s.

3. GENERATOR CONTROL IN MICRO GRID

The control block diagram of synchronous generator control is presented in Figure 7, where the droop terms are automatic voltage regulator (AVR) and frequency references. The droop control is executed by biasing the automatic voltage regulator (AVR) voltage reference and governor frequency reference by calculating real and reactive powers respectively [8].

Table 1
Inverter Control Parameters

Sl. No.	*Parameter*	*Value*
1.	Active power (P) , Reactive power (Q) and voltage calculation filter cut-off frequency	2π*10rad/s
2.	Frequency droop gain	2π*1rad/s
3.	Voltage droop gain	0.05 V_{pu}/Q_{pu}
4.	PI controller k_p	0.5 V_{pu}/V_{pu}
5.	PI controller k_i	44 (V_{pu}/V_{pu})/s

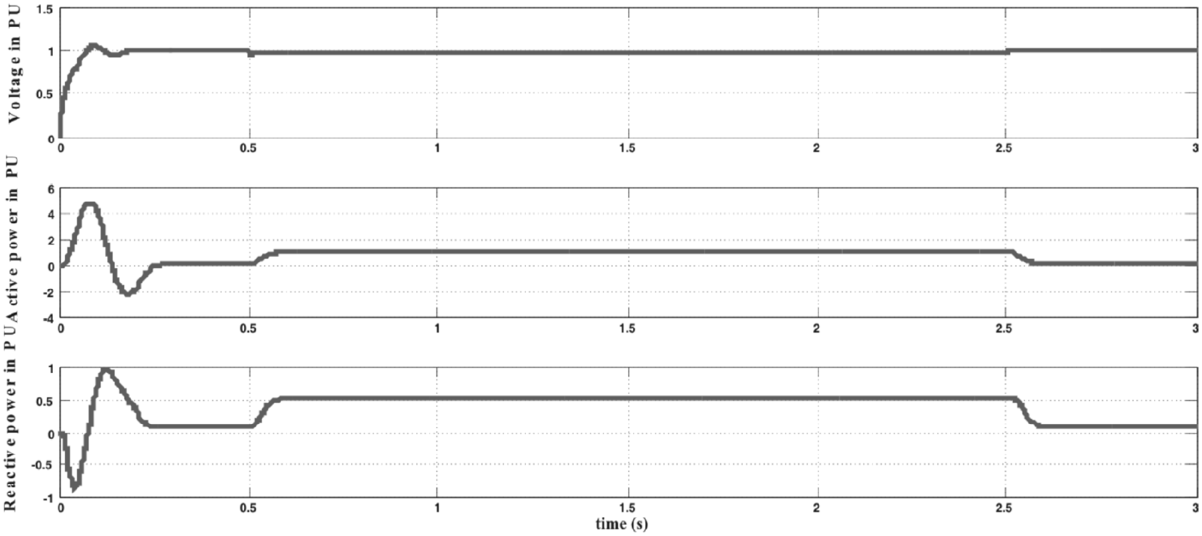


Figure 6: Simulation result with considering inverter alone

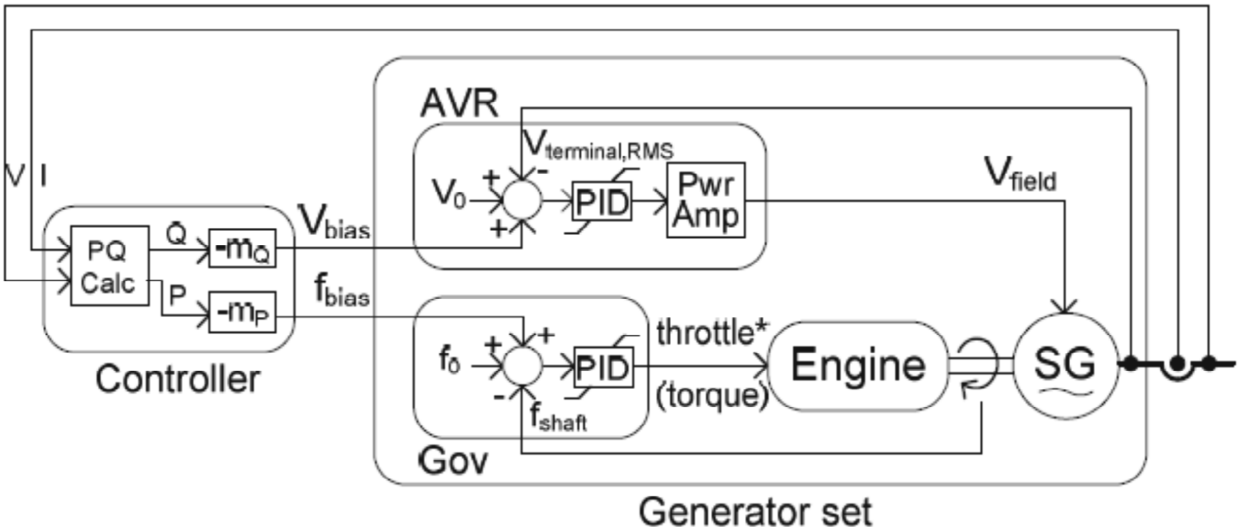


Figure 7: Generator control simulation diagram

Synchronous generator directs the frequency by controlling the engine mechanical torque T_m in order to regulate the mechanical speed of the machine μ_m. However the diesel engine dynamics are neglected.

$$T_m = (\omega^* - w_m), (k_{p\omega} + k_{i\omega}/s) \tag{3}$$

$$\omega_m = \frac{1}{s}\left(\frac{T_m - T_e - B \cdot \omega_m}{H}\right) \tag{4}$$

Where T_e is the electrical torque, B is the friction coefficient, H is the inertia coefficient, $k_{p\omega}$ and $k_{i\omega}$ are control parameters of speed.

Inverter and generator direct the frequency in many ways, the generator changes the torque in view of speed error to regulate frequency, and it adjusts its speed reference in proportion to the measured real power. Also the automatic voltage regulator changes its excitation in proportion to the measured reactive power [9].

Here the generator is rated at 12.5 kVA at 208 V_{L-L}, 50 Hz. The drive runs in closed loop manner to emulate the diesel engine. A load of 1.4 kVA is always connected to the system and an additional load of 12 kVA is connected through a breaker. The 12 kVA load is connected at 0.5 s and is disconnected at 2.5 s. Also, grid is connected initially to this system and is disconnected before 0.5 s. From Figure 8, it can observe that the voltage, active and reactive power of generations in per unit system, where the base quantity is load. And the generator controller parameters are given in table 2.

Table 2
Generator control parameters

Sl. No.	*Parameter*	*Value*
1.	Frequency droop gain	2π*1 rad/s
2.	Voltage droop gain	0.05 V_{pu}/Q_{pu}
3.	AVR controller k_p	1.62 V_{pu}/V_{pu}
4.	AVR controller k_i	10.4 $(V_{pu}/V_{pu})/s$
5.	AVR controller k_d	0.05
6.	Governor k_p	7 T_{pu}/ω_{pu}
7.	Governor k_i	57 $(T_{pu}/\omega_{pu})/s$
8.	Governor k_d	0 $(T_{pu}/\omega_{pu})^{-s}$
9.	Generator Inertia	034 s

While considering simulation results we can observe that the inverter behaviour is initially in transient state, settles after some time when the load is connected at 0.5s.

4. INVERTER AND GENERATOR INTERACTION IN MICRO GRID

The inverter and generator are operating in droop control [10] as shown in Figure 5 and Figure 7 respectively. The same control parameters and settings are used in the simulation. The parameters of the generator are based on the load setup. A 1.4 kVA load is present in the system throughout the entire simulation. The simulation of application and rejection of a 100% load 26.7 kVA (21.4 kW, 16 kVAR) is shown in Figure 9. In the simulation this load is connected at 0.5 s of time and disconnected at 2.5 s. Meanwhile the grid is disconnected before the application of the load at 0.5 s, and inverter picks the entire load step initially, the generator power increases slowly till it reaches to the steady state, wherein they share load relative to their droop settings. When the load is disconnected, inverter rapidly absorbs the most of the load step, and the active power reaches –0.8 *pu*.

This simulation shows need of over sizing inverter to handle the large load steps, and it may have a negative impact on battery storage inverters. The absence of power sharing might be particularly problematic for negative load steps, where a battery storage inverter when it is charging prior to a negative load step would likely trip because of the excessive negative power. Figure 9 shows simulation of the inverter and generator interaction response to a 100% load step, which will result in inverter overloading.

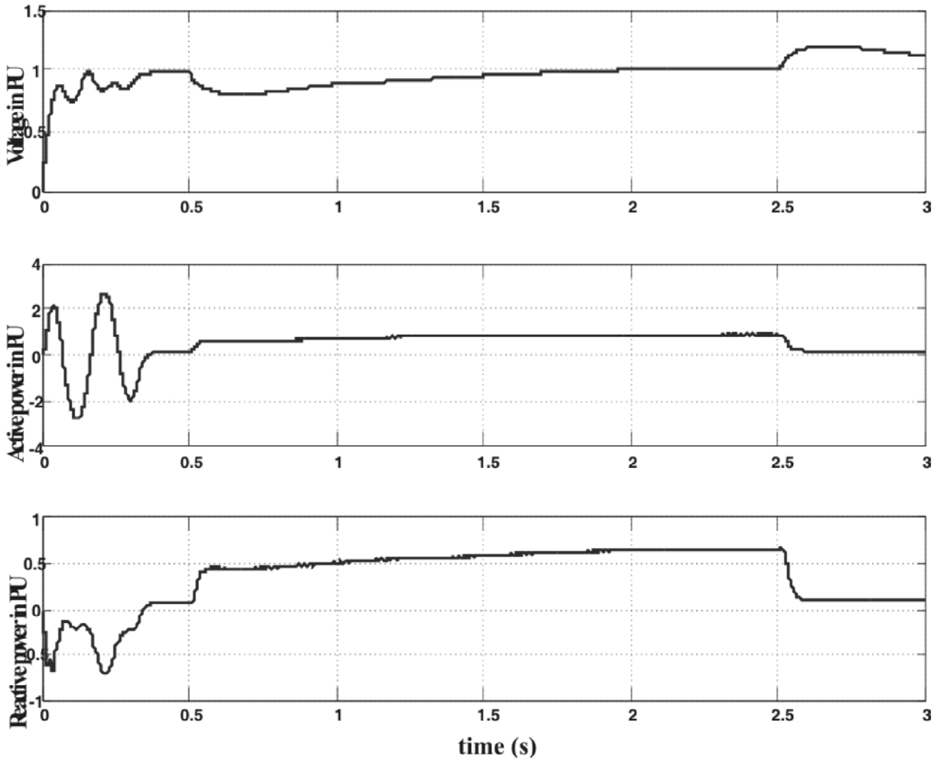


Figure 8: Simulation results with considering generator alone

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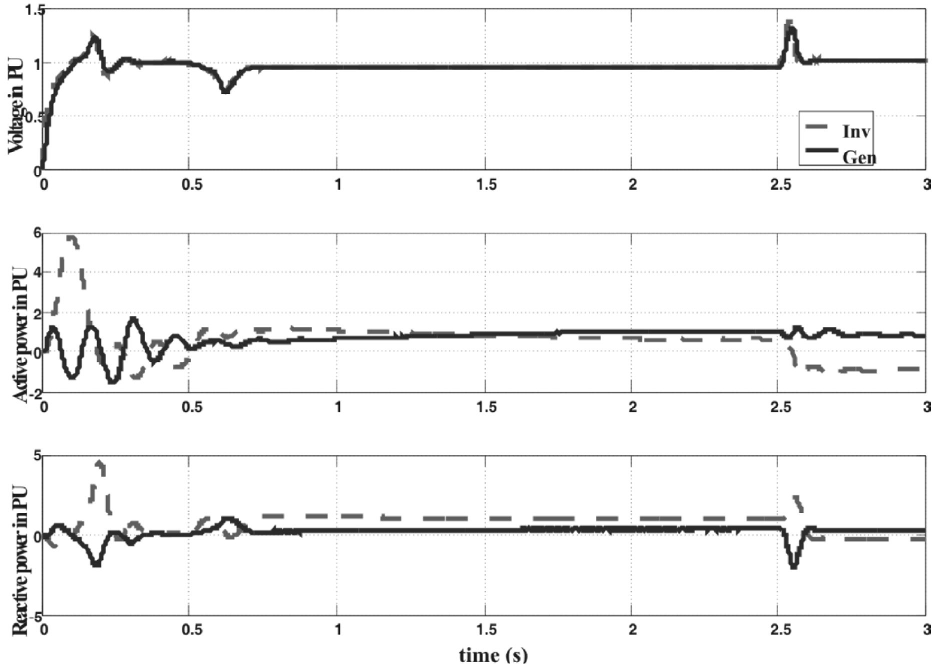

Figure 9: Simulation results when considering both inverter and generator in microgrid

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5. CONCLUSIONS

It has been observed from the simulation results that in micro grid operation with inverter-generator, for a given step load change, initially most of the load sharing is taken by inverter itself and causes burden on inverter switches and reduce the life of inverter. In this aspect there is a potential to develop appropriate controller for inverter to prevent the poor transient load sharing.

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