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Comparative Analysis of Grid Forming and Grid Following Converters in Time Domain and Phasor Domain Form

Umme Mumtahina
Central Queensland University
Rockhampton, Australia
u.mumtahina@cqu.edu.au

Sanath Alahakoon
Central Queensland University
Rockhampton, Australia
s.alahakoon@cqu.edu.au

Peter Wolfs
Central Queensland University
Rockhampton, Australia
p.wolfs@cqu.edu.au

***Abstract*—The purpose of microgrids is to deliver distributed power in distribution network. Microgrids increase the performance and reliability of the whole system by providing grid support services during the normal operation and also in islanded mode. This paper investigates two microgrid control techniques focusing on active-reactive power control and voltage-frequency control. At the converter level, this paper focuses on two microgrid configurations such as grid forming converter and grid following converter both in time domain and phasor domain form. It is shown that the computational time is much less in phasor domain form than the time domain form.**

Keywords—Grid forming converter, grid following converter, time domain form, phasor domain form.

I. INTRODUCTION

Microgrids have become much popular due to aggregate conventional power sources and renewable energy sources [1-2]. Renewable energy sources are interfaced through power converters to the alternating (ac) transmission system [3]. Power converters have started to provide necessary support by modifying their active and reactive power based on local measurements of voltage and frequency [4]. When the renewable sources are connected, they produce more power than consuming which leads to the fundamental modification in the grid. Grid following converter emerges as a concept to inject power to the grid and to do that, it needs some kind of synchronization by using phase locked loop (PLL). However, the Grid following converters replicate the instantaneous inertial response of synchronous machines with a delay. Due to this, the performance is degraded [5]. As a result, Grid forming converters (GFM) are being considered as the foundation of the future power systems [6]. These converters allow transition from grid tied operation to islanded operation in case of any emergency or any fault.

To have an effective and stable microgrid operation, a proper control is necessary. The primary control has to have a feature of maintaining the regular operation without communication. The converters are required to work in a synchronized manner only on local measurements and the control technique will decide the roles of each converter. Several control techniques for grid forming converters have been proposed in [7]. These converters are controlled to maintain a stable voltage and frequency. Moreover, grid following converters are controlled to track the power references. All of these converters controllers are simulated in time domain. However, if these controllers were designed inn phasor domain, computational time would be much less.

In this paper, for grid forming converters two cascaded synchronous controllers are designed. For grid following converter, a power control loop and an inner current loop is designed to track the specified power reference of the grid. These controllers have been tested in three stages. First stage is to include the converter switching stage. Second stage is, instead of using switching stage, controlled sources have been used. These two stages simulation have been done n continuous time domain. Whereas, the last stage simulation is done in phasor domain form. The time required for simulation has been significantly reduced in phasor domain form.

II. POWER CONVERTERS IN MICROGRIDS

A. *Grid Forming Converter (GFM)*

In a microgrid, the grid forming converters (GFM) are controlled in a closed loop to maintain stable frequency and voltage. These converters work as ideal ac voltage sources. GFM inverters represent low output impedance. Therefore, for the parallel operation of several GFM converters, accuracy in synchronization system is needed. When the microgrid operates in a certain limit, these converters remain disconnected. But, in case of emergency such as grid failure or in an islanded mode operation, GFM converters form the grid voltage which will be used as a reference voltage for the rest of the system.

An example of a control block diagram for a grid forming converter with the switching stage is shown in Fig. 1. which consists of an inner current control loop and outer voltage control loop. The inner current loop regulates the converter current and the outer voltage control loop controls the grid voltage. The inputs to the controllers are the given voltage amplitude v and frequency ω at the point of common coupling (PCC). Voltage amplitude v is the vector representation of three phase ac voltages. Similarly, current i is the vector representation of three phase output currents of the converter.

$$v = \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (1)$$

$$i = \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (2)$$

where, v_a, v_b, v_c are the instantaneous voltages of Phase A, B, C respectively. i_a, i_b, i_c are the instantaneous currents of Phase A, B, C respectively.

The three phase voltages are converted into dq voltages which are represented by v_d and v_q. In the outer loop, the input to the controller is the difference between the reference voltages $v_{d(ref)}$ and $v_{q(ref)}$ and the measured voltages v_d and v_q respectively. The output of the PI controller is the current reference signal for inner current loop. The error signal between this reference and measured current i_d and i_q again passes through another PI controller. Then, these voltage signals from both dq reference frame are converted into abc reference frame which is now represented as u_{abc}. As this stage has the switching converters, these signals generate pulse width modulated signals (PWM) for switches.

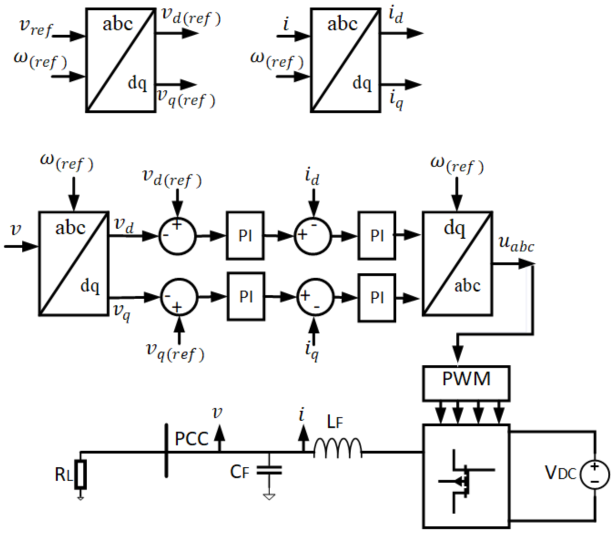

Fig.1 Basic control structure for grid forming converter including switching stage

The control block diagram for grid forming converter without the switching stage is shown in Fig. 2 where u_{abc} is the controlled three phase voltages. In this PWM generation is disregarded and replaced with controlled voltage source.

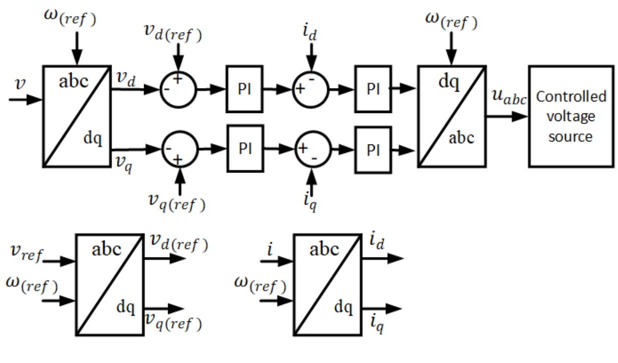

Fig. 2 Control structure for grid forming converter without the switching stage

In this stage, the controlled voltage source has been used instead of using converter switches. The rest of the system is the same. As, in high configuration microgrid, the losses in converter switches do not represent much difference, then it is better to use controlled sources instead of using switches from simulation time perspective.

Grid forming converter in Phasor Form:

Three phase ac voltages in phasor form are represented as:

$$v_a = Ae^{j0} \tag{3}$$

$$v_b = Ae^{j\frac{2\pi}{3}} \tag{4}$$

$$v_c = Ae^{-j\frac{2\pi}{3}} \tag{5}$$

Three phase ac voltages in phasor form are represented as:

$$i_a = Ae^{j0} \tag{6}$$

$$i_b = Ae^{j\frac{2\pi}{3}} \tag{7}$$

$$i_c = Ae^{-j\frac{2\pi}{3}} \tag{8}$$

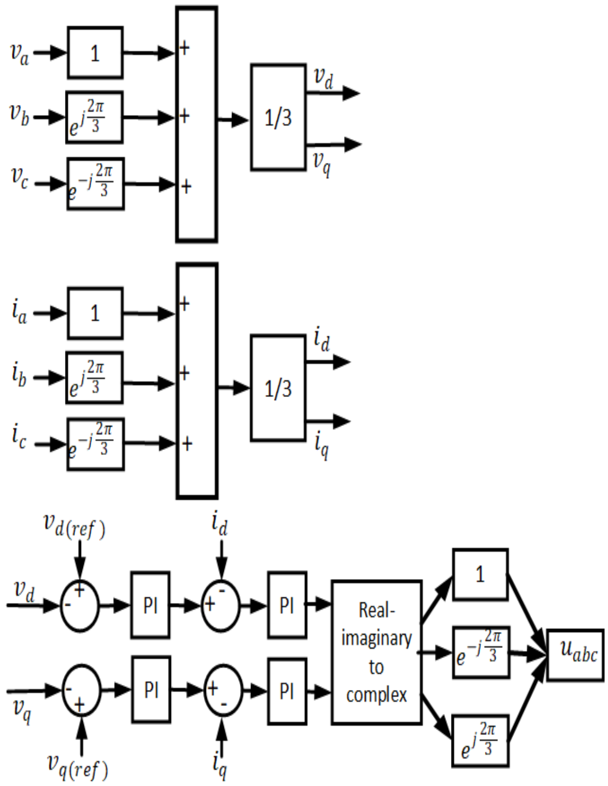

Fig. 3 Control structure for grid forming converter in phasor domain

The control diagram for grid forming converter in phasor domain is shown in Fig. 3.

B. Grid Following Converter (GFL)

The grid following converter tracks the specified power references. The control block diagram of the grid following converter with the switching stage is shown in Fig. 4. For dispatchable micro-sources, the converter power references can be set directly according to the practical requirements. For non-dispatchable micro-sources the voltage controller of the converter DC bus decides the active power reference [8-9]. These converters are suitable for grid connected mode. They cannot operate in islanded mode if there is no grid forming converters connected in parallel to the system. The output active (P) and reactive (Q) power of the converter can be calculated according to the instantaneous power theory by:

$$P = v_d i_d + v_q i_q \tag{8}$$

$$Q = v_d i_q - v_q i_d \tag{9}$$

In the outer loop, the input to the controller is the difference between reference values of the active and reactive power $P_{(ref)}$ and $Q_{(ref)}$ and the output active (P) and reactive (Q) power of the converter. The output of the PI controller is the current reference signal for inner current loop. The error signal between this reference and measured current i_d and i_q again passes through another PI controller. Output of these PI controllers are u_d^* and u_q^*. The voltage signals in dq reference can be found by using coupling of dq axis inductor current components.

$$u_d = u_d^* - i_q * \omega L_F \tag{10}$$

$$u_q = u_q^* - i_d * \omega L_F \tag{11}$$

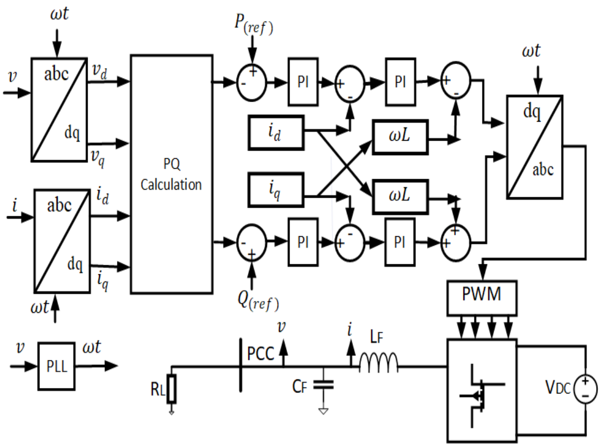

Fig. 4 Basic control structure for grid following converter with switching stage

Fig. 4 can be simplified without the switching stage which is shown in Fig. 5. In this PWM generation is disregarded and replaced with controlled current source. Only the power control loop has been used. Current response is sufficiently fast to disregard inner current loop compared to outer loop.

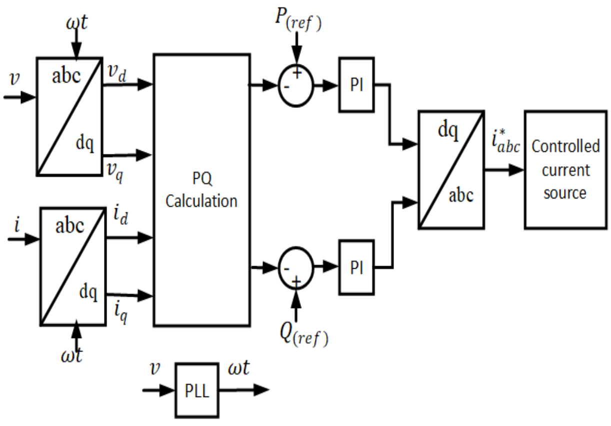

Fig. 5 Basic control structure for grid following converter without switching stage

The control diagram for grid following converter in phasor domain is shown in Fig. 6.

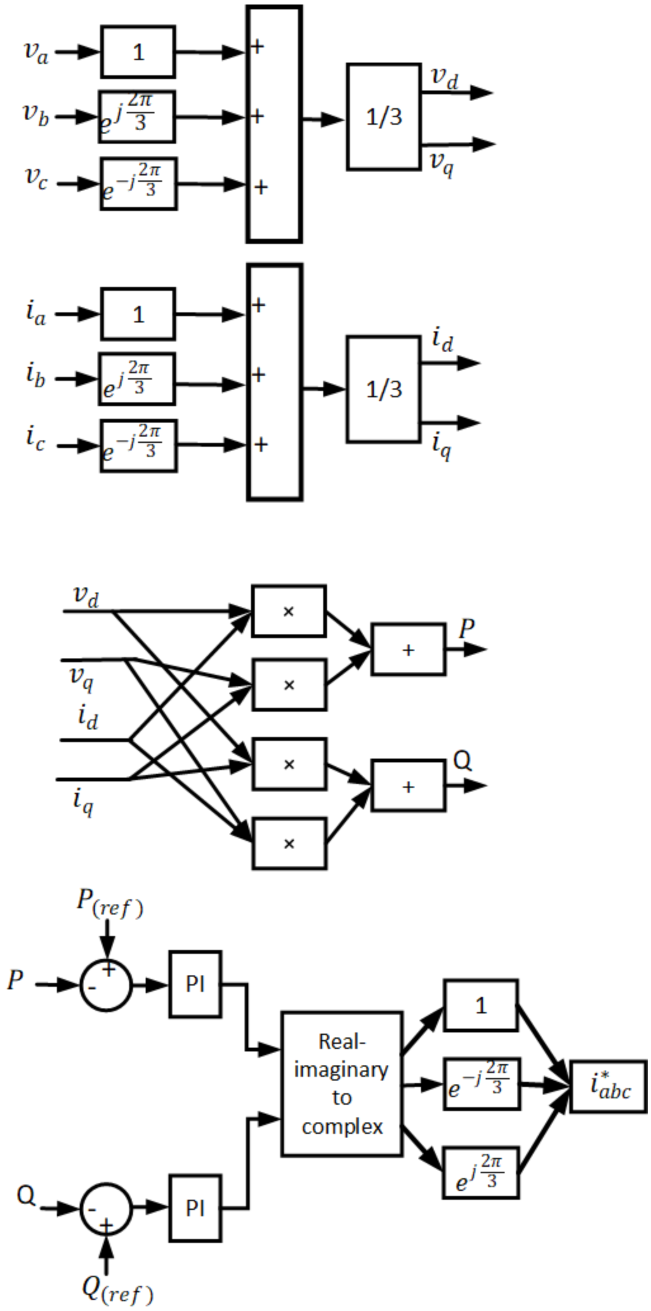

Fig. 6 Basic control structure for grid following converter in phasor domain

III. Simulation Results

A. Grid Forming Converter (GFM)

The three phase voltages and currents of grid forming converter with switching stage at the PCC are shown in Fig . 7. Line impedance is considered as 0.1 Ω and 300 μH. The load is 100kW. At 0.3 sec, a step change of load 100kW occurs and it remains until 0.7 sec. The simulation is done in MATLAB/Simulink environment. The computational time for this stage is 2224.25sec. the computational time is found from the profiler report available in MATLAB. The three phase voltages and currents of grid forming converter with controlled voltage source are shown in Fig. 8. The computational time for this stage is 1320.45 sec. The three phase voltages and currents of grid forming converter in phasor domain are shown in Fig. 9. The computational time for this stage is 780.23 sec.

B. *Grid Following Converter (GFL)*

The three phase voltages and currents of grid following converter with switching stage at the PCC are shown in Fig .10. Line impedance is considered as 0.1 Ω and 300 μH. The load is 100kW. At 0.3 sec, a step change of load occurs, and it remains until 0.7 sec. the computational speed for this stage is 283.47sec. The three phase voltages and currents of GFL with controlled current source are shown in Fig. 11. The computational time for this stage is 91.95sec. The three phase voltages and currents of grid forming converter in phasor domain are shown in Fig. 12. The computational time for this stage is 10.68 sec.

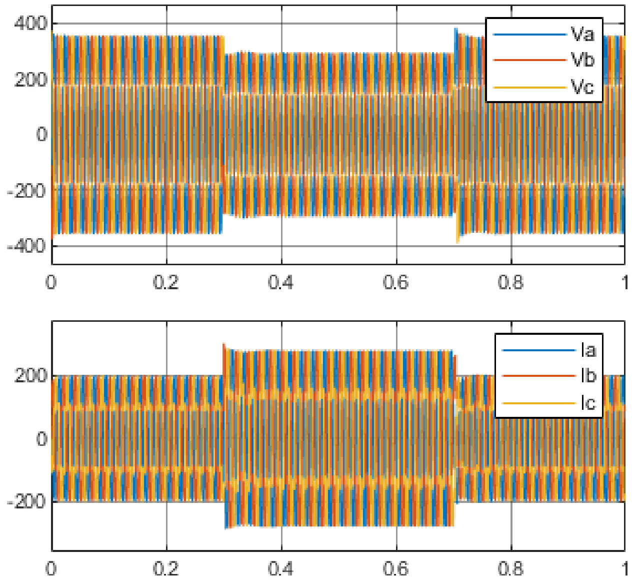

Fig. 7 Three phase voltages and currents of grid forming converter with switching stage with a step change at 0.3s to 0.7s.

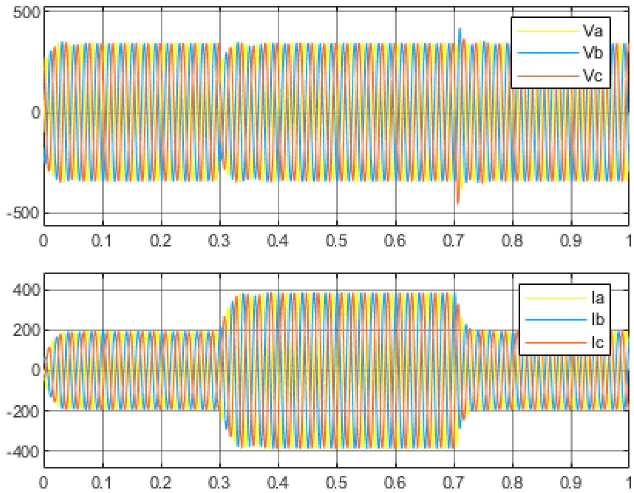

Fig. 8 Three phase voltages and currents of grid forming converter with controlled voltage source with a step change at 0.3s to 0.7s.

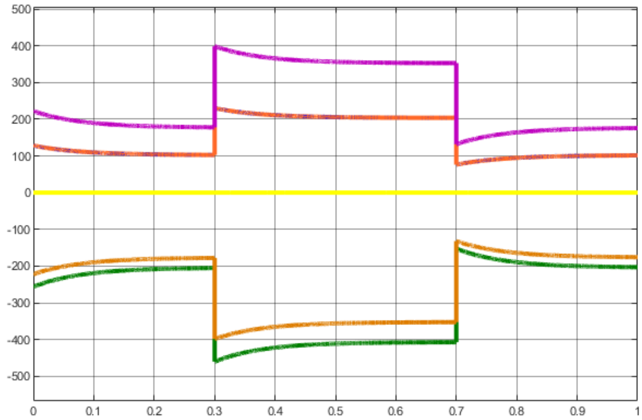

Fig. 9 Three phase voltages and currents of grid forming converter in phasor domain with a step change at 0.3s to 0.7s.

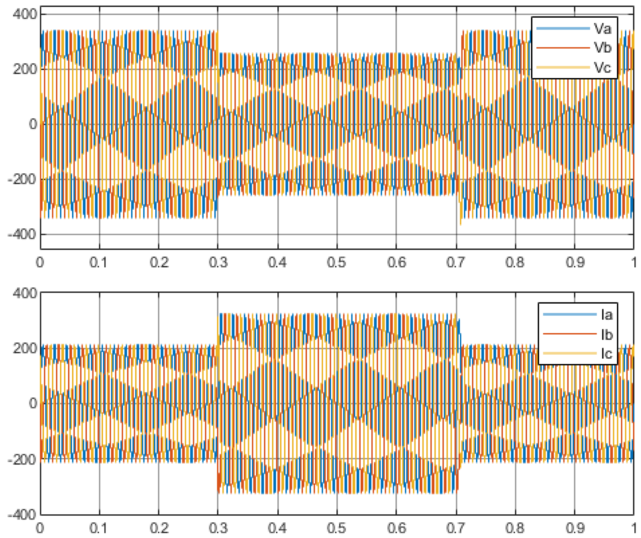

Fig. 10 Three phase voltages and currents of grid following converter with switching stage with a step change at 0.3s to 0.7s.

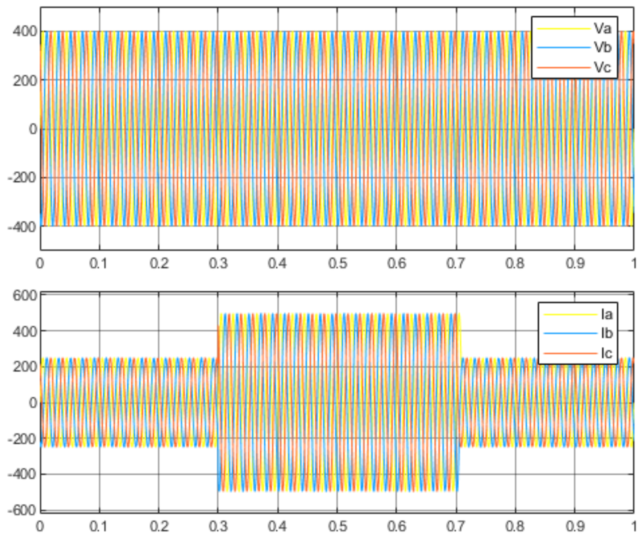

Fig. 11 Three phase voltages and currents of grid following converter with controlled current source with a step change at 0.3s to 0.7s.

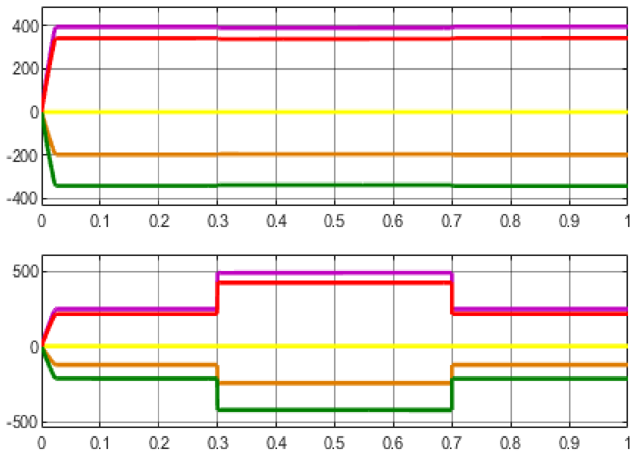

Fig. 12 Three phase voltages and currents of grid following converter in phasor domain with a step change at 0.3s to 0.7s.

IV. Conclusion

This paper has presented the two types of control techniques for grid forming and grid following converters. One is P-Q droop control and another one is V-f control. The paper has also reviewed the computational time required for these two converters in time domain and phasor domain. It is found that the computational time is much less in phasor domain than time domain form. The paper has only presented one converter at a time. However, in a larger microgrid system, these two converters along with multiple sources can be connected. In this paper, it is confirmed that if the simulation can be done in phasor domain, it could save significant amount of computational time required for simulation.

V. References

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