CONTROL TOPOLOGIES INVESTIGATION OF PARALLEL INVERTERS BASED ON VIRTUAL IMPEDANCE

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Abstract. *While designing Microgrid control, it's important to make sure that each unit is stable situation. To connect distributed generation units with loads and the utility grid, microgrids use inverters. Due to the variety of energy sources high-reliability inverters and converters are required to provide regulated power to customers and facilitate microgrid integration. The modelling, control design, and stability analysis for two various inverter topologies are considered in this paper. This makes the system less stable. The Bode Plot method is used to study the stability of single and double loop voltage controllers. To make the system more stable, it is suggested to use a controller based on virtual impedance. The simulation results are put into MATLAB/Simulink to check that the theoretical analysis is correct and that the proposed controllers work well.*

Keywords**:** *microgrid, inverters, virtual impedance, bode plot.*

1. Introduction

The Microgrid (MG) is a key component of Smart Grid. The terms “Microgrid” refers to a single power entity which includes distributed generation, energy storage devices, point of common coupling, power electronic devices (inverter, controller, static switch), and flexible loads. Penetration of distributed energy resources (DERs) to a distribution network causes impacts in the stability of power systems [1]. MG uses inverters to connect distributed generation units (DG) to the grid or to loads [2-4]. The parallel work of inverters provides a high reliability and redundancy of the MG system. One of the best things about parallel inverters is that each one is built to be strong so that they can work together without causing problems in the systems. Droop control is typically used to wirelessly share power between inverters [5-7]. Still, Power-sharing accuracy and stability are impacted by the fact that DG units don't have the same output impedance. This is because all paralleled inverters have different cable lengths. The research suggests a number of ways to deal with these problems [8-10]. But not enough research has been done on how the different feedback signals of the voltage control loop affect the shape of the output impedances. In this paper, the effect of single-loop and double-loop voltage controllers on stability is studied. When feedback is created using the capacitor and inductor currents, the Bode plot method is used to study how the system works. Also, differences between parallel inverters' output impedance types (resistor or inducer) can change how well power is shared and make the system less stable. By making the nature of output impedance the same, the virtual impedance is suggested to make system stable. Results of the simulation are shown to prove that the control strategy works.

2. Materials and methods

This work is continuing our previous works related to MG design and modelling of Karabuk university (KBU) campus as shown in Fig.1 [11-12]. MATLAB/Simulink has been used to check that the theoretical analysis is correct, that the proposed controllers are reliable, and that they work well. The Bode Plot method is used to study the stability of single and double loop voltage controllers.

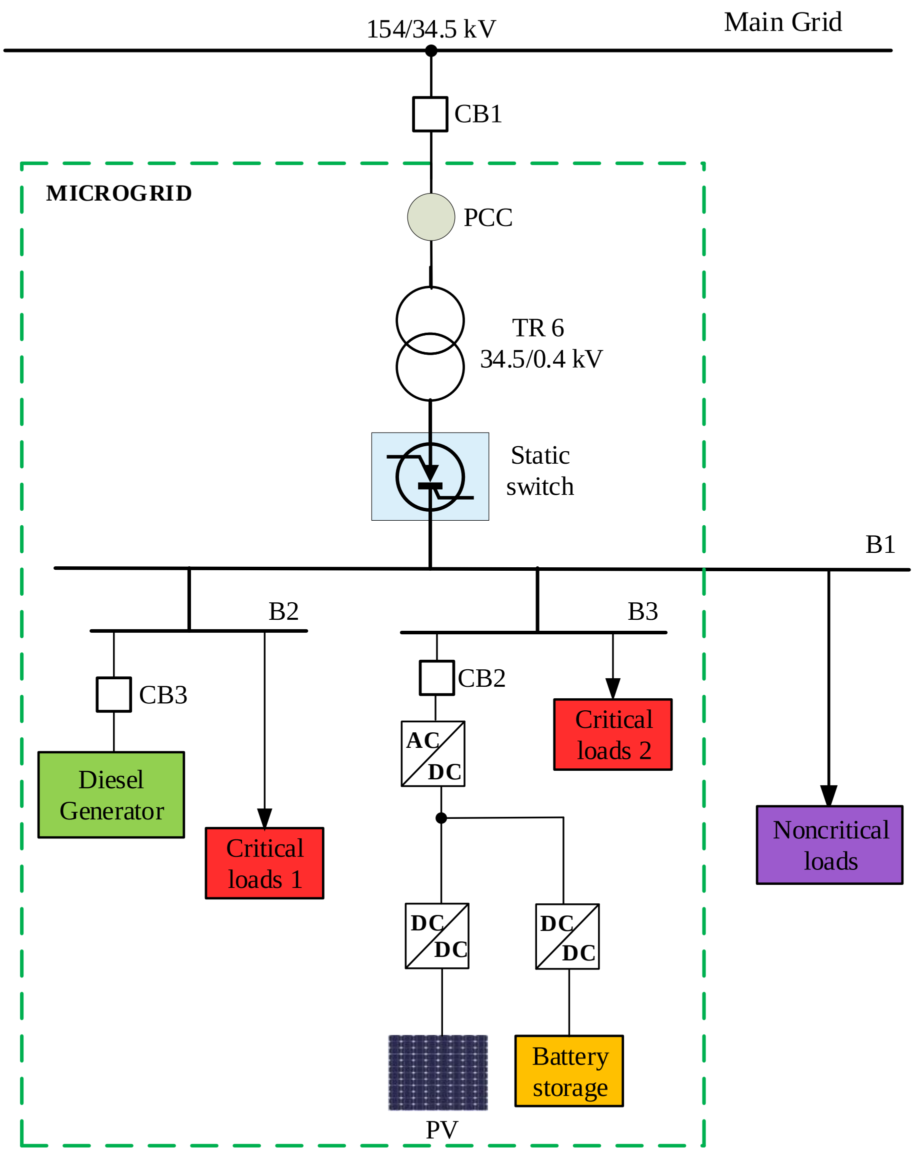


Fig 1. Single line of KBU microgrid [11]

2.1. Single-loop voltage controller

The inverter connects the power source to the load. Fig. 2 shows the structure of the inverter and LCL-filter. Modulated wave signals from voltage controller deliver to IGBT switches. Most of the time, PWM is used to get a modify sine wave. The signal's duty cycle can be changed in some way in which average voltage signal looks like a pure sine wave, which is used to control switching. This makes high-frequency harmonics with a sine signal's fundamental frequency [13].

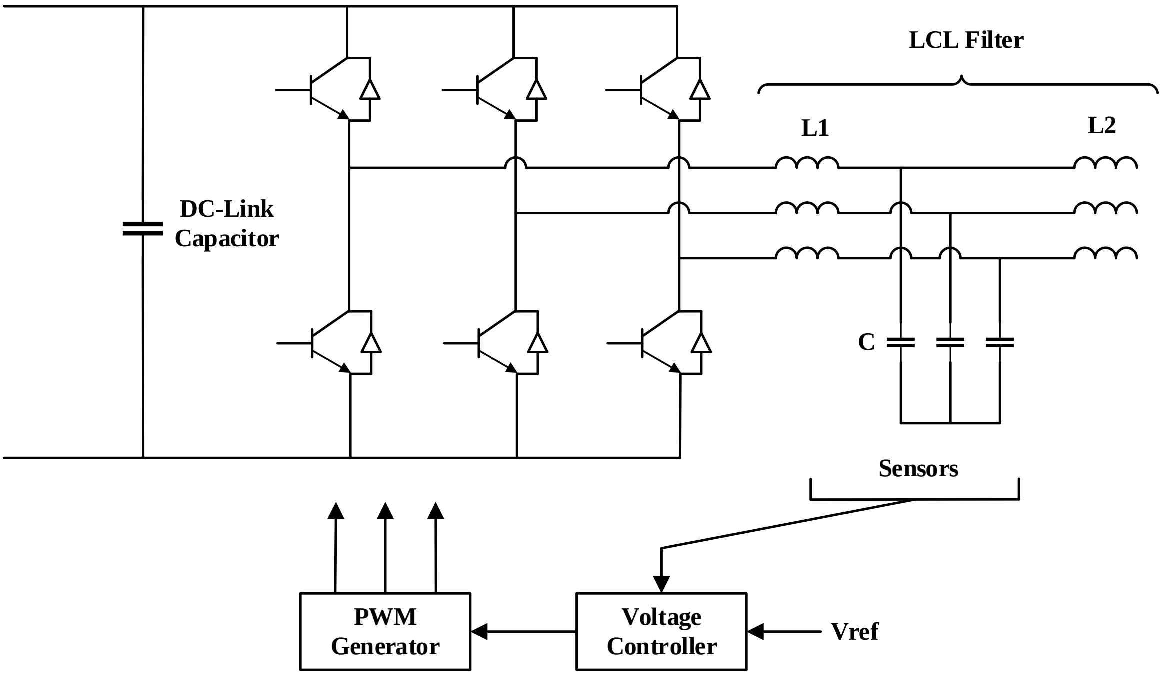


Fig 2. Inverter general structure & LCL [8]

The feedforward loop helps support the proportional controller K_v. This loop cuts down on steady-state mistakes. The physical model of LCL filter and single-loop for the VSI is illustrated in Fig. 3. Voltage feedback is measured at the filter capacitor's ends and compared to a reference point, then controller makes the signal that tells the PWM what to do [13]. The output voltage is calculated as

$$V_o(s) = G(s) * V^*(s) - Z_o(s) * I_o(s) \quad (1)$$

where: $G(s)$ – system transfer function that relate V^* and V_0, Z_o – output impedance closed loop system. Transfer function $G(s)$ is given as follows:

$$G(s) = \frac{K_v+1}{L_1Cs^2+K_v+1} \quad (2)$$

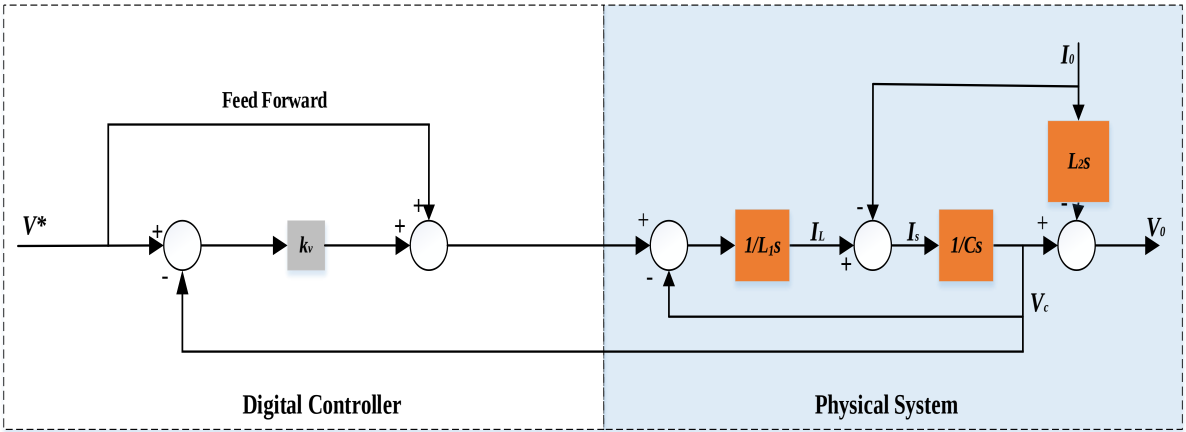


Fig 3. Single-loop voltage controller model

Fig.4 shows this through the Bode plot of transfer function *G(s)*. In Fig.4, peak at 500 Hz is called a resonance, this frequency is easy to change with any harmonic or with noise and interference. This signal is made stronger by large loop gain, which makes the output unstable or distorted. If a more gain is used, the resonance isn't stopped, but the frequency of the resonance moves up a bit.

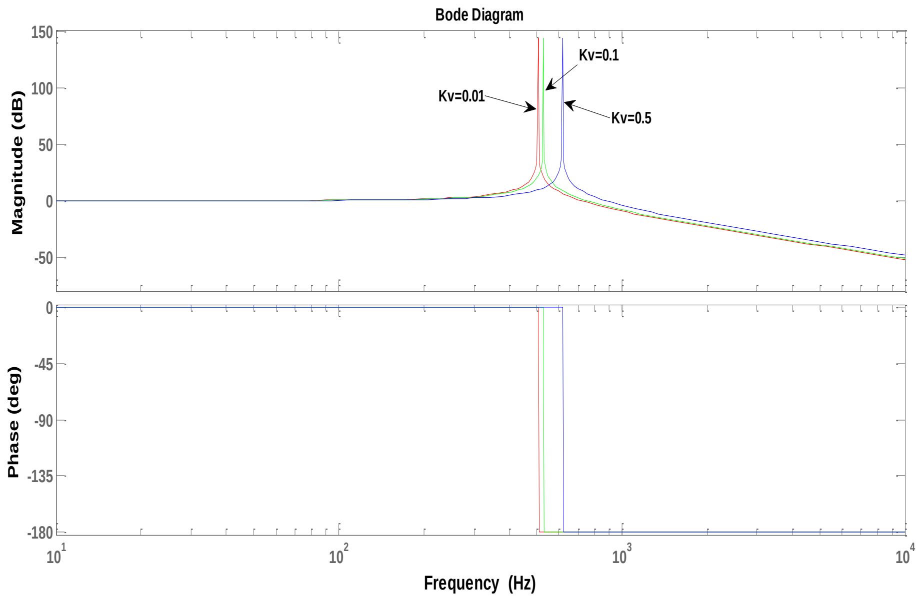


Fig 4. Bode-plot of the single loop voltage controller.

2.2. Double loop voltage controller

The output voltage of double-loop voltage controller is used to feed back into the first loop. Fig. 5 shows that the internal second loop use of the inductor L_1's feedback current or the capacitor C, so in either case, the damping could be done effectively. However, the output impedance is employed in this study to talk about what happens when each of them is chosen [14–16].

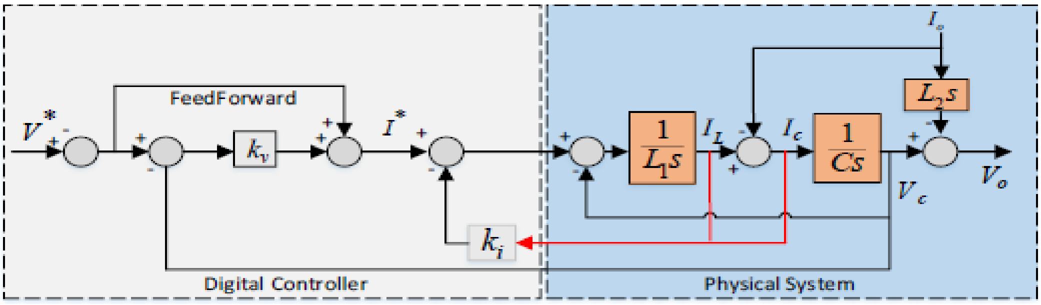


Fig 5. Double-loop voltage controller model

According to the Fig.5 the *G(s)* can be written as:

$$G(s) = \frac{K_v+1}{L_1Cs^2+K_i\text{C}s+K_v+1} \tag{3}$$

In (3), when the feedback loop is included, it is shown by the term "s," which gives damping. In Fig. 6 is illustrated Bode plot, which shows how the voltage loop works with different values of k_i for the current feedback gain. More gain leads will give you more damping. Note that every current feedback choice (I_C or I_L) leads to the same *G(s)*. Concerning $Z_0(s)$, there are 2 types of interior loop feedback, (I_C or I_L) that can happen. If the controller takes over I_L, $Z_0(s)$ can be written as

$$Z_{0L}(s) = \frac{K_i+L_1s}{L_1Cs^2+K_iCs+K_v+1} + L_2s \tag{4}$$

If the controller adopts I_C, $Z_0(s)$ could be obtained as (5) and, identified as Zo_C (s)

$$Z_{0C}(s) = \frac{L_1s}{L_1Cs^2+K_i\text{C}s+K_v+1} + L_2\text{s} \tag{5}$$

Figure 7 shows the Bode plot diagram for output impedance, which can be found in (4) and (5). If I_L is used, the Z_o will be resistive around the fundamental frequency. This means that the gain will be almost the same over a wide range of frequencies. But in the case of I_C, as the frequency goes up, the Z_o acts like inductor. In both cases, There existed a resonance at the natural frequency. However, it was dampened by the internal current loop.

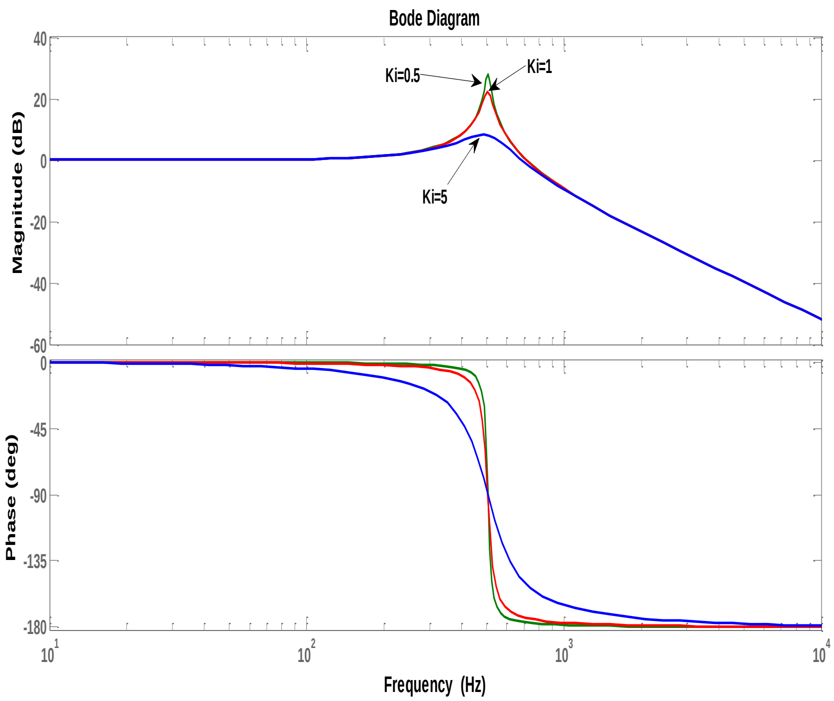


Fig.6. Double loop voltage controller's Bode plot

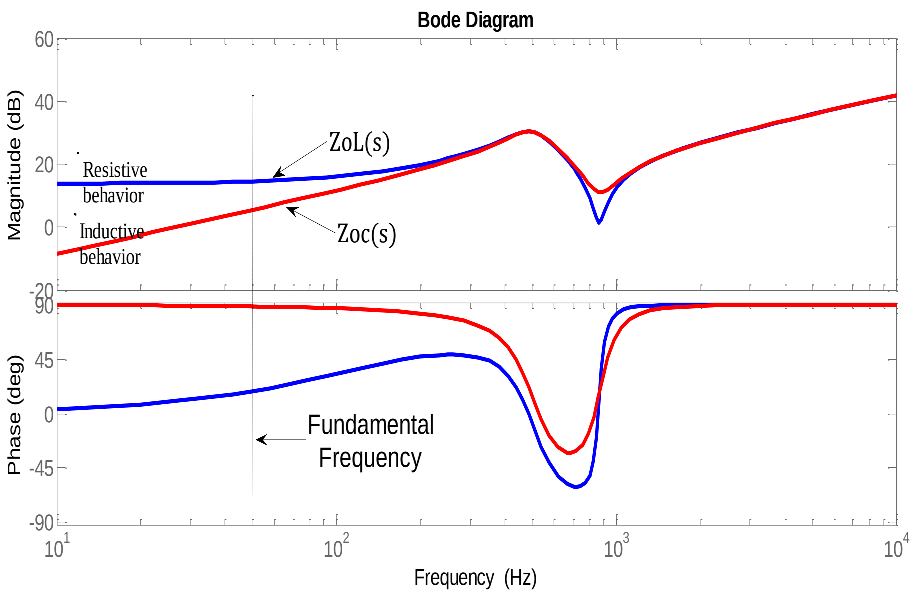


Fig.7. Bodeplot of Z_o with I_L and I_C as feedback

2.3. Proposing of the virtual impedance

In this work, the virtual impedance principle is used to make the output impedances of parallel inverters have the same behaviour. This impedance by a software mimic how a resistor or inductor works. Losses and costs can be cut by using a programmable impedance instead of a physical one. Programmability is also an adaptive process that makes the inverter more resistant to changes in the impedance of the network. the dual-loop voltage controller block diagram including virtual impedance $Z_v(s)$ is given in Fig.8.

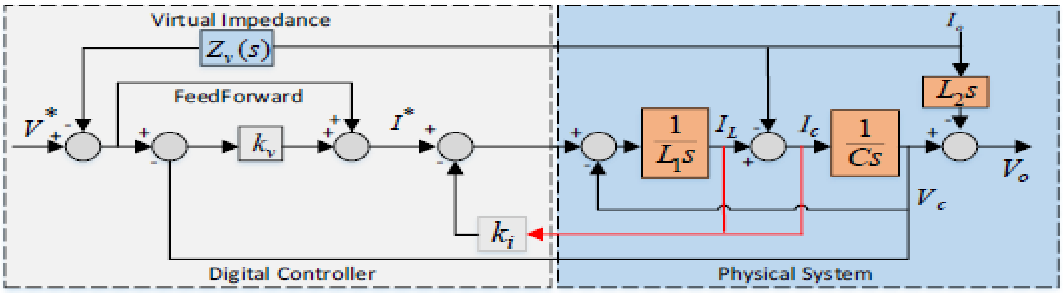


Fig 8. Dual-loop voltage control model with $Z_v(s)$

$Z_{ov}(s)$ can be calculated as follows:

$$Z_{ov}(s) = Z_o(s) + G(s)Z_v(s) \tag{6}$$

Then Z_v can be selected to be inductive as,

$$Z_v(s) = \frac{s}{\tau_v s+1} L_v \tag{7}$$

where L_v is an inductive virtual impedance, and τ_v is a time constant.

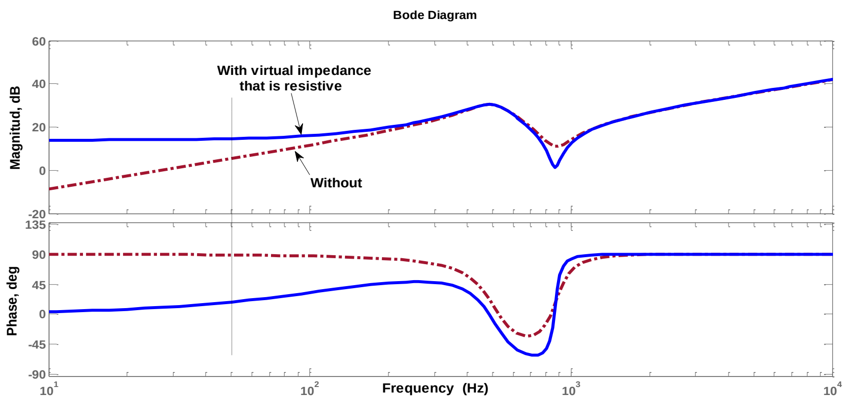
The virtual inductance as follows:

$$Z_v = sL_v \tag{8}$$

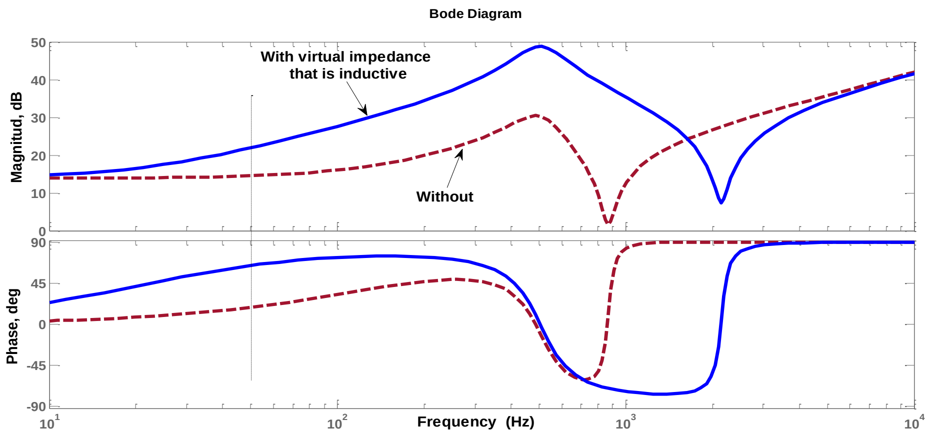
Or it could be resistive as,

$$Z_v(s) = R_v \tag{9}$$

While the parallel inverters work together to share power, their droop equations must be the same for accuracy. It can be done, but only if all of the output impedances are either inductive or resistive in the same way. If the output impedances of parallel inverters are of different types, stability is lost. So, a Z_v has been proposed to make a system stable via making all output impedances the same. The Bode plot method in the MATLAB program is used to study how a system works. Fig. 9 shows how the virtual output impedance Z_{ov} changes this old output impedance from Fig.7. In Fig. 9(a), the Z_{vr} of the resistive type is used to change the inductive properties into the dominant resistance properties. In the same way, Fig. 9(b) uses the Z_{vi} of the inductive type to change the resistive properties into the dominant inductive properties. It is thought that Z_v has a big effect on output impedance and could take over at high values. Based on the results, it looks like the main job of virtual impedance is to help droop control work and keep things stable.



a)



b)

Fig.9. Bodeplot for Z_o using: (a) resistive Z_v; (b) inductive Z_v.

3. Simulation results

A single-line diagram of the parallel inverters for the MG is shown in Fig10. The first Inverter uses I_L as its feedback, while the second uses I_C. So, one of the inverters has an output with resistive impedance, and the other has an output with inductive impedance.

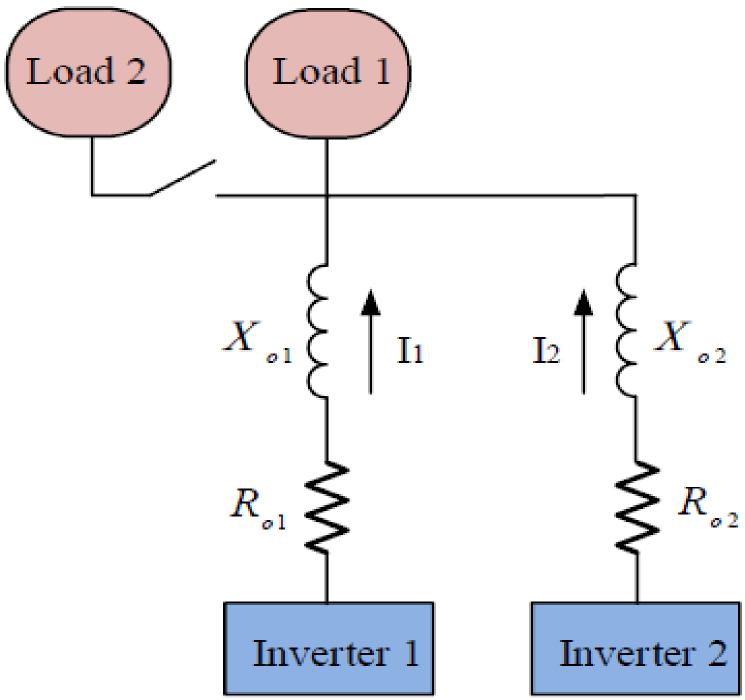
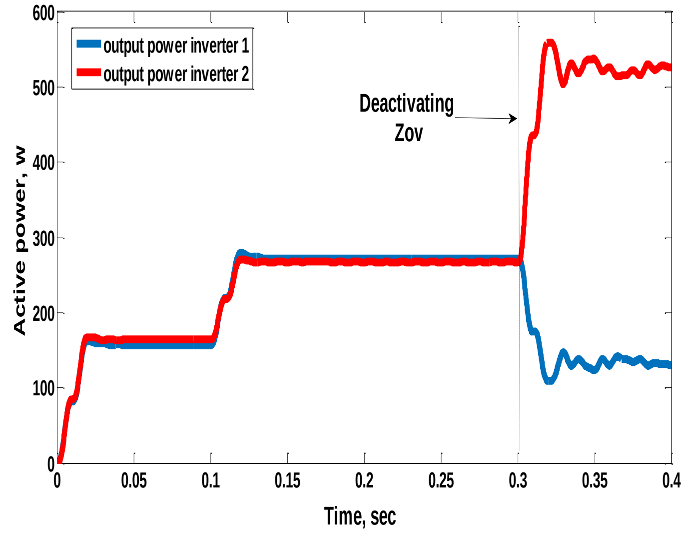
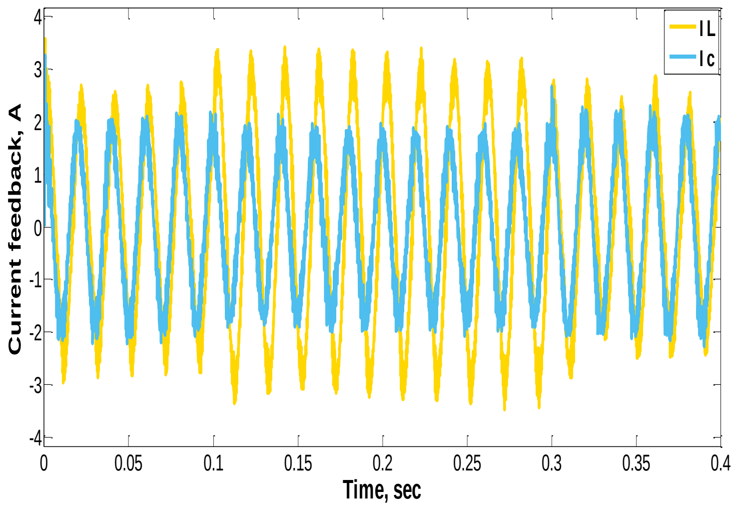


Fig 10. A single-line diagram of the parallel inverters for the MG

Two inverters have asked for the resistive droop controller to share their power. Because inverter 2 has a big inductive impedance, a virtual impedance is done on it. Fig.11 shows the output power of both inverters, which makes it easier to see how well Z_v works. Both inverters should have worked at the same time, and the Z_v works. At the time (t=0.1), a step loading was set up, and it was seen that both output power are well damped and sharing is possible. At the time (t=0.3), the Z_v was turned off, which stopped the power responses from being shared and stable. The results seem to show that virtual impedance is an important part of how droop control works. Low droop gains could help keep things stable. But that slows down the way power works and makes sharing less accurate. So, virtual impedance gives you more room to be stable while getting higher gains.



a)



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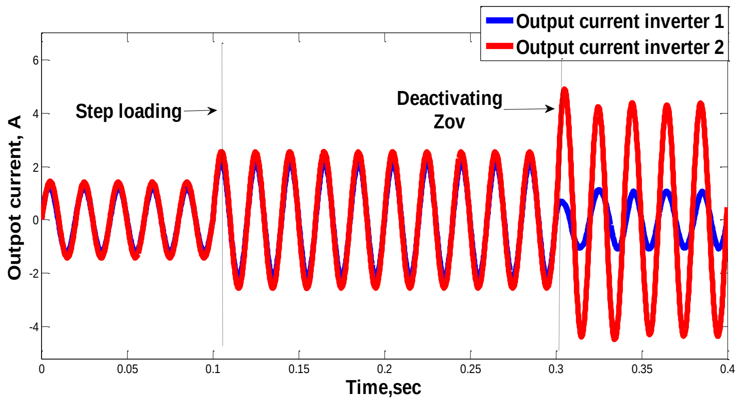

c)

Fig.11. Active power and current responses: a) active power responses; b) current feedback responses; c) output current inverters responses

4. Conclusion

In this study, a modelling analyse of voltage control loops showed that a dual-loop strategy is better at stopping resonance than a single-loop strategy. Also, the results show how the output impedance changes when different feedback signal are looked at. The virtual impedance is suggested as a way to make sure that the droop control works properly and to make sure that all of the controlled inverters have the same kind of output impedance. The results of the simulation were used to check how well and how well the proposed controller works.

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