

# Applications Through Virtual Synchronous Generators (VSG) Simulation Connected in Parallel

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**Abstract**—With the growing development of renewable energies, the concept of distributed generation has emerged, which consists of a cooperation of renewable sources with traditional generation sources. Because renewable sources use electronic devices for conversion to AC power and connection to the grid, virtual synchronous generator (VSG) stands out, which allows the connection between these sources and improving the stability characteristics of the system in the face of frequency and voltage changes in the network. In a distributed generation, commonly have two cases, either several renewable energy sources connected to the grid, or said sources connected to each other in isolation from the grid; in both cases, supplying power to a total equivalent load. Having a parallel connection of two VSGs or more, whatever the cases, allows a better distribution of power handling before a load, however, it is necessary to be clear about the control criteria that are governed, since a bad parameterization of the control parameters can affect the desired response and stability of the network. Both types of connections (on-grid and off-grid) will be analysed for two VSGs with different characteristics connected in parallel and with their respective control strategy; simulation results show the effectiveness of such connections following the appropriate control criteria.

**Index Terms**—VSG, Droop control, On-grid, Off-grid.

## I. INTRODUCTION

The renewable energies developing has given importance to use efficient, clean, and easy access energies with the aim to reduce the environmental impact due to electrical generation [1]. Join to renewable energies developing, the distributed generation concept has taken place and, with that, the microgrid developing, just is the case of photovoltaic energies [2]. However, due to renewable energies use within distributed generation, those are classified either “on-grid” (renewable sources connected to electrical grid to contribute with energy), or “off-grid” (renewable sources that supply energy to a small charge) [3].

Nevertheless, since energy production in distributed generation using photovoltaic panels is in DC, they need inverters to be connected to electrical grid. Inverters can follow the grid [6], a difference of conventional generation systems which provide inertia to grid due to use synchronous generators [4]. Having no inertia, inverters are susceptible to changes into the grids (like frequency and voltage) [5] and, whereby, carry harmonic and instability problems [4]. Because this disadvantage, several methods have been developed to emulate

the synchronous generator behaviour in inverters connected to microgrids [6] through programming its oscillation equations as control strategy [7]. This kind of inverter is known as Virtual Synchronous Generator (VGS) or Synchronous Inverter [8].

Within the features the synchronous inverters are the virtual inertia setting, power distribution and stability [9] [10]. Therefore, one of the most used techniques in this inverter types is the Q-V and P-w droop control to maintain stable the frequency and voltage levels in the network [11]. In this present paper, will be carried out through simulation of the connection of two synchronous inverters connected in parallel being used as on-grid and off-grid and supplying energy to a specific load.

## II. METHODOLOGY.

Figure 1 shows a simplified block diagram for a VGS control. Considering that the renewable energies used in microgrids mainly deliver energy in DC power, its representation will be simplified as only one DC voltage source. This DC source is connected to inverter to convert the voltage in AC power and with frequencies of 50Hz or 60 Hz. As the inverter uses power transistors with a fast-switching process to transform the voltage DC to AC, a LCL filter is connected to the inverter output to delete harmonics [12]. LCL output is connected to the grid, and they together supply energy to the load.

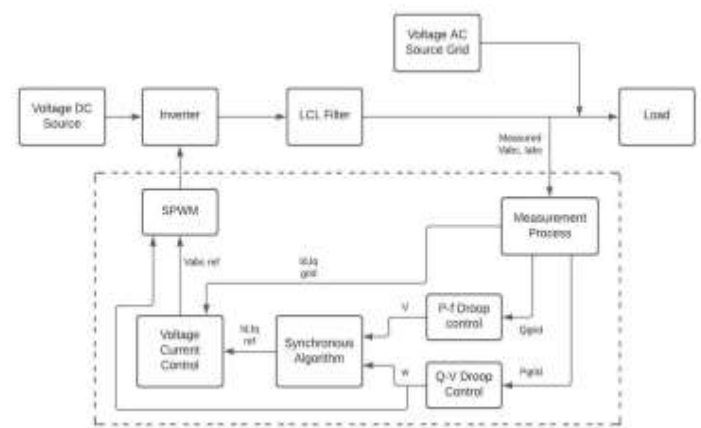


Fig. 1. Block diagram of control for one VGS connected to a small grid.

Talking about control, measurement process block uses Park's transform to have the currents and voltages of the grid in dq quantities to handle these variables in a static plane which facilitates their processing and calculation for analysis [13]. Furthermore, this block delivers active and reactive power to be processed in their respective controls (P-f and Q-V droop controls). Synchronous Algorithm block takes control variables from P- $\omega$  and Q-V droop controllers (frequency and voltage) and estimates the reference current with the aim to calculate the three-phase reference voltage which will be processed by SPWM, and it sends the desired pulse train to the inverter gate [14].

#### A. P- $\omega$ and Q-V control

P- $\omega$  droop control allows control active power flow through grid frequency and maintain it stable, even if the power setpoint changes. In the other hand, Q-V droop control manages the reactive power flow and stabilize the voltage when there are fluctuations in it [12] [15] [16].

Equation (1) describe the power droop behaviour in steady state [17] but, as the control seeks to emulate the operation of a synchronous motor when appears load variations to remain constant frequency and active power, Swing Equation Function used in (2) represents its dynamic features [18] [20]. These equations perform the properly control loop for Power and frequency grid and Figure 2 shows common block diagram for this control.

$$P_{ref} - P = D_p(\omega - \omega_{ref}) \quad (1)$$

$$J \frac{d\omega}{dt} = P - P_{ref} + D_p(\omega - \omega_{ref}) \quad (2)$$

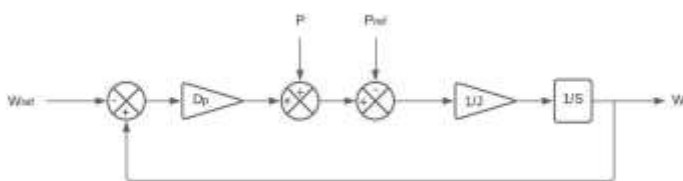


Fig. 2. Control droop P- $\omega$  block diagram of VGS.

Where  $\omega_{ref}$  and  $\omega$  are desired grid frequency and actual virtual frequency of VSG,  $D_p$  is droop coefficient of P- $\omega$  and is founded by counter diagram,  $P_{ref}$  and  $P$  are electromagnetic active power desired and active power given by the grid,  $J$  is the virtual inertia which emulates real synchronous motor inertia.

As mentioned above, terminal voltage of VGS is related with the reactive power flow and they have a droop feature [17]. Equation (3) describe this relation and figure 3. shows a common block diagram for this control.

$$Q_{ref} - Q = D_q(V - V_{ref}) \quad (3)$$

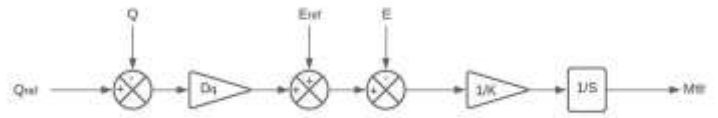


Fig. 3. Control droop Q-V block diagram of VGS.

Where  $V_{ref}$  and  $V$  are expected grid Voltage and actual Voltage of VSG,  $D_q$  is droop coefficient of Q-V and is founded by counter diagram,  $Q_{ref}$  and  $Q$  are electromagnetic reactive power desired and reactive power given by the grid. Sometimes, is useful adding an integrator or an PI controller to enhance the control response if the grid requires it.

#### B. Voltage and Current controls.

Two strategies are used together for the VGS control: voltage and current double closed control; furthermore, dq coordinates is proposed [13]. Voltage control manages the power flow using the shift between grid voltage angle and inverter output angle. Instead, the current control oversees regulating the current injected into the network, using SPWM technique [19]. Fig. 4 shows a general diagram for the control mentioned above.

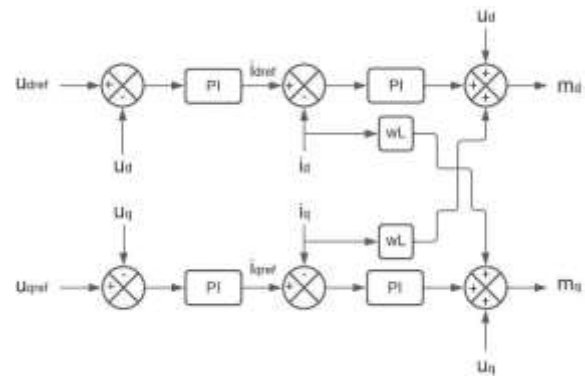


Fig. 4. Control voltage-current double loop block diagram.

### III. SIMULATION RESULTS.

Two cases of two different VSG in parallel will be analyzed under a specific load: On-grid case and Off-grid case. Dynamic and control models are developing in MATLAB/Simulink. Figure 5 shows the proposal control scheme for each VGS and it can be seen that for P- $\omega$  droop control is used an integrator, instead, Q-V control use a PI control to improve the voltage performance. For voltage and current control, the gains of the PI controller have been determined by trial and error.

Figure 6 and 7 shows the schematic for On-grid and Off-grid case, respectively. For both cases, Power measurements (active and reactive) is taken from the load to be fed back

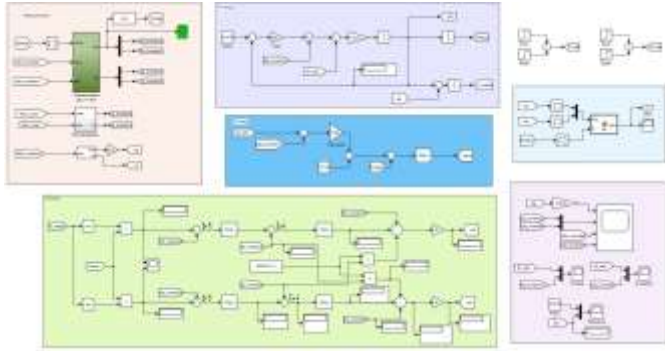


Fig. 5. MATLAB/Simulink model and control design.

in droop controls. In the other hand, for voltage and current control, output voltage and current for each VSG is taken and are being fed back into their respective controllers. In both cases, the VSG an initial charge of  $0.695KW + 0.357KV\ AR$  (In this case, it will be considered as no load), before 0.5 seconds, a load of  $4.33KW + 1.22KV\ AR$ , and finally, in 1.5 seconds  $2.62KW + 2.35KV\ AR$  is added (we will consider the sum of these two loads as full load). One VSG is rated with  $20KV\ AR$  and  $800V$ , and the second one is rated with  $15KV\ AR$  and  $800V$ . Frequency and line voltage grid is  $50Hz$  and  $400V\ rms$ . Droop constant is defined as  $D_p = \Delta P / \Delta \omega$  for  $P-\omega$  control, and  $D_q = \Delta Q / \Delta V$ . To demonstrate stability in the responses, the simulation time used is 5 seconds. Now, separate case results will be discussed.

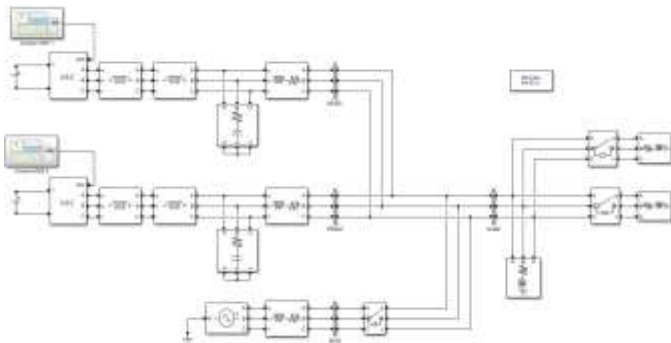


Fig. 6. MATLAB/Simulink schematic for ON-grid.

#### A. ON-Grid.

For ON-Grid case,  $\Delta P$  is taken as the difference between no load and full load, i.e.,  $\Delta P = 4.33[KW] + 2.62[KW] = 6.95[KW]$ ; while  $\Delta \omega$  in this case it must be very small since these VSG are connected to a mainly grid and large changes in their frequencies cause great harmonics in the grid, for this reason it is taken 0.05% of nominal frequency, i.e.,  $\Delta \omega = 0.0005(314.16[rad/s]) = 0.0628[rad/s]$ ; so that,  $D_p = 4.425 \times 10^4[ws/rad]$ . For  $\Delta Q$  is the same explanation said for  $\Delta P$ , so  $\Delta Q = 1.22[KV\ AR] + 2.35[KV\ AR] = 3.57[KV\ AR]$ ; while  $\Delta V$  must be small to don't affect the network voltage, therefore, it is chosen 5% of Line-Neutral grid

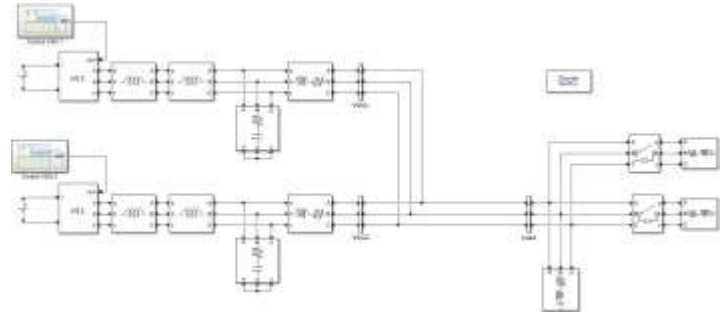


Fig. 7. MATLAB/Simulink schematic for OFF-grid.

voltage, i.e.,  $\Delta V = 0.05(400/\sqrt{3})[V\ rms] = 16.33V\ rms$ , so that,  $D_q = 218.617[\omega/V\ rms]$ .

Figures 8 and 9 show the frequency and voltage for each VGS, and we can realize that at the start of the simulation it is difficult for each inverter to connect to the grid, which is why it suffers a small underdamping within in a very short time but, within a permissible range. After that, each VSG is stabilized, keeps frequency and voltage constant, and contributes to the power delivery in the network. Figure 10 shows the active and reactive power of the load, and figures 11 and 12 show those powers comparing with the reference; the error for each one is small at the beginning, but in full load the error is practically zero. Finally, Figures 13 and 14 show the active and reactive power for grid, each VGS and load, and it can be observed that after the transient until the frequency and voltage values of each VGS, they share the energy which is transmitted to grid and load.

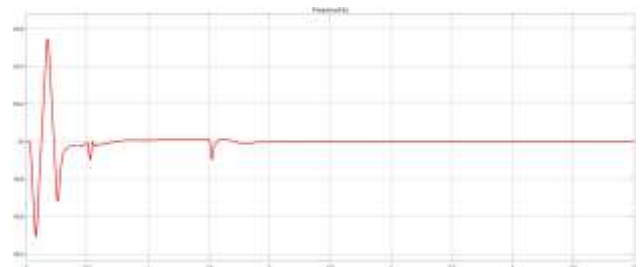


Fig. 8. Frequency for each VSG ON-Grid.

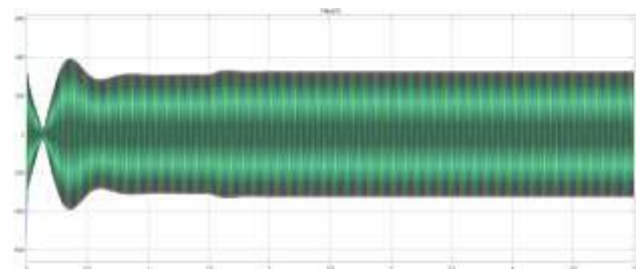


Fig. 9. Voltage for each VSG ON-Grid.

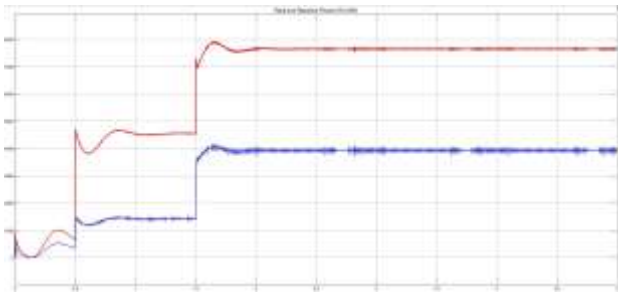


Fig. 10. P and Q on the load ON-Grid.

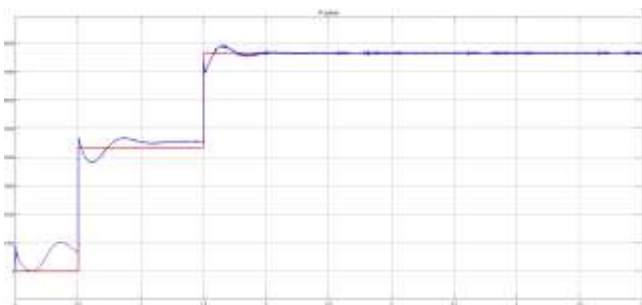


Fig. 11. Real active Power in the load, comparing with the reference. ON-Grid case.

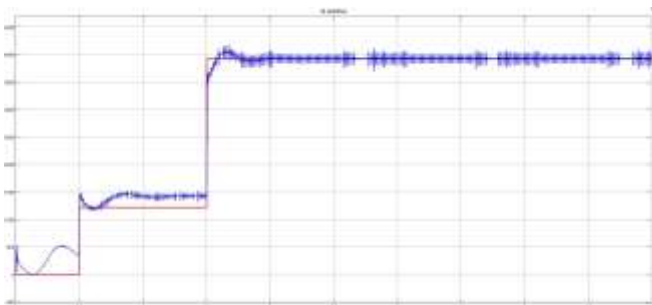


Fig. 12. Real reactive Power in the load, comparing with the reference. ON-Grid case.

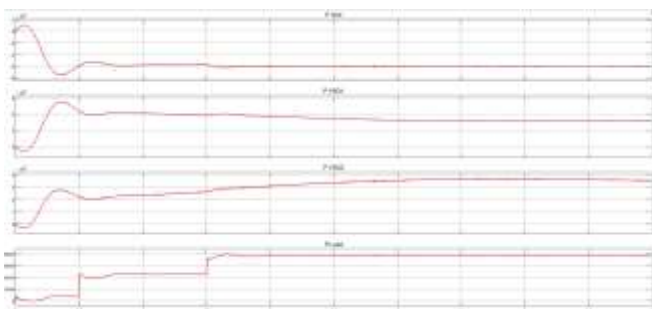


Fig. 13. Active power from the grid, inverters, and load. ON-Grid case.

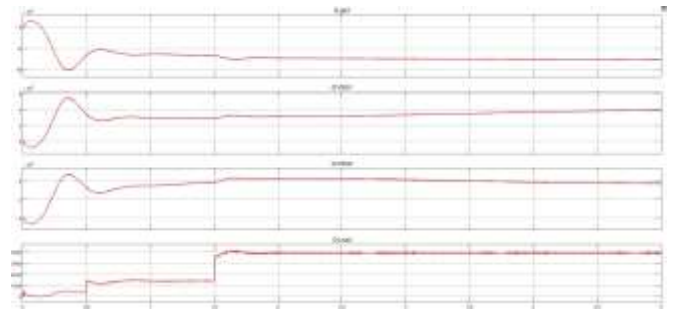


Fig. 14. Reactive power from the grid, inverters, and load. ON-Grid case.

### B. OFF-Grid.

In OFF-Grid case, P still the same but now may vary a little more, since the two VGS will be in charge of adjusting the frequency in the network, so it is taken 0.1% of nominal frequency, *i.e.*,  $\Delta\omega = 0.001(314.16[\text{rad/s}]) = 0.3142[\text{rad/s}]$ ; so that,  $D_p = 2.2123 \times 10^4 [\text{Ws/rad}]$ . Besides,  $\Delta Q$  also still the same and  $\Delta V$  may be a little more than previous case and it is chosen  $\sqrt{10\%}$  of Line-Neutral grid voltage, *i.e.*,  $\Delta V = 0.1(400/\sqrt{3})[\text{V}_{rms}] = 32.66\text{V}_{rms}$ , so that,  $D_q = 109.309[\omega/\text{V}_{rms}]$ .

Simulation results are shown. Figures 15 and 16 show the frequency and voltage for each VGS, there is a transient at the beginning of the simulation for those values and remain stable within a very acceptable range. It is true that the frequency fluctuates but its variations are very small, so it can be said that it is constant. For this case, the voltage varies in proportion to the increase in load, within the 10% established for the  $Q/V$  control. Figure 17 shows the active and reactive power of the load, and figures 18 and 19 show those powers comparing with the reference; and a good response is also presented in the power demand as in the previous case. Finally, Figures 20 and 21 show the active and reactive power for grid, each VGS and load, and it can be observed that the two inverters equally distribute the load according to their nominal powers

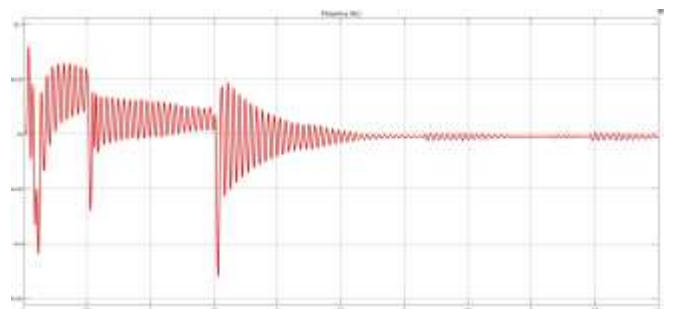


Fig. 15. Frequency for each VSG OFF-Grid.



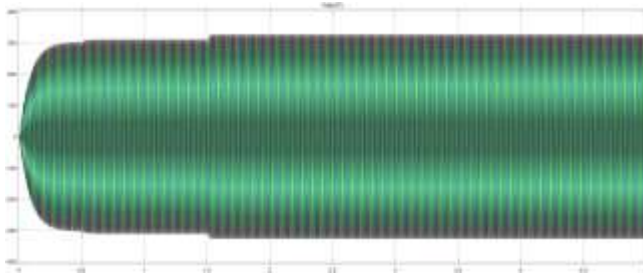


Fig. 16. Voltage for each VSG OFF-Grid.

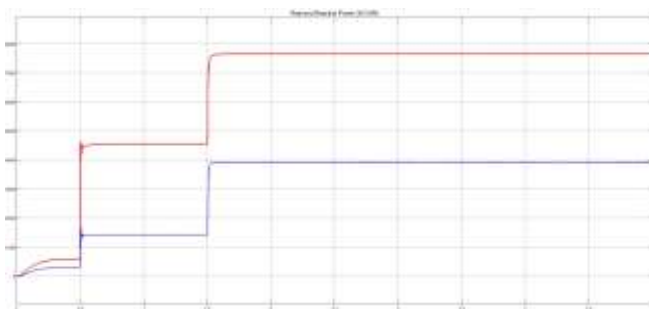


Fig. 17. P and Q on the load OFF-Grid.

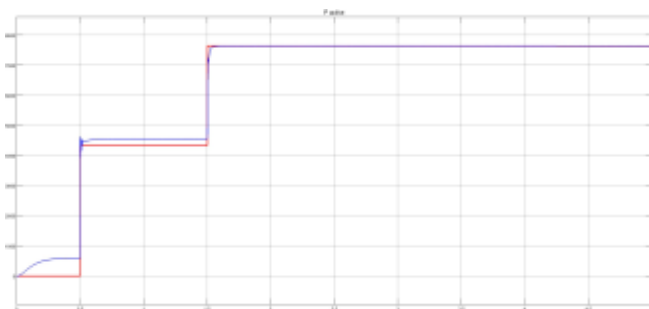


Fig. 18. Real active Power in the load, comparing with the reference. OFF-Grid case.

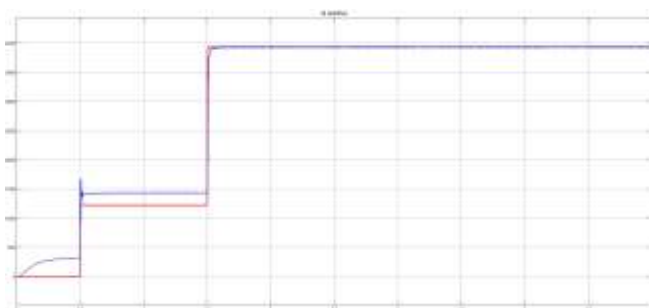


Fig. 19. Active power from the grid, inverters, and load. OFF-Grid case.

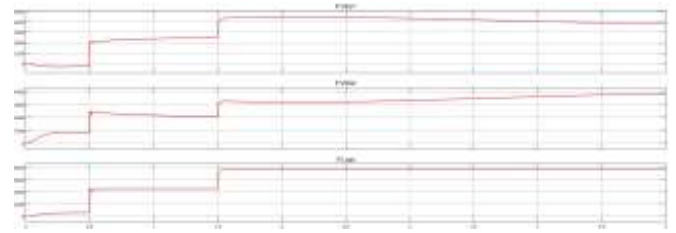


Fig. 20. Active power from the grid, inverters, and load. OFF-Grid case.

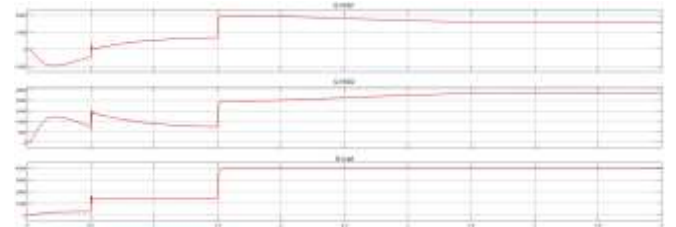


Fig. 21. Reactive power from the grid, inverters, and load. OFF-Grid case.

#### IV. CONCLUSIONS

For the connection between a VSG and an electrical network, a synchronization process is required and with a correct control of frequency and voltage drop, said connection can be achieved. However, when it comes to a connection of two or more VSGs, auxiliary strategies are required to improve synchronization and avoid problems. Several approaches in this field suggest taking the power measurement at the output of each inverter to feedback the droop controls, however, it was shown in this study that it can be practical and useful to take it from the load, if the purpose is to keep constant the power flow for that load, either if it has renewable sources connected in ON-Grid or OFF-Grid, since taking the power feedback in this way, frequency and voltage synchronization problems between the inverters connected in parallel with the network are avoided, having a better facility when designing the control for each VSG. Given the results presented in each simulation, it is crucial to know how to correctly size the constants of each droop control according to the needs of the loads and the nature of the VSG connection (ON-grid or OFF-grid). In these cases, for an ON-grid inverter connection, the frequency and voltage variation percentages must be small for the drop constants since with larger variations, stability in the voltage and frequency is lost, in addition to the fact that the power of the load begins to keep oscillating or having variations around the reference. On the other hand, for an OFF-grid connection, the voltage and frequency variations can be chosen with a higher percentage compared to the previous case, but it is recommended that the variation percentages are as small as possible and thus avoid fluctuations in the network frequency. Finally, this design can be transferred to more than two inverters connected in parallel, as long as the parameters of each controller for each inverter are well sized.

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