Sharing VSG Operation with Synchronous Generator

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Abstract. While several synchronous generators (SGs) are substituted through virtual synchronous generators (VSGs), some SGs remain in today’s microgrids. And the majority of the research assumes that VSG mimics SG characteristics, allowing it to function in parallel among SGs. However, few studies have gone to great lengths to study this concept. As a result, the paper’s goal system is a microgrid that runs both VSG and regular SG in parallel. In this article, new parameters for the VSG are designed in parallel with the SG. Then, in an independent microgrid, identical VSG-VSG and scenario SG-VSG configurations are fixed to equate the complex activity. The emotional responses contrasted when the load requirement is shared fairly and proportionally.

1. Introduction
Distributed generation (DGs) using renewable energy sources (RES) has been developed in recent years [1–3]. A dispatchable small (SG) using a diesel engine or a gas engine is typically used as the main power supply in a remote microgrid where the primary grid is not available. Meanwhile, as a secondary supply, an inverter-interfaced DG using RES, e.g. photovoltaic, can be used to save fuel consumption. Therefore, for parallel opera, the control system of the inverter-interfaced DG. The provision of additional inertia, albeit virtually, is developed to enhance such a grid's dynamic response. By integrating energy storage with suitable control mechanisms for the converter, virtual inertia can be formed in DG. By controlling the output of the converter, the action of a traditional SG is emulated. In this definition, when there are changes in the operating conditions or when disruptions occur in the power grid, the DG can be handled by the converter to exhibit responses close to that of a real synchronous machine [4–6].

The fundamental goal of the VSG is to imitate the complex properties and reaction of an actual SG for distributed generator units based on power electronics to inherit the SG's stability enhancement functionality. It mimics the steady-state action of the SG and its transient features by adding the swing equation to improve inertia in the controls. Therefore, this design is implemented to work in the same way as the synchronous generator, offering inertia and damping properties by regulating terminal voltage amplitude, frequency, and phase angle[7-13]. VSG. Thus, this paper focused on sharing the operation of similar VSG-VSG and SG-VSG with different results scenarios.

2. Third-order VSG model description
Please follow these instructions as carefully as possible so all articles within a conference have the same style to the title page. This paragraph follows a section title so it should not be indented[2-3].

As mentioned in the abstract from this paper, VSG needs to emulate one of the SG model's main characters: the stator voltage equation, especially when the parallel operation of a VSG and SG is
required. It is also beneficial to emulate the stator equation and improve the VSG model by increasing its order level. In the third-order VSG model, the synchronous reactance ($X_s$ and $R_s$) of SG is introduced into the VSG model to emulate the stator voltage equation in $abc$ a frame [14]. Figure 1 shows the equivalent circuit of the VSG. The back electromotive force can be deduced from the models as follows

\[ e = v_s + i_s \left( R_s + jX_s \right) \]  
\[ \frac{dv}{dt} = \frac{1}{C_f} i_s - \frac{1}{C_f} i \]  
\[ \frac{di_s}{dt} = \frac{1}{L_f} v_s - \frac{1}{L_f} v - \frac{R_f}{L_f} i_s \]

Figure 1. Equivalent circuit of a VSG.

Equation (3) describes the third-order VSG model.

\[ \begin{align*}
T_o \frac{d\bar{\omega}}{dt} &= \bar{T}_m - \bar{T}_e - \bar{D}\bar{\omega} \\
\frac{d\theta}{dt} &= \omega \\
e &= v_s + i_s \left( R_s + jX_s \right)
\end{align*} \] (3)

3. Matching VSG and small SG dynamic responses
Because SG can be designed to produce more than one cycle per revolution, it can turn slower and still make 50 or 60 Hz. Since a generator must turn at 3000 or 3600 rpm, we have to gear up the generator to get that speed. The gear ratio is determined by the poles pairs such that

\[ \omega_m = \frac{\omega}{p} \] (4)

Here $p$ is the rotor pole pairs. Since the minimum number of poles in any generator is 2, $p$ is considered equal to 1 pair in every VSG model, which means $\omega_m = \omega$.

For SG, $H$ often takes the following form

\[ H = \frac{1}{2} \frac{J (2\pi f_N / p)^2}{S_B} \] (5)
The nominal system frequency $f_N$ is given in electrical Hz and is independent of the number of the rotor poles.

In a parallel operation with a small SG, the VSG needs to emulate the pole pairs to match its dynamic with the SG dynamic because matching the only parameter $J$ is not enough.

$$\frac{J_{\text{VSG}}}{S_{\text{VSG}} \cdot p_{\text{VSG}}} = \frac{J_{\text{SG}}}{S_{\text{SG}} \cdot p_{\text{SG}}}$$  \hspace{1cm} (6)

Thus, the number of the rotor poles is considered one of the parameters affecting the microgrid dynamics containing VSG and SG.

Substituting $\omega_m = \omega / p$ from (4) into the swing equation, then

$$P_m - P_e = J \frac{\omega}{p^2} \frac{d\Delta \omega}{dt}$$  \hspace{1cm} (7)

When adding the damping term, the following equation can be written

$$J \frac{d\Delta \omega}{dt} = p^2 \left( \frac{P_m}{\omega} - \frac{P_e}{\omega} - D(\omega - \omega_N) \right)$$  \hspace{1cm} (8)

If $p^2$ equal to 1, equation (8) will return to the earlier expressed form.

$$J \frac{d\Delta \omega}{dt} = \frac{P_m}{\omega} - \frac{P_e}{\omega} - D(\omega - \omega_N)$$  \hspace{1cm} (9)

Figure 2 is deduced by the explanation given in (8). Where $D_m$ is the damping coefficient $D_m = p^2D$.

![Figure 2. VSG control diagram using the pole pairs to emulate the SG.](image)

4. Simulation results

4.1. Equal sharing

The dynamic behavior of a VSG with SG is studied in a parallel system. The simulation was carried out for the microgrid shown in Figure 3. The simulation parameters for the VSG are in Table 1. A load of 10kW/3kVar was connected.
Figures 4 displayed the effects for active powers, reactive powers, respectively. The same situation was acted out again, except this time with a VSG instead of the SG. The parameters for VSG2 are identical to those for VSG1. Figure 5 depicts the outcomes. Figures 4 and 5 similar show findings. As a result, we can infer that in the device stability analysis, SG can be substituted by VSG with similar power and gain from VSG's controllability functionality.

![Diagram](image_url)

**Figure 3.** Microgrid structure for simulation.

**Figure 4.** Paralleled-operated VSG and SG under equal sharing.

![Graph](image_url)

a) Active power.

![Graph](image_url)

b) Reactive power.
4.2. Proportional sharing
The VSG and SG have obtained accurate proportional load sharing in 2:1 throughout the operation, as shown in Figure 6, which indicates that the parallel system of a VSG with SG is realized effectively.
The results summarized that; first, it is possible to operate the VSG with SG in an islanded microgrid and realize power-sharing, as well as, it is feasible to replace SG by its equivalent VSG without any problem; second, besides mimicking the inertia, damping, droop functions, VSGs need to mimic the stator voltage equation to maintain the normal operating voltage in the parallel operation with SG. We suggest considering the number of the rotor poles when comparing a VSG with its analog SG.

5. Conclusions

While VSGs have mostly replaced SGs in today's microgrids, some SGs remain. And the majority of the paper inferred that VSG mimics SG characteristics, allowing it to function in parallel. New parameters for the VSG designed in this paper. A microgrid presented with both VSG and SG in parallel. The proposed Equal and Proportional sharing was done for VSG-VSG and SG-VSG configurations. The VSG is occupied with additional characteristics of conventional SGs, such as the stator equation and the number of the rotor poles in this paper. Then, in an isolated microgrid, a parallel arrangement, which included both VSG and SG, was constructed to compare the dynamic behavior of both systems. In addition, have the response under equal and proportional loads. It is still necessary to improve the dynamic behavior. In the MATLAB/Simulink setting, the simulation was run. The simulation results presented two power sources working in parallel and forming a microgrid. The first Scenario is carried out for a VSG/SG combination. The VSG performance is assessed using its comparable SG model from MATLAB by replacing the SG with its equivalent VSG to form the VSG/VSG combination (second Scenario). The paper summarized that; first, it is possible to operate
the VSG with SG in an islanded microgrid and realize power-sharing, besides, it is feasible to replace SG with its equivalent VSG without any problem. The rules and theories of the conventional power system can be still valid for the system with VSGs in the place of SGs. Second, besides mimicking the inertia, damping, droop functions, VSGs need to mimic the stator voltage equation to preservation the normal operating voltage in the parallel operation with SG. Third, it is required to consider the rotor poles' number when comparing a VSG with its analog SG.

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