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Virtual Inertia Implementation in Dual Two-Level Voltage Source Inverters

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***Abstract*—In this paper, the implementation of virtual inertia in a dual two-level voltage source inverter (DTL VSI) configuration is investigated. The derivative control method is employed to provide virtual inertia. The virtual synchronous generator (VSG) topology is presented, and its elements are introduced. According to the frequency changes, the active power reference is generated. Moreover, the control structure is designed and presented to control the DTL VSI properly. By means of the derivative control method, the DTL VSI participates in the frequency regulation, and the frequency oscillations during contingencies are confined. The results show that the controller follows its reference in all cases. The potentiality of the proposed controller is confirmed through MATLAB simulations. Compared to the conventional DTL VSI, the rate of change of frequency (ROCOF) and frequency nadir are reduced during disturbances.**

Keywords—Dual two-level voltage source inverter (DTL VSI), virtual synchronous generator (VSG), virtual inertia.

I. INTRODUCTION

In recent decades, distributed generations (DGs) have become an essential alternative in electrical power generation due to many disadvantages of conventional centralized power generation like air pollution and growing fuel prices. Among the Renewable Energy Sources (RESs), The focus on clean energies has grown more and more over these years. RESs suffer from small or no inertia. By an increase in the penetration of RESs, the overall inertia of the power grid is reduced remarkably. As a result, the power system loses its ability to damp frequency oscillations created by disturbances [1]. Consequently, it would lead to power system instability.

One way to overcome such a situation is to add virtual inertia, which is known as the virtual synchronous generator (VSG) concept. For the first time, the VSG idea was proposed by the VSYNC project. In this project, field tests in the Netherlands and Romania were carried out. The tests verified the effectiveness of the VSG idea [1]. Another VSG method that is named "Synchronverter" is addressed by [2]. In this method, most equations in the electrical and mechanical part of SG are considered. Assumptions such as no damper windings and no magnetic saturation effects are made.

Another method is introduced in [3]. In this method, the swing equation is considered as the central part of the control strategy, like the synchronverter method. The general idea of the two latter methods is the same. Except that in the Ise's laboratory method, instead of taking most SG equations into account, only the swing equation is regarded. Indeed, the Ise's laboratory control strategy is an upgraded version of the droop controller. In [4], the differences between the VSG controller and the droop controller are studied, and the inertial droop control method is presented. One significant superiority of VSG, compared with SG, is its capability of parameter changing in the VSG methods, which is impossible in a real SG. This potentiality is proposed in [5], by choosing proper values of inertia in each disturbance duration, and also in [6], by self-tuning algorithms. In [5], energy function analysis is discussed. However, in [6], the frequency nadir in self-tuning VSG is more significant than in the VSG with constant parameters. In [7], another VSG method is introduced by emulating an induction machine features that is termed as "Inducverter". In [8], a supplementary method to decouple the reactive power and active power in VSG is presented. The utilization of VSG in a multi-area containing the HVDC link is investigated in [9]. In [10], a modified droop controller is applied to regulate frequency during disturbances. In [11], an analysis performed to design the VSG controller parameters properly. In [12], a nonlinear controller is added to the VSG controller to operate in weak grids and the self-synchronization process. Several inverter topologies are introduced among the literature. Vital cascaded inverter topologies are cascaded H bridge inverter, cascaded three-phase inverter, and the dual inverter. The most attractive cascaded inverter topology is the dual inverter configuration, due to its reduced output voltage harmonic and lower switching frequency. Therefore, compared to the conventional inverters, the switching losses in each inverter of the dual inverter configuration is reduced [13].

In this paper, virtual inertia is utilized in the dual two-level voltage source inverter (DTL VSI) configuration. Up to now, among the works done in the field of VSG, virtual inertia has not been implemented in the DTL VSI configuration.

The rest of this paper is organized as follows. Dual inverter topology is briefly introduced In section II. in section III, The VSG method that is based on the VYSYNC method is described. In section IV, the control structure is discussed. In section V, The simulation results verify controller ability in load transitions, and finally, The conclusions of this paper are outlined in Section VI.

II. DUAL INVERTER TOPOLOGY

The dual inverter configuration is shown in Fig. 1. As can be seen, a transformer with the open-end winding configuration on its primary side is applied to employ dual two-level inverter. The windings of the secondary side of the transformer are connected to the utility grid with star configuration.

The most important advantage of utilizing dual inverters is lower output voltage harmonics, which results in a reduced size of the inductance filter; therefore, the overall cost could be reduced [14].

By utilizing two M level inverters in the dual inverter configuration, the output voltage level will be equal to a 2M-1 level inverter voltage level. It leads to a reduction in switching losses and lower switching frequency [15]. The advantage of implementing two isolated DC link voltage sources is the elimination of zero sequence current (ZSC) [14]. Another benefit of dual inverters compared to a traditional two-level inverter is its capability in fault tolerance. When a fault happens in one of the inverters, then another one can continue to work and inject its part of the power to the electrical grid. In the dual inverter configuration, the phase difference of voltage reference space vectors of the two inverters must be 180° to reach the maximum output voltage [15]. The magnitude of their reference voltage space vectors is the same.

III. VIRTUAL SYNCHRONOUS GENERATOR

Frequency excursions occur when a mismatch between generated electrical power and demanded electrical power happens. Unlike centralized power generations, distributed generations are low-inertia systems that make power systems ready for instability during disturbances. A solution in this situation is to add inertia virtually to distributed generations. For this purpose, inverter controllers must be changed, and the concept of virtual inertia, utilizing the swing equation, needs to be added to the controllers. One of the most popular controllers is the current-controlled method.

By the VSG concept, the current controller could respond to the deviation of frequency during contingencies, like the load transitions. The measured frequency is compared with the nominal frequency to obtain frequency changes ($\Delta\omega$). By implementation of (1), the reference output power of a three-phase inverter is generated.

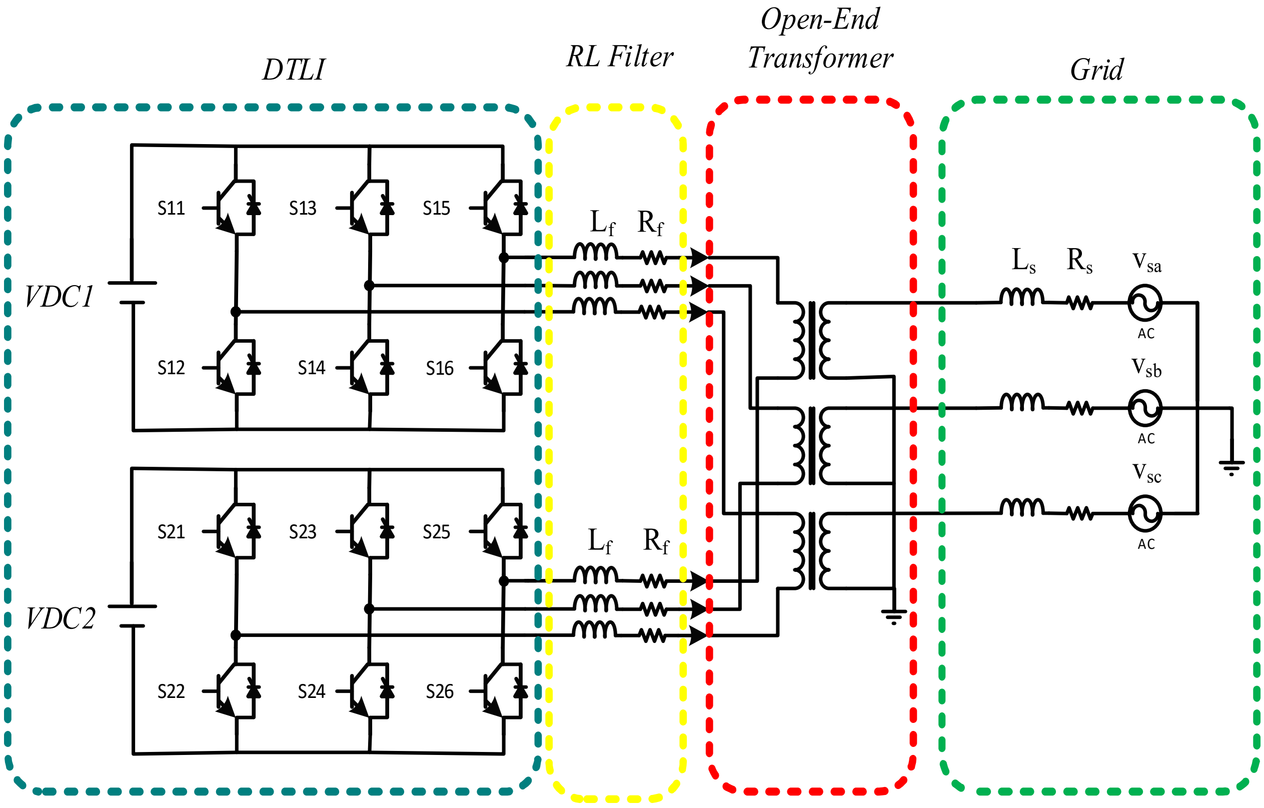


Fig. 1. Dual inverter configuration

$$P_{VSG} = K_D \Delta\omega + K_I \frac{d\Delta\omega}{dt} \tag{1}$$

The output power reference generator block diagram is depicted in Fig. 2. K_D is a coefficient that helps in the frequency nadir reduction during contingencies. It is just like the coefficient in the frequency droop, and by an increase in K_D, active power reference will increase in transients and results in reduced frequency drop. If the ROCOF overpasses its acceptable boundary, ROCOF relays will trip. By increasing the K_I coefficient, the ROCOF is reduced; thereafter, relays will not trip.

By an increase in K_D and K_I coefficients, more virtual inertia will be enabled by the inverter, but the fluctuations in active power reference lead the power system to instability. In these situations, tuning the PLL parameters will no longer help the VSG controller. Hence, the proper selection of the parameters of this controller is essential.

The existence of a short-term energy storage system (ESS) is essential to provide virtual inertia. In Fig. 3. the VSG system block diagram is shown. As can be seen, voltage and current are transformed into the dq0 synchronous rotating frame. The frequency is measured by the PLL, and the VSG creates active power reference for the inverter controller.

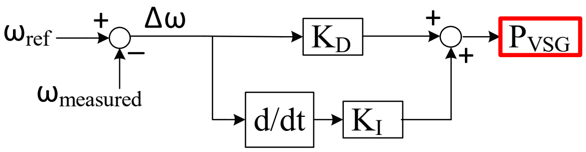


Fig. 2. Block diagram of the active power reference generator

IV. CONTROL STRUCTURE

The control structure is presented in this section. The controller block diagram is demonstrated in Fig. 4. In order to make the control process easier, voltage and current are transformed into dq0 components. This control structure makes DTL VSI configuration follows its active power reference that is obtained by the VSG. The active power reference is compared in the outer loop with the measured active power at the secondary side of the open-end winding transformer. The d-component of the current reference in the rotating synchronous frame is generated after passing through a PI controller. Likewise, the reactive power reference is compared with the measured reactive power at the secondary side of the open-end winding transformer, and the q-component of the current reference in the synchronously rotating frame is generated after passing through a PI controller. In the inner loop, the current reference is compared with the measured current in the d-q frame.

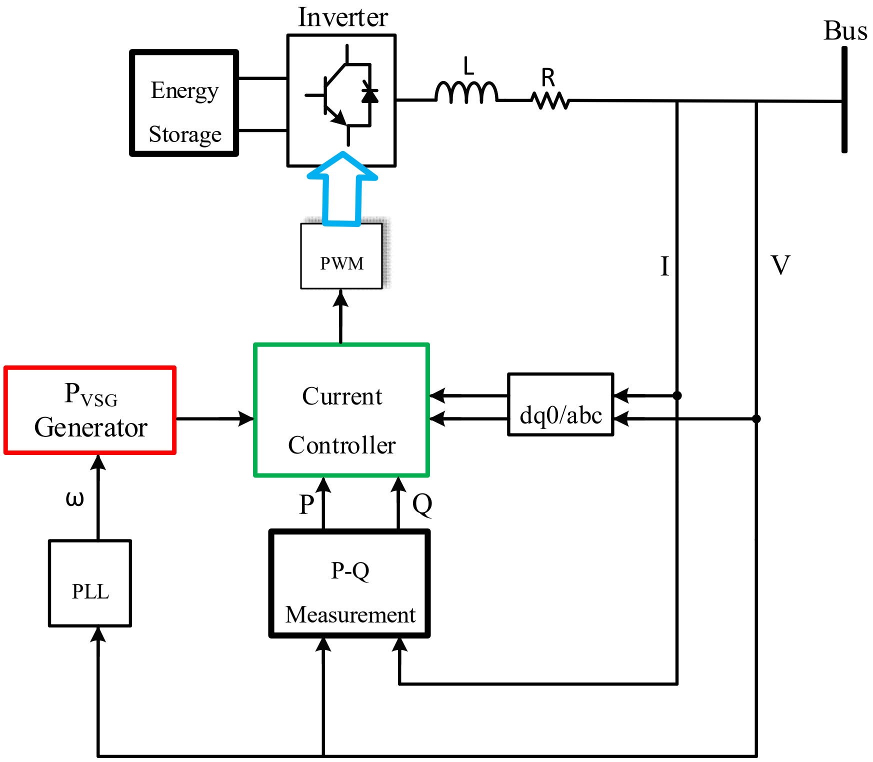


Fig 3. The VSG system block diagram

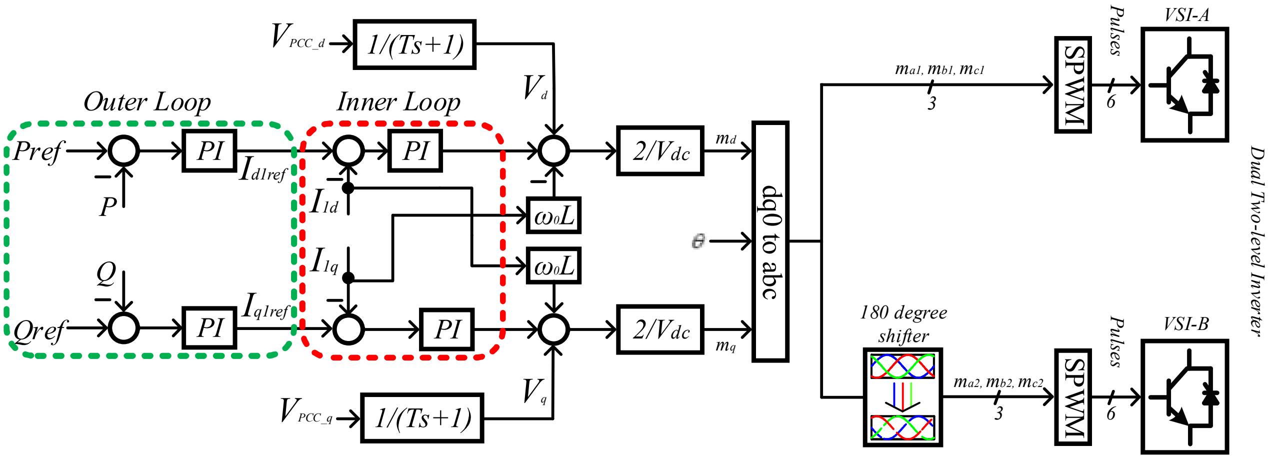


Fig. 4. Control structure

The measured voltage at the point of common coupling (PCC) is passed through a low pass filter (LPF) to enhance the performance of the current controller. As indicated in section II, the phase difference of the reference space vector of two inverters is 180°. Therefore, the reference space vector of the VSI-A will remain unchanged, but the reference space vector of the VSI-B will be180° phase shifted.

V. SIMULATION RESULTS

In this section, two cases are investigated, and simulation results in these cases are investigated, and the virtual inertia effectiveness among the transients is figured out.

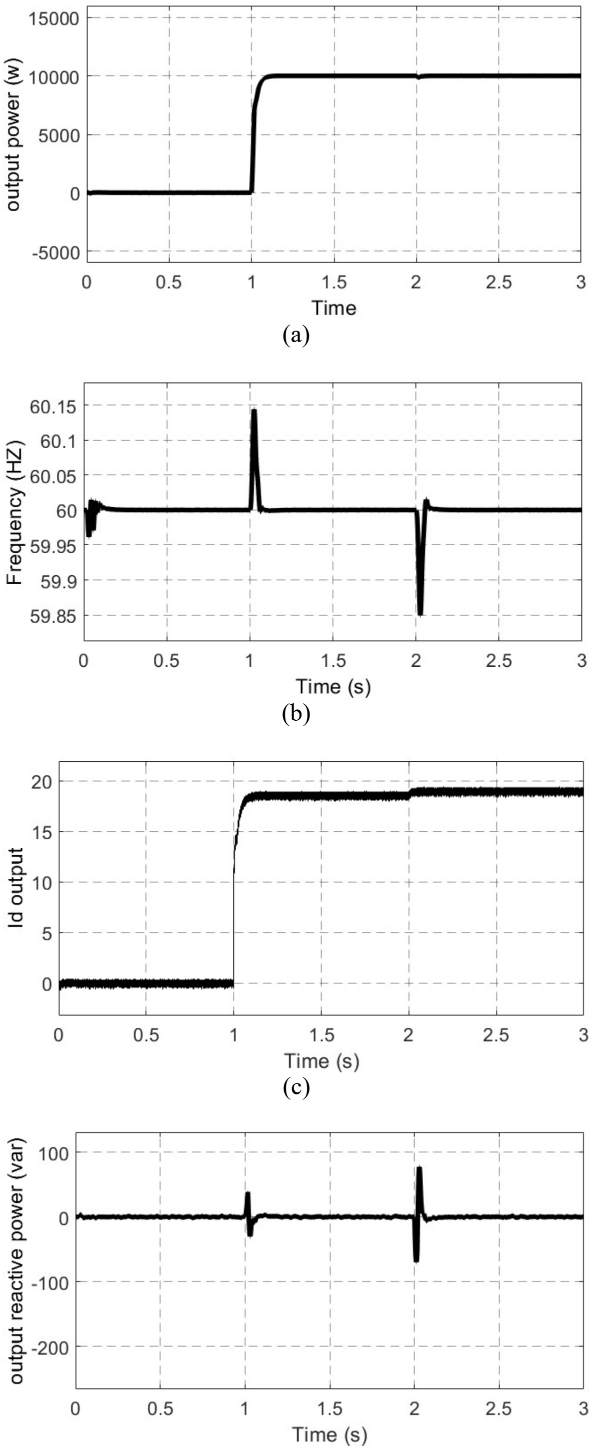
Case A: without virtual inertia

The active power reference of the DTL VSI remains 10kW during the disturbances, such as a load change. Therefore, the output power will be constant, and the DTL VSI will not take part in the frequency adjustment. The initial value of the active power reference is zero until t=1s. Therefore, all demanded power that is 20kW is supplied by the utility grid. The active power reference changes from zero to 10kW by a step at t=1s. Hence, half of the load power is supplied by the DTL VSI. Another 10kW load is added to the system at t=2s. At this moment, because the active power reference is not changed, the grid supplies the added load. In the whole simulation cases, the reactive power reference remains zero. In Fig. 5(a), the active power of the DTL VSI remains zero until t=1s. After this moment, the controller follows its reference. It shows the proper operation of the current controller and tuned parameters of the PI controllers. System frequency is shown in Fig. 5(b). at t=1s, the frequency increases because of the mismatch that occurs between the demanded and the generated power. After a short time, the frequency returns to its nominal value, i.e., 60 Hz. This process continues until t=2s. The DTL VSI will not participate in the frequency adjustment. Thus, the frequency drops to about 59.85 Hz.

Regarding that in this simulation case, a grid is connected to the DTL VSI; this amount of frequency nadir is enormous. If a SG were connected to the DTL VSI, the frequency drop would be almost 1 Hz, which is considerable. Hence, in the next case, the main purpose is to reduce frequency nadir. The reactive power is shown in fig. 5(c), and as demonstrated, it follows its reference exactly. The output d component current is illustrated in Fig. 5 (d).

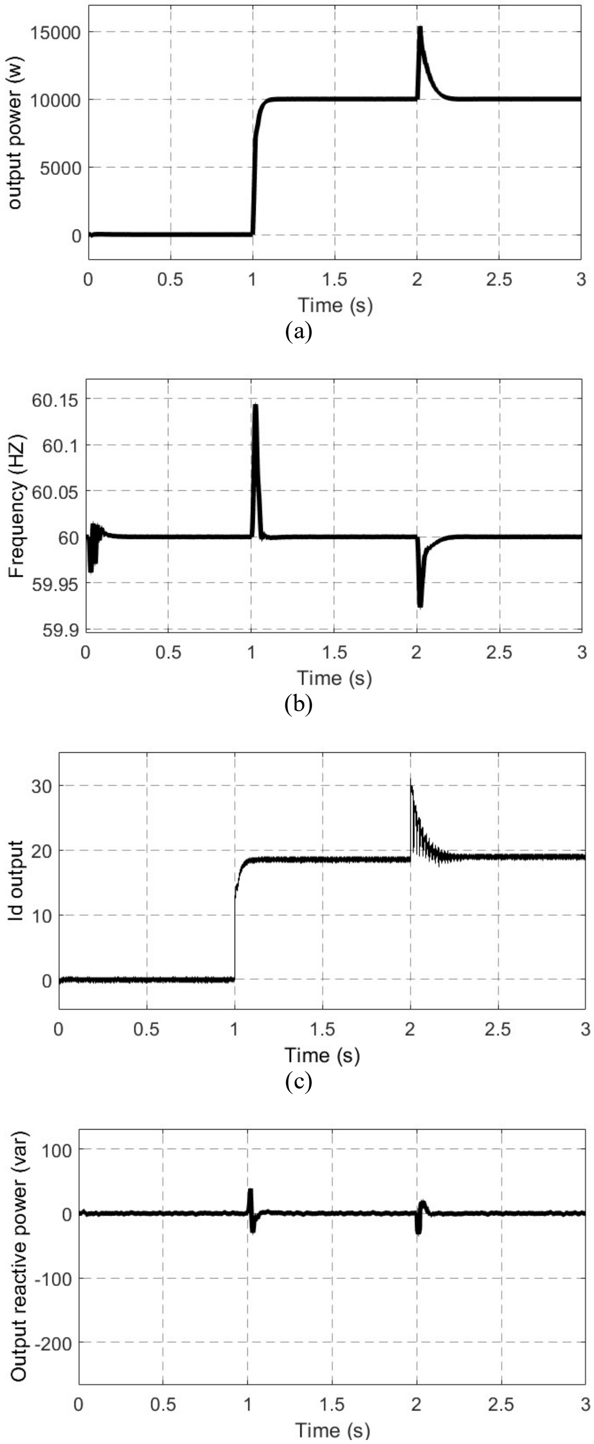
Case B: with virtual inertia

In this case, during the load transitions, the active power reference is changed to its calculated amount that is discussed in section III. Therefore, the DTL VSI takes part in the frequency regulations. Like the previous case, the active power reference remains zero until t=1s, that it changes to 10kW by a step. In t=2s, when a 10kW load is added to the power system, the active power reference of the DTL VSI is changed. The active power changes for the first time at t=1s, as shown in Fig. 6(a). the System frequency is demonstrated in Fig 6(b). As a mismatch happens at this moment, the frequency increases. The VSG topology is added to the DTL VSI at t=1.5s. As can be seen in Fig. 6(a), no changes in the output power and system frequency are represented. It reveals that by adding the VSG, no disturbances occur in the power system. At t=2s, a 10kW load is added, and the active power reference is increased up to about 15 kW, and after a transient, it returns to its previous amount. The frequency nadir is reduced, as depicted in Fig. 6(b). In this case, the frequency drop is almost 0.075 HZ that shows that frequency dropped almost 0.075 HZ lower than case A, which lacks inertia. It means frequency dropped half of the last case. In Fig. 6(b), after the frequency nadir, frequency did not increase from its nominal value, which is another preference of this case, compared to case A. The reactive power remains zero, as demonstrated in Fig. 6(c). The output d component current is depicted in Fig. 6(d). As can be seen, the current increases in transients and returns to its constant value.



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

Fig. 5. Case A: without virtual inertia: (a): active power, (b): system frequency, (c): output d component of current, (d): reactive power



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

Fig. 6. Case B: with virtual inertia: (a): active power, (b): system frequency, (c): output d component of current, (d): reactive power

VI. CONCLUSION

Due to the increased penetration of RESs, the capability of the utility grid to damp frequency oscillations is reduced. Therefore, the slightest disturbance in the system may lead to instability. In order to make the power system resistant to these situations, the transient behavior of the synchronous generator during load changes must be taken into account. In this paper, virtual inertia was applied to the DTL VSI configuration. First, the DTL VSI configuration and the VSG topology were presented. Second, the control structure which is divided into two parts, was introduced. The first part is the derivative control method, which was applied to enable virtual inertia. Through this method, the active power reference is generated. The second part was implemented to make the DTL VSI follows its active power reference. Finally, the simulation results, which ensured the capability of the control structure in frequency oscillation suppression, were performed.

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