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AN IMPROVED DROOP CONTROL METHOD FOR PARALLEL-CONNECTED INVERTER OPERATION IN AC MICROGRID

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ABSTRACT

Conventional droop control is a basic control strategy for power sharing in AC microgrid applications. This strategy has several limitations, such as low transient response, frequency and voltage deviation. This paper presents an improved droop control method for the proper operation of parallel-connected inverters in AC microgrid. The proposed method is able to improve transient response and achieved higher output power without voltage and frequency deviation by introducing a power derivative term into a conventional droop method. The second-order general integrator scheme with low-pass filter was used to obtain the average power signal without DC components from each power electronic inverter. The simulation was developed in MATLAB/Simulink to verify the effectiveness of the improved droop control scheme. Based on the results, an improved droop control strategy was proposed to improve the operation of parallel-connected power electronic inverters in the microgrid systems of existing AC distribution systems.

Keywords: distributed generation, AC microgrid, inverter, droop control, active, reactive power.

1. INTRODUCTION

Distributed generation (DG) technology is undergoing rapid development in many countries because of the availability of different energy resources, such as solar panels, batteries, electric vehicles, and wind turbines. DG is usually managed in a decentralized manner through the concept of a microgrid (MG). MG technology offers numerous research possibilities because it is a new and developing technology. An MG is defined as a cluster of DG units, storage devices, and loads. In practice, MGs are needed to provide sufficient power quality and level to meet consumer demands [1-3]. Power quality is a significant issue because short or long periods of insufficient or unstable output power from MGs directly affects its performance. In an islanded mode, the MG must maintain the system voltage and frequency; otherwise the variation in the component characteristics of the MG will collapse the system. Output power waveform harmonic distortion is a serious issue that often occurs as a result of the high-speed operation of inverter switches. In addition, power sharing between the DG units is a critical concern for proper load sharing, especially in renewable energy resources that are not continuously available. The power quality of an MG mainly relies on the active and reactive power regulation because of MG behaviors, which are mostly influenced by the bulky power distributed system [4–5].

To improve power quality, the droop, master–slave, and average-current-sharing control methods were proposed by researchers. Among these methods, droop control has gained higher popularity because it is based on the local measured information of the inverter. As it does not require any communication signals between the parallel-connected inverters, it can reduce the line losses in MG. However, the conventional droop control method causes frequency and voltage deviation, drawbacks that limit the accuracy of power sharing [6]. In previous works [7-12], modified droop control techniques were proposed to overcome the abovementioned disadvantages. However, the proposed methods in literature can be further improved to enhance power sharing and voltage regulation. The objective of the present study is to propose an improved droop control technique capable of achieving accurate power sharing and enhancing the transient response of parallel-connected inverters. An improved droop controller was developed by adding a derivative term into the conventional droop control technique to improve MG performance.

The remainder of this paper is organized as follows. In Section 2, a brief description of the conventional droop control method is presented. In Section 3, the proposed droop control approach is discussed. In Section 4, the simulation results of the conventional droop and proposed droop control methods are compared. Finally, the conclusion is provided in Section 5.

2. CONVENTIONAL DROOP CONTROL METHOD

A conventional droop control technique based on frequency and voltage droop was proposed in [13]. An assumption was likewise made that the inverter output impedance is purely inductive because of the high inductive line impedance and the large inductor filter [14]. The block diagram of the conventional droop controller is shown in Figure-1. The droop characteristic equations can be expressed as

$$\omega = \omega^{\bullet} - mP, \tag{1}$$

$$E = E^{\bullet} - nQ, \tag{2}$$

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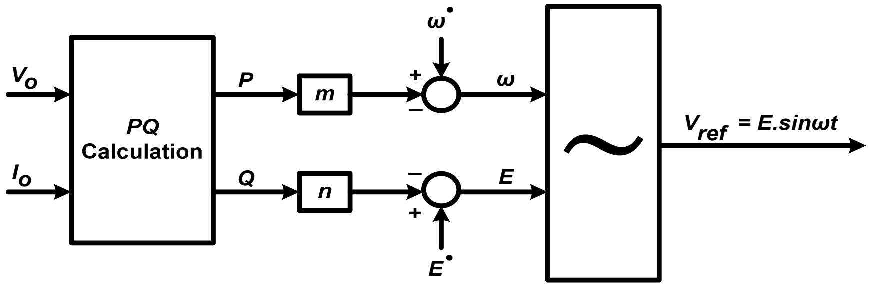

Figuere-1. Block diagram of conventional droop control technique.

where *P, Q, m*, and *n* are the active output power, reactive output power, frequency droop constant, and voltage droop constant of the inverter, respectively; $\omega^\bullet$ is the rated frequency; and $E^\bullet$ is the rate-voltage amplitude. The pros and cons of conventional droop control are described in Table-1 [6].

Table-1. Pros and cons of conventional droop control.

Pros	Cons
▪ No communication ▪ Great flexibility ▪ High reliability	▪ Slow transient response ▪ Poor harmonic load ▪ Trade-off between voltage regulation and load sharing ▪ Coupling inductance

3. PROPOSED DROOP CONTROL METHOD

The structure of the improved droop control method is shown in Figure-2. The average active and reactive powers can be taken by multiplying the output voltage by the output current and filtering the product using a second-order general integrator scheme with low-pass filter (SOGI–LPF):

$$\overline{P} = [(\frac{2\varsigma\omega_f s}{s^2 + 2\varsigma\omega_f s + \omega_f^2}).(\frac{\omega_c}{s+\omega_c})].P, \quad (3)$$

$$\overline{Q} = [(\frac{2\varsigma\omega_f s}{s^2 + 2\varsigma\omega_f s + \omega_f^2}).(\frac{\omega_c}{s+\omega_c})].Q, \quad (4)$$

Here, ω_f, ω_c, and ς are the filter resonant frequency, filter cut-off frequency, and damping factor, respectively.

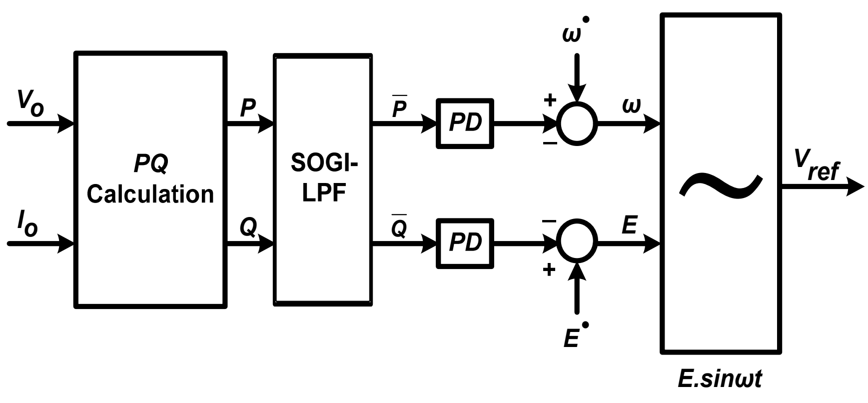

Figure-2. Proposed droop control method.

The improved droop control equations can be written as follows:

$$\omega = \omega^\bullet - m\overline{P} - m_d \frac{d\overline{P}}{dt}, \quad (5)$$

$$E = E^\bullet - n\overline{Q} - n_d \frac{d\overline{Q}}{dt}, \quad (6)$$

where $\overline{P}, \overline{Q}, m, m_d, n$, and n_d are the average active output power, average reactive output power, frequency droop coefficient, frequency droop derivative, voltage

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droop coefficient, and voltage droop derivative of the inverter, respectively; $\omega^{\bullet}$ is the rated frequency; and $E^{\bullet}$ is the rate-voltage amplitude.

4. SIMULATION RESULTS AND DISCUSSIONS

In this section, the proposed droop control and conventional droop control methods are simulated with two 5KVA inverters connected in parallel to verify the validity of the proposed droop control technique. The system parameters are the following: L=1mH, C=20μF, V_{in}=220 V, Z_1=0.12+j0.028, and Z_2=0.12+j0.028. The rated voltage and system frequency are 110V RMS and 50Hz respectively. The conventional droop coefficients *m* and *n* are 0.00015rad.s/W and 0.0016V/VAr respectively. On the other hand, the proposed droop constants m_p, m_d, n_p, and n_d are 0.000015rad.s/W, $6*10^{-7}$ rad.s/W, 0.000004 V/VAr, and $6*10^{-7}$ V/VAr, respectively.

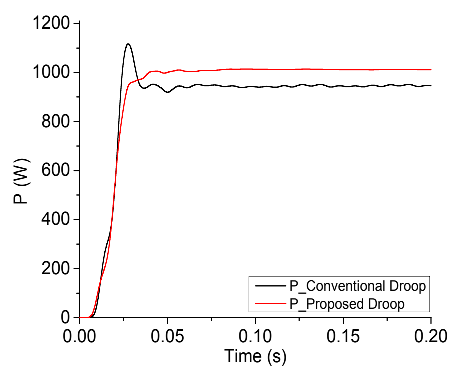

Figure-3. Start-up waveforms of active power of both inverters.

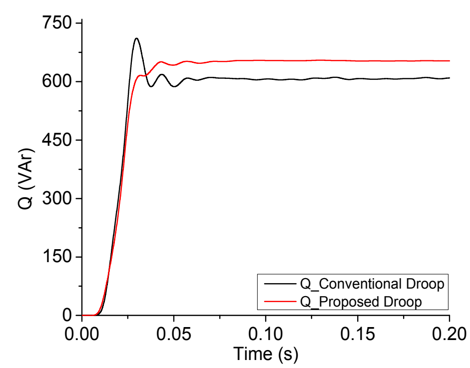

Figure-4. Start-up waveforms of reactive power of both inverters.

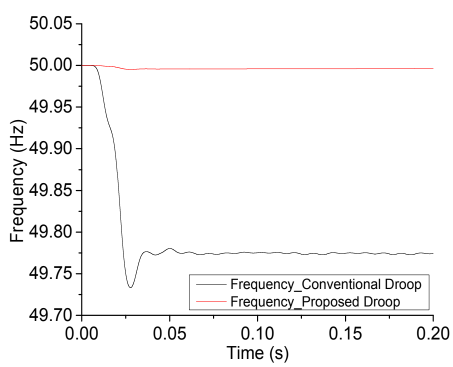

Figure-5. Frequency of both inverters at start-up.

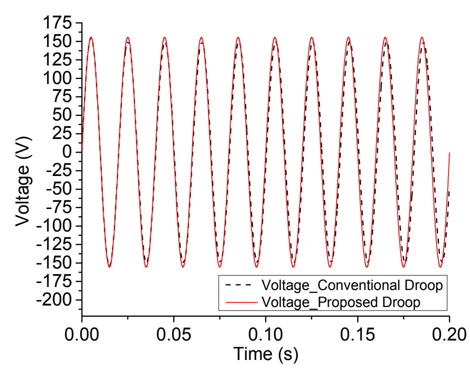

Figure-6. Voltage of both inverters at start-up.

The start-up waveforms of the active and reactive powers of the two inverters are shown in Figures 3 and 4. These waveforms were obtained by using the conventional droop and proposed droop control methods. The proposed droop control method clearly provides higher active and reactive powers compared with the conventional droop method. Moreover, the proposed method is modified the transient response significantly as can be seen from Figure 3 and 4. The frequency restoration and start-up waveform of the voltage are shown in Figure 5 and 6. These figures also show that the frequency and voltage deviations are lower than those of the conventional droop control method.

5. CONCLUSIONS

An improved droop control method for improved load sharing between parallel-connected inverters is proposed in this paper. Simulation results show the efficacy of the proposed droop control over the conventional droop control method. The proposed method provides approximately zero percentage voltage and frequency deviation and achieve desired transient response. Furthermore, the average power calculated by using SOGI-LPF shows better performance than the first-order low-pass filter.

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