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A Sliding Mode Control-Based Master-Slave Power Sharing Method for an Islanded Microgrid Considering Voltage Harmonic Improvement

Yasin Hosseindoost [1], Farhad Pourtahmasbi [2], Seyyed Yousef Mousazadeh Mousavi [3]*, Mahmoud-Reza Haghifam [4]

[1] Msc, Electrical and Computer Engineering Faculty, Tarbiat Modares University, Tehran, Iran.

[2] Msc, Electrical Engineering Department, Sharif University of Technology, Tehran, Iran.

[3] Assistant Professor, Faculty of Engineering & Technology, University of Mazandaran, Babolsar, Iran.

[4] Professor, Electrical & Computer Engineering Faculty, Tarbiat Modares University, Tehran, Iran.

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Abstract:

The proliferation of inverter-based distributed generation (DG) enhances grid characteristics in various respects. Accordingly, this paper presents a control strategy that enables power sharing among inverter-based DG units and improves the voltage harmonic content of an islanded microgrid. In this proposed control scheme, sliding-mode control is implemented in a master-slave configuration and applied to each inverter as a switching method. Two methods for implementing the control approach are proposed in this paper. The first is based on the parallel operation of inverters extended to the MG. In the second proposed method, the transmitted reference current comprises only the output of the voltage-loop control of the master unit; furthermore, the received reference current of each slave DG unit is added to its output current. Therefore, the output currents of units are related to the loading and grid configuration. The simulation study implemented in MATLAB/Simulink shows that both methods perform acceptably across different scenarios. In contrast, the second method leads to greater voltage harmonic distortion in the presence of nonlinear loads.

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***Corresponding Author:** s.y.mousazadeh@umz.ac.ir

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1. Introduction

Regarding the increasing number of DGs and critical loads in the distribution system that have been disconnected intermittently, the islanded mode of Microgrid (MG) has drawn attention to itself [1, 2]. On the other hand, most DGs are renewable energy resources that use inverters to convert and inject power into the AC distribution system [3, 4]. In the presence of these inverter-based DGs, some MGs only use inverter-based resources. In this kind of MGs, inverter-based resources should share load demand among themselves as well as maintain the voltage and frequency of the MGs [5]. In this regard, researchers have proposed various power-sharing strategies.

Maintaining the voltage of an islanded MG involves multiple aspects, including voltage stability, minimum and maximum voltage constraints, and power quality considerations. Power quality is an important characteristic of today's distribution power systems, since loads become more sensitive. The proliferation of nonlinear loads in distribution systems makes harmonic voltage distortion a critical problem for utilities and customers [6]. As noted above, one of the principal objectives of islanded MG operation is to support critical loads. These critical loads require not only continuous electricity but also appropriate voltage quality. Some of them are sensitive to power quality issues and may be damaged by poor power quality.

Given these challenges, it is essential to closely monitor the power quality of islanded inverter-based MGs and the power sharing among these resources. Generally, to the best of our knowledge, past studies in this field are divided into three major categories. The first category concerns special studies that analyze power sharing among parallel inverters or among inverters within an MG. Power-sharing in these studies includes active power or reactive power sharing in steady-state [6-10]. Accordingly, in Mortezaei et al. study [11], power-sharing among DG units is obtained by

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combining both the droop and master-slave control methods and applying the conservative power theory (CPT). operation. In the study by Mortezaei et al. [11], power sharing among DG units is achieved through a combination of droop and master-slave control methods, using conservative power theory (CPT). In this combined load-sharing approach, all current-controlled DG units act as slave units, injecting energy and compensating for undesirable current components in the loads. While all droop control-based DG units operate as master units, sharing of the remaining load power is achieved autonomously. Distributed control schemes based on predictive control (MPC) and sliding-mode (SM) control are proposed by Ferro et al. [12] and Sun et al. [13], respectively, to fairly share active and reactive power among inverter-based DG units. The accuracy of active and reactive power sharing is improved in the method categorized in the first group. However, power quality issues and harmonic current sharing, which are vital challenges in MGs, are not addressed in this category.

The second category is dedicated to studies that assess the control system of the inverter or the control strategy of a group of inverters for power quality enhancement in an MG [3, 14-17]. He and Blaabjerg [14] proposed a droop-control-based scheme for flexible power-quality enhancement in both grid-connected and stand-alone operation of a single-phase MG. Mousavi et al. [17] propose a control strategy that integrates primary control of voltage- and current-controlled mode inverters with a secondary PI droop controller to address voltage harmonic compensation.

The last category encompasses the studies that contain both power-sharing and power quality enhancement simultaneously [11, 18-28]. Some of these studies are based on grid-connected MG [18, 26] and the others are based on islanded MG [22, 25]. Yazdavar et al. [24] defines a virtual harmonic conductance in the form of droop characteristics at each harmonic frequency. Using this virtual admittance, harmonic load sharing among DG units is controlled, thereby enhancing voltage quality in the MG. Mousavi et al. [22] conducted coordinated control of current-controlled mode (CCM) and voltage-controlled mode (VCM) DG units to optimize reactive power sharing and address voltage harmonic compensation. This decentralized control scheme is based on measuring local signals without communication links. This proposed reactive power sharing among DG units is achieved using modified droop and reverse-droop control methods. Although using droop control methods has some advantages that are mentioned by Mousavi et al. [22], and Yazdavar et al. [24], the existence of voltage and frequency deviation, and the dependency of power-sharing precision on the operation point are some drawbacks of this method [20].

A decentralized nonlinear harmonic power sharing approach is proposed by Zhang et al. [27] by considering the harmonic remaining capacity of inverters. Although harmonic current sharing is improved, accuracy is reduced by removing the communication link. Ghanizdeh and Gharehpetian [21], along with Haghshenas [28], propose a distributed hierarchical control scheme for an islanded MG to enhance voltage quality and power sharing. The harmonic compensation effort of each DG unit is determined in proportion to its rated power. The control method proposed by Mousavi et al. [17], Gharehpetian [21], and Haghshenas [28], is based on PI control, which is sensitive to operation points, and the appropriate amounts of its related constants should vary in different load patterns.

Although various control approaches, such as adaptive droop control, MPC, and distributed hierarchical schemes, have been proposed for islanded microgrids, this study employs an SM control scheme combined with a master–slave configuration. SM control provides strong robustness to parameter variations, non-linear loads, and fast transients [29]. In this paper, a new master-slave-based power-sharing method that requires only a low-bandwidth communication link is proposed. This approach provides excellent voltage regulation and proper power- sharing in contrast to droop controllers; hence, the output voltage amplitude and frequency are regulated close to their ratings without using a complex secondary controller [30].

In this paper, master-slave power sharing is first assessed using SM control in an islanded inverter-based MG, which is based on the parallel operation of the inverter units. According to this method, referred to as the first method, the relations are obtained. By analyzing these relations, the reference current, which is transmitted from the master unit to the slave units, is modified to enhance the voltage quality of the MG. A new feedforward current for the slave units is also proposed. Thereafter, by considering the feed-forward current and the newly presented reference current, a new power-sharing method is obtained, which is referred to as the second method. For the second method, the new equations are derived, and the improvement in voltage quality relative to the first master-slave method is demonstrated. Finally, an arbitrary inverter-based MG is considered, and the first and second methods of master-slave power-sharing are simulated in this MG through MATLAB/Simulink. The simulation results support the relationships and demonstrate the superiority of the second method with respect to MG voltage quality. Therefore, the major contributions of this paper can be summarized as follows :

1-Employing the sliding-mode control in parallel operation of the inverters

2-Developing a master-slave control strategy in an arbitrary micro-grid by using Sliding mode control of the inverters

3-Improving the master-slave regarding compensation of harmonics by changing the reference current that is transmitted to slave units

4-Increasing the role of slave units to make improvements to the voltage THD of the micro-grid buses by applying a new feed-forward current in slave units

The rest of this paper is organized as follows. In Section 2, the sliding-mode control of the inverters in the master-slave control strategy and the first power-sharing method are presented. Subsequently, the second master-slave control method for enhancing the voltage quality of the MG and its associated mathematical model are presented. Section 3 presents simulation results for the proposed master-slave control methods and compares them under general conditions. Finally, the conclusion of this paper is expressed in Section 4.

2. Master-Slave Power Sharing by using SM Control

Generally, there are two parallel control strategies for inverters: power sharing and voltage maintenance. The first one is a communication-based control strategy, and the other is a droop control strategy [20]. Both strategies have advantages and disadvantages. In communication-based control techniques, more accurate and appropriate voltage regulation and power sharing are achieved than with droop controllers; however, this control strategy imposes greater costs on the system due to the need for communication systems, particularly in large grids. As smart grid technologies improve, the cost of communication systems is expected to decline. In contrast, the implementation of the droop controller system is more cost-effective, feasible, and scalable. Despite these advantages, in grids with nonlinear loads, the droop control strategy may lead to decreased power quality; since this strategy focuses on fundamental component power-sharing unless using secondary controllers [11].

Among communication-based control techniques, the master-slave control method can provide remarkable power sharing and voltage regulating [31]. On the other hand, this method implementation is more feasible in comparison with the other communication-based methods [32]; Hence, the master-slave power-sharing method is selected in this paper.

As aforementioned, both power sharing and voltage quality enhancements of the proposed methods are investigated in this paper. Although different nonlinear loads are connected to the MG's buses, by choosing the SM switching control method, it can be assured that the voltage quality at the output of the inverter-based DG unit buses is in the desirable range. In this paper, the switching control method proposed by Abrishamifar et al. [29] for voltage-controlled single-phase inverters is developed for both voltage and current-controlled three-phase inverters. First, the aforementioned SM switching control method is extended to master-slave control-based parallel operation of inverter-based DG units. It is then further developed and applied to inverter-based DG units connected to different buses of the MG to control power sharing among these DG units. As mentioned above, to control the MG's voltage and frequency, master-slave control has been chosen. Generally, only one voltage controller VCM unit is required to determine the voltage and frequency reference values of an islanded MG. Other units, known as slave units, are operated as CCM units. The reference current of these units is received from the master unit via a communication system.

The general scheme of an inverter-based MG with this proposed master-slave control is illustrated in Figure 1. To transmit the reference signal from the master unit to the other units, only a low bandwidth communication system is required since the fundamental and harmonic transmitted data are converted into DC form by using a dq reference frame described by Mousavi et al. [23]. In this master-slave control, the reference voltage ($Vabc_{reference}$) is the input signal of the master unit, and the reference current ($I_{ref(dq)}$), which is generated by the master unit and transmitted via the communication system, is the input signal of the slave units.

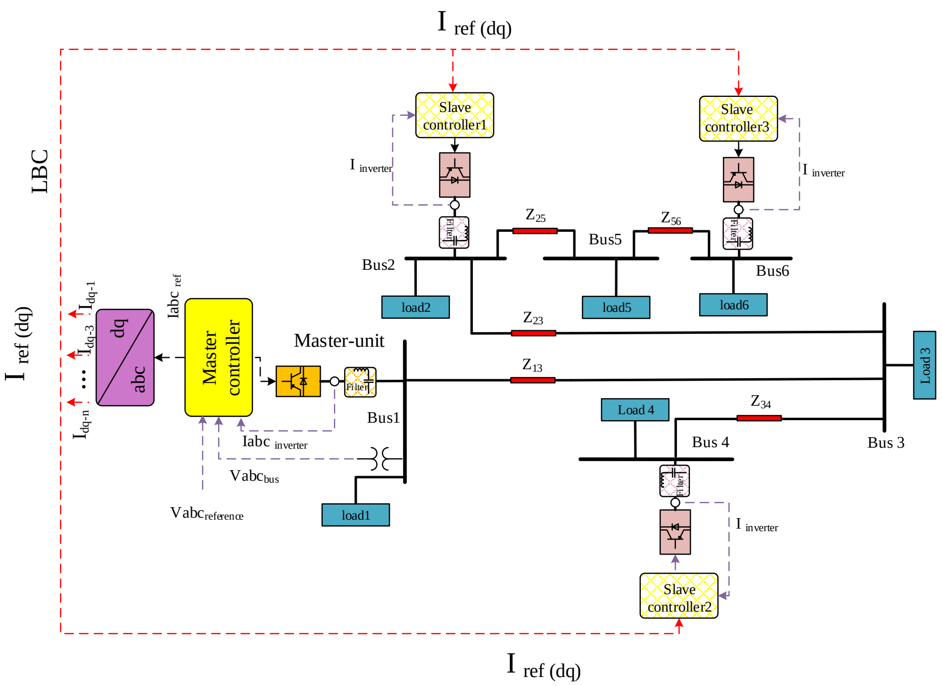

Figure 1. General schematic of proposed master slave control

2.1. SM Control

In Figure 2, a single-phase diagram of an inverter is indicated. The control targets are the regulation of the output voltage and the control of the current, depending on the voltage-controlled or current-controlled operation mode.

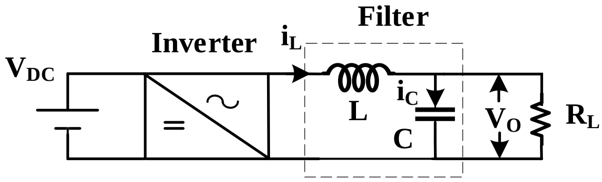

Figure 2. Single line diagram of an inverter

In sliding-mode control, the control law must be defined to map the state variables to the desired points. If the output voltage and the filter inductor current are treated as state variables of this inverter, the first state variable can be the voltage error, and the second is its derivative, in the sliding-mode control equations. These variables can be written as:

$$x_1 = V_{ref} - V_o \quad x_2 = \dot{x}_1 = \dot{V}_{ref} - \frac{i_c}{C} \tag{1}$$

where, V_{ref}, V_o, $\dot{V}_{ref}$, i_C, and C represent reference voltage, output voltage, the derivative of the output voltage, filter capacitor current, and filter capacitance, respectively. Therefore, the state equations will be derived as follows:

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix} = \begin{bmatrix}0 & 1\\ -\frac{1}{LC} & -\frac{1}{R_L C}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}0\\ \frac{V_{DC}}{LC}\end{bmatrix}u + \begin{bmatrix}0\\ \frac{V_{ref}}{LC}\end{bmatrix} \tag{2}$$

where R_L, V_{DC}, and L are load impedance, the input voltage of the inverter, and filter inductance, respectively. u represent the output of the PWM controller, which is 0 or 1.

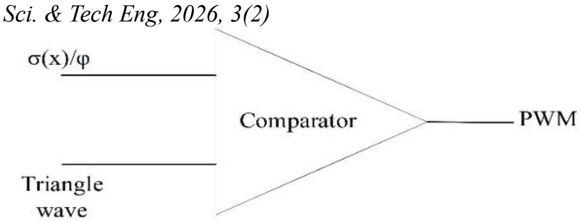

Figure 3. Applying the sliding mode as input of PWM

Considering the above-mentioned equations, an appropriate sliding surface can be described as:

$$\sigma(x) = \left(\frac{d}{dt} + \lambda\right)x_1 = x_2 + \lambda x_1 = 0 \tag{3}$$

where σ and λ represent the scalar function and a positive constant value, respectively. Then *σ(x)* is replaced by *σ(x)/φ*, where *φ* is a constant value that is used to smooth the sliding surface and eliminate the chattering problem. *σ(x)/φ* will be achieved as:

$$\frac{\sigma(x)}{\phi} = \frac{1}{C\phi}\left(i_{Lref} - i_L\right) + \frac{\lambda}{\phi}\left(V_{ref} - V_o\right) \tag{4}$$

σ(x)/φ is used as the input of PWM controller as depicted in Figure 3. More details for stability analysis and determining the range of λ and φ can be found by Abrishamifar et al. [29].

2.2. Master-slave based on SM Control

To achieve master-slave power sharing, the block diagrams of the master unit and the slave units, employing sliding-mode switching control, are shown in Figures 4 and 5, respectively. Based on these block diagrams, the reference

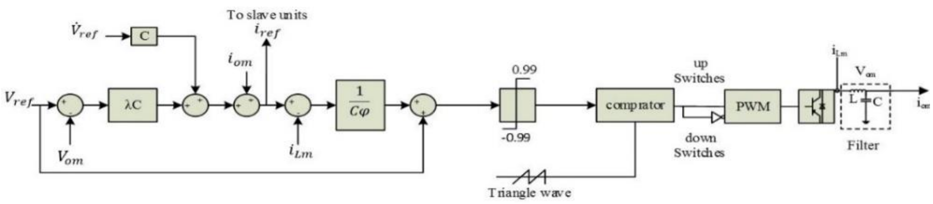

Figure 4. The block diagram of the master unit using a sliding mode controller in the first method

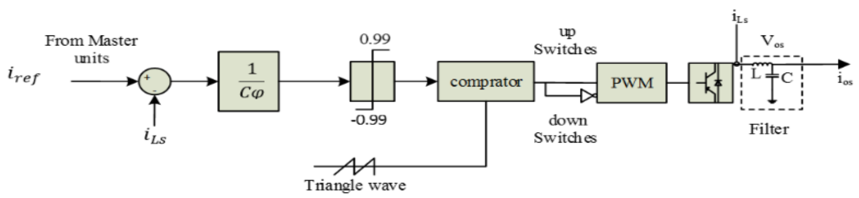

Figure 5. The block diagram of the slave units using a sliding mode controller in the first method

current is generated by the master unit controller and then transmitted to the slave units as an input control signal.

In Figure 4, V_{ref}, $\dot{V}_{ref}$, V_{OM} and V_{OS} represent the reference of the voltage, the derivative of the reference voltage (based on SM control), the output voltage of the master unit LC filter and the output voltage of the slave unit LC filter, respectively. The output current of the master unit's LC filter, the inductor current of the master unit's LC filter, the output current of the slave unit's LC filter, the inductor current of the slave unit LC filter, and the reference of the slave unit are also depicted by i_{OM}, i_{OS}, i_{LM} and i_{LS}, respectively. C and L are also the capacitance and inductance of the LC filter and φ and λ are the SM control parameters, which are described in the previous subsection.

Considering Figures 4 and 5, the mathematical equations of this master-slave control scheme by using the sliding mode control method can be derived. The output voltage of master and slave units (V_{OM} and V_{OS}) based on their reference signals and the load current can be written as:

$$V_{OM} = H_{1M}.V_{ref} + H_{2M}.I_{OM} \tag{5}$$

where H_{1m}, H_{2m}, H_{1s} and H_{2s} are derived transfer functions.

Since the master unit makes the I_{ref}, it will be a function of V_{ref} and I_{OM}; hence, Equation 5 can be rewritten as:

$$V_{OS} = H_{3S}.V_{ref} + H_{4S}.I_{OM} + H_{2S}.I_{OS} \tag{6}$$

Considering Equations 5 and 6 and Figures 4 and 5, the transfer functions of H_{1M}, H_{2M}, and H_{2S} are derived as follows:

$$H_{1M} = \frac{s+(\lambda+\varphi)}{LC\varphi s^2+s+(\lambda+\varphi)} \tag{7}$$

$$H_{2M} = \frac{LC\varphi s}{LC^2\varphi s^2+Cs+C(\lambda+\varphi)} \tag{8}$$

$$H_{2S} = H_{2S1} + H_{2S2} \tag{9}$$

where H_{2S1} and H_{2S2} in Equation 9 and H_{3S}, H_{4S} and H_{2S} in Equation 6 can be written as:

$$H_{2S1} = \frac{LC\varphi s}{LC^2\varphi s^2+Cs+C\varphi} \tag{10}$$

$$H_{2S2} = \frac{1}{LC^2\varphi s^2+Cs+C\varphi} \tag{11}$$

$$H_{3S} = \frac{\lambda+s}{LC\varphi s^2+s+\varphi} - \frac{\lambda(s+(\lambda+\varphi))}{(LC\varphi s^2+s+(\lambda+\varphi))(LC\varphi s^2+s+\varphi)} \tag{12}$$

$$H_{4S} = H_{4S1} + H_{4S2} \tag{13}$$

$$H_{4S1} = \frac{1}{LC^2\varphi s^2+Cs+C\varphi} \tag{14}$$

$$H_{4S2} = \frac{\lambda LC\varphi s}{LC^2\varphi s^2+(Cs+C(\lambda+\varphi))(LC\varphi s^2+s+\varphi)} \tag{15}$$

2.3. Modifying the Master-Slave Power Sharing to Improve Voltage Quality

The aforementioned master-slave method is based on power sharing among parallel inverters connected to a common bus. In this regard, all of the inverters contribute to providing the total load fed from this bus; therefore, the master unit current and the other unit's current have similar characteristics and values.

In a real MG, there are some buses and some linear and nonlinear loads. The master unit is connected to a single bus, which may have a local load, and the slave units are connected to different buses, each with its own load.

From Equations 5 to 15, it follows that the master unit parameters can influence the output voltage of the slave units. Transfer functions of H_{3s} and H_{4s} indicate the effect of the master unit parameters on the slave unit. Power-sharing transfer functions are essential, but they increase harmonic distortion in the slave-unit voltages with respect to voltage quality.

In other words, H_{3s} and H_{4s} should be nonzero for power-sharing, but their presence increases the dependency of the slave unit voltage on the master unit parameters. Notable dependence has caused inevitable and unfavourable effects, particularly on the harmonic components. A portion of this dependence is attributable to the feedforward current of the master unit. This feed-forward current has a suitable impact on the master unit voltage; however, it becomes a part of the reference current of the slave unit, which will be transmitted to the other units. In other words, although adding the feed-forward current to the voltage feedback loop output undoubtedly improves the voltage quality of the master unit, this added current decreases the voltage quality of other units (i.e., slave units).

As explained above, a second master-slave power-sharing method is proposed in this paper. This method is similar to the first proposed master-slave method, but the reference current is modified to address the aforementioned problem.

In the second method, the reference current transmitted to the slave units is only the master unit's output signal of the voltage feedback loop, as pointed out in Figures 6 and 7. When the slave units receive this signal, the output current of each unit will be added to its own reference current as feed-forward current. This addition improves the output-voltage quality of the slave units, and the dependence of these voltages on the master unit's output current decreases. In fact, in this condition, each inverter should provide the main part of its loads or the nearest loads; however, the total power of all inverters must be equal to the total power of loads and losses. The related Equations are written as follows:

$$H_{1M-new} = \frac{s+(\lambda+\varphi)}{LC\varphi s^2+s+(\lambda+\varphi)} \tag{16}$$

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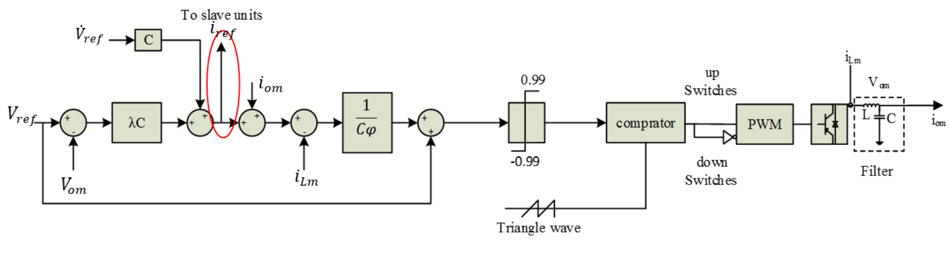

Figure 6. **The block diagram of the master unit using a sliding mode controller in the second method**

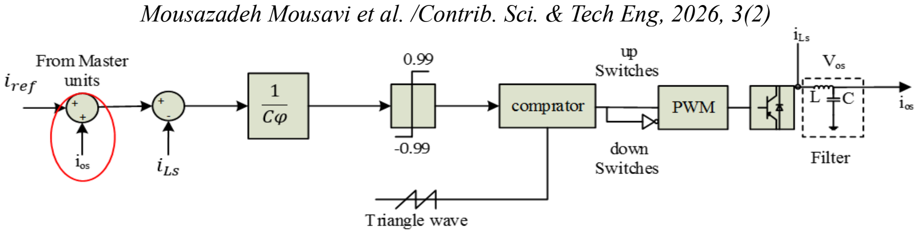

Figure 7. The block diagram of the slave units using a sliding mode controller in the second method

$$H_{2S-new} = \frac{LC\varphi s}{LC^2\varphi s^2+Cs+C\varphi} \quad (17)$$

$$H_{3S-new} = \frac{\lambda+s}{LC\varphi s^2+s+\varphi} - \frac{\lambda(s+(\lambda+\varphi))}{(LC\varphi s^2+s+(\lambda+\varphi))(LC\varphi s^2+s+\varphi)} \quad (18)$$

$$H_{4S-new} = \frac{\lambda LC\varphi s}{LC^2\varphi s^2+(Cs+C(\lambda+\varphi))(LC\varphi s^2+s+\varphi)} \quad (19)$$

According to these equations, compression of $H_{2s\text{-}new}$ and $H_{4s\text{-}new}$ with H_{2s} and H_{4s} - Equations 9 and 13- indicates that the terms of H_{2s2} and H_{4s1} have been omitted by means of the second suggested master-slave strategy. It should be noted that H_{1M}, H_{2M}, and $H_{3s\text{-}new}$ have remained unchanged relative to the old equations, which are related to the first method. Therefore, by using the second method, the master unit equations and the relation between V_{os} and V_{ref} remain fixed. Still, V_{os}'s dependence on I_{om} and I_{os} decreases, thereby enhancing voltage quality.

3. Simulation and Results Discussion

In this simulation, different linear and nonlinear loads, which have different harmonic characteristics, are selected. In this regard, an MG has been assumed, as shown in Figure 1. As shown, this MG comprises six buses, four inverter-based DG units, and six loads. In Figure 8, the current waveforms of these loads are depicted. The inverter-based DG units include a master unit connected to Bus 1 and three slave units connected to Bus 2, Bus 4, and Bus 6. In this MG, six loads are connected to their respective buses, meaning that loads 1-6 are sequentially connected to Bus 1 through Bus 6. Because the voltage quality of the MG should be assessed, different linear and nonlinear loads with varying harmonic characteristics are selected. The purpose of considering all of the above is to assume a general situation. The impedances of the MG branches are treated differently to account for worst-case conditions and are presented in Table 1.

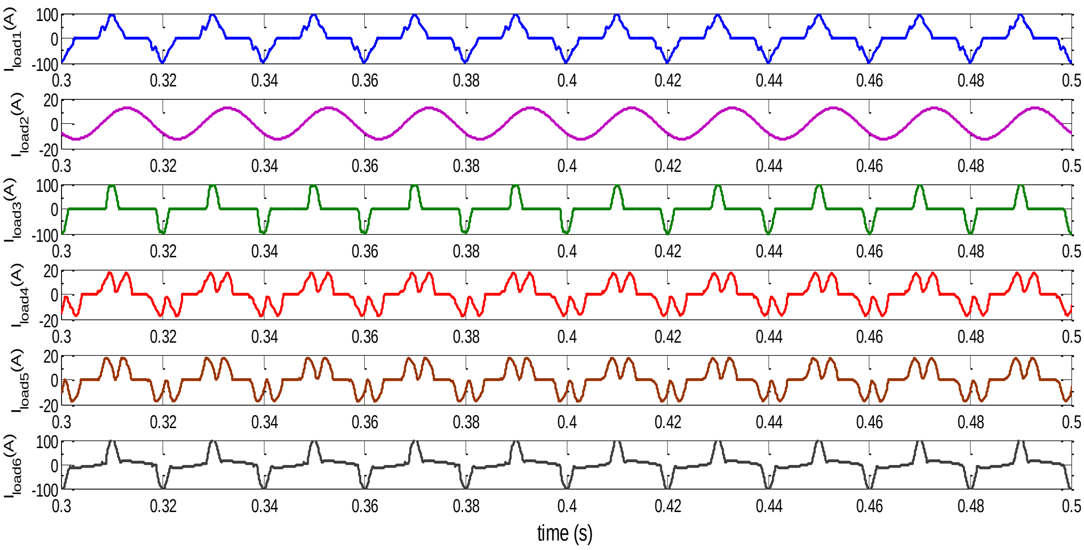

Figure 8. The different load characteristics of the current in the assumed MG

Table 1. The considered impedances of the MG branches

Branch ID	R (Ω)	X(Ω)
Z_{13}	0.05	0.05
Z_{23}	0.075	0.075
Z_{34}	0.09	0.09
Z_{25}	0.1	0.1
Z_{56}	0.04	0.04

When current harmonics pass through the line impedances, the voltage THD of the buses increases, and, because of differences in load characteristics, the role of the control strategy becomes more critical.

The MG depicted in Figure 1, with all details of the assumed loads, is simulated in MATLAB/Simulink. To compare these two proposed master-slave control strategies, both are applied to inverter-based DG units. In this comparison, the condition of MG is assumed to be identical across the two methods.

It should be noted that the inverter units in the simulations are rated at 30 kW. The power of the available loads is assumed to range from 20% to 80% of the inverter's nominal power.

The condition includes the load pattern changes being assumed in the following steps:

- Step 1: Load 6 is increased 100% at t=0.1 and t=0.25 sec (slave 3 is connected to this Bus)
- Step 2: Load 4 is increased 100% at t=0.4sec (slave 2 is connected to this Bus)
- Step 3: Load 3 is decreased 50 % at t=0.6 sec (any inverter-based DG unit is not connected to this bus)

In Figure 9, the changes in the mentioned load currents are illustrated. The target of the mentioned load pattern - including different load change steps- is the definition of conditions that cover all aspects of possible behavior of the inverter-based DG units in the assumed MG. Two independent simulations are performed under identical conditions, except for the applied control strategy. Through these simulations, the harmonic spectra of all bus voltages, the output power of each inverter-based DG, and the total generated power versus total load are evaluated.

In Figure 10, the voltage harmonic spectra by applying these two control schemes are compared and indicated as a histogram diagram. According to this figure, the harmonic components of voltages possess fewer values in the second method compared to the first. Moreover, the improvement in the total harmonic distortion of the bus voltages is evident in this method. In the second method, the role of an inverter-based DG unit in supplying the nearest load is greater than in the first method; therefore, harmonic currents flow through low-impedance paths, thereby enhancing voltage harmonics. It should be mentioned that the fundamental harmonic of voltages is omitted in this figure because of its great value in comparison with the other harmonics. In Table 2, the summarized results of this figure are presented. The THD values of the voltages are calculated at t=0.5 sec, which is the time with maximum loads.

Figures 11 and 12 depict the active power delivered by DG units by applying the first and second proposed methods, respectively. As shown in these figures, all DG units respond to load changes using the first control method; that is, when the load increases or decreases, all inverter-based DG units adjust their output power in proportion to the load change. On the other hand, in the second method, the inverters behave differently.

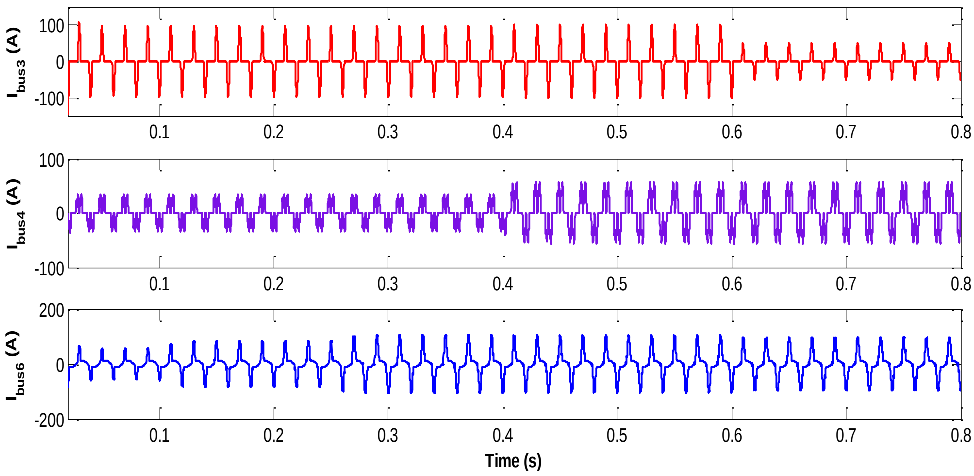

Figure 9. The changes in the mentioned loads current (Load 6 is increased 100% at t=0.1sec and t=0.25sec - Load 4 is increased 100% at t=0.4sec - Load 3 is decreased 50 % at t=0.6 sec)

Table 2. THD of the voltages by applying these two methods

method	THD (%)						
	V_{bus1}(master)	V_{bus2}(slave1)	V_{bus3}	V_{bus4}(slave2)	V_{bus5}	V_{bus6}(slave3)	Average
First Master-slave	0.89	3.62	2.42	5.0	4.27	4.91	3.52
Second Master-slave	0.93	1.43	1.73	2.06	1.81	2.11	1.68

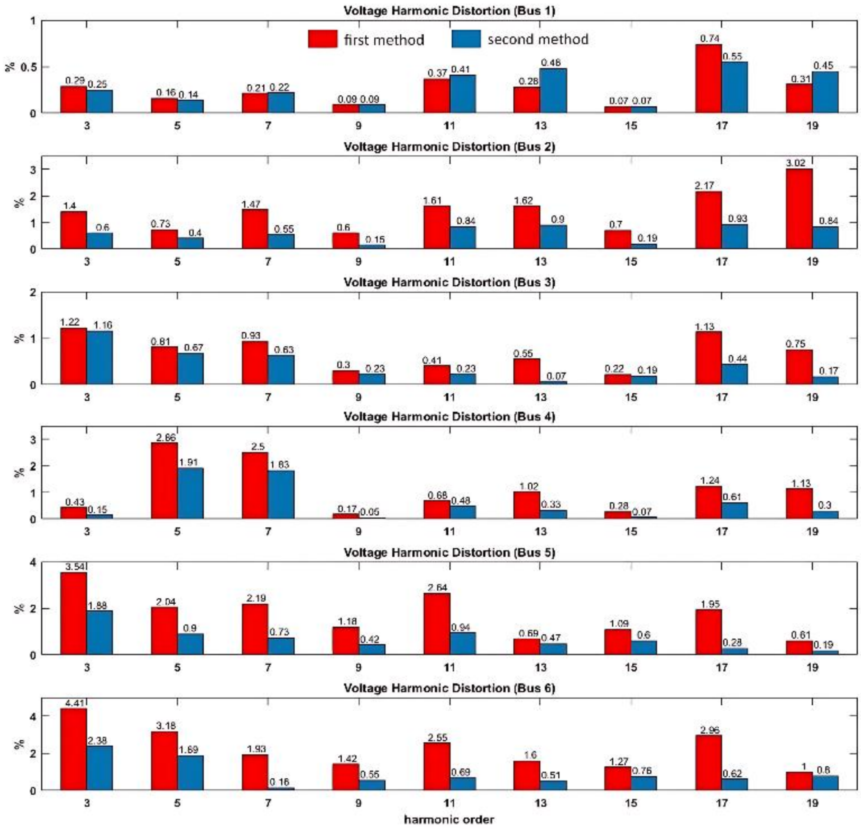

Figure 10. Comparison of voltage harmonic distortions in simulated microgrid buses with both methods

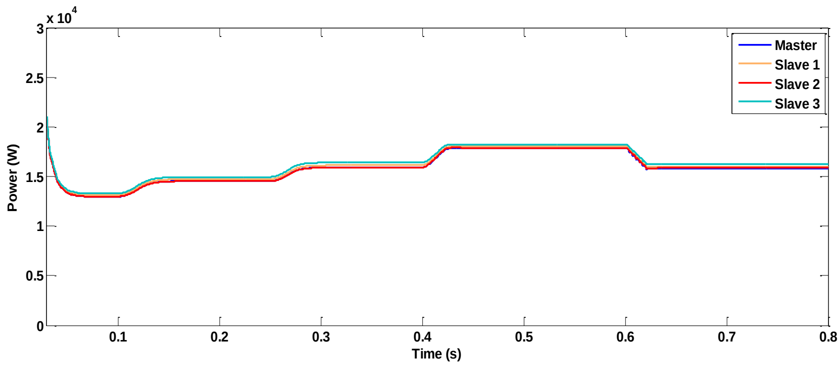

Figure 11. The output power of DG units by applying the first method

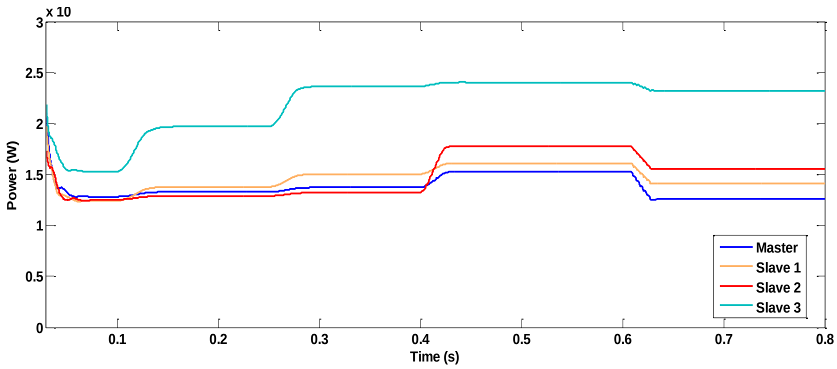

Figure 12. The output power of DG units is obtained by applying the second method

By incorporating the second control method, each DG unit contributes more to feeding the closest load; If a load of a bus changes, the output power of the nearest DG unit will respond more to this change compared to the other DG units.

Considering Figure 12, it is observed that the DG unit named Slave 3 in Bus 6 has the main response to the load 6 changes in Step 1 (t=0.1(sec) and t=0.25(sec)) while in Step 2, Slave 2 (DG unit which is located in Bus 4) contribute more to these changes of load 4 (the load in Bus 4 according to Figure 8). The main response to the changes in load 3; which is connected to Bus 3 (the bus without DG units), belongs to the master unit that is electrically closer to this load. In Table 3, the power loss of this MG under both methods is compared. As expected, using the second method will also decrease the grid loss.

Table 3. Power loss values by applying both of the two proposed methods

Method	Loss (KW)
First Master-slave	2.03
Second Master-slave	1.78

Considering these results, the loads are supplied primarily by the nearest inverters in the second method; therefore, the following two advantages are achieved. Since the nearest DG units supply the loads, network losses will decrease.

Since harmonic currents pass through the fewest impedance routes, the harmonic distortion will be decreased. The related results were shown in Table 2.

Although the first method exhibits poorer operational performance in terms of loss and harmonic distortion, it has an advantage: it prevents inverter overloading, whereby the load exceeds the inverter's nominal capacity. For optimal use of these master-slave power-sharing control methods, combining both methods is recommended. When no inverter is overloaded, the second control method can be used; after any inverter is overloaded, the control strategy should be switched to the first method.

4. Conclusion

In this paper, a master-slave power-sharing control based on sliding-mode switching is presented, and the corresponding mathematical equations are derived. According to these equations, two master-slave power control methods have been introduced. The first method is based on the parallel operation of inverters and equal sharing of the total load power. In contrast, the second method modifies the first to enhance voltage harmonics in an inverter-based islanded MG by implementing appropriate power-sharing.

While the proposed sliding-mode master–slave control approach appears advantageous for reducing voltage harmonics and improving power-sharing accuracy, we acknowledge that its implementation in larger or more complex microgrids may present practical challenges. These concerns include tuning the sliding surfaces for a larger number of DG units, mitigating potential chattering at high switching frequencies, and ensuring reliable low-bandwidth communication as the system scales. Addressing these issues through adaptive parameter-tuning algorithms, hybrid control structures, or distributed implementations of sliding-mode control makes up an important direction for our future work.

5. References

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