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An Approach to Decrease Transient Circulating Current of VSIs in Islanded Microgrid

M. Kohansal, G. B. Gharehpetian, M.Aghaei and M. J. Sanjari

Electrical Engineering Department, Amirkabir University of Technology, Tehran. Iran
Phone/Fax number: +0098-21-64543504,
E-mail: mh.kohansal@aut.ac.ir, grptian@aut.ac.ir, aghaei68@yahoo.com, m_j_sanjari@aut.ac.ir

Abstract. This paper investigates new methods of transient power sharing in parallel inverters. In order to obtain a faster transient response, a control unit is added to conventional droop method. In this control unit, the nominal frequency and voltage of inverters are changed to control the circulating current during transients. In this wireless method, the amount and period of circulating current between inverters are reduced. A detailed analysis shows that the proposed method has a superior transient performance and power sharing in comparison with the other methods. The simulation results indicate the accuracy of the proposed method.

Key words

Microgrid, Parallel inverter, Circulating current, Conventional droop method, Voltage source inverter

1. Introduction

A microgrid (MG) is a group of distributed generators (DGs) and loads, that normally operates connected to a traditional grid (main grid) (Fig. 1). Many forms of DGs are not natural 50 or 60 Hz sources and the question arises for how to incorporate them into a standard electricity grid. The common solution is that DGs are connected via power electronic interfaces and provide loads with high quality power.

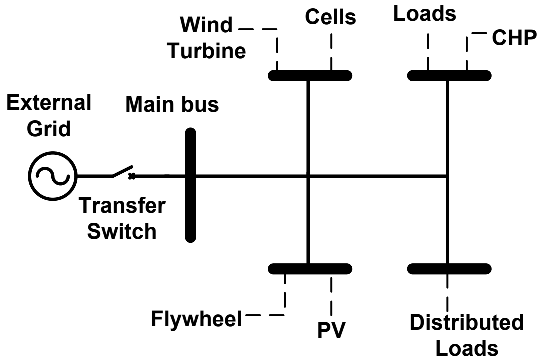

Fig. 1. Typical microgrid system

MGs can operate connected to or isolated from an External Grid (EG). In grid-connected mode, the voltage and frequency of MG are controlled by an External Grid. To control voltage and frequency of MG, demand and supply of active and reactive powers should be balanced. External grid compensates the power in the case of its deficiency and in contrast, absorbs its surplus to control the frequency and voltage. In this mode of operation, inverters control the generated active and reactive powers through DGs' current. This type of inverter control mode is called current source inverter (CSI). In isolated MG, the DGs and inverters are responsible for balancing the generating power and demand. Actually, the inverters control the frequency and voltage of the MG when it operates autonomously. Working with parallel inverters, problems such as circulating current (CC) in the system is faced. This current results in power losses in the inverters and in some cases, the system leads to instability. So the control of parallel inverters is very important in the islanded MG.

There are two possible techniques to parallel operating inverters:

1) Wired parallelism: A method in which inverters are connected through a communication signal, such as master-slave control method [1], the control area network communication [2], etc. In the case of the circuit failure to operate it may lead to the lack of proper operation of the supplying system and also may affect its efficiency so these systems are not reliable enough.

2) Wireless parallelism: In this method, any connections between the parallel inverters are avoided and they can be controlled by electrical signals that are measured locally. In which, frequency and voltage drop, by an increase in active and reactive power [3-7]. Thus, this method is called conventional droop. In this method, the communication signals aren't used, however the network cable impedances and inverter impedance do not allow a precise P (active) & Q (reactive) sharing.

Many improvements are held in conventional droop method to minimize the CC in steady state such as virtual impedance [8-9], SOGI algorithm [10], etc. In most of these methods, the transient time of power sharing is neglected. But in some cases the amount of transient CC will lead to the damage of the inverters and to the system instability.

In this paper, a wireless controller was developed to decrease the amount and period of transient CC. In this method, a feedback from RMS value of current is used to control the nominal frequency (w_0) of inverter. By changing w_0, the active power (P) of inverter can be controlled. The same conclusion can be made on reactive power (Q) and nominal output voltage (E_0). By controlling P and Q, we can prevent the increase in the amount of circulating current during transient time. The Proposed method is simulated in the MATLAB Simulink Program and the results are compared to the conventional droop method.

2. Theoretical Analysis of Conventional Droop Method

Fig. 2 shows the equivalent circuit of inverter. If i and $E\measuredangle\varnothing$ is the output current and voltage of inverter, $V\measuredangle 0$ is the voltage of the common ac-bus and $Z\measuredangle\theta$ is the impedance of the line and inverter, so the complex power drawn to the ac-bus is as follow:

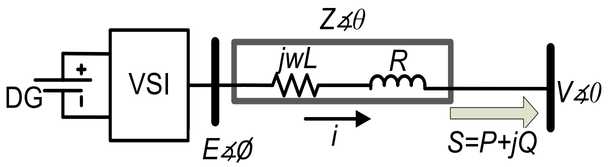

Fig. 2. Equivalent circuit of parallel inverter

$$S = V.i^* = P + jQ \tag{1}$$

$$i = \frac{E\measuredangle\varnothing - V\measuredangle 0}{Z\measuredangle\theta} \tag{2}$$

Using (1) and (2), the active power (P) and reactive power (Q) are concluded as below:

$$P = \frac{V}{Z}((E.\cos\varnothing - V)\cos\theta + E.\sin\theta.\sin\varnothing) \tag{3}$$

$$Q = \frac{V}{Z}((E.\cos\varnothing - V)\sin\theta + E.\cos\theta.\sin\varnothing) \tag{4}$$

So the power delivered depends on the impedance angle θ but in the most of the power systems, the line impedances are considered inductive thus:

$$P = \frac{EV}{X}.\varnothing \tag{5}$$

$$Q = \frac{V.(E - V)}{X} \tag{6}$$

Based on these equations, the droop method of inverters is desired, in which every inverter is a grid-forming unit that defining the voltage frequency and magnitude of the MG buses. This method simulates the synchronous generator controller in inverters. The inverters controlled by droop controller are called voltage source inverters (VSI).

First of all, in a droop controller, the output active (P) and reactive powers (Q) are calculated using common bus voltage (V) and current (i) (Fig.3). Therefore, V and i are transformed to dq frame and then the instantaneous active and reactive powers are calculated using the following equations:

$$p = v_d i_d + v_q i_q \tag{7}$$

$$q = v_d i_q - v_q i_d \tag{8}$$

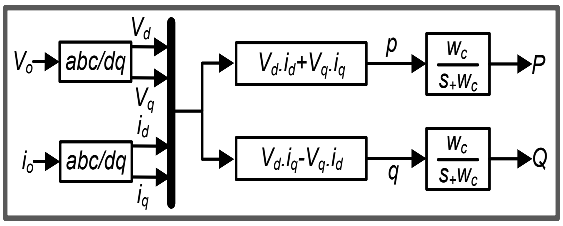

Fig. 3. Power calculation unit

The instantaneous power components are passed through low-pass filters to obtain the active and reactive powers. w_c represents the cut-off frequency of low-pass filters. After calculating P and Q, the fundamental voltage frequency and magnitude of the output voltage are obtained based on the following equations:

$$\omega = \omega_0 - m \times P \tag{9}$$

$$E = E_0 - n \times Q \tag{10}$$

where w_0 and E_0 are the constant coefficients of frequency and voltage characteristics, and m and n are the static droop gains. The set points in (9) and (10) act as a virtual communication agent for different inverters in autonomous operation. The complete model of droop controller is shown in Fig.4.

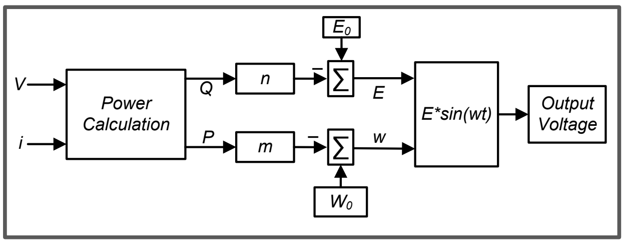

Fig. 4. Droop controller

In ac systems such as conventional power system and MG, frequency is a global signal. On the other hand, active power is highly affected by frequency. According to these facts, using droop controller, it is possible to provide almost an exact active power sharing between the inverters in a MG and maintain the active power dispatched precisely.

Similarly, using the droop controller, the injected reactive power is shared between the inverters of MG. In this process, the output voltage magnitude of each inverter drops against the increasing in its reactive power output. But this process is related to some other features of the

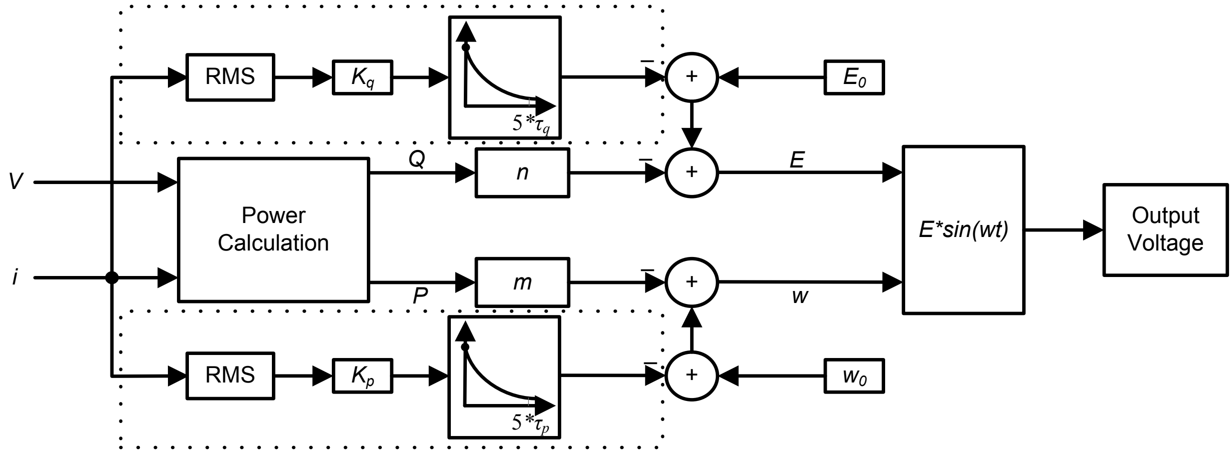

Fig. 5. Diagram of proposed droop method

system which decrease the precision of reactive power sharing. The main reason is that *E* is not global parameter like *w* in power system. Moreover, in steady state, the accuracy of this process is affected by active power control as well as the impedance of the network cables or other system parameters. Furthermore, in a MG, because of short length of the lines, the resistance of them is comparable with their inductance.

On the other hand, during transient state, LPFs applied in the power calculation unit lead to delay in the power sharing process. This delay may reach up to 5τ where τ is the time constant of LPF. During this delay duration, power sharing becomes dependent on the lines impedance and usually, overcurrent is inevitable which is harmful for the inverters and should be limited.

3. Proposed Droop Method

As mentioned in previous section, the Low Pass Filter in the calculation unit (when the load attaches to the system), leads to a great delay in the VSIs responses. As a result, the losses of the system are increased. During transients, the less the impedance of the inverter, the more is the growth of the current, and if its current exceeds the rated value, in a long period of time it may cause damage to the inverter.

In order to reduce the transient current the block diagram in Fig.5 is used. In this diagram, constant coefficients of droop method are influenced by the output current feedback in the transient state, for example if the increase dip of current in inverter one is more than inverter two so the frequency will decline more in inverter one, and as shown in Fig.6 the power generated by this inverter reduces and does not let the current to increase any more.

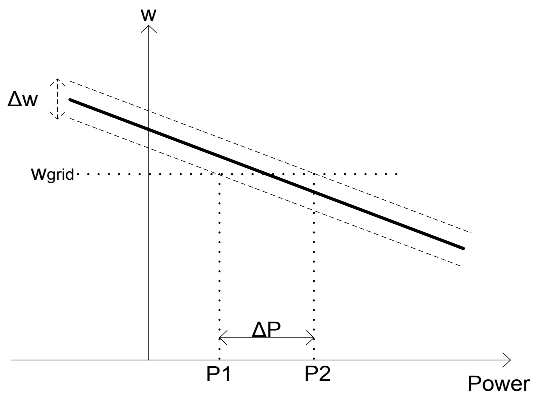

Fig. 6. power changes versus nominal frequency changes

The damping block is used to damp the effect of output current in the frequency in steady state. The frequency can be expressed as below:

$$w=(w_0 - K_p.I.e^{-t_0/\tau_p}) - m.P \quad (11)$$

Where *I* is the RMS value of current and t_0 is the time that *I* change (after occurrence of disturbance). This expression is same for *Q-E*. The proposed method does not affect the frequency and voltage in the steady state; therefore, the power can be shared between VSIs based on the conventional droop method in this state. The advantages of the proposed method are the fast response speed of VSI and reduction in the amount of CC between VSIs.

4. Simulation Results

Two single-phase inverter units were simulated in MATLAB Simulation. These parallel inverters feed 800KW load at 0.2s. The parameters of the simulation have been shown in table I.

Table I. Parameters of the control method

Item	Value
Inductor #1 (line 1)	20mH
Inductor #2 (line 2)	10mH
Resistor #1 (line 1)	0.2Ω
Resistor #2 (line 2)	0.1Ω
Nominal output power	1kVA
Nominal Frequency	50Hz
Nominal Amplitude	200V
P-f droop (m)	0.0084
Q-V droop (n)	0.015
Coefficients of feedback (K_p and K_q)	0.5
Time constants of feedback(τ_p and τ_q)	50ms

Fig.7 displays a comparison of CC between proposed method and conventional droop method. In this method CC posses a faster and less transient response but they both tent to a same value in the steady state.

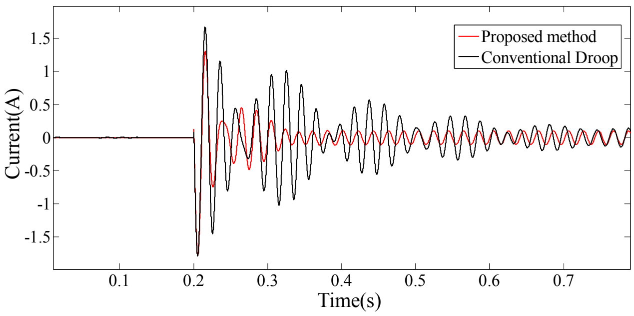

Fig. 7. Comparison of CC between proposed and conventional droop method

Fig.8 compares the ratio of powers between new method and the conventional droop method as it can be observed powers can reach faster to the equilibrium state in the proposed method.

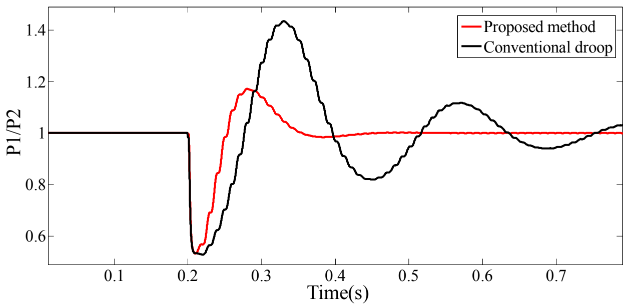

Fig. 8. Comparison P_1/P_2 between proposed and conventional droop method

5. Conclusion

In this paper, a wireless controller was developed to decrease the amount and transient period of CC. In this method, a feedback from RMS value of the current is used to control the nominal frequency and voltage. By changing these parameters, the active and reactive powers of the inverter can be adjusted to prevent the increase of CC during transients. The advantage of the proposed method was studied by two inverters connected in parallel. The transient power sharing of inverters was compared with the conventional droop and the improvement was confirmed.

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