International Research Journal of Engineering and Management Studies (IRJEMS)
Volume: 03 Issue: 03 | March -2019 e-ISSN: 2395-0126

Control of Parallel operation of inverters in islanding mode

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Abstract:

The idea behind this project is to show control of parallel operation of inverters in islanding mode. Parallel-connected inverters are utilized extensively due to their advantages such as expandable output power and improved reliability. In order to have desirable operation of the paralleled inverters, employing an efficient control approach is essential. Generally, in conventional control methods amplitude and frequency of the inverters output voltage are adjusted to achieve balanced current distribution and desirable power sharing between them. The conventional methods have several shortcomings such as complicated control structure as well as frequency and voltage deviations. In this project, We have studied about operation of inverters in islanding mode and latest research that is being carried out in this field.

Key Words: **islanding mode, paralleled inverters, power sharing, reliability, control structure.**

1. INTRODUCTION

Distributed Generations (DGs) based on renewable sources have some merits such as contribution in reduction of greenhouse gas emissions, access to unlimited resources, and having low cost energy. Utilization of such DGs in conventional power systems may be aimed to realize different targets such as increase in reliability and power quality of the networks [1]. Power inverters can be utilized to connect these resources to the network [2]. In many cases such high power, power delivering through a single inverter may has some drawbacks including:

- Poor extensibility
- Poor reliability
- Poor flexibility and maintenance.

A parallel structure of inverters is one of the effective solutions to overcome the aforementioned difficulties. Additionally, it helps to achieve the high power rating as well as increase in system redundancy and reliability. However, parallel-operated inverters may be encountered to some challenges such as the required control to achieve accurate load sharing and decline circulating current.

Several control approaches have been reported in the literature for paralleled inverters. The droop control strategy is one of the most popular technique which is applied more in microgrid application [3–5]. In this technique, active power sharing between the inverters is accomplished by adjusting the frequency and also reactive power sharing is obtained by adjusting the amplitude of the inverter output voltage. Since the droop control strategy is able to generate current reference individually, the requirement for communicated information between the parallel inverters is eliminated. In [3], with regard to the effect of complex impedance to achieve the proper power balance, a droop controller has been designed which makes the circulating current is reduced in different impedances. In [4], a load sharing strategy has been presented, in which a voltage control loop with a direct droop scheme for the dispatchable sources of microgrid and also a power control loop with a complementary inverse droop for the non dispatchables ones have been utilized. In [5], control loops for voltage and current have been proposed based on the stationary reference frame to share active and reactive powers. In addition, mathematical models of the voltage source inverters has been derived for stability analysis of paralleled inverters. However, the conventional droop control strategy has several drawbacks such as high frequency and voltage deviations, poor voltage regulation, slow dynamic response, and the need of having the same per-unit output impedance over a wide range of frequency.

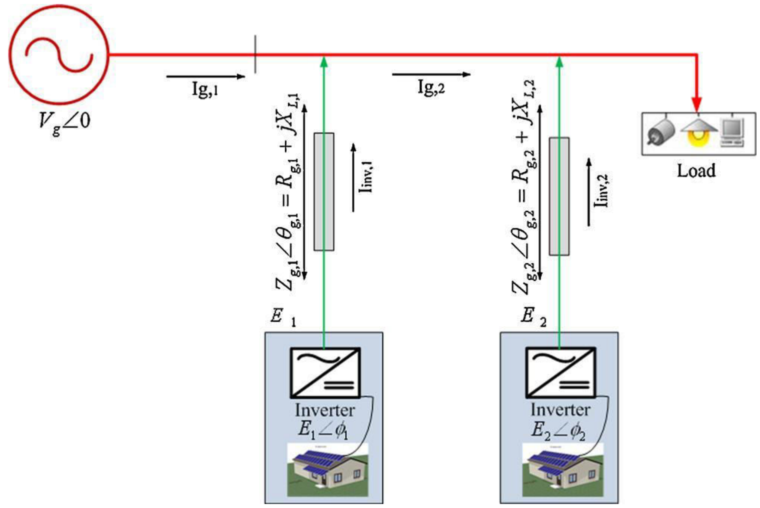

Fig. 1. Equivalent circuit of parallel inverter connected to the grid

2. Principle of parallel operation of inverters

Balance between generated and consumed real (P) and reactive (Q) power indicates the stable operation of a power system. There-fore, implementing effective control over P and Q is very important from the operational and control points of view. The real (P_1) and reactive (Q_1) power transferred from the inverter to the common bus or grid can be calculated as described in [6] and from the fol-lowing diagram, as shown in Fig. 1;

$$P = [\left(\frac{E1\, Vg\, cos\varphi 1}{Zg,1} - \frac{Vg2}{Zg,1}\right) cos\theta g,1 + \frac{E1Vg}{Zg,1} sin\varphi 1 \sin\theta g,1]$$
(1)

$$Q = [\left(\frac{E1\, Vg\, cos\varphi 1}{Zg,1} - \frac{Vg2}{Zg,1}\right) sin\theta g,1 + \frac{E1Vg}{Zg,1} sin\varphi 1 \cos\theta g,1]$$
(2)

Here E_1 and V_g represent the inverter output voltage and grid voltage, respectively. For only real power transfer,

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V_g and E should have the same amplitude with a phase angle difference. Different amplitude of voltage with the same phase will give a reactive power circulation. When both of the magnitude and phase angle differ between the two voltage sources, it causes real and reactive power flow. Control of frequency dynamically controls the power angle and hence, the real power flow. As the output impedance of the inverter is very low, a small change in $_1$ (phase difference between the inverter and grid voltage) could result a very large imbalance in the active power flow [7]. For parallel operation, the output voltage of all inverters must be kept strictly in phase in order to guarantee equality of the output active power for the corresponding inverters. Reactive currents can still circulate between inverters, as shown in Fig. 2, if their output voltage magnitudes differ from each other and this can overload the inverters unnecessarily.

To suppress the circulating current and prevent the dc-link over-voltage, an isolation transformer can be used as a passive control measure, as shown in Fig. 3(a) [8–10], but then the size of the trans-former for high power application could be a problem. Some active methods, such as zero-sequence current control loop, coordinate control, and space vector modulation control are also described in [11–13] respectively. A simple protective control algorithm, as shown in Fig. 3(b), has also been proposed in [14] where the regeneration protection concept based on
3. the rising dc-link voltage is considered.
If V_{dc} is greater than V_{dcref}, the converter stops delivering power from the battery/dc side. Here a proportional controller detects the error signal of the dc-link voltage.

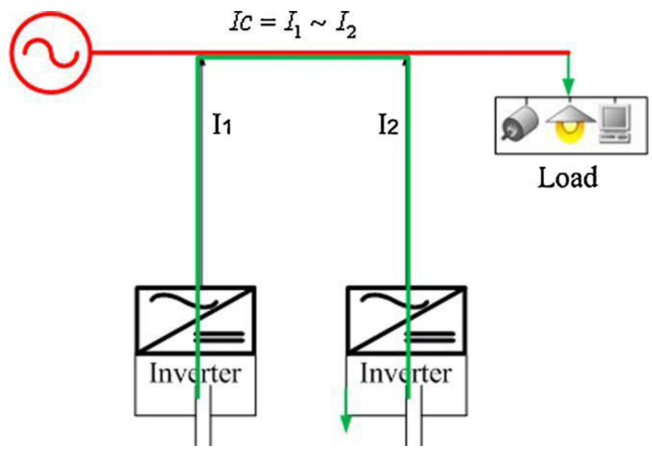

Fig. 2. Circulating current flow between the parallel inverters.

3. Control strategies in parallel operation of inverters

Some of the outcomes of recent research on parallel operation of inverters are given below. The conventional control strategies for the parallel-connected inverters can be classified into two types; active load sharing/current distribution and droop control.

3.1 Active load sharing/current distribution

The objective of the active current distribution control is to generate a reference current for each parallel-connected inverter and this can be subdivided into;

(i) central limit control (CLC);

(ii) master–slave control (MSC);

(iii) average current sharing (ACS)/distributed logical control (DLC);

(iv) circular chain control (3C).

In CLC mode, all the modules should have the same configuration and each module tracks the average current to achieve an equal current distribution [15]. Perfect and equal current distribution can be achieved by using DSP-based control for the voltage and current controller and by tracking the averaged inductor cur-rent of the inverters. Thus the system stability and robustness can be improved [16].

In the MSC method, one inverter is specified as the master, and all others are as the slaves. The master inverter supplies a reference current to the slave inverters. Thus the master module is respon-sible for the output voltage regulation [17]. In such a system, if the master module fails, the system will shut down. This is a major drawback. This can be partially overcome by introducing a separate current-controlled PWM inverter unit to generate the distributing current independent for the slave inverters. Hence, precise current division between the inverters are very important. This strategy is easy to implement in the parallel operation of UPS. In other cases, another module can take the role of master in the event of a main master unit failure. The control scheme can be of dedicated, rotary or high-crest current type [18].

In the MSC and CLC methods, the output currents of all parallel-connected inverters must be collected, and the number of parallel-connected inverters must be pre-known. If one of the parallel-connected inverters fails, the parallel-connected system will fail. This problem can be overcome by the DLC mode where redundancy is also achievable.

In the ACS/DLC mode, an individual control circuit is used for each inverter. The current control mode is used to control its output current and to trace the same average reference current. When a defect is found in any module, others can still operate in parallel [19–21]. It can also be used as a power-sharing technique where each inverter controls the active and reactive power flow in order to match the average active power of the system [22].

In the 3C mode, the successive module tracks the current of the previous module to achieve an equal current distribution, and the first module tracks the last one to form a circular chain connection. The output voltage and current of each inverter can also be varied and internally controlled to achieve a fast dynamic response. A coordinated control strategy for different load sharing controls can be implemented to eliminate the circulating currents due to unbalance of parallel inverters [23].

3.2 Droop control

The droop control method for the parallel-connected inverters can avoid the communication mismatch of reference current. It is also defined as wireless control (WC) with no interconnection between the inverters. In this case, the inverters are controlled in such a way that the amplitude and frequency of the reference voltage signal will follow a droop as the load cur-rent increases and these droops are used to allow independent inverters to share the load in proportion to their capacities [24]. This technique is then improved for non-linear load where harmonic components can be shared properly [25]. The impact of line impedance on reactive power sharing in the conventional frequency/voltage droop concept is further enhanced in [26] to make the controller ideally suited for distributed ac power supply systems.

3.3 Outcomes

A detailed review and performance comparison of these control strategies has been presented in [27] which shows that within active load sharing control schemes, current-sharing control is good for output voltage regulation and harmonic current control. However it requires high speed communications. Active power sharing requires low bandwidth communication for active and reactive power sharing, but the harmonic power sharing is poor and therefore sharing non-linear loads with a high crest factor is a problem. Active synchronization is also a major problem for both the schemes.

4. Parallel operation of inverters in DG or microgrid

Recent work on parallel operation of inverters in DG has concentrated on two applications: a) standalone AC system–Microgrid (island/off-grid mode) and b) grid-interconnection to the utility. In island mode of operation, a number of DGs supplies all the power needed by the load, like the parallel operation of the uninterruptible power supply (UPS) systems. In a grid-tie operation, each distributed energy source is connected in parallel to the utility, and directly provides power to the grid in order to cover increased power required by the loads.

Considering the parallel operation of DGs in any of the modes, voltage stability is a major concern. If appropriate controlling is not done, then the power system may become unstable under the heavy load condition and thus exhibiting voltage drops that can lead to a voltage collapse and resulting in a black-out. Again, when renewable energy sources are connected to the grid, the system should have the ability to dispatch the optimum energy as well as to control the power conversion system in (i) utility interactive grid-tie inverter mode, (ii) off-grid inverter back-up mode, (iii) active rectifier mode and (iv) active power filter mode.

As the parallel operation of inverters for load sharing conditions and the application of DG in microgrids are increasing rapidly, control strategies of parallel inverters in microgrids are being given more attention. A countable number of researches have been done considering active load sharing condition [15-23] and droop control [24–30] or a combination of both [31-33]. Due to the advancement of digital signal processing techniques, some of these controlling methods have been applied to achieve voltage harmonics elimination and fast recovery performance on load transient in digital mode [32–36]. Transient response can also be improved by introducing proportional–integral–derivative (PID) terms [28],or an adaptive output impedance controller [29], into a conventional droop scheme. In addition, an instantaneous current control loop is also included to ensure correct sharing of harmonic components when supplying nonlinear loads

The possible resonance due to long wiring cables having non-negligible inductance and resistance and its detrimental effect on system stability and performances should be considered during the design stage [37-38]. The line impedance ratio between the grid and inverter can be implemented to cancel voltage harmonic disturbances [28]. A grid impedance parameter estimation technique in advance has been presented in [39] and then applied to an adaptive droop controller to operate inverters in grid-connected or islanded mode.

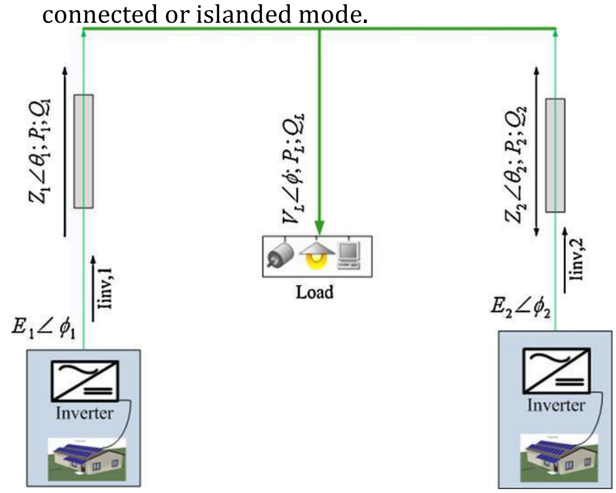

Fig. 3 Droop control method

Fig. shows that the droop control method can also be applied where DGs are working in parallel to cover the local load demand and sharing the common load during off-grid conditions [40]. Further improvement of stability and load sharing capability in an autonomous microgrid has been achieved by implementing a supplementary controller into the droop control method [41].

Most of the power electronics converters are based on the variable frequency controller. Research on fixed or constant switching frequency controllers by using simple circuitry has also been con-ducted. One-cycle control (OCC) is one of these types which can be successfully implemented in a grid connected inverter with its parallel operation mode [42]. Again, as the switching frequency of the inverter is fixed, a conventional load–frequency control scheme cannot be used for load-sharing control. To alleviate this problem, a load–voltage control scheme has been developed in [43] where the control strategy distributes the load among the different energy sources based on their pre-defined load–voltage droop characteristics.

5. Conclusion

In this paper, Study of operation of inverters in islanding mode and latest research that is being carried out in this field has been provided. The control strategies of parallel operation of DG inverters are initially described. From the inverter control strategies it is found that active load sharing control techniques have some limitations. Due to intercommunication requirement between the inverters, control complexity is significant. Although active load sharing techniques for parallel operation of a fixed number of inverters can be better due to its robust control, expansion of capacity due to the additional load may not be easy. On the other hand, droop control seems better for most purposes. Research indicates that most efforts are being put into droop control techniques due to its capacity expansion flexibility, independent inverters and hot-swap facilities.

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