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Application of a suitable control strategy for grid-connected inverters to the power management of a Microgrid

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1. Introduction

The ever increasing energy demand, the necessity of a reduction in costs and higher reliability requirements are driving the present scenario towards Distributed Generation (DG). The DG has been considered as a promising alternative for the coordinated and flexible expansion of the present energy distribution system with reduced cost and improved reliability (Pepermans et al., 2005). In particular, the small DG systems, typically from 1KW to 10 MW and located near to the loads, are gaining popularity due to their higher operating efficiencies and lower emission levels as provider of electrical energy to the consumers. These DG systems are powered by one or more microsources such as: fuel cells, photovoltaic cells, batteries, wind-turbine, micro-turbines etc.
A recent evolution resulting by the diffusion of the DG systems is emerged with the concept of Microgrid, which consists in a cluster of loads and paralleled DG systems operating as a single power system that provides power to its local area (Lasseter, 2002). A Microgrid is a systematic organization of DG systems and therefore it has larger capacity and more control flexibility to fulfil system reliability and power quality requirements, in addition to all the inherent advantages of a single DG system.
The above characteristics can be obtained thanks to the use of grid-connected inverters able to quickly manage power generated by the microsources and to generate reactive power near loads, allowing losses reduction. Therefore, high performance control algorithms for power flows control and voltage regulation are required (Li et al., 2006; Katiraei & Iravani, 2006). These algorithms should preferably have no communication links between the paralleled DG systems, which can be located far apart; thus, the control algorithms of each individual DG system should be based on feedback variables that can be measured locally and moreover, they have to ensure a safety operation of the Microgrid avoiding instability problems, which can occur especially when many DG systems are located in a same area.
A good solution for the aforementioned problems can be obtained by the application proposed in this chapter. It is based on the use of a control strategy for grid-connected inverters able to dynamically change the energetic contribution of the microsources, that so adapts oneself to variations of the grid characteristics and contributes to the power management of the Microgrid. The control strategy is developed so as to combine the

advantages of current control and voltage control strategies; as known, the former is to be preferred to ensure stability of the whole conversion system, while the latter one allows a more accurate generation of the reference voltages necessary to apply the PWM voltage technique (Rodriguez et al., 2005). As demonstrated in (Menniti et al., 2007 ; Menniti et al., 2008), the combined use of the two control strategies allows the implementation of a simple and effective single phase control scheme, particularly adapt to deal with critical conditions that can occur in the Microgrids.
The performance of the proposed application is verified in simulation on a Microgrid test, in which several DG systems are contemporary connected to the main bus.
The rest of this chapter is arranged as follows. Section II briefly illustrates the concepts and control issues of Microgrids, while the properties of the grid-connected inverters are given in Section III. Then, in Section IV the Microgrid configuration under examination is shown and in section V the specific used control approach is discussed. Finally, Section VI provides some simulation results, which show the good performances of the proposed power management applied to the Microgrid test.

2. Microgrid Concepts

It is a widespread opinion that small generation should be part of the building energy management systems. In all likelihood, the DG energy output would be ran more cost-effectively with a full range of energy resource optimizing: peak-shaving, power and waste heat management, centralized load management, price sensitive fuel selection, compliance with interface contractual terms, emissions monitoring/control and building system controls. The Microgrid paradigm provides a general platform to approach power management issues.
It has been found that, in terms of energy source security, multiple small generators are more efficient than relying on a single large one for lowering electric bills (Flannery et al., 2004). Small generators are better at automatic load following and help to avoid large standby charges seen by sites using a single generator. Having multiple DG systems on a Microgrid makes the chance of all-out failure much less likely, particularly if extra generation is available.
Moreover, as already explained, the DG systems in Microgrid are generally powered by emerging technologies such as photovoltaic or wind-power and often equipped by inverters to interface with the electrical distribution system. The major issue with these technologies is the nature of the generation; indeed, the availability of their energy source is driven by weather and not by the loads of the systems. These technologies can be labelled as intermittent and ideally they should be operated at maximum output.
An example of a basic Microgrid architecture is shown in Fig. 1, where two paralleled systems DG1 and DG2 are employed. Each DG system is comprised of a dc source, a pulse-width modulation (PWM) voltage source inverter (VSI) and LC filters. In this mode, the two DG systems are controlled to provide local power and voltage support for critical loads A, B and C. This configuration reduces the burden of generation and delivery of power directly from the main grid and enhances the immunity of critical loads to system disturbances in the grid (Flannery et al., 2004 ; Li et al., 2004).
As shown in figure, the Microgrid is connected to the main grid at its point of common coupling (PCC) usually through a static transfer switch (STS).

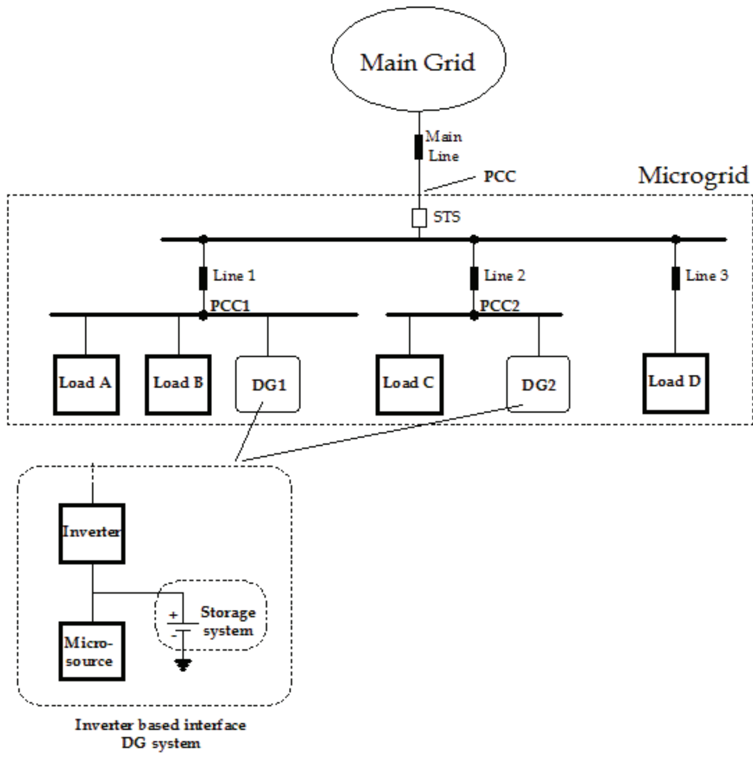

Fig. 1. Microgrid Architecture diagram

An important problem, that can be resolved by the DG systems is the impact of unbalanced grid voltages (usually caused by faults or unbalanced connected) on the overall system performance. If the unbalance in voltages is serious, STS opens to isolate the Microgrid from the main grid; however, also if the voltage unbalance is not so serious, STS may remain closed, resulting in sustained unbalanced voltages at PCC. Such a voltage unbalance can cause an increase in losses in motor loads (and hence motor overheating) and abnormal operation of sensitive equipments in the Microgrid.
Another issue regarding Microgrid is related to the ability of DG systems to increase system reliability and power quality due to the decentralization of supply. Indeed, using a decentralized control for each DG system, expensive communications systems can be avoided and problems connected to transient conditions in the grid (i.e. frequency oscillations) can be reduced.

3. The Grid-connected inverter

With the development of solid-state-based packages, power electronic devices can now convert almost any form of electrical energy to a more desirable and usable form. This is why power electronic interfaces are ideal for DG system applications.
Indeed, many power sources used in DG systems generate electric power in a waveform that the present power distribution grid cannot accept. Sources as photovoltaic cells or fuel cells supply dc electric energy, while the present distribution grid accepts ac electric energy. Often, in wind power generation systems it is necessary to convert the ac voltage from wind

turbine generator to dc voltage, being the frequency and amplitude of the ac voltage from the wind turbine generators variable in time due to the random nature of the wind.
As a consequence, the power electronic interfaces may include both ac-dc conversion systems (rectifiers) and dc-ac conversion systems (inverters).
Another benefit of power electronic devices is their extremely fast response times; in fact, the dc-ac power interface, usually called grid-connected inverter, can respond to power quality events or fault conditions that occur in the grid within the sub-cycle range.
In addition to allowing the transfer of power supplied by the microsource of the DG system, the grid-connected inverter can also permit the control of voltage and reactive power at the PCC of the generation source (Kroposki et al., 2006). In particular, most inverters for DG systems are self commutated and can produce an ac voltage of an arbitrary amplitude and phase. This allows the DG systems to produce any power at any power factor so as a wider operating power factor range than a synchronous generator can be obtained.
The grid-connected inverter can also contain protective functions, for both the distributed energy system and the local electric power system, that allow paralleling and disconnection from the electric power system. Moreover, also some level of metering and control functionality are contained and this shall ensure that the distributed energy system can operate as designed.
Finally, it is worth to highlight that the grid-connected inverter controls must ensure different important requirements: new microsources can be added to the system without modification of existing equipment, set-up can be independently chosen, the Microgrid can connect to or isolate itself from the grid in a rapid and seamless fashion, reactive and active powers can be independently controlled and can meet the dynamic needs of the loads.

4. The Microgrid configuration

In the context described in two previous sections, this paper proposes the application of a suitable control strategy for grid-connected inverters in a simple distributed system in which several DG systems are contemporary connected to the same bus of a Microgrid.
In particular, the Microgrid configuration under examination is shown in Fig. 2 and it consists in four DG systems, based on inverters connected to the main bus by different line impedances.

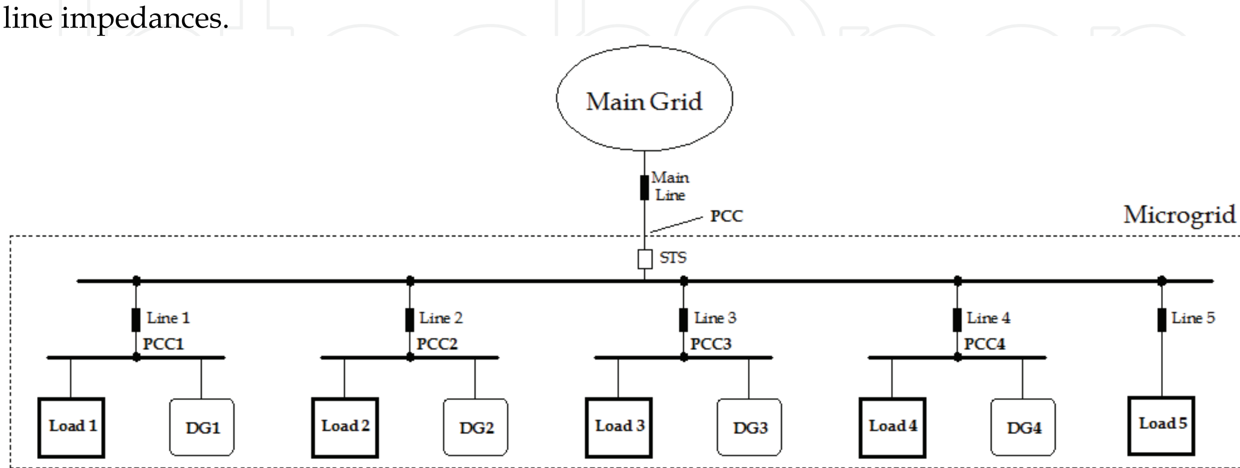

Fig. 2. Microgrid configuration considered.

Each DG is directly connected to a critical load that absorbs a different amount of active and reactive power for each phase. Besides, a linear and balanced load (Load 5) is connected at the main bus.

It is worth to underline that each DG system has merely information about the voltage at its own PCC and the currents absorbed from the critical load connected at the same PCC. Using this information, each DG system should operate in order to correct the power factor and to balance the active power absorbed by each phase of the load, so as to effect a regulation of the voltage and avoid that unbalances scatter in the main system. Obviously, each DG system provides active power to the grid supplying a share of the energy required by the loads in the Microgrid.

Thanks to the potentiality of the grid-connected inverters, the DG systems are able to influence the power flows of the Microgrid very quickly and in significant manner. However, a so fast action can bring out perturbations in the Microgrid and generate instability. Certainly, this can occur when many DG systems are present; for this reason, it is important that the DG systems control manages to avoid negative impacts on the Microgrid stability.

In the following section the control strategy used for the application and proposed by the authors in (Menniti et al., 2007), is explained and illustrated in detail.

5. Strategy control for power management

The configuration of the grid-connected inverter, used in each DG system of Microgrid configuration under examination is shown in Fig. 3.

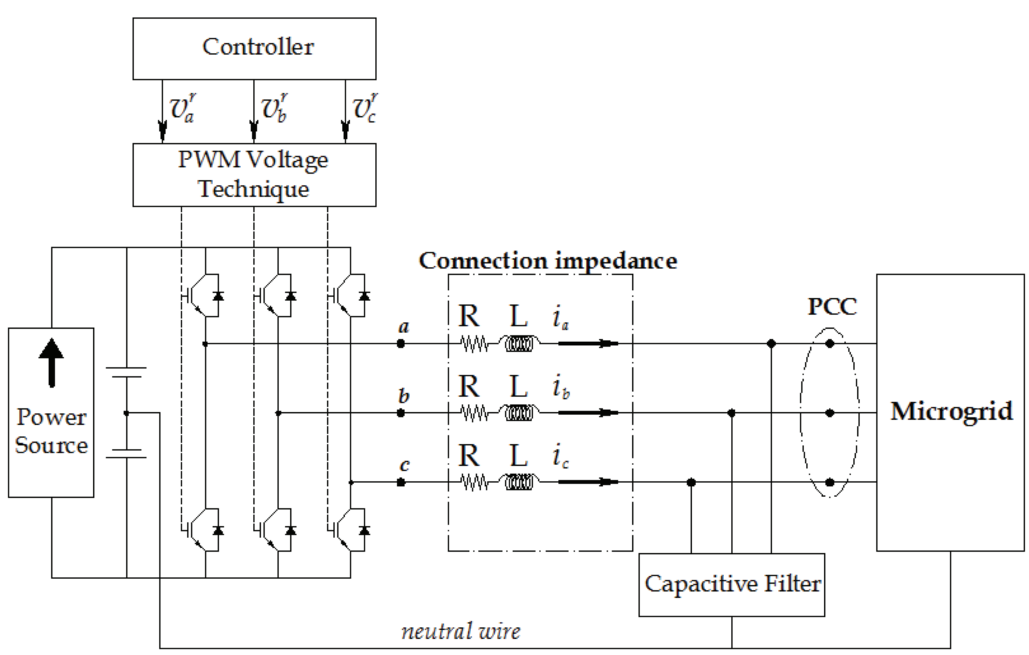

Fig. 3. Grid-connected inverter configuration.

It comprises a three-leg VSI connected on the ac-side to the Microgrid by a suitable connection impedance and on the dc-side to a dc-power source by capacitors. The inverter

works in order to transfer the energy produced by the dc-power source on the Microgrid, controlling the power flows through the connection impedance. This is constituted by three connection impedances each with resistance R and inductance L and a parallel capacitive filter providing a path for some high-order harmonics at the switching frequency.
Considering that the inverter operates in voltage control mode, its controller generates three reference signals v_j^r (where $j = a,b,c$), each of which is referred to the output voltage to be applied on the *j-th* phase, so that the connection impedance current i_j tracks its desired value corresponding to the power flows required between the dc and ac sides. Obviously, it is needed that the output voltages of the VSI track the reference voltages by properly applying the PWM technique; so in the following it will be assumed that $v_j = v_j^r$.
The block diagram relevant to the control strategy applied to the generic phase of the grid-connected inverter, is shown in Fig. 4 (where for sake of simplicity the subscript *j* is omitted).
As clearly evidenced, it includes two parts: one indicated with *Voltage Control* and the other with *Current Control*. Both the parts need the estimation value for the rms *V* and the phase φ_v of the correspondent PCC voltage v (obtained by block A operating as Phase Locked Loop) and information about the desired power flows P^* and Q^* to be exchanged with the grid. Moreover, the reference voltage v^r is obtained as sum of two contributions: v_v^r given by the *Voltage Control* and v_c^r given by the *Current Control*.

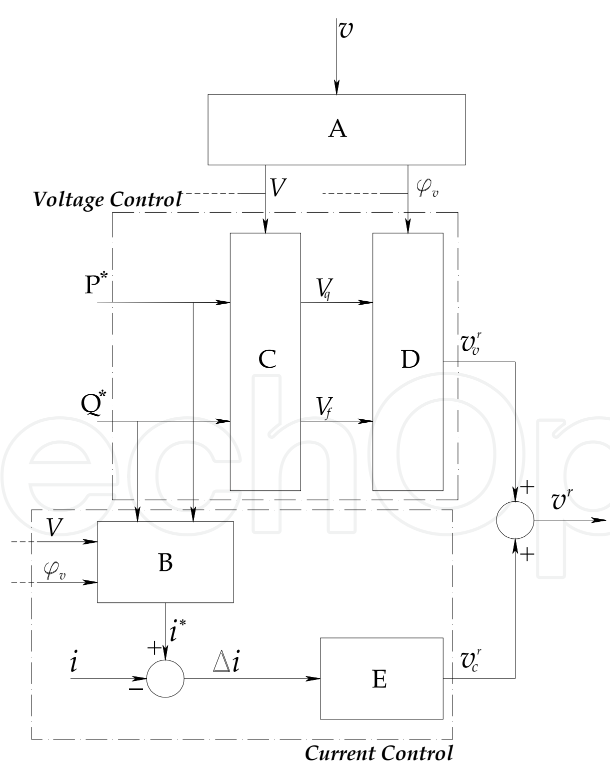

Fig. 4. Block diagram of the control strategy

5.1 Voltage Control

The basic equation of the *Voltage Control* are obtained by considering the simple circuit of Fig. 5. It shows the voltages and the currents relevant to the branch "***a***" of the connection impedance. Obviously, by considering only the components at fundamental frequency, the current flowing through the capacitive filter can be neglected.

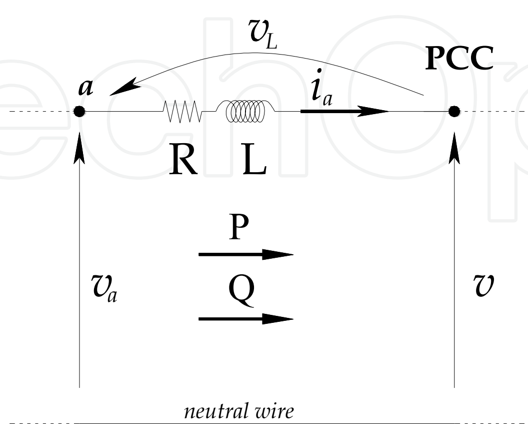

Fig. 5. The equivalent circuit at fundamental frequency.

For sake of simplicity only the powers exchange on the phase "***a***" will be analyzed, because the relationships that rule the power flows through the others phases can be obtained in a similar way.

In particular, in Fig. 5, the fundamental components of the voltages at PCC and at node "***a***" are denoted as v and v_a respectively. Analogously, i_a and v_L denote the current and the voltage on the connection impedance, while P and Q are the fundamental active and reactive power flows from node "***a***" to PCC.

By expressing the quantities v, v_a, i_a and v_L as phasors $\bar{\mathbf{V}}$, $\bar{\mathbf{V}}_a$, $\bar{\mathbf{I}}_a$ and $\bar{\mathbf{V}}_L$ respectively and choosing $\bar{\mathbf{V}}$ as the reference one, the phasor diagram shown in Fig. 6 is obtained.

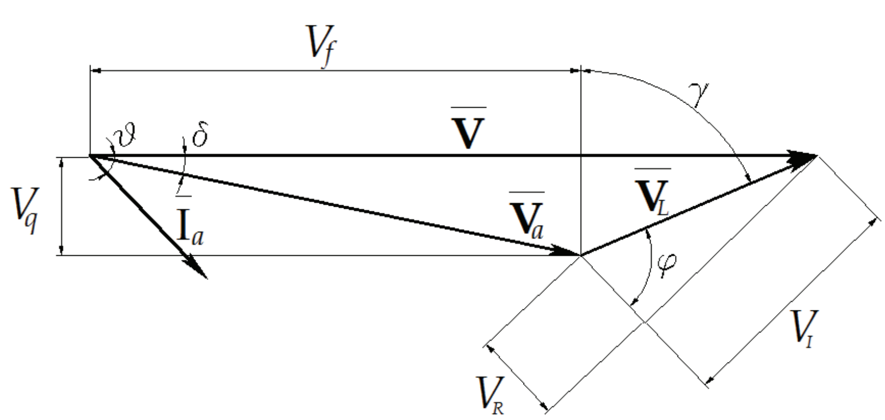

Fig. 6. The phasor diagram relevant to the circuit of Fig. 5.

In detail, in Fig. 6: δ is the phase angle of $\bar{\mathbf{V}}_a$, V_f and V_q are the forward and the quadrature components of $\bar{\mathbf{V}}_a$ with respect to $\bar{\mathbf{V}}$; ϑ is the phase angle of $\bar{\mathbf{I}}_a$; φ is the characteristic angle of the connection impedance and it is equal to $\arctan(X_L/R)$, where

$X_L = \omega L$ represents the reactance of the connection impedance at the particular angular frequency ω; the angle γ is defined by the following relationship

$$\gamma = \frac{\pi}{2} + \vartheta - \varphi \,. \tag{1}$$

Moreover, the magnitude of the resistive and the inductive voltage components of $\bar{\mathbf{V}}_L$, V_R and V_I respectively, are obviously defined as

$$V_R = V_L \cos\varphi \,, \qquad V_I = V_L \sin\varphi \,, \tag{2}$$

where V_L is the amplitude of $\bar{\mathbf{V}}_L$.

As known, the active and reactive power flows from the node "***a***" to the PCC can be expressed by the following relationships

$$\mathrm{P} = V I_a \cos\vartheta \,, \qquad \mathrm{Q} = V I_a \sin\vartheta \,. \tag{3}$$

Considering (2) and the amplitude of the connection impedance current, it is possible to obtain the following law for the active and reactive powers

$$\mathrm{P} = \frac{V}{\sqrt{\mathrm{R}^2 + \mathrm{X}_\mathrm{L}^2}} \frac{V_I}{\sin\varphi} \cos\vartheta \,, \qquad \mathrm{Q} = \frac{V}{\sqrt{\mathrm{R}^2 + \mathrm{X}_\mathrm{L}^2}} \frac{V_I}{\sin\varphi} \sin\vartheta \,. \tag{4}$$

From the phasor diagram of Fig. 6, it is easy to observe that

$$\begin{aligned} &V_I \cos\vartheta = V_a \sin\delta + V_R \sin\vartheta, \\ &V_L \sin(\varphi - \vartheta) = V_a \sin\delta = V_q. \end{aligned} \tag{5}$$

Then, considering the first one of (2) and using the Werner formulas, it is possible rewrite

$$\mathrm{P} = \frac{V}{\sqrt{\mathrm{R}^2 + \mathrm{X}_\mathrm{L}^2}} \frac{V_I + V_L \sin(\vartheta + \varphi)}{2\sin\varphi} \,. \tag{6}$$

Moreover, from the phasor diagram of Fig. 6, the following angular relationship can be easily obtained

$$\vartheta + \varphi = \gamma - (\pi/2 - 2\varphi) \,, \tag{7}$$

therefore, by means simple algebraic manipulations, the sinusoidal term of (6) can be written as

$$\sin(\vartheta+\varphi)=2\sin\gamma\ \sin\varphi\ \cos\varphi-\left(\cos^2\varphi-\sin^2\varphi\right)\ \cos\gamma\ . \tag{8}$$

Consequently, by substituting (8) in (6) and observing, from Fig.6, that

$$\begin{aligned} V_L\sin\gamma &= V-V_f\,,\\ V_L\cos\gamma &= V_q\,, \end{aligned} \tag{9}$$

the following relationship for the active power flow can be obtained

$$\mathrm{P}=\frac{V}{\sqrt{\mathrm{R}^2+\mathrm{X}_\mathrm{L}^2}}\left[\sin\varphi V_q+\cos\varphi\left(V-V_f\right)\right]. \tag{10}$$

In a similar way it is possible to provide the relationship which describe the bond between the voltages on the connection impedance and the reactive power flows supplied by the inverter:

$$\mathrm{Q}=\frac{V}{\sqrt{\mathrm{R}^2+\mathrm{X}_\mathrm{L}^2}}\left[\sin\varphi\left(V-V_f\right)-\cos\varphi V_q\right]\cdot \tag{11}$$

Neglecting the resistance of the connection impedance, i.e. considering $\varphi=\pi/2$, the expressions for the active and reactive power flows become:

$$\mathrm{P}=\frac{V}{\mathrm{X}_L}V_q\,,\qquad \mathrm{Q}=\frac{V}{\mathrm{X}_L}\left(V-V_f\right)\cdot \tag{12}$$

These equations show that the active power flow only depends on V_q, while the reactive power flow only depends on V_f; therefore, by controlling the forward and the quadrature component of $\bar{\mathbf{V}}_a$ (i.e. the amplitude and the phase angle of $\bar{\mathbf{V}}_a$ with respect to $\bar{\mathbf{V}}$), it is possible to control the fundamental active and reactive power flows of the circuit of Fig. 5.
It is worth to underline that in the real case the resistance R is not just equal to zero, but surely it is very low, representing a parasitic resistance of an inductive filter; therefore (12) can be considered as acceptable approximations of (10) and (11).
On the basis of the presented analysis, the *Voltage Control* marked in Fig. 4 is simply realized through the two blocks C and D. In fact, on the assumption that the connection filter is purely inductive, the block C calculates V_f and V_q according to the following equations, directly obtained from (12):

$$V_f=V+\frac{\omega\mathrm{L}}{V}\mathrm{Q}^*\,,\qquad V_q=\frac{\omega\mathrm{L}}{V}\mathrm{P}^* \tag{13}$$

and block D determines the share v_v^r of the reference voltage on the basis of the following relationships:

$$v_v^r(t) = \sqrt{2}\sqrt{V_f^2 + V_q^2}\sin(\omega t + \varphi_v + \delta),$$
$$\delta = \arctan(V_q/V_f) \tag{14}$$

5.2 Current Control

As illustrated, the basic equations of the *Voltage Control* have been obtained by using a phasor representation assuming a sinusoidal waveform at the fundamental frequency for the voltages and the currents; since the bond between currents and voltages can be described by phasor diagram only if the system is in steady-state condition, a suitable *Current Control* has been developed in order to provide a corrective action mainly during the transient period.

The block B, included in the *Current Control* (see Fig. 4), uses the values V and φ_v to calculate the instantaneous value of a reference current i^* necessary to obtain the desired power flows P^* and Q^*, by means of the following equation

$$i^*(t) = \sqrt{2}I^*\sin(\omega t + \varphi_i) \tag{15}$$

where

$$\varphi_i = \varphi_v - \arctan\left(\frac{Q^*}{P^*}\right),$$
$$I^* = \frac{\sqrt{[P^*]^2 + [Q^*]^2}}{V}. \tag{16}$$

The block E represents the regulator determining, on the basis of the error $\Delta i = i^* - i$, the other share v_c^r of the reference voltage.

Since the *Current Control* has to act as support of the *Voltage Control* substantially only during the transient period, its contribution can be estimated as proportional to the inductor energy, necessary to carry the actual current value i to its desired value i^*, that can be written as:

$$E = \frac{1}{2}L\Delta i^2 . \tag{17}$$

This consideration suggests to use for the block E the following relationship

$$v_c^r = k\Delta i^2\,\mathrm{sgn}(\Delta i), \tag{18}$$

represented by the instantaneous characteristics shown in Fig. 7 and where k is a suitable constant.

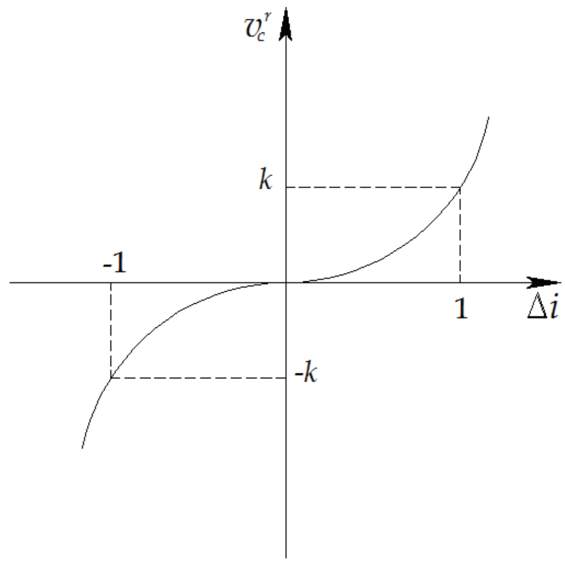

Fig. 7. Instantaneous characteristics of the *Current Control* regulator (block E).

5.3 Management Power Flows

The choice of the desired power flows P^* and Q^* has been effected in order to prove the benefits brought by the DG when many sources are present in a Microgrid. The value Q^* has been chosen equal to the reactive power absorbed by each local load in order to realize the load power factor correction and then to reduce the transmission losses. The desired active power flow P^* has been obtained as sum of two contributions. The former is equal for each phase to one third of the active power provided by the dc-power microsource. The other contribution is calculated in order to balance the power absorbed by an unbalanced load. In particular, the desired active power to be provided by each interfacing inverter on the *j-th* phase has been chosen as:

$$P_j^* = \Delta P_{Lj} + \frac{P_{ms}}{3} , \tag{17}$$

where P_{ms} is the active power given by the microsource and ΔP_{Lj} is the difference between the power absorbed by the local load on the *j-th* phase and the average power absorbed by all the phases, as shown by the following relationships:

$$\Delta P_{Lj} = P_{Lj} - P_{ave} , \qquad P_{ave} = \frac{(P_{La} + P_{Lb} + P_{Lc})}{3} . \tag{18}$$

6. Numerical results

Some numerical results have been carried out to demonstrate the effectiveness of the proposed application. The reactive power compensation obtained by the grid-connected inverters, controlled by the used control strategy for each PCC node and for a generic phase is displayed by Fig. 8. It shows as the reactive power absorbed by every local load is

immediately compensated, when the control action for the reactive power management starts at 0.1 sec.; in fact each line current i_{Lh} , with h=1,..4 (suitably amplified for necessity of visualization), is carried out in phase with each PCC voltage v and then it is also significantly reduced.
It is important to notice that the current i_{L2} is in opposition of phase with the voltage. This is because DG2 is able to produce more energy than that needed to its load and therefore the active power flow through Line 2 is inverted.

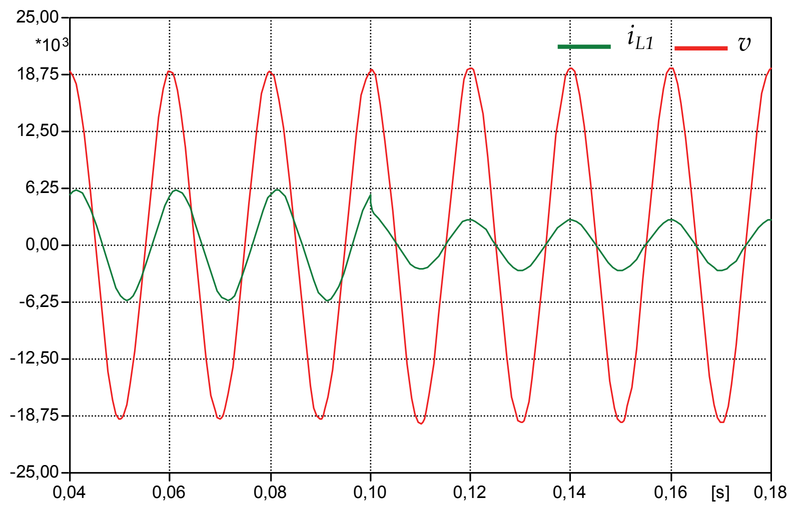

Fig. 8a. Power factor correction for one phase of Load 1.

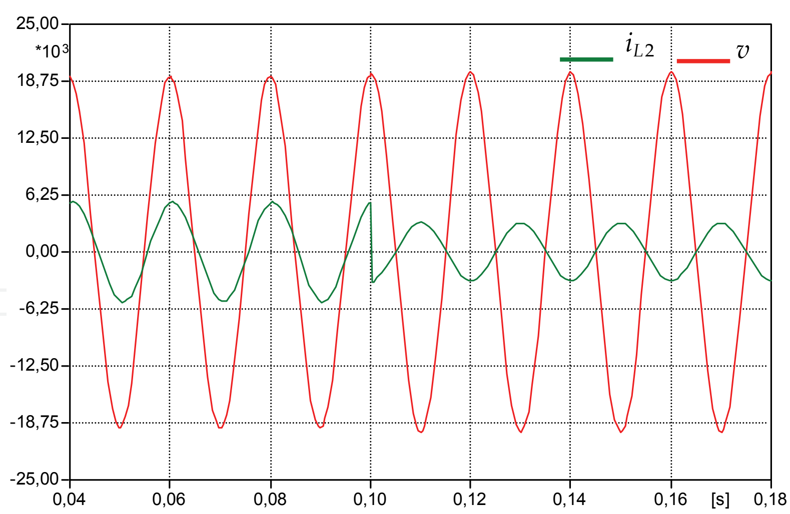

Fig. 8b. Power factor correction for one phase of Load 2.

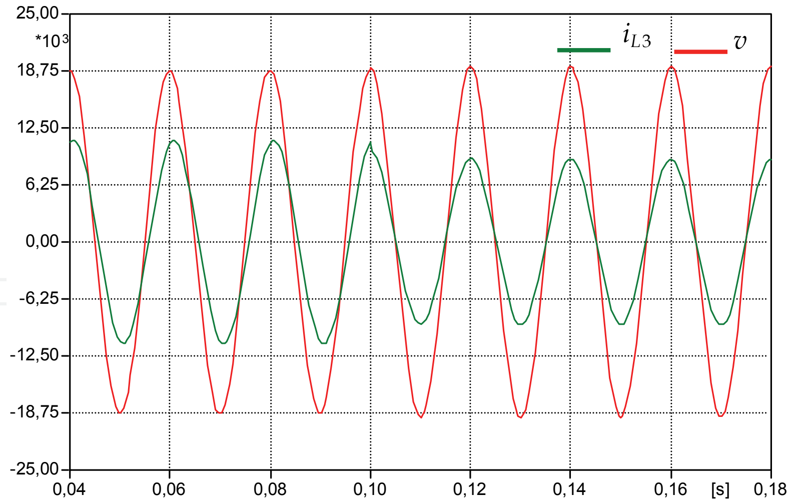

Fig. 8c. Power factor correction for one phase of Load 3.

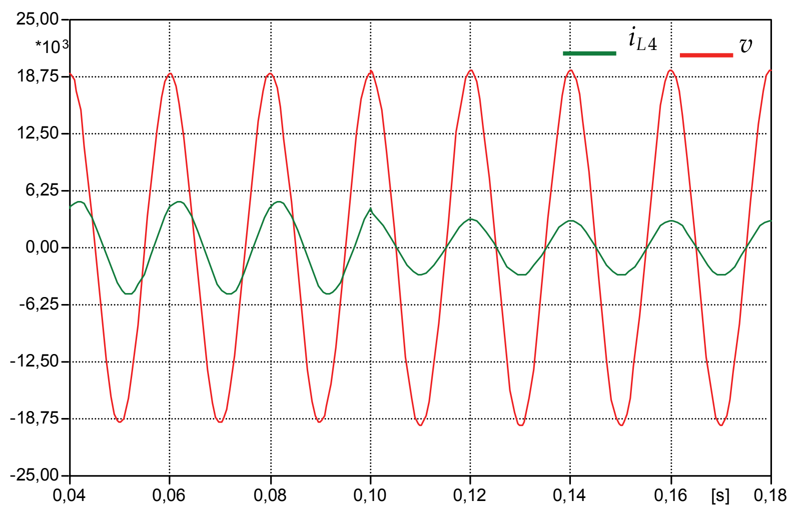

Fig. 8d. Power factor correction for one phase of Load 4.

Another effect of the reactive power compensation, carried out by all the DG systems, is clearly evidenced in Fig. 9. In fact, as a consequence of the reactive compensation the reactive power supplied by the main grid for each phase is significantly reduced. This due to the fact that, in the operating conditions subsequently to the reactive compensation, the only load which needs reactive supply by the grid is the balanced Load 5, being far apart of the DG systems.
A further interesting result is presented in Fig. 10, that shows the effect of the power management used in order to balance the active power absorbed by the critical loads near the DG systems. As a consequence of the power management algorithm, each DG system, together with its critical load, is seen as a balanced Load from the main grid; in this way, the negative and zero current sequences present in the main grid currents are easily cancelled before the compensation action, making so that the power provided by the main grid is balanced (see Fig. 11).

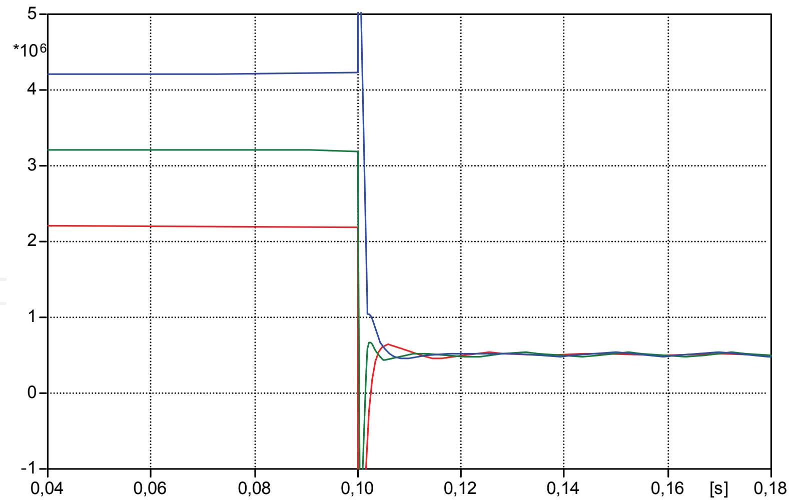

Fig. 9. Reduction of the reactive powers provided by the main grid [Var].

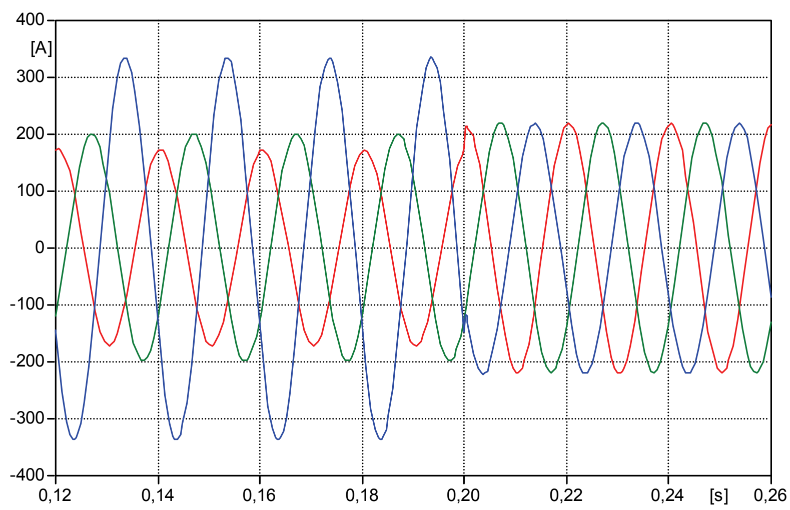

Fig. 10. Balancing of the main grid currents [A].

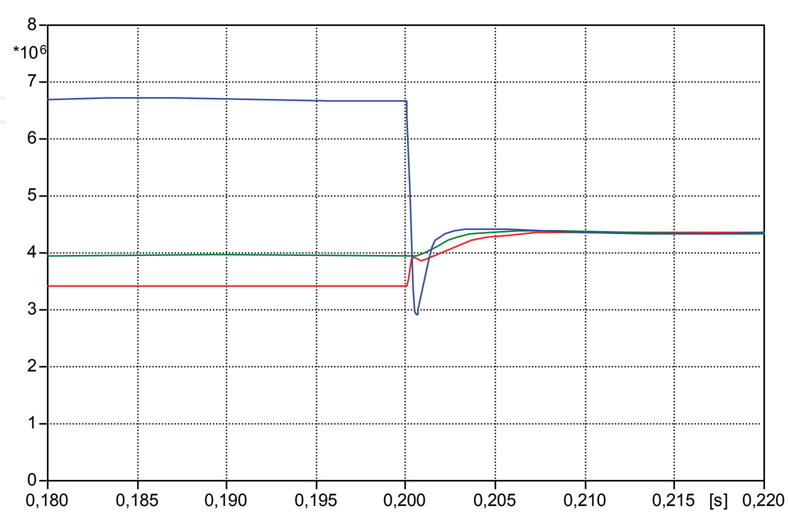

Fig. 11. Balancing of the main grid active powers [W].

Finally, Fig. 12 points out that the power management made by the DG systems avoids that unbalanced currents can unbalance the main bus voltages. Therefore, also the balanced Load 5 absorbs the same value of active power for each phase.

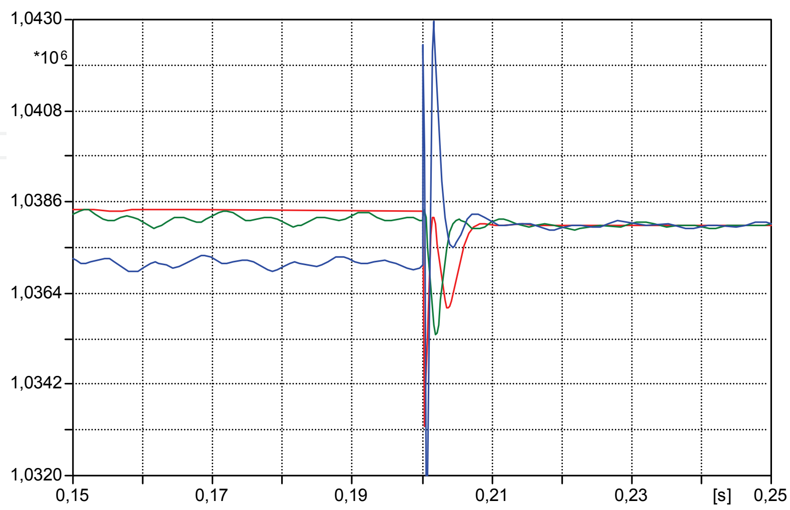

Fig. 12. Active powers absorbed by the Load 5 [W].

7. Conclusions

This chapter has dealt with the application of a suitable control strategy for grid-connected inverters used in DG systems operating in a Microgrid.
First, this chapter has illustrated the concepts and control issues of Microgrids, which consist in clusters of loads and paralleled small DG systems operating as single power systems.
As clearly explained in the chapter, the microsources, used in the DG systems, having different output characteristics, in voltage and current, are connected to the utility grid using voltage source inverters based interfaces, usually known as grid-connected inverters.
Due to the development of the power electronic devices, the grid-connected inverters are able to perform different useful functions such as the control of voltage and reactive power at the PCC of the generation source and a fast response to power quality events or fault conditions.
The control strategy used in the application illustrated in this chapter has been recently presented in literature by the authors and it has been developed so as to combine the advantages of the current control and the voltage control strategies. Moreover, it is important to underline that this control strategy is suitable to deal with three-phase and single-phase systems, assuring at the same time an optimal control of the power flows both in stationary conditions and in transient ones. As a consequence, the control strategy can be applied to large size plants as well as those small size, which are very common in the Microgrids.
In fact, the control strategy has been applied to a Microgrid configuration, consisting in four DG systems, based on interfacing inverters connected to the main bus by different line impedances. Each DG is directly connected to a critical load that absorbs a different

amount of active and reactive power for each phase. Besides, a linear and balanced load is connected at the main bus.
The application has been verified by various numerical simulations. In particular, the simulations have point out as, by using grid-connected inverter, the DG systems have been able to influence the power flows of the Microgrid very quickly and in significant manner. However, thanks to the good characteristics of the control strategy used, such fast performances have been achieved without generating perturbations and instability problems on the Microgrids. In fact, the numerical simulations show that the DG systems effectively provide services as reactive power compensation and load balancing without influence each other.

8. References

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Distributed Generation
Edited by D N Gaonkar

ISBN 978-953-307-046-9
Hard cover, 406 pages
Publisher InTech
Published online 01, February, 2010
Published in print edition February, 2010

In the recent years the electrical power utilities have undergone rapid restructuring process worldwide. Indeed, with deregulation, advancement in technologies and concern about the environmental impacts, competition is particularly fostered in the generation side, thus allowing increased interconnection of generating units to the utility networks. These generating sources are called distributed generators (DG) and defined as the plant which is directly connected to distribution network and is not centrally planned and dispatched. These are also called embedded or dispersed generation units. The rating of the DG systems can vary between few kW to as high as 100 MW. Various new types of distributed generator systems, such as microturbines and fuel cells in addition to the more traditional solar and wind power are creating significant new opportunities for the integration of diverse DG systems to the utility. Interconnection of these generators will offer a number of benefits such as improved reliability, power quality, efficiency, alleviation of system constraints along with the environmental benefits. Unlike centralized power plants, the DG units are directly connected to the distribution system; most often at the customer end. The existing distribution networks are designed and operated in radial configuration with unidirectional power flow from centralized generating station to customers. The increase in interconnection of DG to utility networks can lead to reverse power flow violating fundamental assumption in their design. This creates complexity in operation and control of existing distribution networks and offers many technical challenges for successful introduction of DG systems. Some of the technical issues are islanding of DG, voltage regulation, protection and stability of the network. Some of the solutions to these problems include designing standard interface control for individual DG systems by taking care of their diverse characteristics, finding new ways to/or install and control these DG systems and finding new design for distribution system. DG has much potential to improve distribution system performance. The use of DG strongly contributes to a clean, reliable and cost effective energy for future. This book deals with several aspects of the DG systems such as benefits, issues, technology interconnected operation, performance studies, planning and design. Several authors have contributed to this book aiming to benefit students, researchers, academics, policy makers and professionals. We are indebted to all the people who either directly or indirectly contributed towards the publication of this book.

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