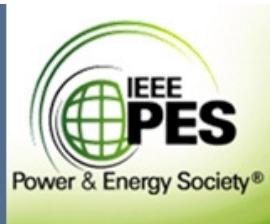




ICHQP 2010

14th International Conference on
HARMONICS AND QUALITY OF POWER
Bergamo, Italy, 26 – 29 September 2010



ICHQP 2010 Conference Program

Sessions at a glance

Sunday 26th September 2010

10:00 – 17:00	Tutorial "Harmonics in the Changing Power System" (restricted entrance through registration)	
	10:00 – 13:00	<ul style="list-style-type: none">• Professor Math Bollen – Introduction to harmonic distortion• Professor Sarah Rönnberg and Professor Anders Larsson – Emission by modern energy-efficient equipment and possible impact on communication• Professor Math Bollen – Harmonics and windpower: emission and resonances• Professor Alfredo Testa – Interharmonics due to modern switching techniques
13:00 – 14:00	Lunch	
	14:00 – 17:00	<ul style="list-style-type: none">• Professor Guido Carpinelli – Advanced signal processing techniques for monitoring waveform distortion• Professor Paola Verde – Economics of waveform distortion• Professor Math Bollen – Summary and conclusions
17:30 – 17:50	Conference Opening	
17:50 – 18:20	<p>Keynote Address "An Introduction to the Concept of Randomness Power" Alexander Eigeles Emanuel, Worcester Polytechnic Institute</p>	
starting from 18:30	Welcome Cocktail Reception - Congress Center "Centro Congressi Giovanni XXIII"	

101 –"Harmonic Domain Modeling of Transformer Nonlinear Characteristic with Piece – Wise Approximation"

A. Damnjanovic, A. Islam, A. Domijan, *University of South Florida, USA*

SESSION 6B – Interharmonics & Other Non-Harmonic Distortion – Tuesday 10:30–12:00

Room: Sala Oggioni

Chairman - A. Testa, *Seconda Università di Napoli, Italy*

501 –"Measurement result from 1 to 48 fluorescent lamps in the frequency range 2 to 150 kHz"

E.O.A. Larsson, M. H. J. Bollen, *Luleå University of Technology, Sweden*

502 –"On the Effects of Interharmonic Distortion on Static Converters Controlled by means of PLL Systems"

R. Langella, P. Marino, G. Raimondo, L. Rubino, N. Serbia, A. Testa, *Seconda Università di Napoli, Italy*

503 –"New Phasor Estimator in the Presence of Harmonics, DC Offset, and Interharmonics"

R. Vianello, M. O. Prates, C.A. Duque, A.S. Cequeira, *Federal University of Juiz de Fora, Brazil*;

P.M. da Silveira, *Itajubá Federal University, Brazil*;

P.F. Ribeiro, *Calvin College, USA*

505 –"An Equivalent Model Of A Single-Phase Load Under Non-Sinusoidal Conditions"

V. Kolar, P. Orsag, J. Kijonka, *VŠB–Technical University of Ostrava, Czech Republic*

SESSION 6C – Renewable Generation/Distributed Generation and PQ – Tuesday 10:30–12:00

Room: Sala Alabastro B

Chairman – T.B.D.

1302 –"Control of Islanded Inverter Interfaced Distributed Generation Units for Power Quality Improvement"

A.A. Ghadimi, *Arak University, Iran*;

F. Razavi, *Islamic Azad University, Iran*;

R. Ghaffarpour, *Tafresh University, Iran*

1321 –"Differential Evolutionary Algorithms in Optimal Distributed Generation Location"

C. Bulac, F. Ionescu, *University POLITEHNICA of Bucharest, Romania*;

M. Roscia, *University of Bergamo, Italy*

1323 –"Divergence Operator for the Stability Assessment of a Microgrid Weakly Connected to the Power System"

D. Falabretti, M. Delfanti, M. Merlo, *Politecnico di Milano, Italy*;

J.M. Zaldívar, *Joint Research Centre "European Commission", Italy*;

F. Strozzi, *Carlo Cattaneo University, Italy*

Control of Islanded Inverter Interfaced Distributed Generation Units for Power Quality Improvement

A. A. Ghadimi, F. Razavi, and R. Ghaffarpour

Abstract-- A load sharing control strategy for operating of a distribution system consisting of multiple inverter interfaced Distributed Generation (DG) unit when isolated from a main utility in order to improve continuity and quality of electricity to important loads is presented and tested in this paper. In the stand-alone network, a Master DG unit exists as voltage and frequency reference and the other units work on synchronize with this unit and produce energy to loads. A supervisory controller defines all Distributed Generation units' reference powers with consideration of system and unit normal rating in order to maintain reliable and high quality power to the loads. Simulation results on IEEE 37 node test system verify that the proposed control scheme is effective for stable working of the stand-alone network.

Index Terms-- Distributed Generation (DG), Stand-Alone Network, Load sharing, Supervisory Control, Power Quality

I. INTRODUCTION

Today construction of large power plants is economically unfeasible in many regions because of fuel costs and environmental limits. Furthermore, in some far regions such as rural areas it might be no connection to utility. Therefore, interest in Distributed Generation (DG) systems such as micro turbines, photovoltaic, wind turbines, and fuel cells with small capacity is rapidly increased [1]-[4]. The utilities use DG to help them for improve power supply flexibility, quality and expandability, system stability, optimize the distribution system, provide the spinning reserve, and reduce the transmission and distribution cost. DGs are also very attractive for customers as it can be used to reduce their demand charge and also feed them in the event of an outage in the utility [1]-[8].

There are two way for using DG units in distribution network: a stand-alone system and a grid-connection to the utility mains [4]-[10]. In a grid-connected mode, each DG unit is interconnected in parallel to the utility and provides power directly to ac mains in order to cover increased power required

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by the loads and decrease demand charges. Hence, after any outage of utility, it can be possible to supply important load with the installed DG units if the system technical issue considered.

Consider that a network is working with multiple DG supporting units. A fault or a scheduled disconnecting scheme can convert the network to stand-alone mode and island it from the main utility. In this case, the DG units can be used for supplying energy to loads. To meet technical requirements, the DG unit must include protection, control and communication components. The ultimate aim is coordination of this several generators for sharing the real and reactive power output and control the system frequency and voltage during absence of utility grid.

Load sharing and voltage and frequency control of an islanded network can be achieved in different ways that have been addressed in several literatures [7]-[12]. In [9]-[11] a concept has been developed and improved using reactive power/voltage and active power/frequency droops for the power control of the inverters. The droops are similar to those in utility grids. This method uses the grid quantities voltage and frequency for coordination of the components. As [11] shows this method have good results for controlling the power and voltage of each DG unit. The main advantage of the droop method is that it does not need communication system and it is suitable for distribution system with long distance between DG units. However, the droop method needs complex control system and if the optimized working needed, then using a low speed communication system is necessary.

A system with a voltage source converter as a master and additional controllable power sources presented in [13]. This method has simple control algorithm in components, high expenditure for busses and their cabling and instead it require a supervisory control and communication between all units.

Because of advantage of this control scheme, short distances in small distribution networks, and advances in communication links this approach is suitable in distribution network with multiple DG units and is modified to use as a load sharing control strategy in stand-alone network with multiple DG units in this study.

Proposing a control strategy for the parallel operation of distributed generation systems (DG) in a stand-alone distribution network with multiple DG units is the aim of this paper. In particular, the paper proposes a method to control

power sharing between each DG unit and maintaining voltage profile and stability of network.

The paper is organized as follows. Section 2 highlights the characteristic and control strategy for inverters. Section 3 describes the proposed system controller and the strategy for load sharing between DG units. Section 4 shows study system configuration. In section 5 simulation results and discussion on a typical simulation system described and in section 6 conclusion of work presented.

II. CHARACTERISTICS AND CONTROL OF AN INVERTER INTERFACED DG UNIT

Inverter interfaced generation units have different characteristics to synchronous machines and so the power system consisting this equipment has different situation [11-17]. Some characteristics of this electrical generation units are:

- An inverter can operate as voltage sources (also current source) with independent control of the magnitude and phase of each phase that cannot performed with a synchronous generator.
- An inverter can produce absolutely sine wave or any waveform with the control of reference waveform but they produce high frequency distortion and need filtering.
- Over current situation can be tolerated by inverters only in short periods so the current limiting action and short circuit protection must considered.
- The active and reactive power that is supplied by an inverter interfaced DG unit can be controlled independently with parameter of the interfaced inverter.

The control strategy and filter have a significant effect on system performance. A second-order LC filter is a good choice for overcoming the high order harmonic components and it is used in this study and designed according to switching frequency of the inverters.

A. Grid-Connected mode

If a set of Distributed Generation units have a connection to utility grid, there would be a reference for voltage and frequency. In this situation, the objective is to export a controlled amount of power into the established voltage in order to reduce demand charge and all the extra demand can be covered by the grid. Control of the exported power is through control of the in-phase component of current. Phase-locked loop (PLL) techniques are used to ensure synchronism. Control in d_{q0} axis (synchronous reference frame) form is usually preferred to magnitude-angle form. The current demands are generated from the power demands using the local voltage magnitude (available from the PLL). The power demands references come from the system central controller or adjust by user.

The inverter control structure is shown in Fig. 1. The current is controlled in closed-loop form. The current references (d- and q-axes) are set on the basis of the required real and reactive powers. This configuration called PQ mode.

B. Stand-Alone mode

In case of stand-alone operation, there are two main problems. The main problems with isolated systems is the presence of some low response and inertia less generation unit which necessitates putting some compensating devices such as storage on dc link to realize fast load tracking. The second problem is the lack of frequency and voltage reference and so one or perhaps more than one of the DG units should play such a role and being a reference for voltage and frequency. Therefore, the reference DG unit should be suitably sized to be able to perform such desired regulation on power and voltage. The suitably sized storage included on the DC bus of this unit insures fast response to any change in power demand (fast load tracking) and stable ac voltage. The other DG units may work in constant power control scheme (PQ mode) to have contribution in stable load balance. Such a reference unit called Master DG unit in this study. The control strategy for producing desired voltage and frequency called VF control mode and is shown in Fig. 2.

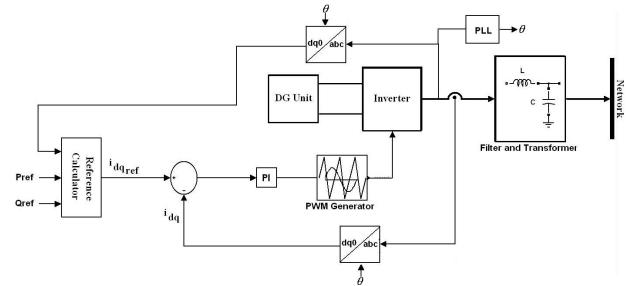


Fig. 1. Control Structure for PQ mode of inverter

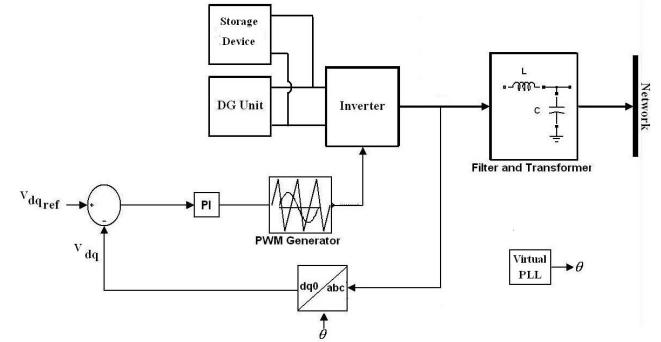


Fig. 2. Control Structure for VF mode of inverter

III. PROPOSED STAND-ALONE DISTRIBUTION SYSTEM CONTROLLER

The proposed method for generation control in isolated power systems consist of inverter interfaced DG units is based on the following assumptions:

- At least one of the DG units act as Master DG unit with suitable amount of storage and its duty is to produce voltage and frequency reference and supplying needed power after any transient.
- However Master unit is not the only unit which is responsible for supplying the power. The other units in the system may be work in constant power and may contribute in supplying extra power by changing their set points.

- There is communication link between the units. So through this link the set points of the units can be changed with central controller. Data communication between units with a present advances in the field of communication technology is not a complicated task.

- A central controller is used to identify amount of needed power and share it between generation units with consideration of system and DG unit constraints.

In the proposed scheme, the aim is to provide conditions for stable operation of stand-alone distribution system with satisfactory control of active and reactive power flow in the system in order to balance the generation and the demand. The proposed strategy for controlling power sharing between DG units is as follow:

- At first, it is assumed that all the units in the stand-alone system operate below their ratings.
- After any change in load demand, if total power consumption is more than generation, the Master DG units inject more power to the system to meet the requirement of the loads, whereas the other DG units in the system continue to supply the same power as scheduled.
- When any change in load happened and after a delay (e.g 0.2 seconds), the central controller measure extra power from initial output of the Master units and divide it among other units proportional to their nominal power rating.
- The communication links send new reference of power to the DG units.
- As the system is in distribution level with short distance between all units and loads, this scheme of dividing power to all DG units can be suitable for balancing demand and generation and preventing voltage collapse in the network.
- If the required power is more than the capability of each DG unit, its set point is adjusted to its rating value and then power share between other available DG units.

It is obvious that the Master DG unit should be able to produce extra load demand in the interval of load change and receiving new set point to other DG units and so the capacity of storage device should be determined with consideration of maximum load change and delay time of controller and units speed for changing their output. If there is only one master unit, its output in normal condition should be far from its rating in order to compensate any load change. If there is more than one master unit the duty of regulating power can be handled with them, they can work near their rating, and storage device can be designed in smaller capacity. When the slave units received the new commands and increased their output, the master unit's storage device can be charge with available output in the master units.

The time delay for commencement of power sharing between different units is just to let the system reach the steady state. If power sharing control starts simultaneously after load change, then the process will be done based on inaccurate or wrong information because of the transients. In the other hand, the more delay time needs more storage device

for Master DG units.

Like conventional power system, if the master unit fails, one of other unit should play such role and controller of the new master unit should change to mode of frequency and voltage control.

Some case such generation outage or demand greater than total DG units powers, can cause under voltage in the system and so load shedding scheme should be used. In this study, it is considered that the load and generation are balance and it is no need for load shedding.

IV. STUDY SYSTEM

The proposed load sharing control strategy has been experienced on the IEEE-37 node test system that is shown in Fig. 3. Table I in appendix indicates study system data [18]. The system consists of four DG unit which are connected to the system through voltage source inverters in buses number 23, 13, 2, and 30. Initially load flow calculation shows the best value of active and reactive power for each unit to have normal voltage in all buses.

When the utility is available, the Distributed generation units (DG 1-DG 4) produce some part of energy in order to reduce demand charge. The system is considered to become islanded from the main grid after a fault for the utility or a scheduled disconnecting from utility via turning the main switch in bus 1 off.

In a distribution system consist several inverter interfaced DG units, control of inverters plays the main role in the system. As described before, the master DG unit inverter work in VF control mode and regulate voltage and frequency of the system and other units work in PQ mode of operation with amount of active and reactive power that receive from central controller. Fig. A1 in appendix show the detailed block diagram of controllers that use for PQ control of each DG units and the parameter of controller adjusted according to system parameter and method presented in [16]. Optimal P and I coefficient calculated and used in simulation listed in table III in appendix for all four DG units.

It is considered that DG 1 with suitable storage device is Master DG Unit and it act like a synchronous generator for producing voltage and frequency reference because it have storage device to overcome load change rapidly. Since this unit is the only master unit in the system, its loading capacity is considered at least 50% less than its rating in order to have ability to compensate +/- 50% in the time before the slave units' output is altered in response to a load change. The other units synchronize themselves with the main unit via PLL and work at PQ mode of operation and their reference power can change with supervisory control. It is obvious that this adoption of a single Master unit makes this system vulnerable to single point of failure modes either by the generator or by the communications.

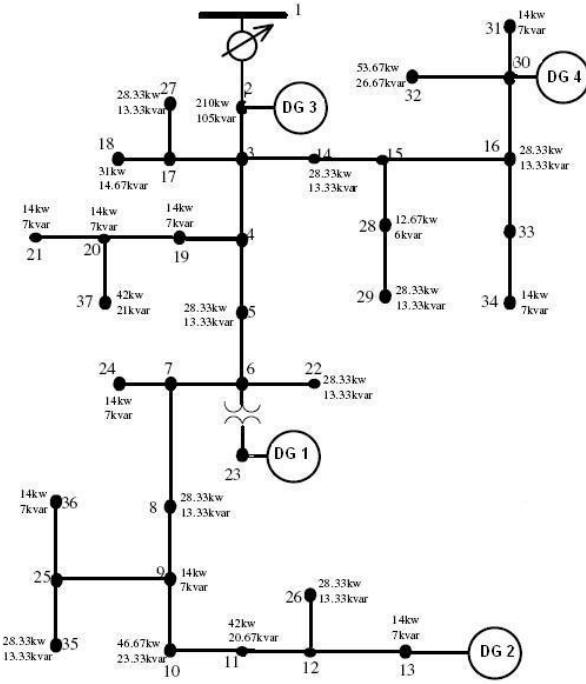


Fig. 3. Single Line Diagram of the system Under Study

V. SIMULATION RESULTS

The previously discussed concepts are now applied in the study system to explain more effectively the mechanism of generation control in a stand-alone power distribution system. Simulation test bed using Matlab/Simpower Toolbox is constructed for the AC 4800 V (LL)/50 Hz system that its single line diagram showed in Fig. 3. A perturbed condition happens, for example insertion of a load in the system and again removing it from the system. In such a case, the aim is to study the mechanism of generation or power control in the system.

A. initiate the system

Initially it is considered that system work with reference value of load flow calculation that showed in table II in appendix. It can be seen from Fig. 4 and Fig. 5 that in this case the controllers adjusted output power of DG 2-DG 4 in desired value and as expected remaining needed power supply by Master unit, DG 1 (time interval before 0.8 seconds)

B. inserting a load

At $t=0.8$ seconds a heavy load of 150 KW and 80 KVAR inserted in bus 8 and it can be seen from Fig. 4 and Fig. 5 that the increased power supplied by master unit DG 1 and the other units work in constant power at predefined reference value.

The central controller detect this increase in power at Master unit terminal and divide it between the other unit in 1 seconds and increase the reference value of DG 2 –DG 4 according to their rating. It is obvious from Fig. 4 and Fig. 5 that DG 2 –DG 4 power raise and Master unit DG 1 power reduce and it will be prepare for next disturbance.

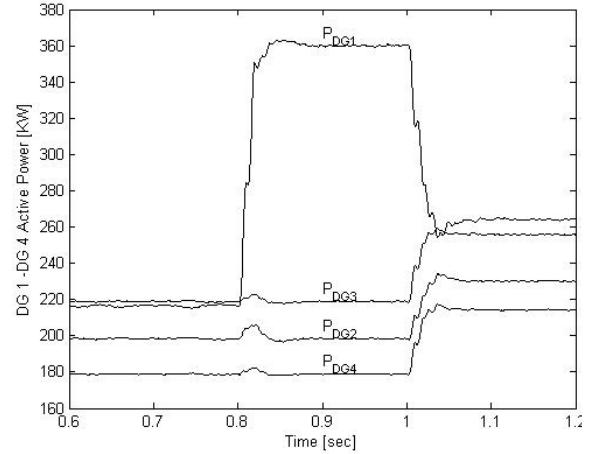


Fig. 4. DG 1-DG 4 Active output power when a load inserted to system

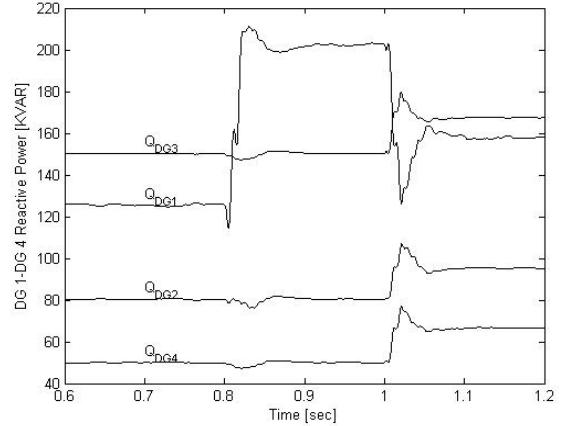


Fig. 5. DG 1 – DG4 Reactive output power when a load inserted to system

C. Removing the extra load

Similar case happens in 1.3 second when the load get out from the system and the Master DG unit reduce its power in order to balance the system generation-demand. Again, in 1.5 seconds, the central controller reduces the DG 2–DG 4 reference value and the Master unit turns back to its initial condition. Fig. 6 and Fig. 7 show this case and the response of DG units to removing the load.

Fig. 8 and Fig. 9 show DG buses voltages and the remote buses (Buses Number 18, 21, 29, 34, 35) voltages respectively.

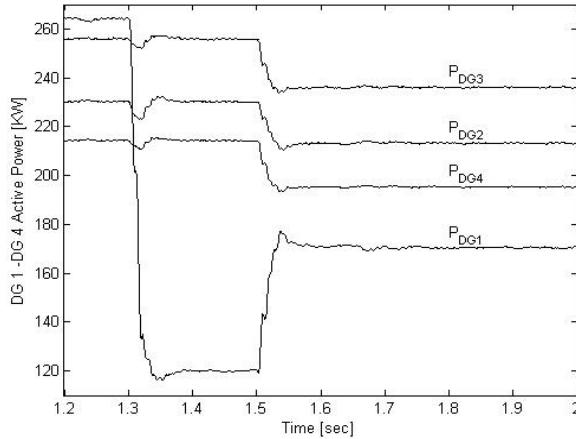


Fig. 6. DG 1- DG 4 Active output power when the load removed from system

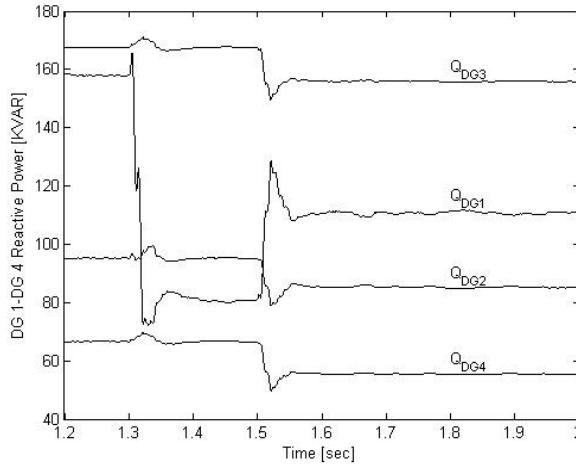


Fig. 7. DG 1- DG 4 Reactive output power when the load removed from system

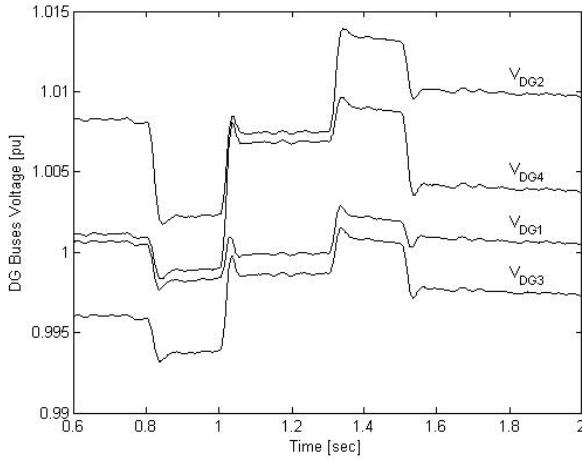


Fig. 8. DG units' buses voltage

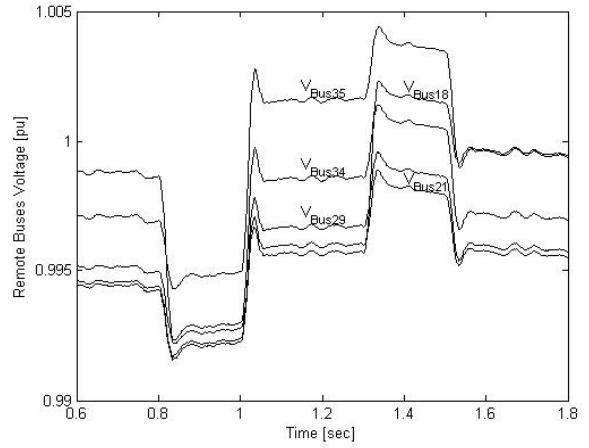


Fig. 9. Remote Buses (Buses No. 18, 21, 29, 34, 35) voltages

As it can be seen, all buses voltages are at standard values ($\pm 5\%$). The figure shows that in this distribution network with short distances between units and loads, regulating voltage in DG unit buses guaranteed standard voltage profile for other buses. In case of any bus voltage deviation from normal range, voltage regulation scheme and compensators or load shedding should be considered.

As it is clear from the simulation results, the proposed method for controlling DG unit is effective and can reply to the network needs during islanding from main grid and the scheme can guarantee continuity of power to loads.

VI. CONCLUSION

This paper has presented the control strategy needed for successful load sharing and accurate voltage and frequency control in a stand-alone distribution network.

For this aim, there should be some DG units responsible for demanding power and some of them responsible for perturbed conditions to inject the regulating power. It means that some of units which are connected through voltage source inverters should be PQ controlled and some in Vf controlled mode.

The proposed method suggest that divide the responsibility of injecting the regulating power to all the DG units in the system similar to what exists in conventional power systems consist of multiple synchronous generators. The proposed method for load sharing control in stand-alone power distribution systems is based on data communication between DG units.

Simulation results showed that the system controller is able to keep the system stable and all buses voltage in standard value and the power is shared between DG units and the method of control guarantee continuity and quality of power supply after islanding from main utility grid.

VII. APPENDIX

In this appendix inverter control block diagram in PQ mode, data of IEEE 37 node test system, all DG units rating, and Data of controller is given in fig. A1 and tables I, II, and III respectively.

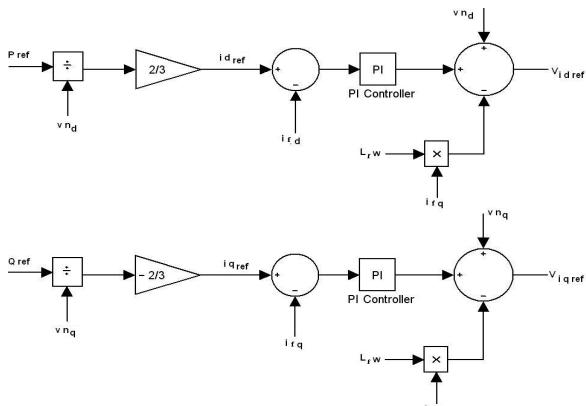


Fig. A1. block diagram of controller in PQ mode

TABLE I
IEEE 37 NODE TEST SYSTEM DATA

From Bus	To Bus	Resistance (Ohm)	Reactance (Ohm)	Bus No.	Active Power (kW)	Reactive Power (kVar)
1	2	0.2978	0.2049	2	210	105
2	3	0.1545	0.1063	3	0	0
3	4	0.2125	0.1462	4	0	0
4	5	0.4420	0.2245	5	28	14
5	6	0.1473	0.0748	6	0	0
6	7	0.2357	0.1197	7	0	0
7	8	0.2357	0.1197	8	28	14
8	9	0.4125	0.2095	9	14	7
9	10	0.4715	0.2394	10	46	23
10	11	0.2947	0.1496	11	42	21
11	12	0.2947	0.1496	12	0	0
12	13	0.2947	0.1496	13	14	7
3	14	0.2591	0.1347	14	28	14
14	15	0.3831	0.1945	15	0	0
15	28	0.0589	0.0299	16	28	14
28	29	0.3831	0.1945	17	0	0
15	16	0.5893	0.2993	18	31	15
16	33	0.4420	0.2245	19	14	7
33	34	0.2063	0.1047	20	14	7
16	30	0.6777	0.3442	21	14	70
30	31	0.5599	0.2843	22	28	14
30	32	0.0884	0.0449	23	0	0
3	17	0.2947	0.1496	24	14	7
17	18	0.2357	0.1197	25	0	0
17	27	0.1768	0.0898	26	28	14
4	19	0.1768	0.0898	27	28	14
19	20	0.2063	0.1047	28	12	6
20	21	0.2063	0.1047	29	28	14
20	37	0.1473	0.0748	30	0	0
6	22	0.4420	0.2245	31	14	7
6	23	0.0001	0.0001	32	53	26
7	24	0.2357	0.1197	33	0	0
9	25	0.3831	0.1945	34	14	7
25	36	0.9429	0.4788	35	28	14
25	35	0.1473	0.0748	36	14	7
12	26	0.1473	0.0748	37	42	21

TABLE II
DISTRIBUTED GENERATION UNIT DATA

Distributed Generation	Rated Power (KVA)	Initial Active Power (KW)	Initial Reactive Power (KVAR)
DG 1	700	-	-
DG 2	430	200	80
DG 3	500	220	150
DG4	480	180	50

TABLE III
DISTRIBUTED GENERATION UNITS INVERTER CONTROLLER DATA

Distributed Generation	P- Coefficient	I- Coefficient
DG 1	1.1	3.3
DG 2	3	.3
DG 3	3	.3
DG4	3	.3

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Main Identity

From: <ichqp2010@polimi.it>
To: <a-ghadimi@araku.ac.ir>
Sent: Saturday, July 17, 2010 11:47 AM
Subject: Letter ICHQP Conference

Dear Author,
on behalf of the 14th IEEE International Conference on Harmonics and Quality of Power (ICHQP), we are pleased to inform you that your paper titled

"Control of Islanded Inverter Interfaced Distributed Generation Units for Power Quality Improvement "

authored by: A. A. Ghadimi, F. Razavi and R. Ghaffarpour

has been accepted for presentation at the 14th IEEE International Conference on Harmonics and Quality of Power (ICHQP), which will be held from 26th September to 29th September 2010 at the Centro Congressi Giovanni XXIII, Bergamo, Italy.

Your paper is accepted without changes.

Please, upload your paper in PDF format in the "Final submission" field in your Reserved Area of the Conference website created or checked using the PDF Express service at:

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ichqp2010@polimi.it

Publication in the Proceedings is conditioned by payment of Full Conference Registration fee.

Author's registration deadline is 15th August 2010. The paper will not appear in the IEEEXplore if none of the authors register to the conference.

Conference and Hotel registration forms are available on the Conference website <http://www.ichqp2010.org/>

We are looking forward to seeing you in Bergamo,

Enrico Tironi and Dario Zaninelli
Conference Chairs

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ICHQP 2010

14th International Conference on HARMONICS AND QUALITY OF POWER

Bergamo, Italy, 26 – 29 September 2010



The 14th IEEE International Conference on Harmonics and Quality of Power (ICHQP 2010) is organized by the Politecnico di Milano. It will be held in Bergamo, Italy, from 26th September to 29th September, 2010.

This conference is one of the premier international conferences and strives to present research work of academic and technical excellence in the area of power quality. The Conference will feature special sessions and tutorials by international experts.

CALL FOR PAPERS

The Organizing Committee of the 14th International Conference on Harmonics and Quality of Power, (ICHQP 2010) invites researchers, practitioners and students worldwide to submit papers for consideration to be presented at the conference. The conference scope covers topics in power quality including, but not limited to:

- Power Quality Analysis
- Power Quality Mitigation Technologies
- Distribution System Planning for Power Quality
- Power Quality Monitoring / Reporting Methodologies and Indices
- Power Quality State Estimation
- Impacts on Systems and Equipment
- Power Quality Standards
- Equipment Power Quality Immunity
- Transients – Propagation, Measurements and Modeling
- Harmonic Generation and Propagation
- Interharmonics and Other Non-Harmonic Distortion
- Power Quality Case Studies
- Probabilistic Aspects of Power Quality
- Economic Impacts of Power Quality
- Renewable Generation / Distributed Generation and Power Quality
- Smart Grids for Power Quality

All accepted papers will be published in the IEEE Xplore digital library

Selected best papers will be invited for submission to a special issue of European Transactions on Electrical Power (ETEP).

Conference website

<http://www.ichqp2010.org/>

Important dates

Full paper submission: June 10th 2010

Notification of paper acceptance: July 15th 2010

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Further Information

For more information please write to ichqp2010@polimi.it or visit the website www.ichqp2010.org

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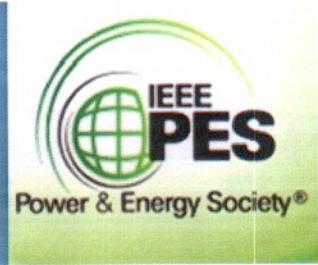
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This is to certify that

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A blue rectangular box containing a handwritten signature in cursive script.

Prof. Ing. Dario Zaninelli