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Load Sharing In Inverter Based Islanded Microgrid Using Virtual Impedance

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Abstract
The Concept of DGs is developed to utilize the small scale renewable energy resources to meet the local power demand and microgrids are getting importance as they allow the penetration of DGs. Microgrid should be operated in an islanded mode to increase supply reliability. To operate a microgrid in islanded mode, there are two major issues to be addressed. First is power-sharing between the DGs and second is the maintenance of system voltage and frequency. One of the widely used methods to solve the above issues is the droop control method. Droop controller poses simplicity, modification possibility, and no requirement of communications between the DGs. However, the performance (mostly reactive power-sharing) of conventional droop controller degrades when the DGs have unequal feeder impedances and required to share non-linear and unbalanced loads. The conventional droop control method is modified by introducing the virtual impedance in the controller to solve the impedance mismatch issue. The use of an inner current and voltage controller helped to regulate the voltage and minimize the harmonics in the outputs. The control scheme is used in various grid scenarios such as inductive, resistive, and general LV distribution systems. The value of feeder impedance is varied to observe the performance of the controller. Also, the controller is used to share the load between four DGs to decide its effectiveness with a large number of DGs. MATLAB software is used for the simulation of the microgrid and the controllers. FFT analysis of MATLAB/Simulink is done for harmonic analysis. The simulations results verify that the controller can be used for load sharing in the microgrid having different feeder impedances and supplying different types of loads.

Keywords
Islanded Microgrid, Parallel Operation of Inverters, Droop Control, Virtual Impedance. Non-linear and Unbalanced loads

1. Introduction

The emission of greenhouse gases is getting concerned nowadays. To reduce the emission of greenhouse gasses with clean and renewable energy resources such as wind turbines, photovoltaic, the concept of Distributed Generation (DG) has came up. DGs are connected to power distribution lines and form microgrid. A microgrid has to be operated in gird connected as well as in isolated mode. Grid support maintaining the voltage and frequency when the microgrid is grid-connected. However, one of the problems with the microgrid operation pertains to its voltage and frequency control in island mode especially when different loads are connected or disconnected and voltage and frequency distortion cannot be avoided [1]. One of the major problems with microgrid operations in power systems is maintaining the microgrid voltage and frequency within permissible ranges and sharing microgrid loads among participating distribution generations (DGs) in an islanded mode. The droop control method will pose a degraded performance when feeder impedances of DGs are different. It is desirable in a microgrid that all DGs respond similarly to load steps to avoid the overloading of some DGs and to utilize the total capacity of each DG. With the conventional droop control technique, if the impedances of inverter-based DGs are not equal, the DGs with smaller impedances respond more quickly to load steps and pick more of shared power. To overcome this drawback of droop control in load sharing, certain modifications are needed.

To overcome the limitations of conventional droop many methods are proposed by researchers. An adaptive droop control with virtual impedance is proposed in [2] for inverter-based microgrid 'to limit the circulating current cause from the unequal voltage drop due to unequal feeder impedances. To overcome the difficulties generated by unequal feeder impedance [3] proposes the Q–˙V* droop control method, where ˙V* represents the time rate of change of the converter output voltage magnitude. A method based on virtual impedance is used to share the harmonics, caused by the non-linear loads, to reduce their impact is proposed in [4]. A hierarchical control concept for droop controlled AC and DC microgrids are discussed in [5]. To improve the transient state of the droop control method a multi-loop controller is proposed in [6].

In this paper virtual impedance in the controller of the DG with lower feeder impedance is used. The virtual impedance concept is very suitable for impedance matching. It is introduced just to compensate for the voltage drop imbalance and VI doesn't cause any losses.

2. Methodology

2.1 Microgrid

The modern microgrids powered by renewable energy resources are inverter dominated grids. The inverter dominated grids are non-inertial. With the advancement of Voltage Source Inverters (VSIs), it is possible to operate an inverter-based microgrid in the islanded mode. The simulation model of the test microgrid system is shown in figure 1.

In this simulation, an inverter with a fixed DC voltage source in its input is considered a Distributed Generation (DG). Two parallel DGs are connected to the point of common coupling (PCC). The feeders connecting DGs and the PCC have certain impedances. A combination of loads; linear, non-linear, and unbalanced are supplied from the PCC. The switching of loads is achieved by using three-phase circuit breakers. Each DGs is controlled by their controller and independent to each other that's why it doesn't require any kind of communications links between DGs.

The non-linear load used in this paper is modeled by placing two antiparallel diodes in each phase. This combination of loads is considered to observe the harmonics and load sharing effectiveness with various loads.

2.2 Conventional droop

The idea of conventional droop came from the operation of the alternator i.e to increase the active power loading its frequency droops and vice versa. Similarly, to increase the reactive power loading its voltage droops and vice versa. This can be expressed as

$$\omega = \omega^* - mP,\ E = E^* - nQ \qquad (1)$$

Where, ω^* and E* are the nominal angular frequency & voltage.
m and n are the Active Power/Frequency droop coefficient and Reactive Power/Voltage droop coefficient respectively. Their values are calculated from the active and reactive power rating of DGs and acceptable frequency deviation and voltage deviation respectively.

2.3 Concept of virtual impedance

When the DGs have unequal feeder impedances, due to the unequal voltage drop in the feeders, a circulating current flows between the parallel DGs which affect the load sharing. The reactive power-sharing, being dependent on the voltage, adversely affected. So, the output impedance of the DG with smaller feeder impedance is increased using virtual impedance. No real impedance is added in the line but impedance effect is virtually included in the controller. The selection of virtual impedance is based on the following relationship

$$S_1 * (Z_1 + Z_1 v) = S_2 * (Z_2 + Z_2 v) \qquad (2)$$

Where,
S_1, S_1 =KVA rating of DG1 and DG2 respectively
Z_1, Z_2 = Feeder impedance of DG1 and DG2 respectively
$Z_1 v, Z_2 v$ =Virtual impedance of DG1 and DG2 respectively.
The figure 2 shows the simulation of virtual impedance loop.

The proportional resonant (PR) controller in the stationary reference frame ($\alpha\beta$) is used in the virtual impedance loop. The PR controller is generally used to track the reference current with zero steady-state error in the abc or $\alpha\beta$-reference frame for voltage source inverters. PI commonly used in the

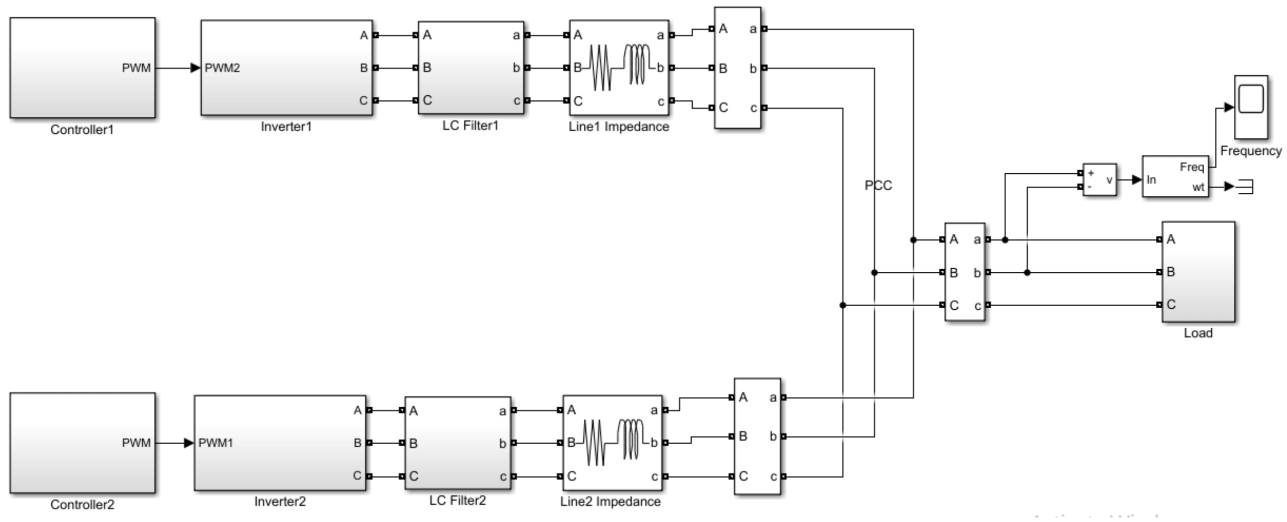

Figure 1: system Layout

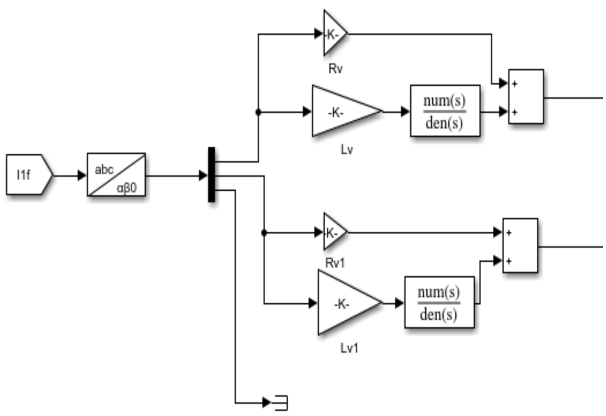

Figure 2: Simulation of virtual impedance

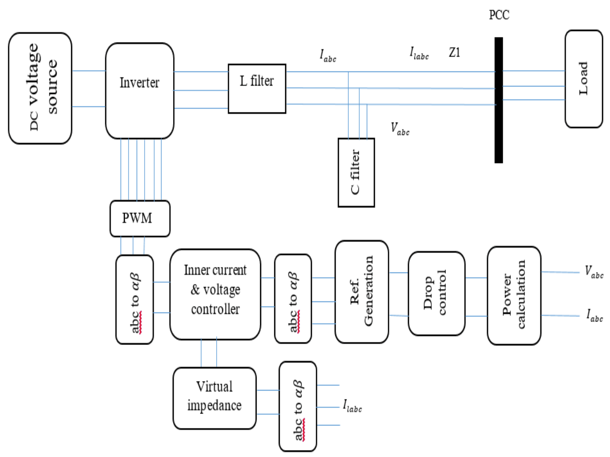

Figure 3: Overall controller block diagram

dq-reference frame requires infinite gain for zero steady-state error [7].

2.4 Overall controller section

The controller of each DGs has a similar structure except the virtual impedance is used for the DG with smaller feeder impedance. The line voltage and current in abc reference are taken for the active and reactive power calculation. Three-phase instantaneous power block is used for power calculation and a low pass filter is used to remove the higher-order harmonics present in the active and reactive power. The P/F and Q/V droops give angle and magnitude respectively for the generation of reference voltage in abc reference frame. The generated voltage reference is transformed into $\alpha\beta$ frame and supplied to the voltage controller. The voltage controller compares the actual line voltage with the reference generated and an error signal is passed through the PR controller. The PR controller tracks the reference voltage with a minimum steady-state error. In unequal feeder impedances case, the effect of virtual impedance is also included by multiplying the line current with the value of virtual impedance. Now even in the unequal feeder impedances, both the controller see the equal voltage drop in the feeders. Consequently, power-sharing gets improved. The output of the voltage controller is used as a reference for the inner current controller. The only proportional controller acts on the error signal produced by comparing the line current with reference. Finally, the controlled signal is transformed back to abc reference and passed to three-level PWM to generate the gate pulse. The voltage controller regulates the voltage and eliminates the harmonics generated. Thus, it made possible for a VSIs based microgrid to operate in the islanded mode.

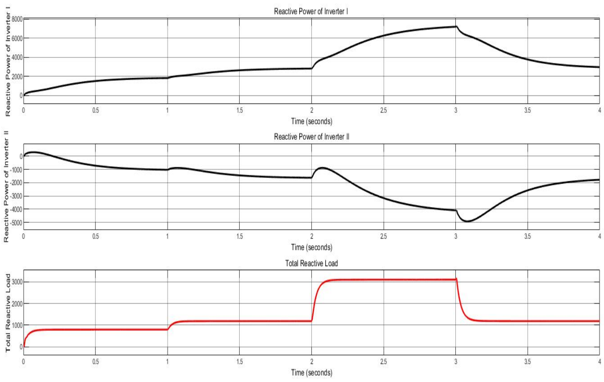

Figure 4: Reactive power sharing without VI

3. Simulation, Results and Discussion

The microgrid along with the DGs, Controller, and Loads are modeled using MATLAB/Simulink. The parameters used in the simulations are presented in the table below.

Table 1: Simulation parameters

S.N	Parameters	Value
1	Vdc	800V
2	Switching Frequency	20 KHz
3	Filter L, C	100mH,300 μF
4	Line impedance L_1	0.6+j0.02
5	Line impedance L_2	1+j0.04
6	m, n	2π/5000,1/1000
7	Virtual impedance	0.4+j0.02
8	Kp, Ki for PR	0.08,100
9	Linear load	2000+j800
10	Non-linear loads	1000+j400
11	Unbalanced load	A:1000+j400 B: 2000+j800 C: 3000+j1200

3.1 Load sharing with unequal feeder impedance and different types of load

When DGs are connected to PCC through unequal feeder impedances, in absence of virtual impedance, the load sharing between the DGs (mainly reactive) is affected as shown in figure 4.

However, active power-sharing is not affected (figure 5). To correct the reactive power sharing the virtual impedance loop is connected and the reactive power sharing gets improved (figure 6). As the DGs are of the same capacity and have the same droop coefficients, the load sharing is equal.

When the load is increased to the system, load frequency is slightly decreased. However, the droop in

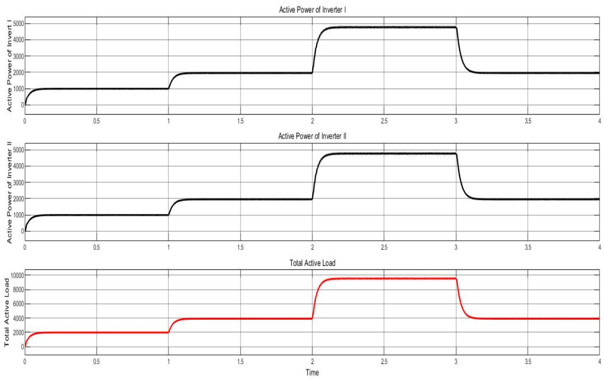

Figure 5: Active power sharing

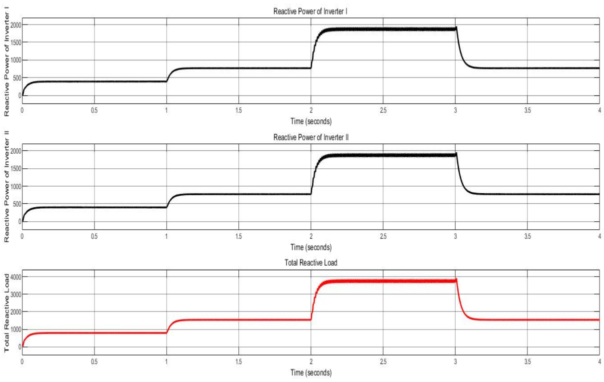

Figure 6: Improved reactive power sharing

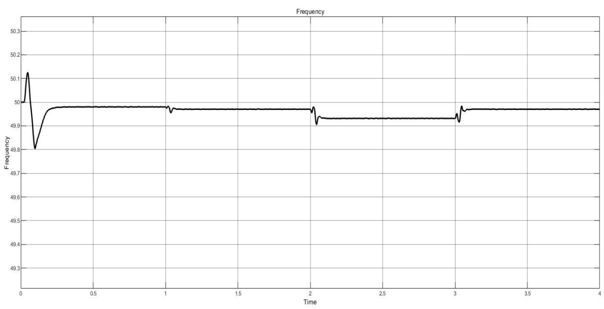

Figure 7: Load frequency

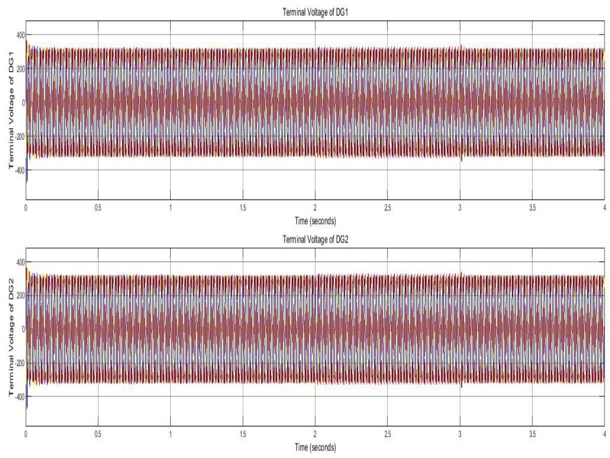

Figure 8: DG terminal voltages

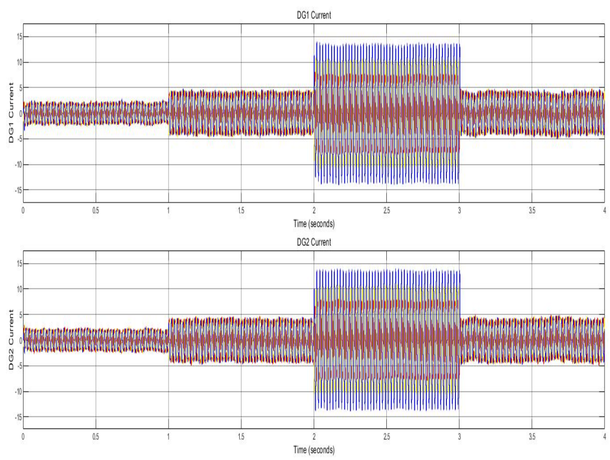

Figure 9: DG currents

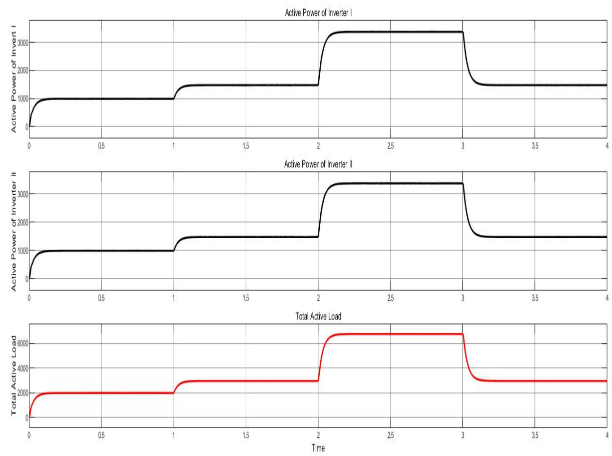

Figure 10: Active power sharing in resistive grid

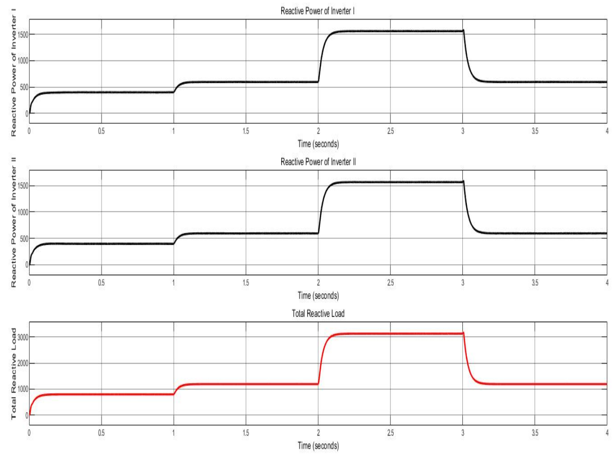

Figure 11: Rective power sharing inductive grid

frequency is within the acceptable limit, (2.5%), as shown in figure 7. The DG terminal voltages are uniform and have the rms value of 230V as shown in figure 8. The voltages and currents are found sinusoidal when zoomed.

The harmonic analysis of the inverter output voltages and currents is done using MATLAB/FFT. 5 cycles after 2.5 seconds (when all loads are connected) are selected for harmonic analysis. The THD for voltages and currents are presented in the table below:

Table 2: THD in voltages and currents

S.N	Parameters	THD (%)
1	DG1 terminal voltage	1.79
2	DG1 current	1.59
3	DG1 terminal voltage	1.8
4	DG2 Current	2.02
5	PCC voltage	1.80
6	PCC current	1.47

3.2 The control scheme in various grid scenarios

The control scheme is used for different values of r/x ratio. A high value of r/x ratio resembles the resistive grid and very low value (<<1) resembles the inductive grid. The general Low Voltage distribution line has line resistance and inductance in the same range so that one can't be ignored with respect to another [8]. The control scheme is used for r/x=30; 1/30; and 1.

From the above active and reactive sharing figures 10 & 11, it is seen that the load power-sharing is not affected by the change in r/x ratio. Further DG terminal voltages are also uniform and within their THD limit.

3.3 Four DGs in parallel

To find the effectiveness of the control scheme in a microgrid having a large number of DGs in parallel, it is used to share loads among four parallel DGs.The

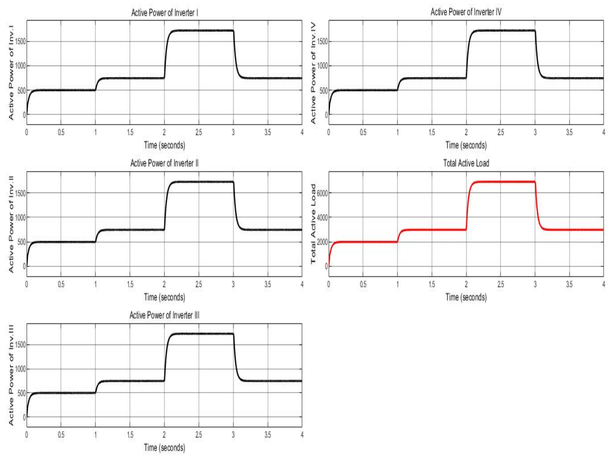

Figure 12: Active power sharing with four DGs

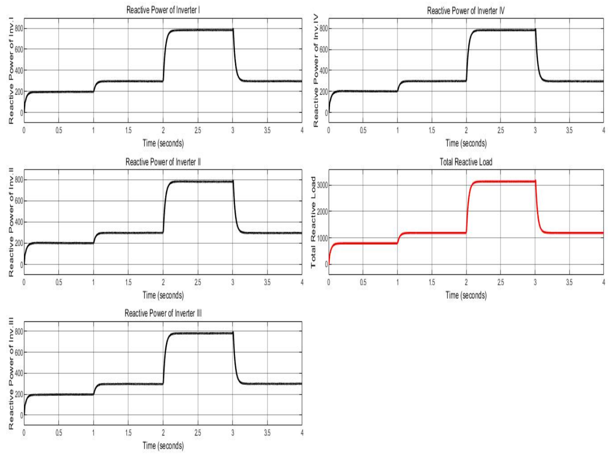

Figure 13: Rective power sharing with four DGs

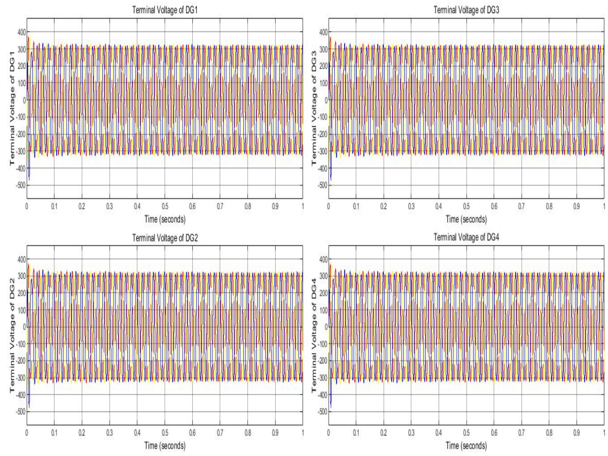

Figure 14: Terminal voltages with four DGs

four DGs are connected to PCC with unequal feeder impedance. The VI is used in all the controllers except in the controller with the highest feeder impedance. The droop coefficients in all controllers are the same so each DGs share an equal amount of active and reactive load.

From figures 12 & 13, it is seen that when the load (active and reactive) is added to the system, it equally shared between four DGs.

The currents drawn by the DGs, as shown in figure 15, are identical and DG terminal voltages, as shown in figure 14, are uniform through out the simulation. The frequency droop is also found within the acceptable range.

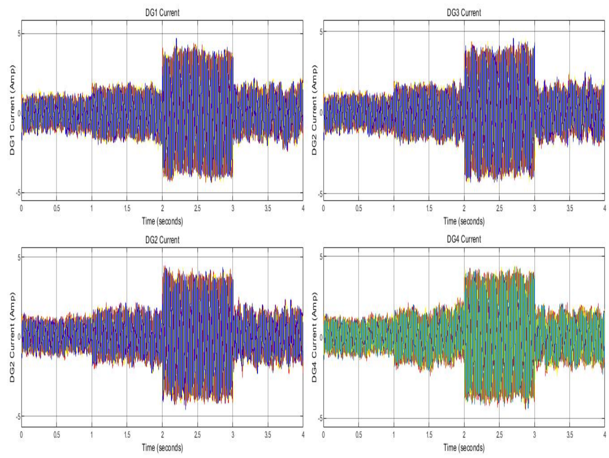

Figure 15: Currents with four DGs

4. Conclusion

In this paper, a droop based control scheme has been used to share the active and reactive power between the DGs in a islanded microgrid with the consideration of unequal feeder impedance, different grid conditions, and with a number of DGs in parallel. The performance of the control scheme is observed by active and reactive power sharing, DG output voltages and currents, PCC voltage and current, and load frequency in each case. Based on the results obtained following conclusions are made.

i. The control scheme can share linear, non-linear, and unbalanced loads without exceeding the standard THD limit.
ii. When the DGs have different feeder line impedances the power-sharing mainly reactive power-sharing is disturbed. This is due to the unequal voltage drop in the feeder which sets up the circulating current and the power-sharing is disturbed. To solve this problem a virtual impedance is introduced in the controller of the DGs with lower impedance. With this virtual impedance loop, reactive power-sharing is improved
iii. The same control scheme can be used in various grid conditions such as resistive, inductive grid and general LV distribution line i.e. insensitive to the change in r/x ratio.
iv. Also, the controller can be used to share power in a microgrid with a number of DGs.

5. Appendix

List of abbreviations used:

DC	Direct Current
DG	Distributed Generation
FFT	Fast Fourier Transform
LV	Low Voltage
MATLAB	Matrix Laboratory
P/F	Active Power/ Frequency
PCC	Point of Common Coupling
PWM	Pulse Width Modulation
Q/V	Reactive Power/ Voltage
RES	Renewable Energy Resource
THD	Total Harmonic Distortion
VAR	Volt Ampere Reactive
VI	Virtual Impedance
VSI	Voltage Source Inverter

References

[1] Abbas Ketabi, Sahba Sadat Rajamand, and Mohammad Shahidehpour. Power sharing in parallel inverters with different types of loads. *IET Generation, Transmission and Distribution*, 11(10):2438–2447, 2017.

[2] Jaehong Kim, Josep M. Guerrero, Pedro Rodriguez, Remus Teodorescu, and Kwanghee Nam. Mode adaptive droop control with virtual output impedances for an inverter-based flexible AC microgrid. *IEEE Transactions on Power Electronics*, 26(3):689–701, 2011.

[3] Chia Tse Lee, Chia Chi Chu, and Po Tai Cheng. A new droop control method for the autonomous operation of distributed energy resource interface converters. *IEEE Transactions on Power Electronics*, 28(4):1980–1993, 2013.

[4] Jinwei He, Yun Wei Li, Josep M. Guerrero, Frede Blaabjerg, and Juan C. Vasquez. An islanding Microgrid power sharing approach using enhanced virtual impedance control scheme. *IEEE Transactions on Power Electronics*, 28(11):5272–5282, 2013.

[5] Josep M. Guerrero, Juan C. Vasquez, José Matas, Luis García De Vicuña, and Miguel Castilla. Hierarchical control of droop-controlled AC and DC microgrids - A general approach toward standardization. *IEEE Transactions on Industrial Electronics*, 58(1):158–172, 2011.

[6] Wei Yao, Min Chen, Jingjing Chen, and Zhaoming Qian. An improved multiple-loop controller for parallel operation of single-phase inverters with no control interconnections. *PESC Record - IEEE Annual Power Electronics Specialists Conference*, pages 448–452, 2007.

[7] Soukaina Essaghir, Mohamed Benchagra, and Noureddine El barbri. Comparison between PI and PR Current Controllers of a Grid- Connected Photovoltaic System Under Load Variation. *International Journal of Power Electronics and Drive Systems (IJPEDS)*, 9(3):1311, 2018.

[8] Rajendrasinh Jadeja, Amit Ved, Tapankumar Trivedi, and Gagandipsinh Khanduja. Control of Power Electronic Converters in AC Microgrid. *Power Systems*, 27(11):329–355, 2012.