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Power Management in Microgrid: Analysis in Grid Connected and Islanded Mode of Operation

Niraj Kumar Choudhary, Soumya Ranjan Mohanty, Ravindra Kumar Singh
Department of Electrical Engineering, Motilal Nehru National Institute of thechnology Allahabad, Allahabad, India

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ABSTRACT

This paper presents an investigation about the impact of integrating renewable energy based generation sources on the existing distribution system in terms of load sharing. The study of load sharing among various distributed generators (DGs) and utility grid has been performed for two cases: (a) when equivalent source based DG is connected and (b) when real PV/Fuel cell based DG is properly integrated to the distribution system. The real photovoltaic and fuel cell based DG do not behave as stiff current/voltage source due to disturbances happening either internally in system known as parametric uncertainties or due to external disturbances like weather conditions, load change etc. Further it has been observed with extensive analysis using simulation result, that even though all DGs are of equal capacity in their generation but when the load is either increased or decreased this doesn’t essentially guarantee that all DGs will equally share the active and reactive power demand.

Corresponding Author:

Niraj Kumar Choudhary,
Department of Electrical Engineering,
Motilal Nehru National Institute of Technology Allahabad,
Teliarganj, Allahabad-211004, Uttar Pradesh, India.
Email: niraj.mnnit@gmail.com

1. INTRODUCTION

Due to exponential increase in population, economic growth and rise in industrial sector the generation capacity needs to be increased. There are several limitations and environmental constraints in the path of power generation by conventional methods. These limitations can be overcome by using renewable energy sources and hence the application of distribution generation is becoming popular [1], [2]. Microgrid can be defined as a cluster of Distributed Energy Resources (DER) along with storage devices which can operate either in grid connected mode or in islanded mode. In a microgrid (MG) each DER shares active and reactive power by maintaining the voltage and frequency of the system. Load shared among various Distributed Generators (DG) also depends upon the mode of operation of microgrid. In the grid connected mode of operation it is very important to study the overall system performance with different types of loads available on distribution system. Presence of such loads in MG may cause voltage disturbances at the Point of Common Coupling (PCC) for which the proper compensating action is to be taken.

In [3], several control techniques has been proposed for enhanced operation and also for proper load sharing. In [4], a local load sharing scheme is proposed where the controllers are capable of compensating the nonlinear and unbalanced loads. It has been proposed that the impedance between various DGs and loads impact the load sharing. However, in [5-6] the active and reactive power sharing has been achieved by power angle and fundamental voltage. A wide range of literature has been suggested for different load sharing techniques in microgrid. In [7] equivalent power theory is described where, by determining the equivalent impedance from filter output side, load sharing has been improved. In [8] authors proposed the load sharing control technique for PV generator and wind turbine containing DFIG ,where centralized as well as localized controller is implemented to achieve the desired objective. In [9] a hybrid microgrid system has been proposed, where decentralized power sharing is happening without communication between DG and Micro grid. In [10] master and slave configuration of VSI is presented, where data requirement for load sharing require only local measured value of voltage and current. In [11] cooperative control of DERs has been proposed where narrow band communication is required but it improves the efficiency as well as it increases the capacity of the grid to considerable extent.

In [12-13], focus is given on the minimization of circulating current in micro grid system. In this paper adaptive droop control method is proposed and using it circulating current is reduced to avail the balanced current sharing. In [13], it has been shown that circulating current develops due to uneven voltage on voltage source inverter where capacitive emulation control scheme is used to reduce the same. In [14-15], emphasis is given on the importance of maintaining supply to demand ratio, where it maintains the same by regulating the utilization level of generator using the distributed sub gradient based solution especially for DFIG based wind turbine.

This paper proposes a control strategy to insure the proper load sharing in the dual mode of operation of a microgrid. In the developed distributed network each DG is associated with local critical and noncritical loads. The impact of each DG is to compensate the influence of these critical/noncritical loads. In the grid connected mode of operation the utility grid and all DGs shares the load according to various conditions of load sharing to compensate the undesirable effect of these loads. Whereas, in the islanded mode of operation the sharing of load among various DGs is through the droop characteristics.

2. MICROGRID ARCHITECTURE

Now a day's microgrid is widely used around the globe both in real life applications as well as in laboratories. This section presents the architecture of microgrid along with some existing microgrid test beds. A microgrid consists of different types of distributed energy resources combined to form an efficient and flexible structure. One major advantage of microgrid is that power flow becomes bidirectional and in case the generation capacity of microgrid exceeds the local demand, the excess power can be fed back to the utility grid or it can be stored. In the islanded mode of operation there should be proper coordination among various distributed generators to maintain both steady state and transient stability in the system by maintaining the power balance.

There are basically two types of Distributed Energy Resources (DER): (a) Electrically coupled DER and (b) Traditional rotating machine based DER. The first group consists of DC/AC or AC/DC/AC converters which couples the DER to the utility grid. However the second group contains traditional rotating machine based DERs and these are interfaced to grid through transformers. Figure 1 shows a schematic, where large number of DGs along with various loads is connected to a common point known as Point of Common Coupling (PCC). The PCC acts as a power exchange highway between the microgrid and the utility grid. In case there occurs any fault on the grid side, the entire microgrid system can be isolated and can be operated in isolation from the utility grid. Depending upon the geographical and environmental conditions the various types of DERs can be properly integrated with the utility grid.

For the details, working of photovoltaic system, wind energy system and fuel cell the literature cited in the paper could be referred. From the system configuration shown in Figure 2, it can be observed that there are three DGs among which DG1 and DG2 are solar photovoltaic cell based and DG3 is a fuel cell based DG. All the DGs are associated with power electronic converters. The detailed modeling and circuit diagram of fuel cell based DG is explained in [16] in which the voltage-current characteristics of fuel cell based DG system is mathematically represented by (1) and the characteristics is shown in Figure 2.

$$V(I) = 371.3 - 12.38\log(I) - 0.219I - 0.224e^{0.005I} \tag{1}$$

The various limitations of fuel cell are absence of energy storage facility, slow dynamic characteristics, disturbance in output voltage and difficult cold start [17-19]. For avoiding the problem of energy storage and cold start an ultra-capacitor is used in this paper which improves the dynamic performance of the fuel cell system.

Several photovoltaic cells are connected in series and parallel to form a PV array. In PV array the output voltage is a function of load current, ambient temperature and solar radiation [20-21]. In this paper Perturb & Observe (P&O) method is used for maximum power point tracking. The different characteristic of PV array is realized by using (2) and shown in the following figures (Figure 3-Figure 5).

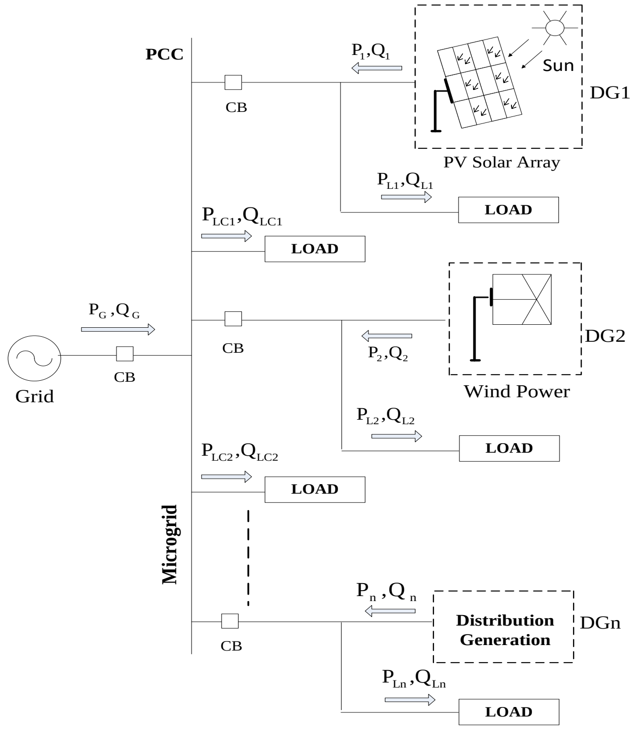


Figure 1. Microgrid architecture

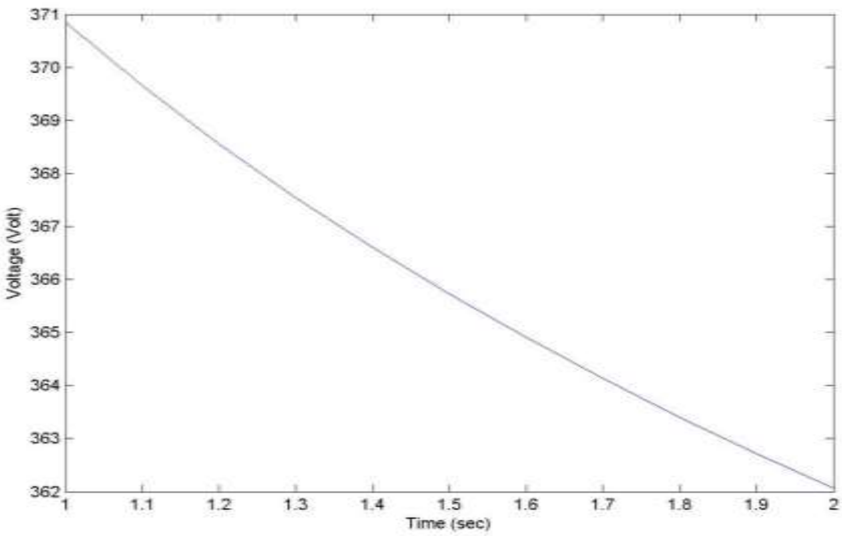
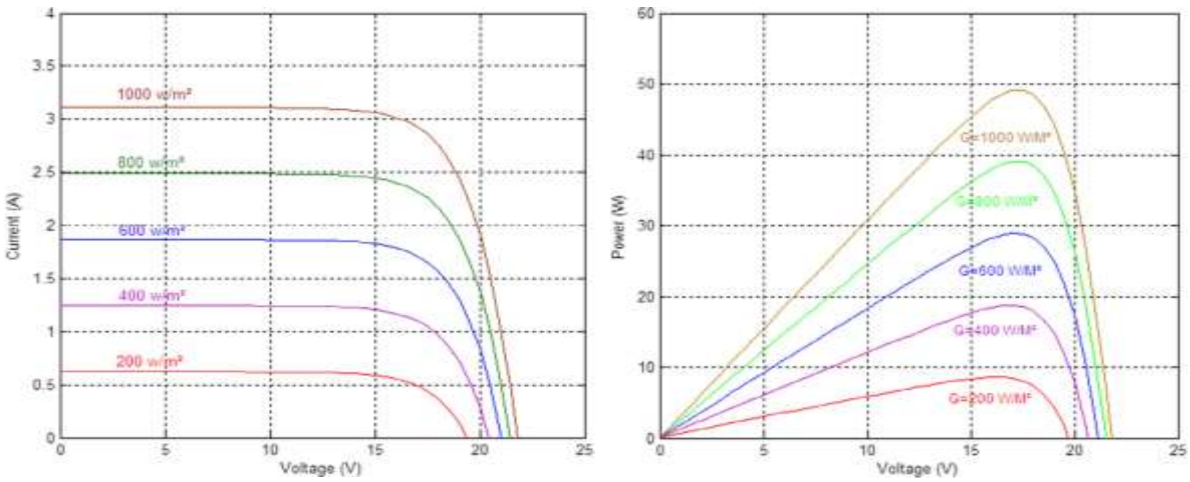


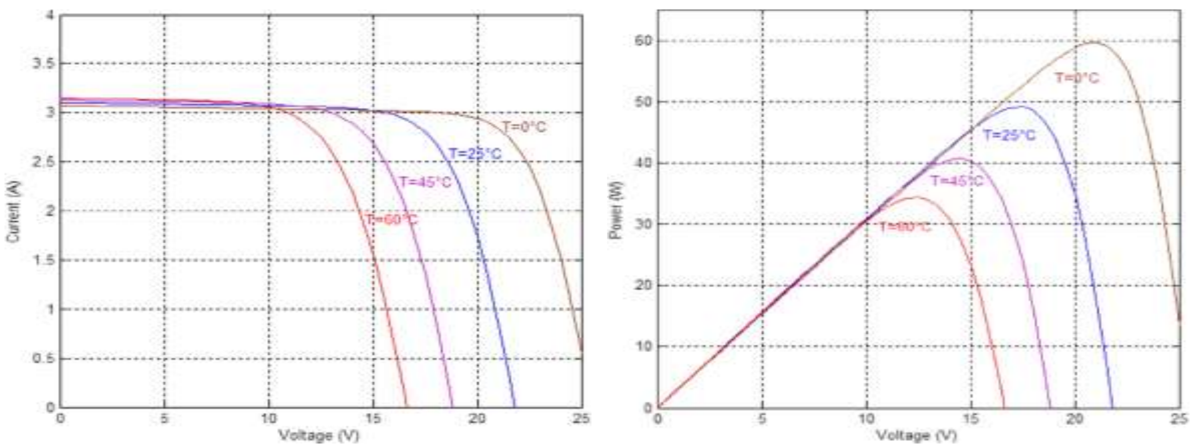
Figure 2. V-I Characteristics of fuel cell

$$I = I_{PV} - I_0[e^{\frac{q(V+IR_s)}{aKT}} - 1] - [\frac{V + IR_s}{R_p}] \quad (2)$$



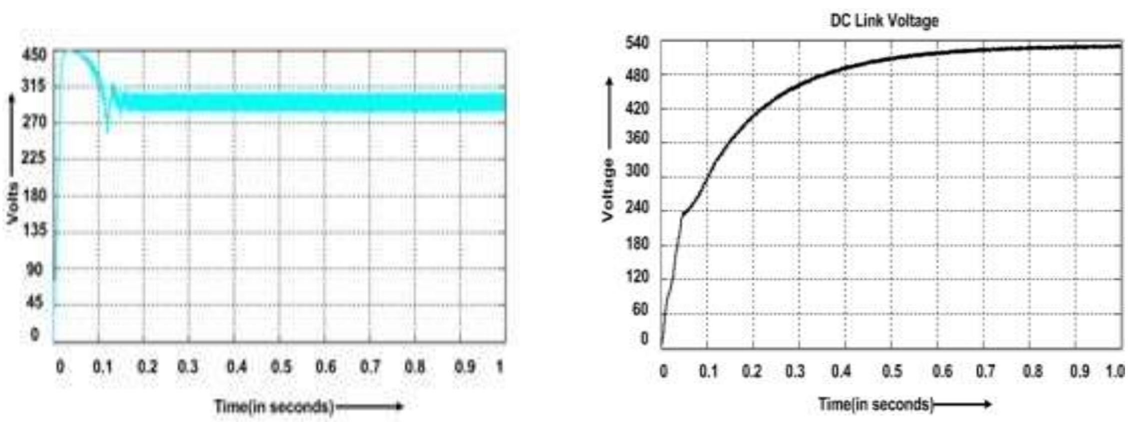
(a) (b)

Figure 3. Characteristics at different irradiance: (a) I-V (b) P-V



(a) (b)

Figure 4. Characteristics at different temperature: (a) I-V (b) P-V



(a) (b)

Figure 5. (a) MPPT VOLTAge (b) DC link voltage

3. SYSTEM UNDER CONSIDERATION

Figure 6 demonstrates a four node ring type distribution system which contains three DGs, three critical loads and two noncritical loads. The active and reactive power withdrawn/transferred is represented by P and Q respectively. All the DGs are connected to respective node through circuit breakers. In general distributed generator shares its local load with the utility in grid connected mode whereas during islanding the local load is supplied by the nearest DG and common loads are shared by all DGs present in the system.

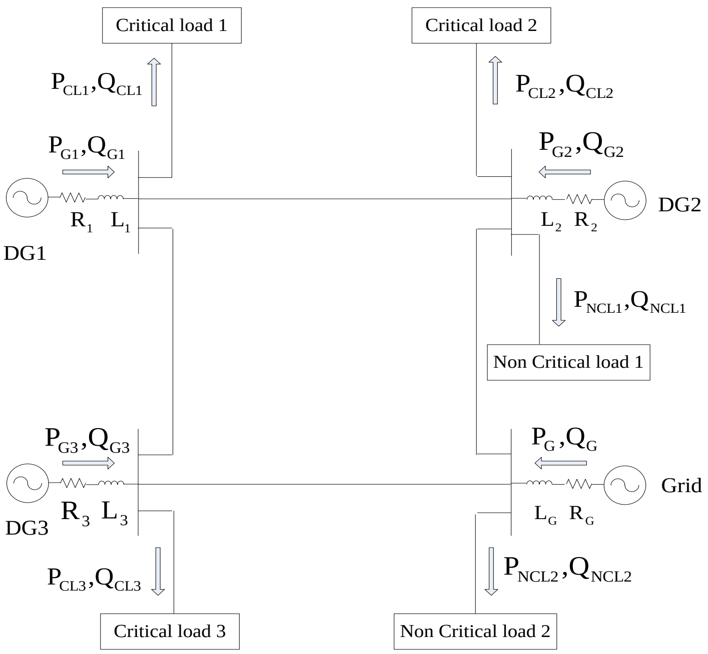


Figure 6. System under investigation

It can be observed that the total power drawn by the critical loads are (PCL1+jQCL1), PCL2+jQCL2 and (P_{CL3}+jQ_{CL3}). The complex power taken by the noncritical loads are (P_{NCL1}+jQ_{NCL1}) and (P_{NCL2} + jQ_{NCL2}). The grid supplies power to the local load connected to it and remaining power is fed back to the loads present in the microgrid. In the system under consideration the total complex power supplied by the utility grid is (P_G+jQ_G). The detailed description of proposed system such as system voltage, frequency, feeder impedance, rating of critical and noncritical loads etc. are presented in next section of this paper.

$$P_i + jQ_i = \frac{E_i V_{pcc}}{X_i}\sin\delta_i + j\left[\frac{E_i V_{pcc}\cos\delta_i - V_{pcc}^2}{X_i}\right] \tag{3}$$

In (3), V_{pcc} and E_i represent the voltage at PCC and individual buses respectively. X_i is the line reactance between PCC and bus. Usually the phase shift angle is small and therefore, the real and reactive power of each DG unit can be regulated by δ_i and the output voltage amplitude E_i.

4. RESULTS AND DISCUSSION

This section deals with the control of active and reactive power in a microgrid where distributed energy resources are represented by equivalent sources. The system description, the operational regimes considered to investigate the sharing of active and reactive power by different DGs along with the loads is mentioned in the Table 1 and Table 2.

Figure 6 gives the schematic of system under investigation. In this paper a four bus distribution network has been considered which consists of three critical and two noncritical loads. The system has been simulated with a base voltage of 11 kV.

Table 1. System Description and Simulation Parameters

Components	Parameters
Source voltage (DG1, DG2, DG3 and Grid)	11 kV
System frequency	60 Hz
Feeder impedance	Rs=0.462 Ω, Ls=0.083 H
DC link capacitor	4400 μF
Critical load 1	P=100 kW, Q=50 kVAr
Critical load 2	P=200 kW, Q=100 kVAr
Critical load 3	P=300 kW, Q=150 kVAr
Non critical load 1	P=200 kW, Q=100 kVAr
Non critical load 2	P=100 kW, Q=50 kVAr

Table 2. List of Events Incepted on System for Analysis

Sl. No.	Event	Time
1	Grid connected mode to islanded mode	0.2 s to 0.5 s
2	Non critical load 1 switched off	0.35 s to 0.5 s
3	Non critical load 2 switched off	0.42 s to 0.5 s
4	At t=0.5 s grid is again restored and connected to the remaining system at the point of common coupling	-

4.1. Simulation results for equivalent source based microgrid

The active and reactive power profile of utility grid and various distributed energy resources is shown in Figure 7, Figure 8, Figure 9 and Figure 10 respectively. From the various simulation results it has been observed that in islanded mode of operation (from t=0.2 s to 0.5 s), due to the shortage of power from the grid as shown in Figure 7, the compensating requirement of active power of load is being supplied by DER_1 which is shown in Figure 8. Further, it is notable from Figure 8 & Figure 10, the reactive power requirement of the load which was earlier being supplied by the grid, is now shared between two DGs, namely DER_1 and DER_3. The interesting fact, in contrast to the classical power sharing philosophy of equal power generating sources, here in microgrid, neither the active nor the reactive power is being shared equally between the DGs, though they are of same rating.

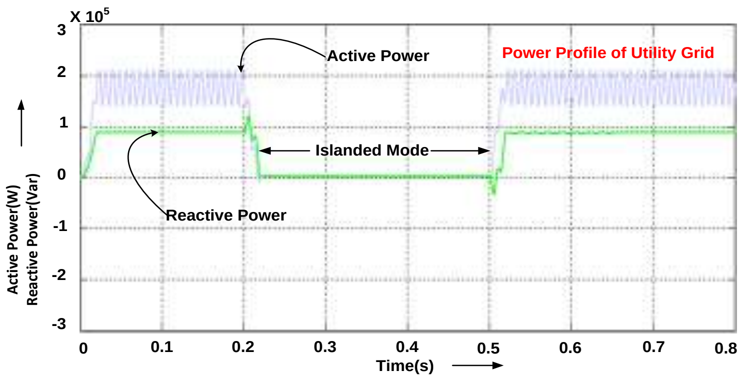


Figure 7. Power profile of utility grid

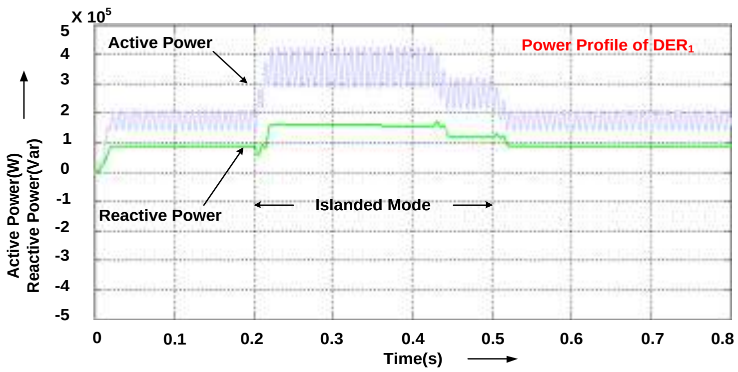


Figure 8. Power profile of DER_1

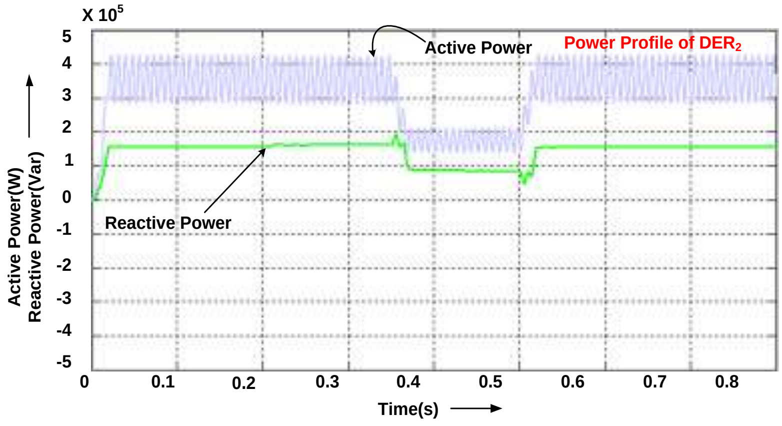


Figure 9. Power profile of DER_2

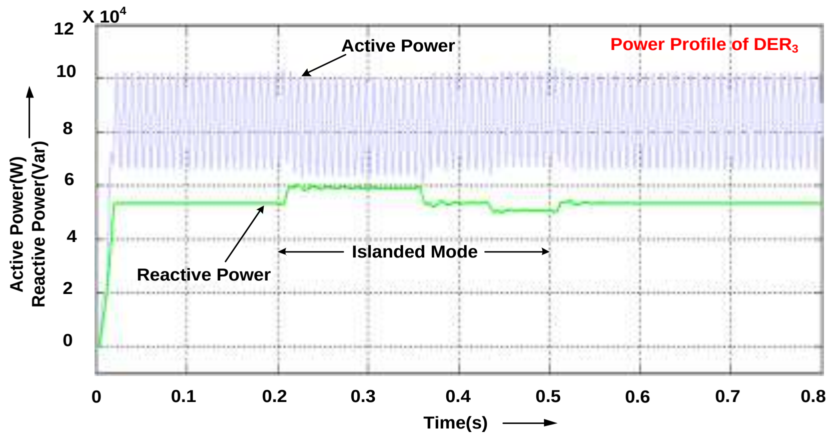


Figure 10. Power profile of DER_3

To investigate the power sharing between the different DGs, when non-critical loads are switched off, i.e. event 2 and 3 in Table 2, are considered. Now, when first non-critical load is switched off, at t=0.35 s, the active power profile of DER2, goes down from 380 kW to 180 kW, and the rated power requirement of non-critical load 2 is 200 kW. So, let it to be a remarkable conclusion that system power balance philosophy still holds well. The reactive power of the DG_1 goes down by an amount of 40 kVAr (Figure 11) and for DG_2 it goes down by an amount of 50 kVAr (Figure 12) and for DG_3 it goes down by an amount of 20 kVAr (Figure 13). So, total reduction in reactive power is close to 110 kVAr. The reactive power demand of the non critical load is 100 kVAr, so almost reactive power also remains balanced.

It can be seen from Figure 9 and Figure 10 that when the grid is switched off at t=0.2 sec the active power profile of DER_2 and DER_3 remains almost same. Now, when the second non-critical load is disconnected at t=0.42 s, the active power profile of DER_2 and DER_3, remains unchanged in their average value whereas DER_1 goes a transition from 350 kW to 250 kW, i.e. a real power decrease of 100 kW which is same as the rating of non-critical load 2 (see Table 1). So, it gives an implication that position of the load and DG doesn't decide that which DG will have more impact on its reactive and active power profile when some load connected nearest to it is switched off.

4.2. Simulation results for real PV/fuel cell based microgrid

This section deals with the control of active and reactive power in a microgrid where distributed energy resources are represented by equivalent sources. The system description, the operational regimes considered to investigate the sharing of active and reactive power by different DGs along with the loads are same as it was in the case of equivalent source based DGs.

To understand how actually the system dynamics differ from equivalent source microgrid to real source microgrid, the system configuration has been taken same as discussed in the above section. The output of the either of the DC renewable sources (Fuel/PV) is 220V. This output is boosted to a voltage level of 360 V. The DC link Voltage given to inverter gives an ac voltage with r.m.s value 240V.

The active and reactive power profile of the fuel cell based DG is having quite fast transient response as compared to classic fuel cell system as shown in Figure 11. This mainly is because of the novel concept “addition of a DC ultra-capacitor of size 10.7 F". The different characteristic in this case is demonstrated in the following figures (Figure 11-Figure 15).

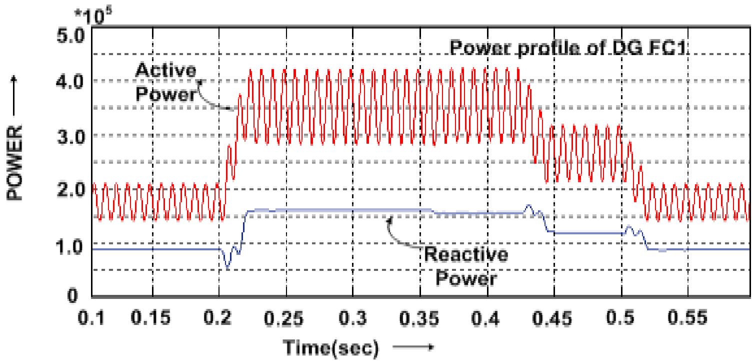


Figure 11. Active and reactive power profile of fuel cell based DG

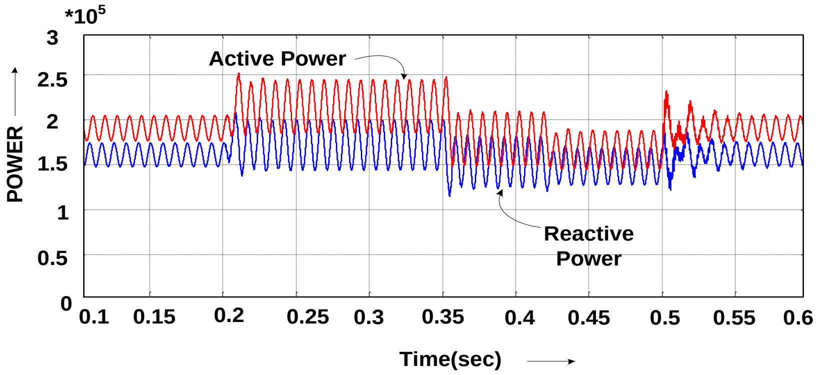


Figure 12. Active and reactive power profile of PV cell based DG

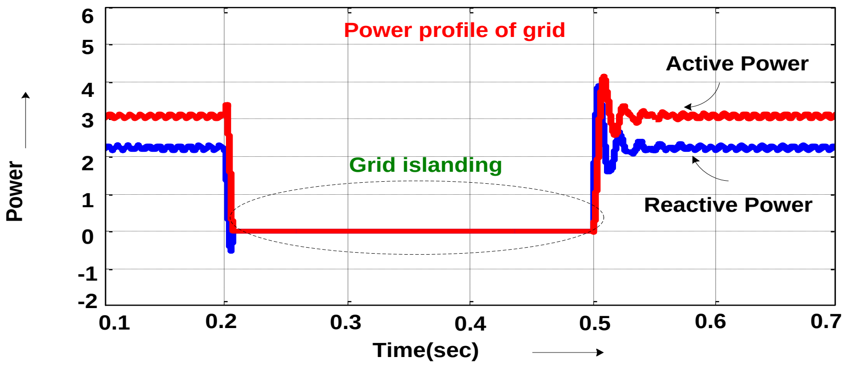


Figure 13. Active and reactive power profile of grid

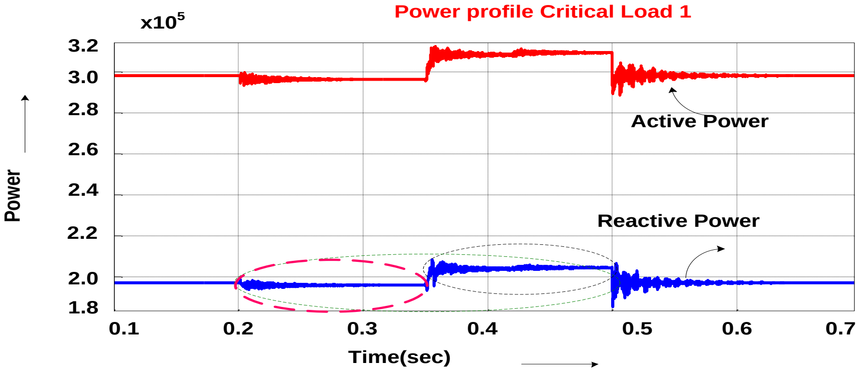


Figure 14. Active and reactive power profile of critical load 1

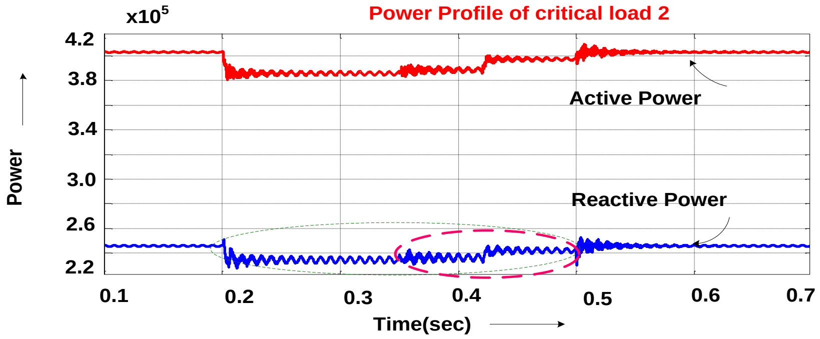


Figure 15. Active and reactive power profile of critical load 2

When switching from grid connected mode to islanded mode t=0.2 s the active and reactive power profile of the grid has oscillatory transient which was a kind of sustained steady state behavior in equivalent source based system presented in the previous section of this paper. Bringing back the islanded mode to grid connected mode at t=0.5 sec the similar behavior has been shown by the active and reactive power profile of the grid. The point which is of remarkable conclusion is that when real time DGs they are being connected to grid, the oscillations in the power profile of the grid becomes an integral part. The oscillation will die out or will remain same that actually depend upon the design methodologies opted in tuning of PID controller involved in control of either PV or fuel cell dynamics.

As far as the power balance philosophy is concerned in real time DG based microgrid system, it holds well as in case of equivalent source based system. As discussed earlier that whenever there is a transient requirement of the power the fuel cell due to its slow dynamics will not be able to supply the power, till the point the required amount of fuel is raised, so an ultra-capacitor is added to the front of the inverter which takes care of immediate power requirement upto 2-3 sec, which is nominal fuel level rising time of a typical fuel cell. The time up-to which the ultra DC capacitor can supply the immediate requirement of real power, actually depends upon time constant of the circuit being formed with load, and inverter system and ultra-capacitor. For the system under investigation time constant of circuit was close to 2.8 sec, till this much time immediate requirement of the power can be fulfilled.

5. CONCLUSION

Position of the load and the DGs may or may not play a crucial role in active and reactive power management in a micro-grid. Further as has been discussed with extensive analysis using simulation result, that even though all DGs are of equal capacity in their generation but when the load is either increased or decreased this doesn't essentially guarantee in a microgrid that all DGs will equally share the active and reactive power demand of the loads. This becomes the major drawback of conventional droop control theory.

The controllers are able to compensate the effect of critical and non-critical loads. The local loads can be commonly shared among the utility grid and distributed generators in any desired ratio. The non-critical loads that are generally fed by the utility grid in the grid-connected mode are shared among the different DGs in proportion to their rating in the islanded mode.

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BIOGRAPHY OF AUTHORS

Niraj Kumar Choudhary received B.Tech in Electrical Engineering from HIT, Haldia, West Bengal in 2009 and M.E. in Power System specialization in 2011, from Bengal Engineering & Science University Shibpur which is currently known as IIEST, Shibpur. Currently he is working as an Assistant Professor in the Department of Electrical Engineering since Nov. 2012. His area of interest includes Distributed Generation, Microgrid and Electrical Machines.

Dr. Soumya Ranjan Mohanty received his B.E. in Electrical Engineering from Utkal University in 1997, M.E. in Power System in 1999 from Sambalpur University and Ph.D in Electrical Engineering in 2007 from IIT Kharagpur. Dr. Mohanty has a teaching and research experience of 11 yrs and 6 yrs respectively. His area of interest includes Distributed Generation and Smart Grid and Signal processing applied to Power System Protection.

Professor Ravindra Kumar Singh received B. Sc. (Engg.) degree (Gold Medalist) from B.C.E. Bhagalpur (Bhagalpur University), M.Tech degree from IT BHU (Currently IIT BHU) and Ph.D from IIT Kanpur in 1987, 1992 and 2002 respectively, all in Electrical Engineering. Currently he is a Professor in Department of Electrical Engineering, MNNIT Allahabad. His area of interest includes Power Electronics and Control Systems. Dr. Singh is a Fellow of Institution of Engineers (IE) India, Member of Institution of Electrical & Electronics Engineers (IEEE), Life member of Indian Society for Technical Education (ISTE) and Member of IET, UK.