Educational Administration: Theory and Practice
2023, 29(2), 416-427
ISSN: 2148-2403
https://kuey.net/
Research Article

Real And Reactive Power Flow Control Between The Utility Grid And MG System With VSC

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Citation: L. Nadam, et. al (2023), Real And Reactive Power Flow Control Between The Utility Grid And MG System With VSC, *Educational Administration: Theory and Practice*, *29*(2), 416-427
Doi: 10.53555/kuey.v29i2.6647

ARTICLE INFO
Received-10-06-2023
Accepted-20-07-2023

ABSTRACT

This paper proposes a novel control method for the flow of power between utility and micro grid by controlling real and reactive power flow through back to back converter .The propose control strategy run in two different cases , in case 1 - real and reactive power are shared between the load and the micro grid through back to back converter. Case 2 , the required load demand by the utility is first taken until the DG reaches its maximum limit .the balanced required power to the utility is only taken by the micro grid .

It is also shown the voltage or frequency fluctuation in the load side has no impact on the voltage or Power fluctuation. Proper relay coordination is also proposed during fault condition for seamless operation. The impedance and motor type load are considered for verifying system stability. The DC voltage fluctuation and their impact is also investigated. The proposed control arrangement has been validated for various operating condition by simulating in MATLAB. The reactive power requirement of the load is validated and supplied by connecting capacitor Bank at the utility. the effect of load demand has also been investigated through the two DGS connected in the micro grid system.

Keywords: Microgrid, Utility Grid, Voltage Source Converter, Real & Reactive Power

1. Introduction:

Power electronic converters allow distributed generators to be connected to the utility grid, however this has led to challenges on exactly how various distributed generators must share load with the grid. A set of distributed generators connected to the main utility grid, typically using voltage-source-converter based interfaces, and this is commonly referred to as a microgrid. When connecting a microgrid to the utility system, it's necessary that the distributed generators execute effective load sharing.

Using droop characteristics is the most preferred methodology. In order to provide the system with the proper real and reactive power, parallel converters have been operated. In an actual system, the distance between the converters can make inter-communication impractical, so using local signals as feedback for operating the converters is important. In view of this, this research presents a configuration which serves good for supplying the microgrid with high-quality electrical power, particularly when it comes from controlled a conversion.

Developing a distributed generator microgrid with power electronics interface is the primary objective of this paper. A scheme is provided to regulate DGs that are connected in parallel with the objective of proper load sharing. Back-to-back converters are used to connect the microgrid and utility. Both converters must be controlled in order to achieve bidirectional power flow control between the utility and microgrid. Connecting the utility and the microgrid, the back-to-back converters give an essential frequency and power quality isolation. This might be advantageous to coordinate relay breakers properly to provide protection during breakdowns. The approach offers a smooth resynchronization when the fault is resolved in addition to a quick reliable islanding at the fault's start.

2. Related work: S. Ansari et al [1] The control algorithms for AC/DC MG and accompanying power converters have advanced recently. This page provides a concise, up-to-date summary of recent research on the various AC/DC MG topologies, power converter types, power converter controls, and control methodologies. The paper concluded by outlining some of the remaining problems that must be fixed before a sustainable and reliable management plan for AC/DC MG could be developed. Babatunde, O.M.; Munda, J [2] This study provides a comprehensive overview of key topics surrounding the drivers and specific benefits of HRES adoption. Also included is a description of the many renewable energy options available for use in HRES systems, both on and off the grid. Jaynendra Kumara [3] Control at multiple levels, including hierarchical control, has been discussed, as has decentralised and dispersed control. Grid-connected, island, and transitional power management strategies have been introduced. Energy management plays a crucial role in determining the optimal size and rating of energy storage systems, as well as ensuring that they are used to their full potential, prompting the presentation of a variety of energy management solutions. B. A. Vaccaro, M. Popov [4] The microgrid (MG) paradigm is an unusual concept that has been proposed as a way to fix the technological, financial, and ecological problems plaguing today's power grids. Extensive research and testing have been conducted on the potential uses of MG. It is well acknowledged that MGs systems present a variety of technological issues related to their operation, monitoring, control, and protection. Jamal, S [5] The MG and NG EMS aids in meeting crucial economic objectives such minimising operational costs by optimising fuel costs, emission costs, and battery degradation costs and extending the useful life of MG equipment. On the other hand, the PMS aids in accomplishing technical goals like making MG and NG systems more stable, adaptable, reliable, and high-quality. Farrokhabadi, M [6] Microgrids (MGs) are a type of energy distribution system that can include multiple forms of distributed generation, including renewable and standard power plants and energy storage systems. In order to meet the need of small populations like college campuses, companies, and hospitals, an MG can supplement these sources. Karavas, C.-S [7] In order to manage MG operations most effectively, scientists used fuzzy logic with cognitive maps. The study's authors then contrasted the centralised and decentralised methods, finding that the latter offered more practical benefits in the event of a system failure. Chaouachi, A.; Kamel [8] Solar photovoltaics (PVs), wind turbines (WTs), microturbines (MTs), fuel cells (FCs), and a battery storage system were all part of the effective EMS outlined by the researchers in. This algorithm reduced the MG's environmental impact and operating operating costs. Nduwamungu, A [9] This review provides some helpful information on the coordination and energy management of microgrids generally based on PQ controller and droop control. System controls and energy management strategies are described after the presentation of potential DER unit structures, options, and control methods. Wang, Y., Tan [10] This paper presents a survey of the literature on PQ controller and droop control as they pertain to microgrid coordination and energy management. The paper will proceed as follows. In Section II, we take a quick look at droop control from various perspectives, each of which pertains to some facet of microgrid power transmission and distribution. Vandoorn, T.L., Vasquez [11] Power quality (PQ) controllers and droop controls should provide reliable power regulation in both grid-connected and off-grid settings. When there is a mismatch between generation and consumption, as might happen with flexible load and DER, a microgrid operating in standalone mode has additional challenges.

3. System Structure:

The power system model is shown in fig, it having two distributed generations, one is microgrid load and the back to back voltage source converter is connected between at point A & PCC. The real & reactive power is denoted by P, Q and power drawn by the microgrid are P1, P2, Q1, Q2, Load power is PL, QL. The utility grid power supplies to the back to back converter is PG, QG and power supplied from grid to microgrid is PT, QT. Circuit breakers CB-1 & CB-2 can isolate microgrid to utility grid supply. The back to back converter having a common dc voltage.

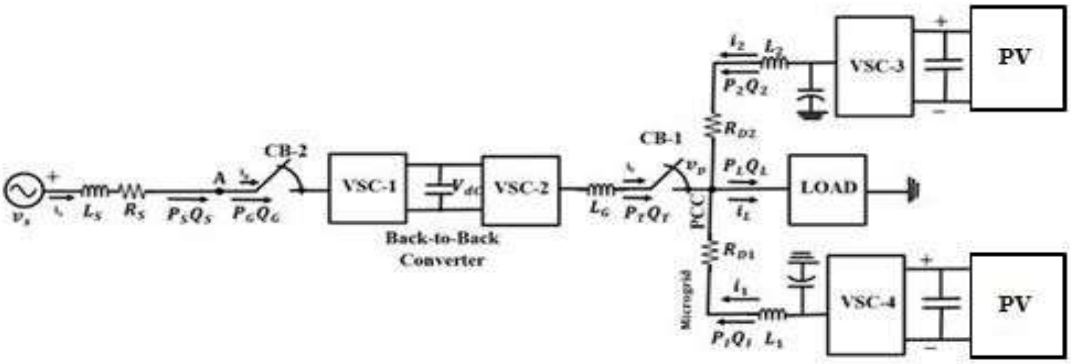

Fig. 1. Microgrid system structure

Depending on the microgrid's power requirements, the system may function in one of two modes. Through the back-to-back converters, a certain quantity of real and reactive power can be delivered by the utility to the microgrid in mode 1. The DGs provide the remaining portion of the load demand. The DGs get an equal portion of the power requirements, which are allocated by their ratings. The extra electricity generated by the DGs is given back to the utility when it exceeded all that is required to power the load.

A fixed power flow from the utility to the microgrid may not be possible if the microgrid's power requirements exceed the entire maximum available generating capacity of the DGs (for example, when cloud cover reduces PV generation). Later then, the utility will operate the DGs in maximum power mode while supplying the microgrid with the remaining electricity needed under mode-2 control. The microgrid switches from mode-1 to mode-2 operation when all of the DGs have reached their power limits. Although mode-1 offers a secure contractual arrangement with the utility, mode-2 offers a more predictable power supply and offers the capacity to manage high loads and unexpected generation.

The rating requirement of the back to back converters will depend on the maximum power flowing through them. The maximum power flow will occur when the load demand in the microgrid is maximum and minimum power is generated by the DGs (power flow from utility to microgrid) and maximum power is generated by DGs, while the load demand in the microgrid is minimum (power flow from microgrid to utility).

4. Voltage source converter structure:

The voltage source converter (VSC) having three H-bridges and that are connected to 3- single phase transformer in star connections as shown in fig. In this LCL filter is used for switching harmonics and **L_f** is leakage reactance of the transformer, and also **L_1** represent output inductance of DG source.**R_f** is switching losses & transformer . **C_f** is connected to the output of the transformers and **L_1.**

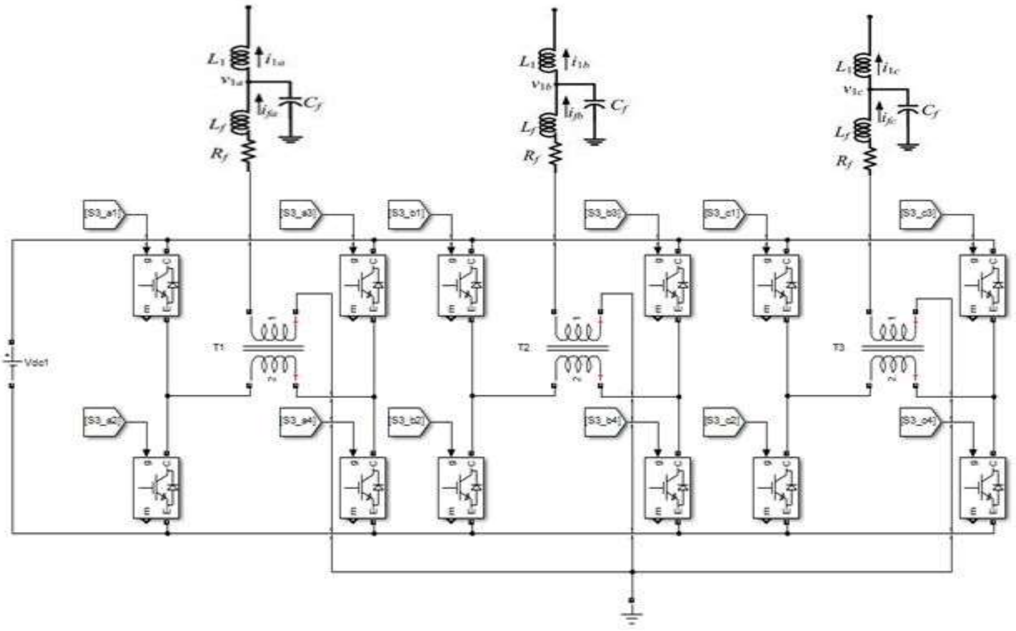

Fig.2.Simulation diagram for Voltage source Converter (VSC-3) structure

The converter structure of VSC-4 is same as VSC-3. The converters of the back-to-back converters have same structure but they are supplied by the common capacitor voltage.

5. VSC-1 Reference generation:

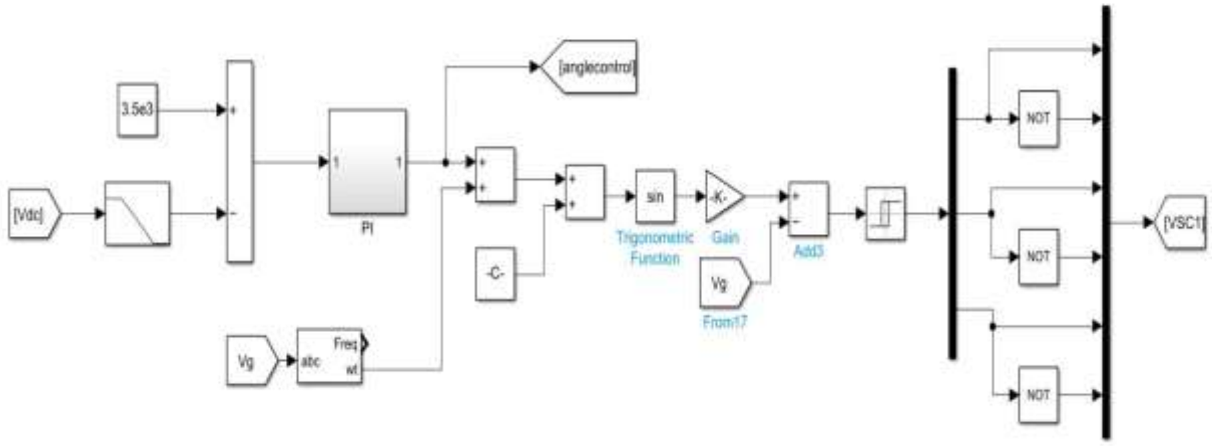

Fig.3. Simulation diagram for Reference generation VSC-1

In fig, Capacitor voltage is measured first then pass to low pass filter and compare to referee voltage , then error is fed to a PI controller to generate reference angle as shown in fig above.

6. VSC-2 Reference generation:

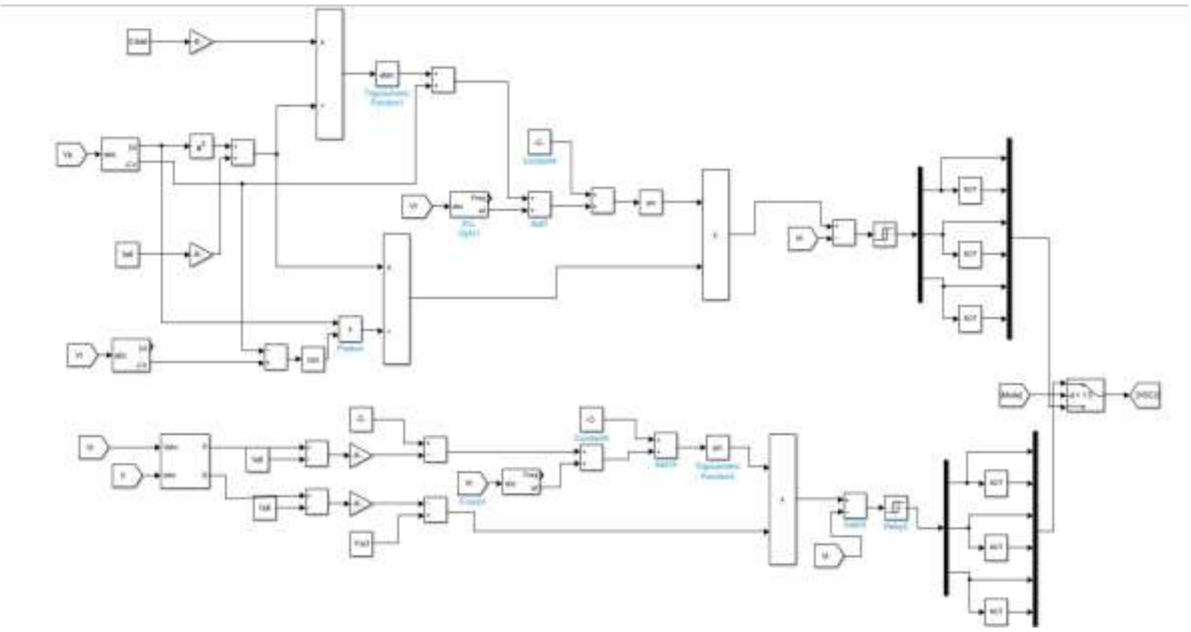

Fig.4. Simulation diagram for Reference generation VSC-2

In State-1, P_{ref} and Q_{ref} are the required active and reactive powers which should be transferred between grid and MG through VSC-2. The output voltage of VSC-2 is represented by $V_T\angle\delta_T$, and the PCC voltage is denoted by $V_P\angle\delta_P$. Then the reference voltage magnitude and angle at the terminals of VSC-2 can be defined as:

$$V_T^{ref} = \frac{V_P^2+Q_{ref}X_G}{V_P COS(\delta_T-\delta_P)} \qquad (1)$$

$$\delta_T^{ref} = tan^{-1}\left(\frac{P_{ref}X_G}{V_P^2+Q_{ref}X_G}\right) + \delta_P \qquad (2)$$

These references are computed subject to the load demand. Reference voltage can be calculated by using V_T^{ref} and δ_T^{ref}. And switching pulses are generated by SPWM. The sign of the reference active and reactive powers should be negative if power transfer is from MG to the grid.

6.1. Reference signal generation for VSC-2 in State-2

In State 2, if both DGs supply their maximum available power, the grid compensates for any power shortage of consumers by utilizing the back-to-back converters. Let P_{max} and Q_{max} denote the peak capacity of the back to back converters. Then reference voltage magnitude and controller angle are calculated as follows:

$$\delta_T = \delta_{max} - m_T \times (P_T - P_{max}) \qquad (3)$$
$$V_T = V_{max} - n_T \times (Q_T - Q_{max}) \qquad (4)$$

Here, V_{max} and δ_{max}represent the magnitude and controller angle of the reference voltage, when supplying the maximum load. m_T and n_T are the droop coefficients and can be chosen depending on power limits of the converter.

7. Reference generation for VSC-3:

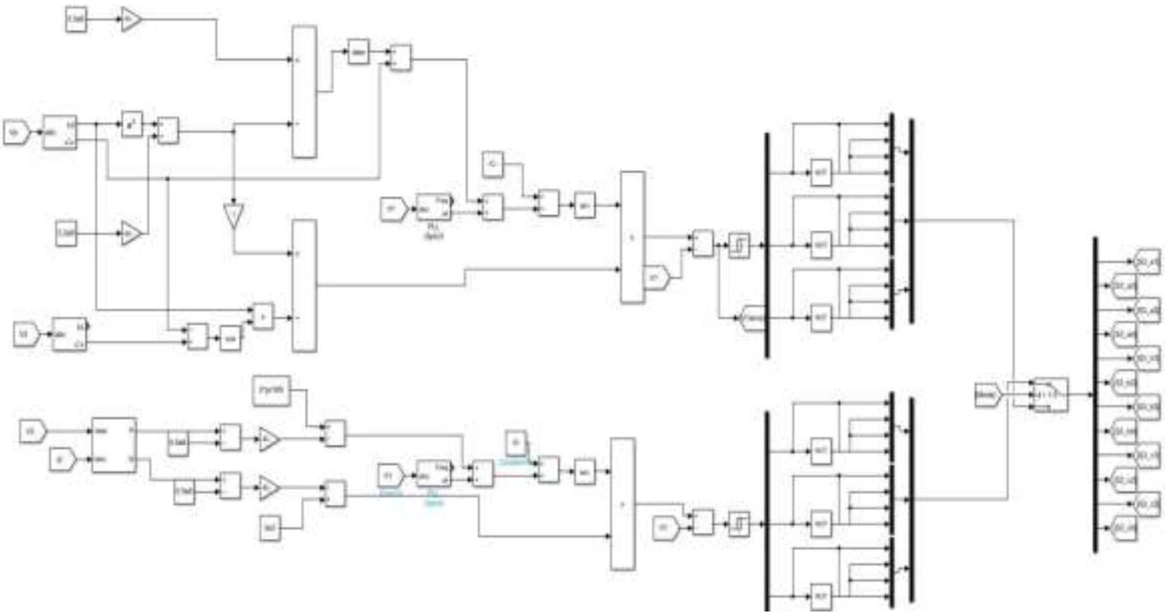

Fig.5. Simulation diagram for Reference generation VSC-3

In State 1, it is considered that the grid provides a fraction of the consumers requirement, and both DGs supply and regulate the remaining requirement of the consumer. The converted voltages by VSC-3 can be controlled by considering the load proportionally of its respective DG. Controlling the real and reactive power from PVGS to the microgrid involves adjusting the magnitude and controller angle of the voltage. Injected active and reactive powers from the PVGS is given as

$$P_1 = \frac{V_1 \times V_{P1} sin(\delta_1 - \delta_{P1})}{X_1} \qquad (5)$$
$$Q_1 = \frac{V_1^2 - V_1 \times V_{P1} cos(\delta_1 - \delta_{P1})}{X_1} \qquad (6)$$

if the difference between phase angle of V_1 and phase angle of V_{p1} is less then the active power provided by PVGS may be regulated by δ_1 and reactive power can be regulated by V_1. This enables the distribution of power requirements among the DGs, by adjusting the V_1 and δ_1 using droop coefficients which is given as follows:

$$\delta_1 = \delta_{1rated} - m_1 \times (P_1 - P_{1rated}) \qquad (7)$$
$$V_1 = V_{1rated} - n_1 \times (Q_1 - Q_{1rated}) \qquad (8)$$

In this equation, δ_{1rated} and V_{1rated} denote the rated magnitude and angle of the voltage of PVGS when it is delivering P_{1rated} and Q_{1rated} power to the load. m_1 and n_1 are the droop coefficients for controller angle to regulate active power and for magnitude to regulate reactive power respectively.

8. Reference generation for VSC-4:

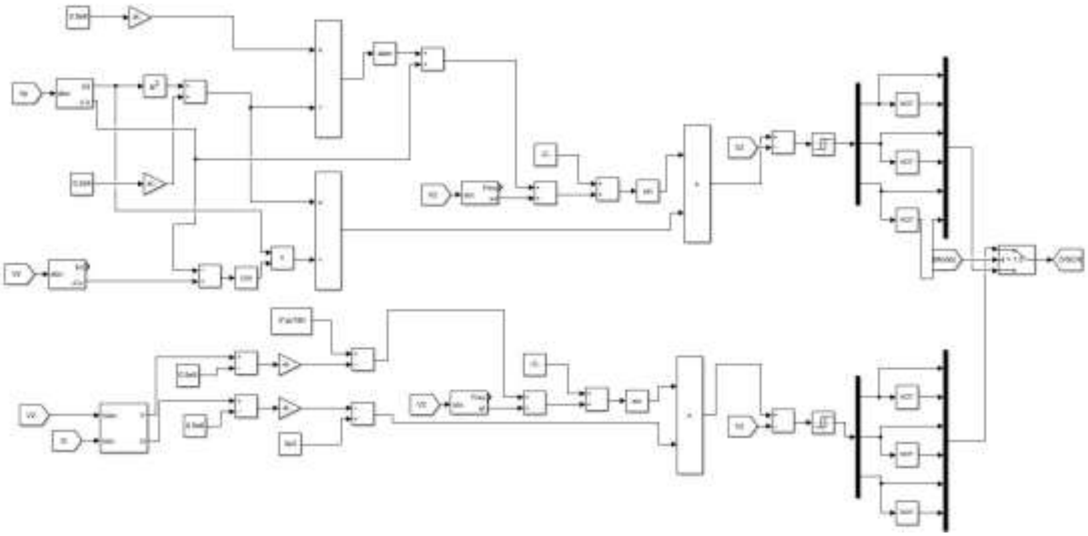

Fig.6. Simulation diagram for Reference generation VSC-4

the PV systems generate their permissible peak power and remaining required power by the load can be provided by the grid. Using required active power and reactive power termed as P_{1avail} and Q_{1avail} reference voltage magnitude and controller angle can be calculated as,

$$V_1 = \frac{{V_{P1}}^2 + Q_{1avail}\,X_1}{V_{P1}cos(\delta_{P1} - \delta_P)} \qquad (9)$$

$$\delta_1 = \left(\frac{P_{1avail}\,X_1}{{V_{P1}}^2 + Q_{1avail}\,X_1}\right) + \delta_{P1} \qquad (10)$$

Table 1. Microgrid Parameters

System Quantities	**Values**
Source Voltage (Vs), frequency	11kV rms L-L, 50Hz
Rs, Ls	Rs=3.025Ω, Ls=57.75mH
Impedance Load Induction motor	R_L=100Ω, L_L=300mH Rated 40hp,11kV rms(L-L)
VSC Transformer ratings VSC losses Inductances Filter capacitances PV Array	3.5kv 3 kv/ 11 kv , 0.5MVA, 2.5% reactance L_f 1.5 Ω L_1=20mH, L_2=16mH and L_G=28.86 mH 50uf 460kW
Angle controller	Kp=0.2 K_i =0.5
Droop coefficients(power-angle) (voltage-Q)	m_1= 0.3 rad/MW, m_2=0.24 rad/MW n_1=0.15 kv/MVar , n2= 0.12 kv/MVar

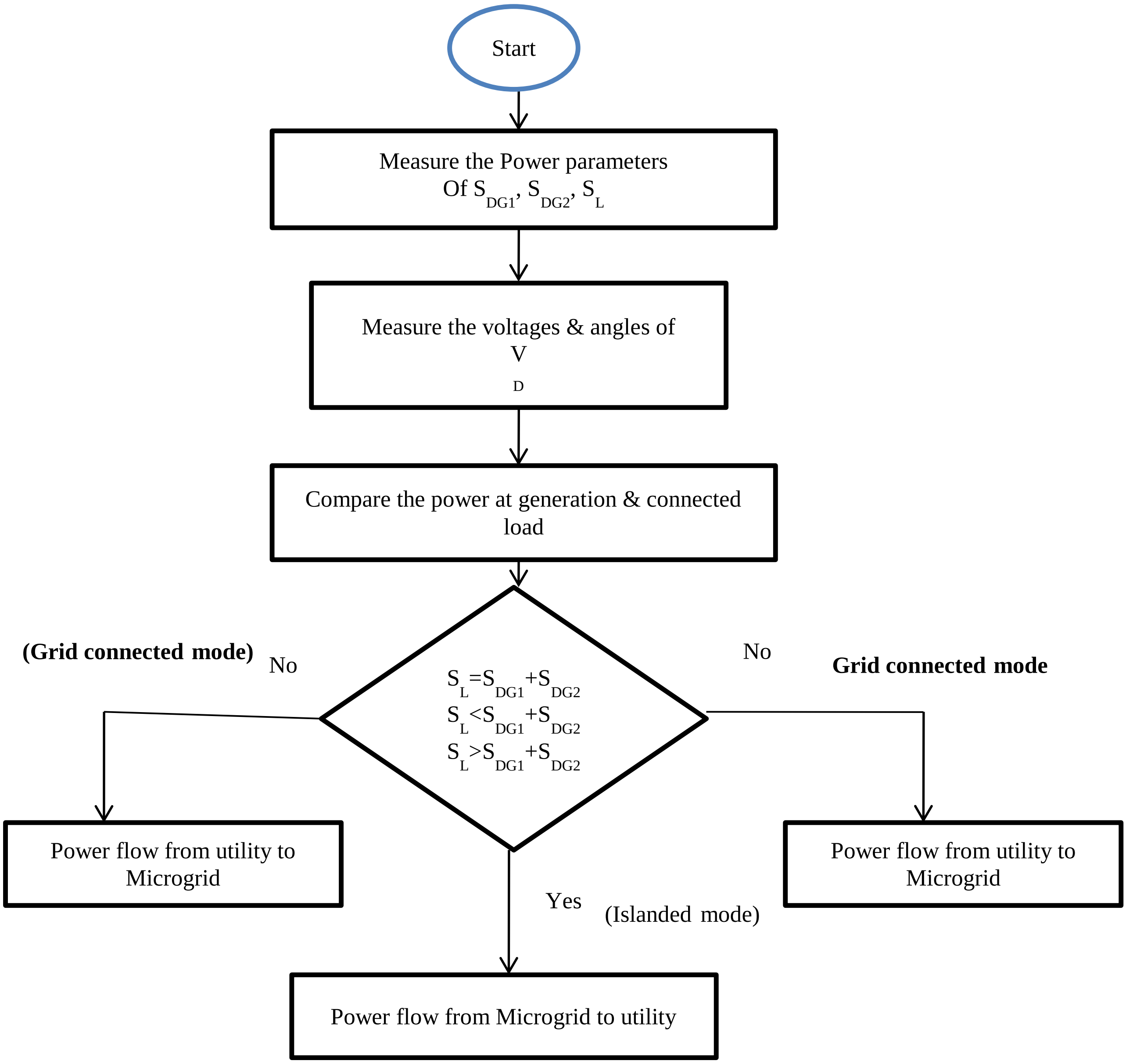

Fig.7.power flow Control sequence from a grid connected mode to islanded mode

Table: 2.Voltage source converter reference Numerical values for Mode-1 & Mode-2

S.No	**VSC-1 reference value**	**VSC-2 reference value**		**VSC-3 reference value**		**VSC-4 reference value**	
	Mode-1	Mode-1	Mode-2	Mode-1	Mode-2	Mode-1	Mode-2
Case-1 : Load sharing DG's with Utility	V_{Cref}=3.5kV	P_{Tref}=0.6MW Q_{Tref}=1MVAr X_G=9.06Ω	P_{Tmax}=1MW Q_{Tmax}=1MVAr V_{Tmax}=11kV m_T=0.3rad/MW n_T=0.15kV/MVAr	P_{Tref}=0.5MW Q_{Tref}=0.2MVAr X_G=6.06Ω	P_{2rated}=0.5MW Q_{2rated}=0.5MW V_{2rated}=3kV δ_{2rated}=0.	P_{Tref}=0.5MW Q_{Tref}=0.2MVAr X_G=6.06Ω	P_{2rated}=0.5MW Q_{2rated}=0.5MW V_{2rated}=3kV δ_{2rated}=0.
Case-2: Change in power supply from grid	V_{Cref}=3.5kV	P_{Tref}; Initial value 0.3MW, Final value 0.1MW Q_{Tref} : Initial value 0.5MVAr, Final value 0.1MVAr X_G=9.06Ω	P_{Tmax}=1MW Q_{Tmax}=1MVAr V_{Tmax}=11kV m_T=0.3rad/MW n_T=0.15kV/MVAr	P_{Tref}=0.5MW Q_{Tref}=0.2MVAr X_G=6.06Ω	P_{2rated}=0.5MW Q_{2rated}=0.5MW V_{2rated}=3kV δ_{2rated}=0.	P_{Tref}=0.5MW Q_{Tref}=0.2MVAr X_G=6.06Ω	P_{2rated}=0.5MW Q_{2rated}=0.5MW V_{2rated}=3kV δ_{2rated}=0.
Case-3 :	V_{Cref}=3.5kV	P_{Tref};	P_{Tmax}=1MW	P_{Tref}=0.5MW	P_{2rated}=0.5MW	P_{Tref}=0.5MW	P_{2rated}=0.5MW

Power supply from micro grid to utility		Initial value 0.3MW, Final value - 0.3MW Q_{Tref} : Initial value 0.5MVAr, Final value - 0.3MVAr $X_G=9.06\Omega$	$Q_{Tmax}=1MVAr$ $V_{Tmax}=11kV$ $m_T=0.3rad/MW$ $n_T=0.15kV/MVAr$	$Q_{Tref}=0.2MVAr$ $X_G=6.06\Omega$	$Q_{2rated}=0.5MW$ $V_{2rated}=3kV$ $\delta_{2rated}=0.$	$Q_{Tref}=0.2MVAr$ $X_G=6.06\Omega$	$Q_{2rated}=0.5MW$ $V_{2rated}=3kV$ $\delta_{2rated}=0.$
Case-4 : *Variable Power Supply from Utility*	$V_{Cref}=3.5kV$	P_{Tref}; Initial value 0.3MW, Final value 0.3MW Q_{Tref} : Initial value 0.2MVAr, Final value 0.2MVAr $X_G=9.06\Omega$	$P_{Tmax}=1MW$ $Q_{Tmax}=1MVAr$ $V_{Tmax}=11kV$ $m_T=0.3rad/MW$ $n_T=0.15kV/MVAr$	P_{Tref}; Initial value 0.5MW, Final value 60kW $Q_{tref}=0.2MVAr$, Final value $X_G=6.06\Omega$	$P_{2rated}=0.5MW$ $Q_{2rated}=0.5MW$ $V_{2rated}=3kV$ $\delta_{2rated}=0.$	$P_{Tref}=0.5MW$ $Q_{Tref}=0.2MVAr$ $X_G=6.06\Omega$	$P_{2rated}=0.5MW$ $Q_{2rated}=0.5MW$ $V_{2rated}=3kV$ $\delta_{2rated}=0.$

9. Simulation Results: Different configurations of load and its sharing are considered. The DGs are considered as inertia-less dc source supplied through a VSC. The system data are given in Table I. The droop coefficients are chosen such that both active and reactive powers of the load are divided in a ratio of 1:1.25 between DG-1 and DG-2

9.1. Microgrid load sharing between DG's & Utility Grid: In this case , 50% of micro grid load demand is shared by distribution generation and rest of load demand is shared by utility grid as shown in fig.

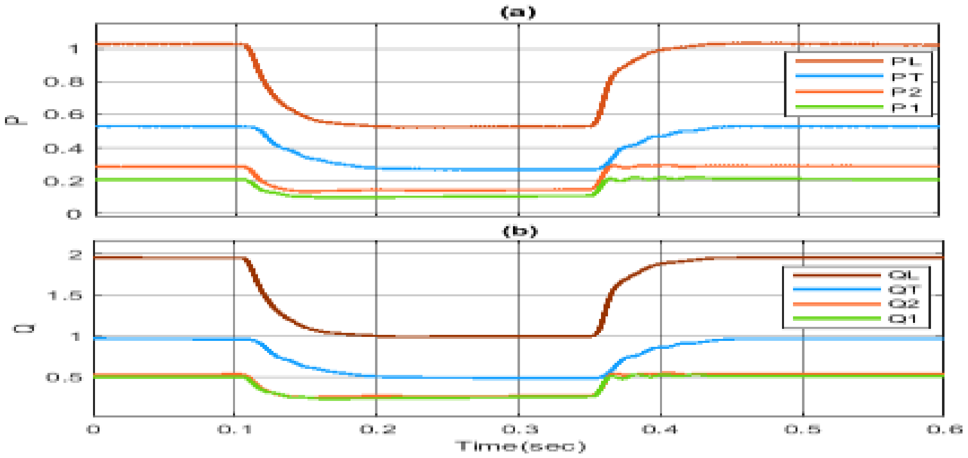

Fig.7.Active(MW) & Reactive(MVAr) power sharing between DG's & Grid

Numerical values for power transfer between microgrid and utility grid is shown below.

Table 3. Load sharing DG's with Utility

Time in sec from fig 7	**Microgrid Load**		**Power supply Utility side to Micro grid**		**DG-1 Power**		**DG-2 Power**	
	P_L	**Q_L**	**P_T**	**Q_T**	**P_1**	**Q_1**	**P_2**	**Q_2**
0 to 0.1s	1MW	2MVAr	0.5MW	1MVAr	0.2MW	0.5MVAr	0.3MW	0.5MVAr
0.1 to 0.35 s	0.52MW	1MVAr	0.3MW	0.5MVAr	0.1MW	0.25MVAr	0.12MW	0.25MVAr
After 0.35 s	1MW	2MVAr	0.5MW	1MVAr	0.2MW	0.5MVAr	0.3MW	0.5MVAr

From fig 8 a, it is observed that the tracking voltage error is 0.2%. the capacitor voltage V_C and its angle is at 0.1 sec, the load impedance increased and at 0.35 sec it is changed to its initial value as shown in fig 8.b.

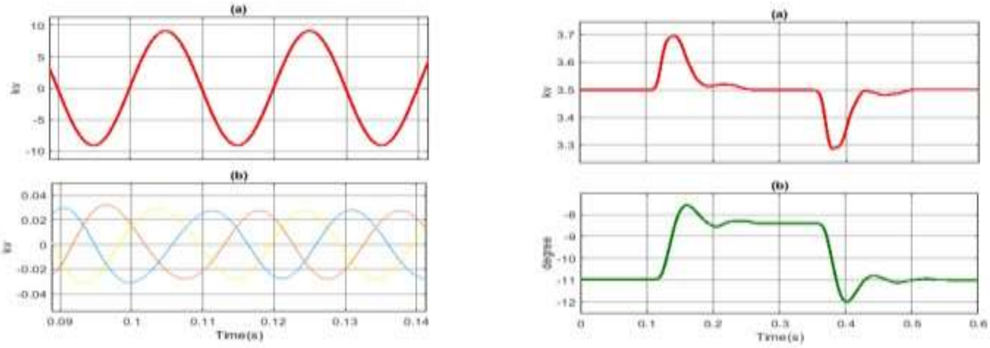

Fig 8. a)DG-1 voltage tracking & b)capacitor voltage and its angle controller

9.2. Utility supply change: If the power flow from the utility to microgrid is changed by changing the power flow reference for VSC-2, the extra power requirements is automatically pick up by the DG's.

Table 4: Change in power supply from grid

Time in sec from fig 15	Microgrid Load		Power supply Utility side to Micro grid		DG-1 Power		DG-2 Power	
	P_L	Q_L	P_T	Q_T	P_1	Q_1	P_2	Q_2
0 to 0.1s	0.51MW	1MVAr	0.3MW	0.5MVAr	0.09MW	0.22MVAr	0.12MW	0.28MVAr
After 0.15 s	0.51MW	1MVAr	0.1MW	0.2MVAr	0.18MW	0.4MVAr	0.24MW	0.4MVAr

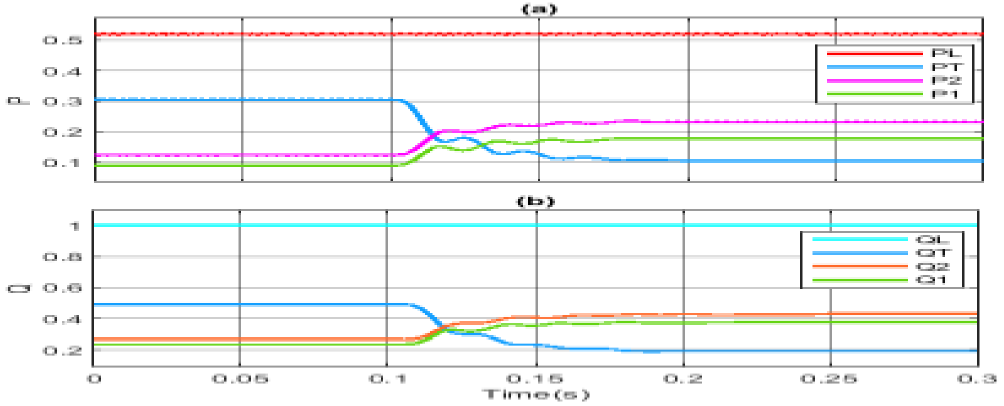

Fig.9. Real(MW) & Reactive (MVAr)power sharing for change in supply

9.3. Power supply from micro grid to utility (Power Reversal): power generation of the DG's is more than the power requirements of the load the excess power can be fed back to utility through back-to-back converters. The utility supplies 50% of the microgrid load initially at 0.1sec , the same amount of power fed back to utility by changing sign of the power flow reference for back-to-back converter as shown in fig 9.

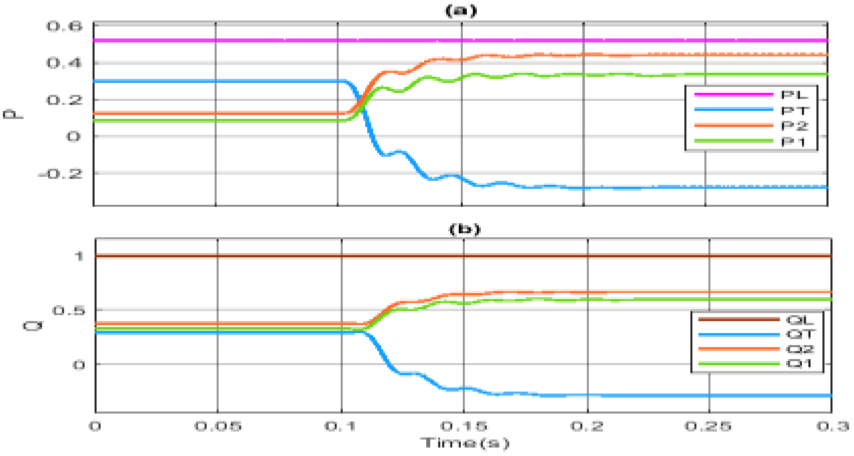

Fig. 10. Real (MW) & Reactive (MVAr) power sharing during power reversal

9.4: Variable Power Supply from Utility: when the maximum available power that can be supplied by the DGs is reached. Initially, the micro grid is running in mode 1. At 0.1 s, the input power from DG-1(P1 avail) suddenly reduces to 60 KW. DG-2 then supplies the shortfall. Suddenly load changes at 0.35 sec , power demand in microgrid is increases from, 0.53MW to 0.64MW. However, max power that can be supplied by DG-2 is set at 300kW.now both DG's combined supply power to load is 360kW. Utility grid was supplying 200kW before, now therefore an additional 80kW of power is required from utility grid. Hence a mode changes from mode-1 to mode-2.

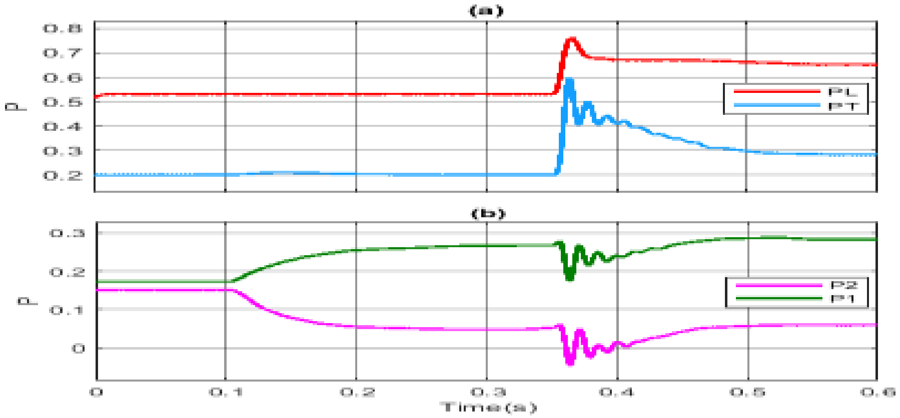

Fig. 11. Real (MW) power sharing during power limit and mode change a) P_L, P_T b) P_1, P_2

9.5. Different Micro grid load conditions: Microgrid load for different conditions i.e. increment load as well as decrement load conditions. Simulink model was designed and verified with the results with effective power flow between back-to-back converter & micro grid. active and reactive power reference for grid converter 0.6MW and 1MVAr.

9.5.1. When the Microgrid Load Increased: At initial condition(0-0.1s) the true power load is 100% (100kW) ,at time (0.1s to 0.35s) the true power load is increased to 125% , at time (0.35s to 0.6s) the true power load is increased to 150% , at time (0.6s to 0.85s) the true power load is increased to 200% , ,at time 0.85s the true power load is reached is in initial positions ,similarly for reactive power sharing as shown in fig 12.

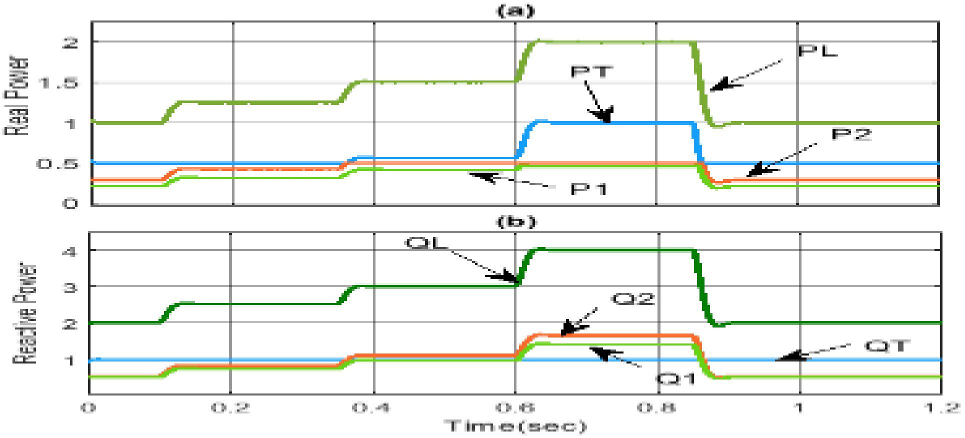

Fig .12. Real (MW) & Reactive(MVAr) power sharing when the Microgrid load is increased

9.5.2 .When the Microgrid Load decreased: From fig 13. At initial condition(0-0.1s) the P,Q power load are 100kW , 2000kVAR at time (0.1s to 0.35s) the P,Q power load is reduced to 25% , at time (0.35s to 0.6s) the P,Q power load is reduced to 50% , at time (0.6s to 0.85s) the P,Q power load is reduced to 75% , at time 0.85s the true, reactive power load is increased to 100% , the power exchange between true power & reactive power are as shown in fig 13.

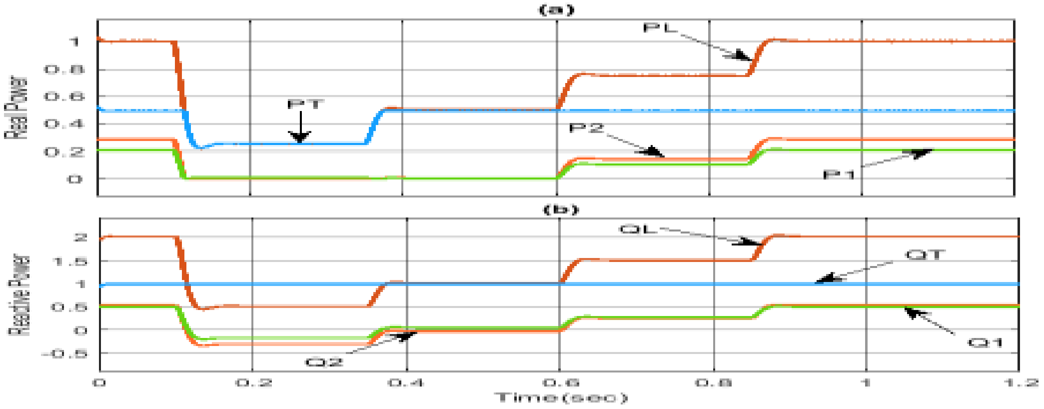

Fig .13.Real (MW)& Reactive (MVAr)power sharing when the Microgrid load is decrement

9.5.3. Varying Reactive power load by kept real power load constant: when reactive power load changes by keeping true power constant, power sharing between the main grid & DG's as shown in fig 14. At initial condition(0-0.1s) the reactive power load is 2000kVAR. after 0.1 s it is increased to 25% i.e. 2500kVAR, at time (0.35 to 0.6 s) the reactive power 3000kVAR, then at time 0.6 to 0.85 s reactive power load is increased by 4000kVAR. the true and reactive power sharing as shown in fig14.

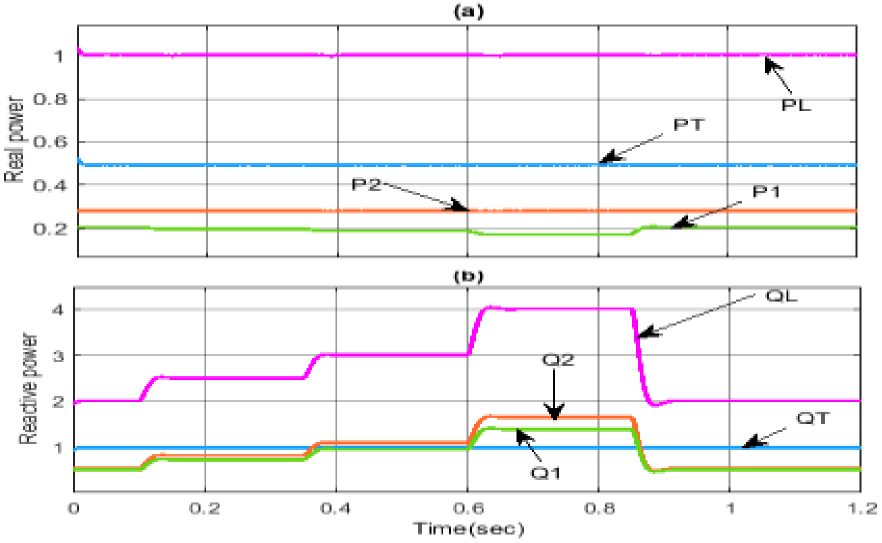

Fig .14.Reactive power (MVAr)load variations with real power(MW) are kept constant

Conclusion:

Load exchange between main grid & micro grid is presented in this paper, Active and Reactive power control to achieve proper power sharing under grid connected mode of operation. The power management strategies determine output active & reactive powers of DG's and control the voltages and frequency at same time. Power management system should share the power demand between the existing AC & DC sources by a specified droop method.

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