Simulation and Small Signal Stability Analysis of Droop Controlled Islanded Micro-grid

Flow of the presentation

1. Introduction
2. Islanded Inverter Interfaced Microgrid
   a) Small Signal Stability: Brief Overview
3. Modeling
   a) Converter
   b) Network
   c) Load
4. Real-Time Simulation Results
5. Small Signal Stability Analysis
   a) With Equal Droop Coefficients
   b) With Unequal Droop Coefficients

Microgrid

- Small autonomous regions of power systems
- Contains Generation, Transmission and Distribution of electrical energy
- Can work as islanded system mode or grid connected mode
- Fuel-cells, Photo-Voltaic and Micro-turbines can be interfaced to the network through power electronic converters
- Increased reliability and efficiency also can help integrate renewable energy

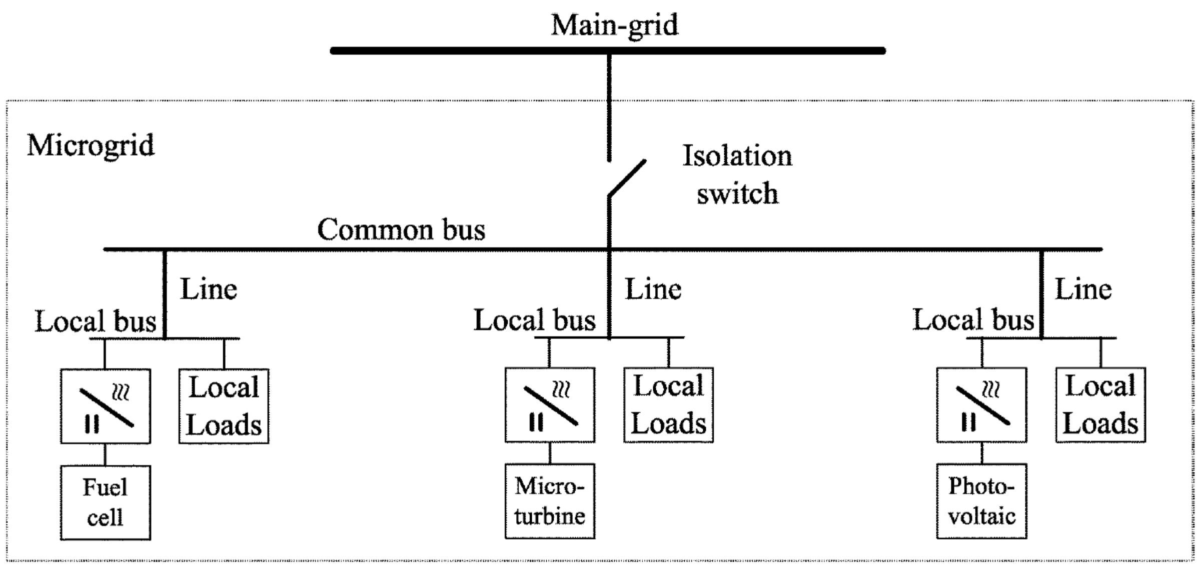


Fig.1 Structure of Microgrid

Microgrid

- Due to it's negligible physical inertia they also make the system potentially susceptible to oscillation resulting from network disturbances
- One of the important concerns in the reliable operation of a microgrid is small-signal stability in islanded mode of operation

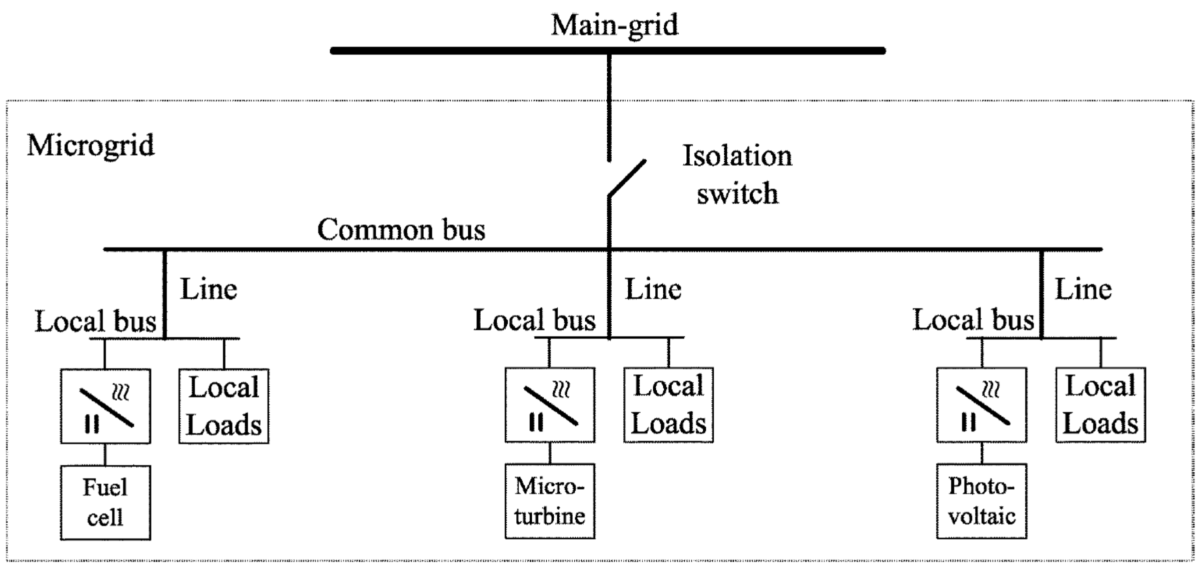


Fig.1 Structure of Microgrid

Islanded Inverter Interfaced Microgrid

- The Microgrid concept assumes a cluster of loads and micro sources (<100 kW) operating as a controllable system that provides power to various loads.
- A system with clusters of micro sources and storage could be designed to operate both isolated and connected to the power grid.
- In islanded operation, load-tracking problems arise since Renewable energy sources have a slow response and are almost inertia-less [2].
- For the islanding operation of ac microgrids, two important tasks are

    a) to share the load demand among multiple parallel connected inverters proportionately

    b) to maintain the voltage and frequency stabilities.

Islanded Inverter Interfaced Microgrid

- The reason for using a conventional droop control strategy for Voltage Source Converters in an islanded microgrid is to emulate a synchronous generator’s governor [4].

- It can be observed that droop control does not provide inertia, as is the case with traditional synchronous generators. Generally, the rotating inertia plays an important role in stabilizing electrical systems by providing temporary power to the system for a short time in case of frequency variation.
- It becomes necessary for the islanded microgrid to have inertia and power damping to ensure its stability[5].

- The inertia concept can be applied to the islanded microgrid to increase the system stability and reliability making the system sustain disturbances i.e.to make converters act as virtual synchronous generators.

Small Signal Stability: Brief Overview

- It is important concern to analyze the small signal stability of islanded microgrid structure as it does not have high inertia to sustain disturbances

- Small Signal Stability is the ability of the system to maintain synchronism(stable steady state) when subjected to small disturbances

- To analyze the small signal stability of the system if we need to have a linearized system model

Small Signal Stability: Brief Overview

- The small-signal state-space model of an individual inverter is constructed
- An arbitrary choice is made to select one inverter frame as the common reference frame and all other inverters are translated to this common reference frame, similarly, a small signal model of line and loads is formed.
- Once the small-signal model has been formed, eigenvalues (or modes) are identified that indicate the frequency and damping of the oscillatory terms of the system transient response
- The analytical nature of this examination then allows further investigation so that the relation between system stability and system parameters.

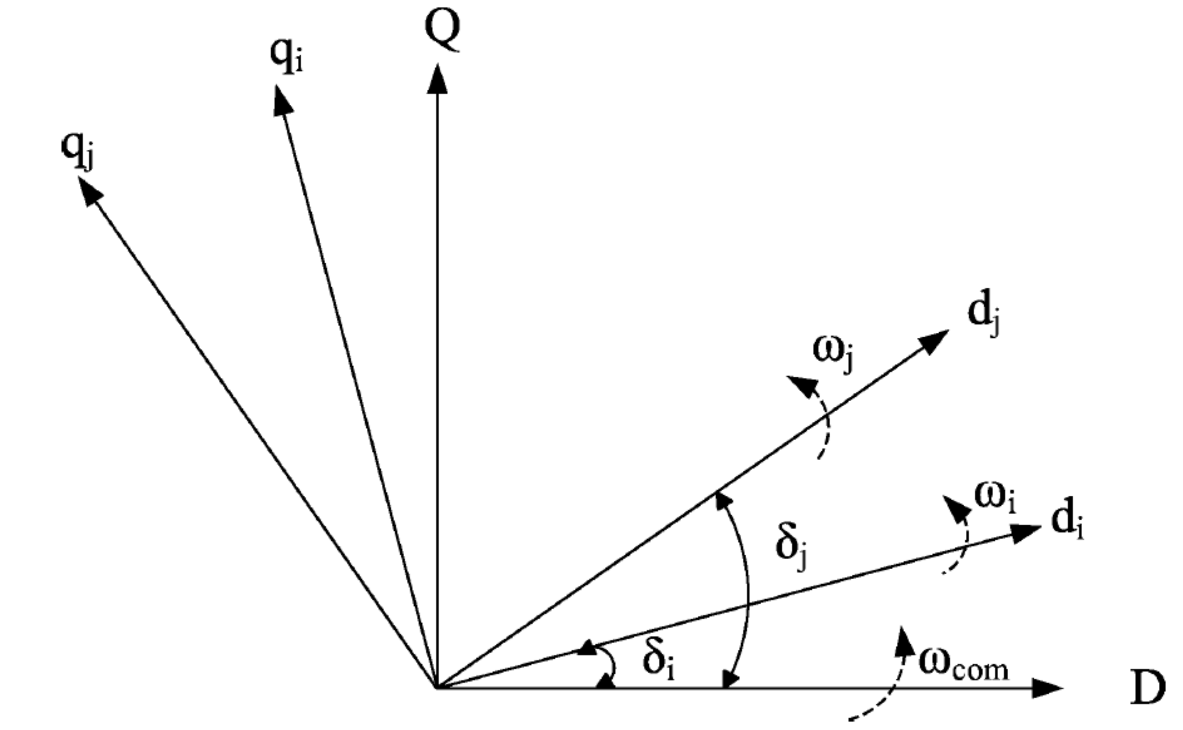


Fig.2 Reference Frame Transformation

System Under Study

- The system under study consists of islanded microgrid of two Invertor Interfaced Distribution Generators(IIDG) units with four different loads
- All buses are connected through a transmission line network
- Modeling of Systems can be subdivided into three categories

1) IIDG Submodule
2) Transmission Line Submodule
3) Load Submodule

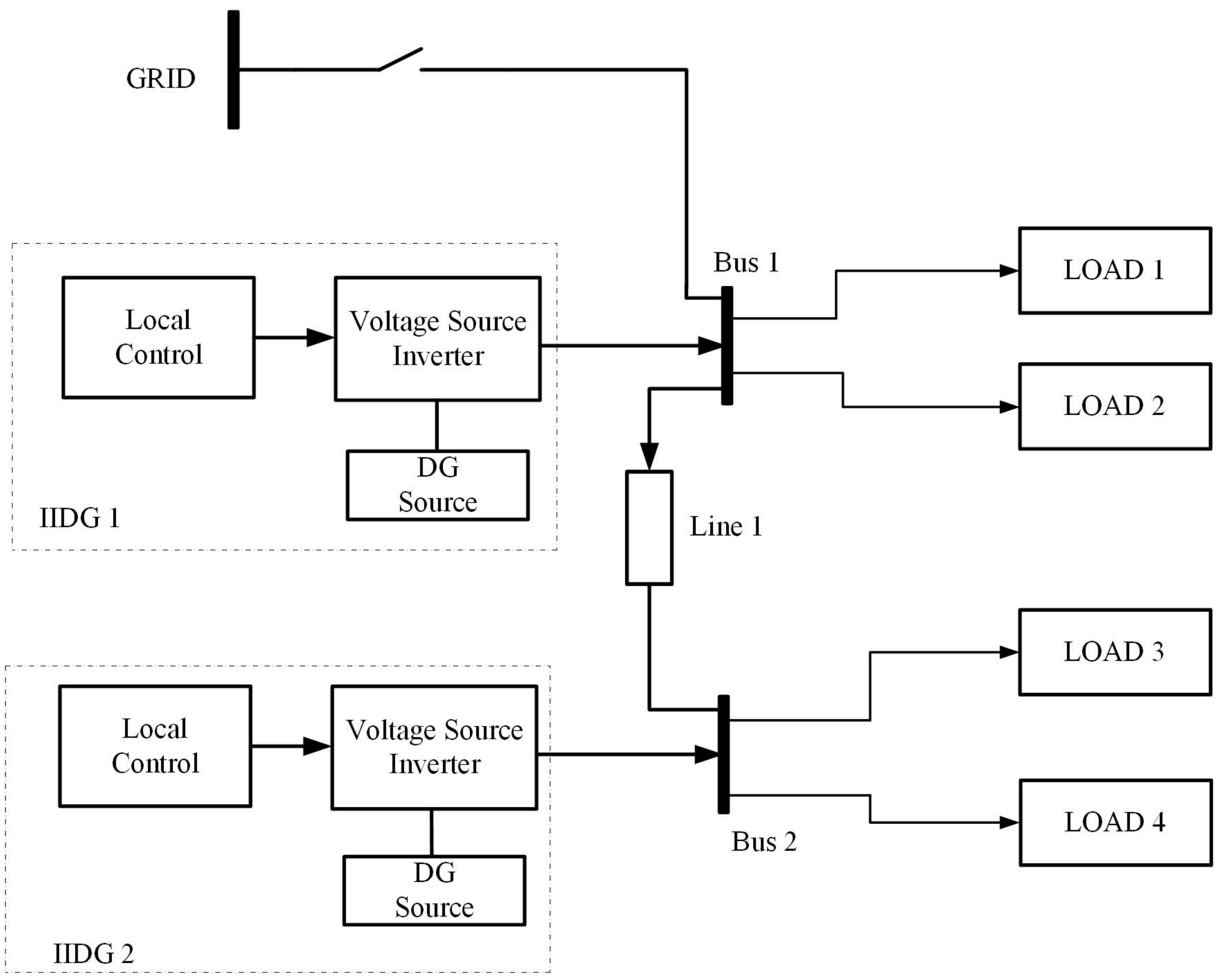


Fig.3 Test system

Inverter Modelling

- The power processing section consists of a three-leg inverter, an output filter, and a coupling inductor
- External power control loop which sets the magnitude and frequency for the fundamental voltage component of the inverter output according to the droop characteristics set for the real and reactive powers
- Other parts of a control system are the voltage and current controllers, which are designed to reject high-frequency disturbances and provide sufficient damping for the output LC filter

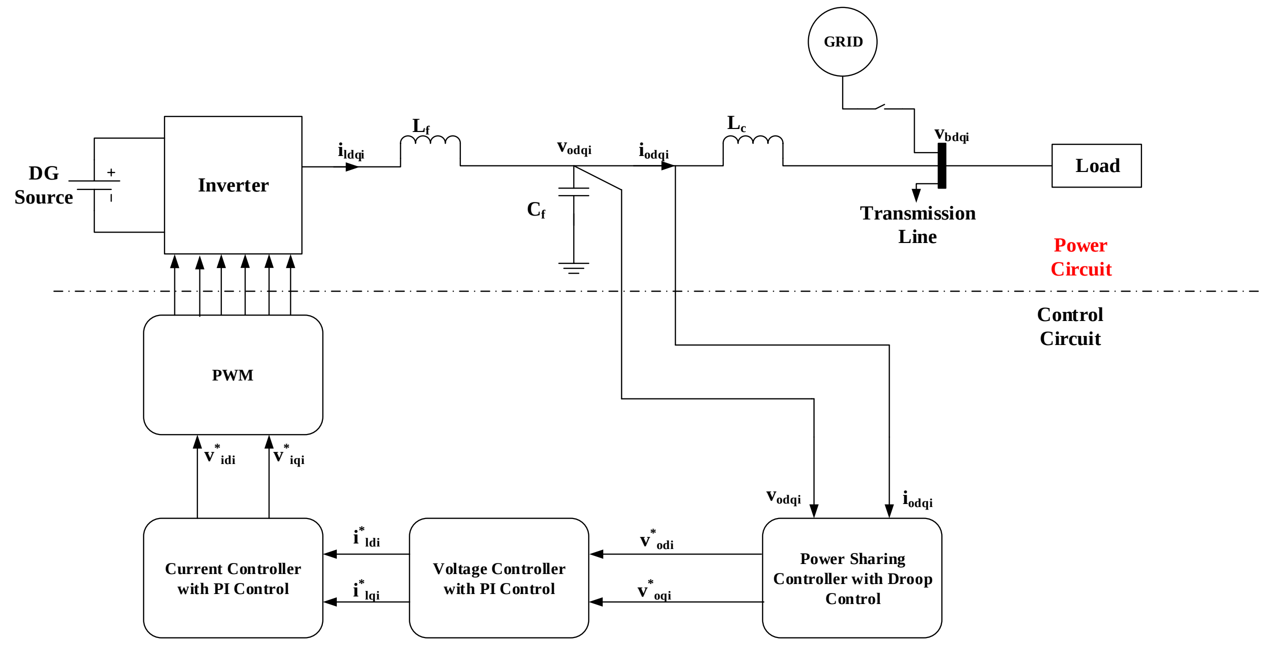


Fig.4 Model of single DG Inverter Submodule

Power Controller

- Governor principle is implemented in inverters by decreasing the reference frequency with increase in the load.
- Similarly, reactive power is shared by introducing a voltage droop characteristic.
- The outputs of the power controller are the small-signal variation of output voltage reference and the frequency.

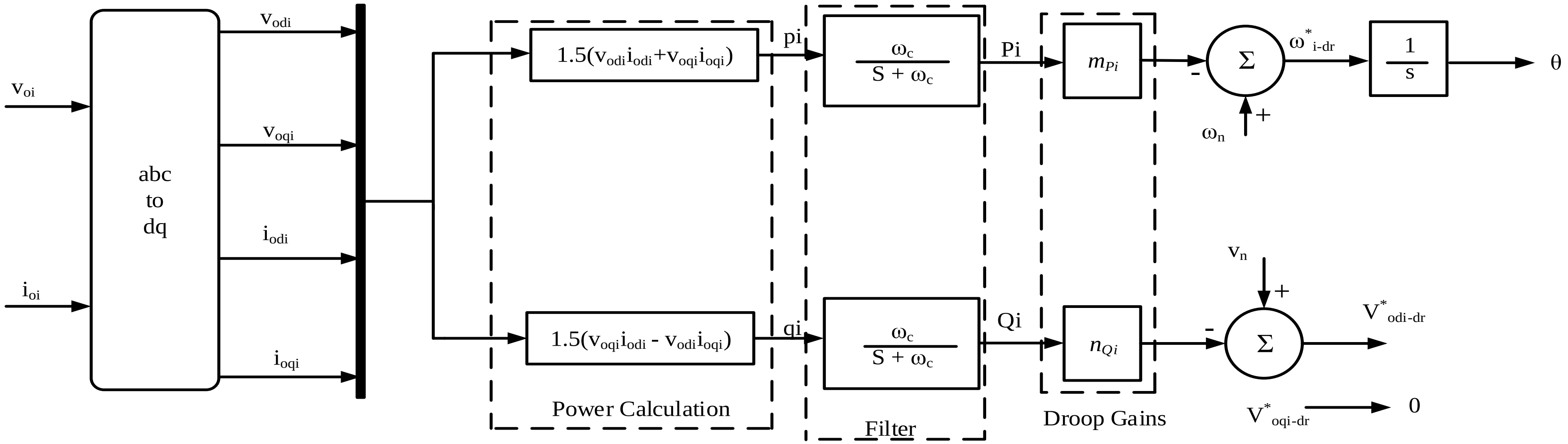


Fig.5 Power Controller unit

p' is instantaneous active power and P is an average active power
q' is instantaneous reactive power and Q is average reactive power
m_P is static active power droop gain and n_Q is static reactive power droop gain

Current Controller

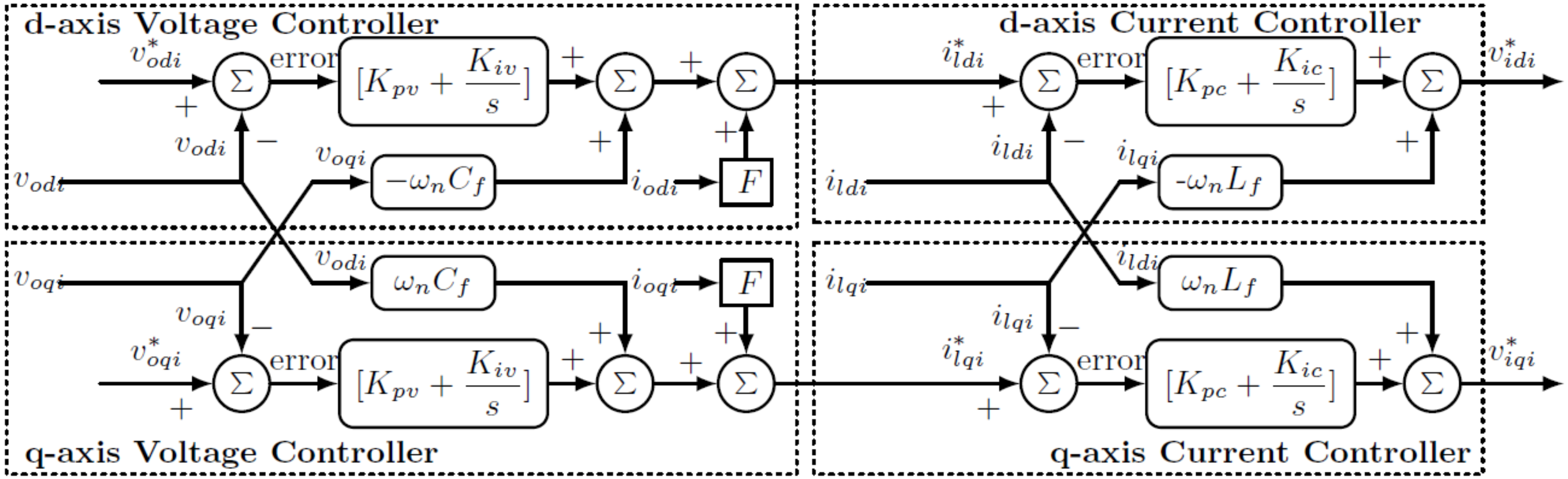


Fig.6 Voltage and Current Controller units

- Voltage controller produces the reference filter-inductor current
- To eliminate error PI controller is used
- F – Feedforward gain (to increase the speed of response of system)
- Bandwidth is 0.2times that of current loop bandwidth

- Used to control the output inductor current
- Uses PI for Ideal tracking
- Generates the voltage signal to feed to PWM module
- Terms of ωL are used to make d and q components decoupled
- Designed to reject high frequency disturbances

Filter with Coupling Inductor

Filters are used to improve power quality
L_f - to reduce current ripple at output of inverter
C_f - to bypass high frequency current ripples
L_c - to avoid damage from high current to the inverter

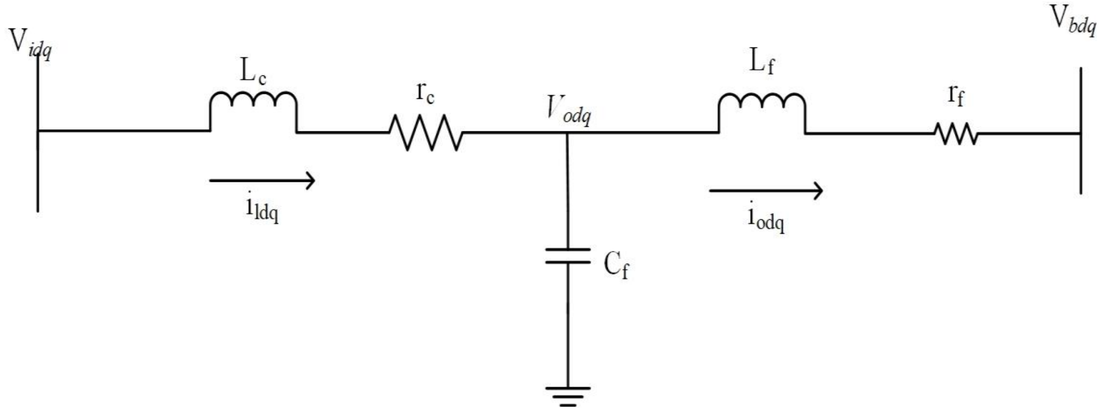


Fig.7 LC Filter with coupling inductor

$$\dot{i}_{0dqi} = \frac{1}{L_{ci}}\left(v_{0dqi} - v_{bdqi} - r_c i_{0dqi}\right) \pm \omega i_{0qdi}$$

$$\dot{i}_{ldqi} = \frac{1}{L_{fi}}\left(v_{idqi} - v_{0dqi} - r_f i_{ldqi}\right) \pm \omega i_{lqdi}$$

$$\dot{v}_{ldqi} = \frac{1}{C_{fi}}\left(i_{ldqi} - i_{0dqi}\right) \pm \omega v_{0qdi} + R_d\left(\dot{i}_{ldqi} - \dot{i}_{0dqi}\right)$$

Transmission Lines

Transmission lines in electric power circuit increases the reliability of system
Also, power transfer from one bus to another is possible because of transmission lines

In traditional synchronous generator system, time constant of synchronous generator is high compared to line so line parameters are ignored but in IIDG system invertors have low time constants, so line parameters are considered in this case.

$$\dot{i}_{linedqi} = \frac{-R_{linei}}{L_{linei}} i_{linedqi} + \frac{1}{L_{linei}} \left(v_{bdqj} - v_{bdqk} \right) \pm \omega i_{lineqdi}$$

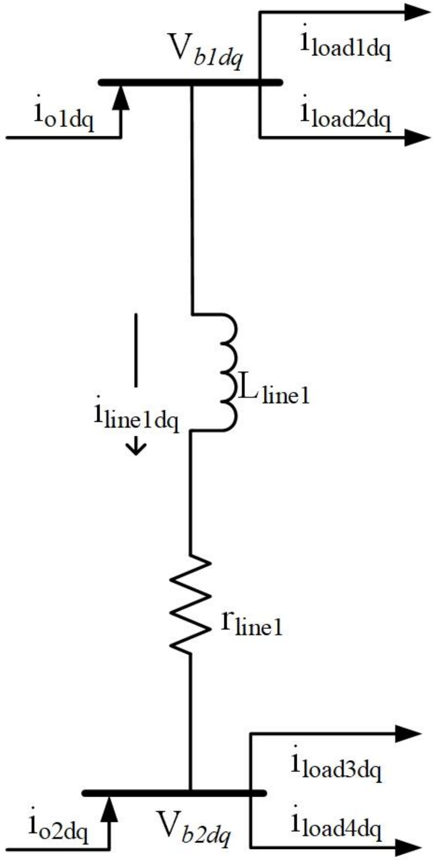


Fig.8 Network

Loads

Four different loads on different buses are used.
Bus one has RL load and Constant Power Load(CPL)

Bus three has Pure Resistive load and Rectifier Interfaced Active Load i.e., RIAL

RL loads are generally loads consisting of Induction Motors like fans, vacuum cleaners, washing machines, etc

CPL loads consists of metal cutting machine spindle, milling machine, paper machine, etc

Resistive loads represents the incandescent lights, toasters, ovens, water heaters, etc

RIAL load represents the electrical vehicle battery chargers and other DC loads

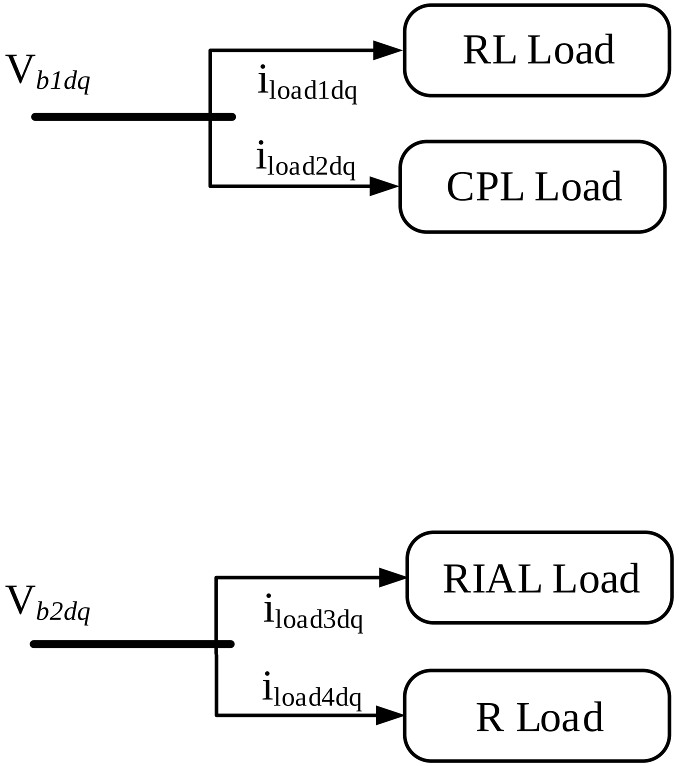


Fig.9 Loads

Passive Load Modelling

All passive loads (R, RL, CPL loads) are modelled in same way i.e. as a RL load.
For R load small inductance is assumed to get the eigen value otherwise it contributed to zero matrix.

For CPL, R_{CPL} and L_{CPL} values are taken as negative because of its characteristics.

$$\dot{i}_{loaddqi} = \frac{-R_{PLi}}{L_{PLi}} \dot{i}_{loaddqi} + \frac{1}{L_{PLi}} v_{bdqi} \pm \omega i_{loadqdi} S$$

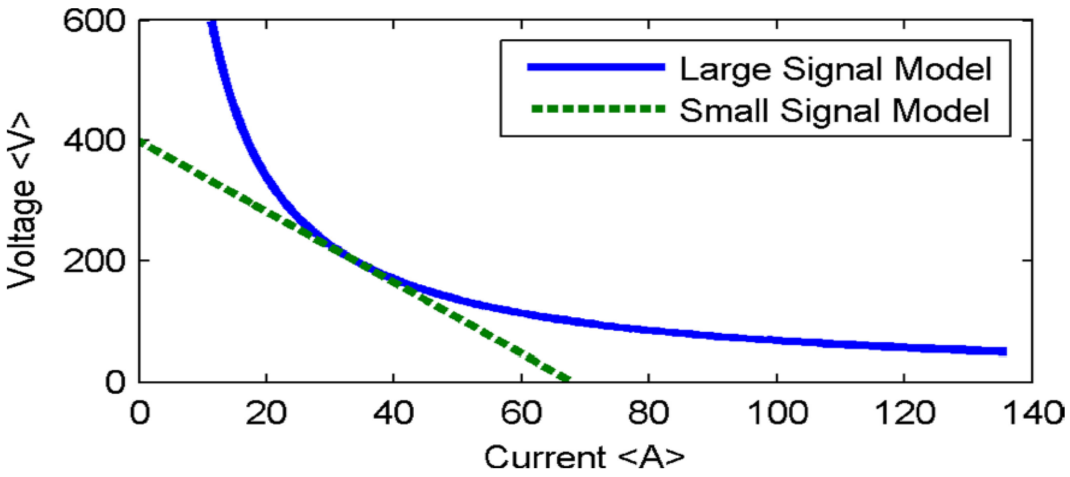


Fig.11 CPL Characteristics

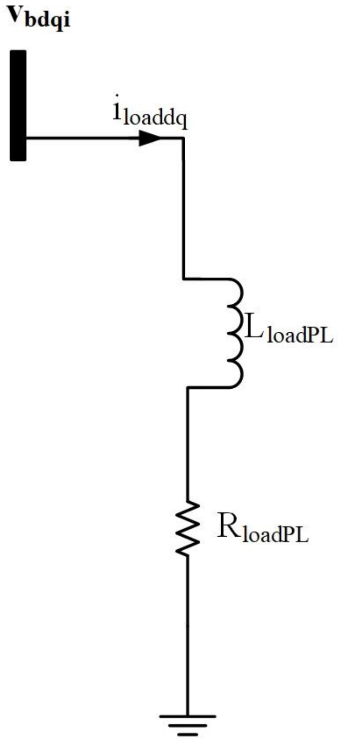


Fig.10 Passive Load

RIAL Modelling

Rectifier Interfaced Active Load is basically load which requires DC supply

Various blocks used are same as IIDG module

Only power controller unit is absent and voltage references are directly provided according to load requirement.

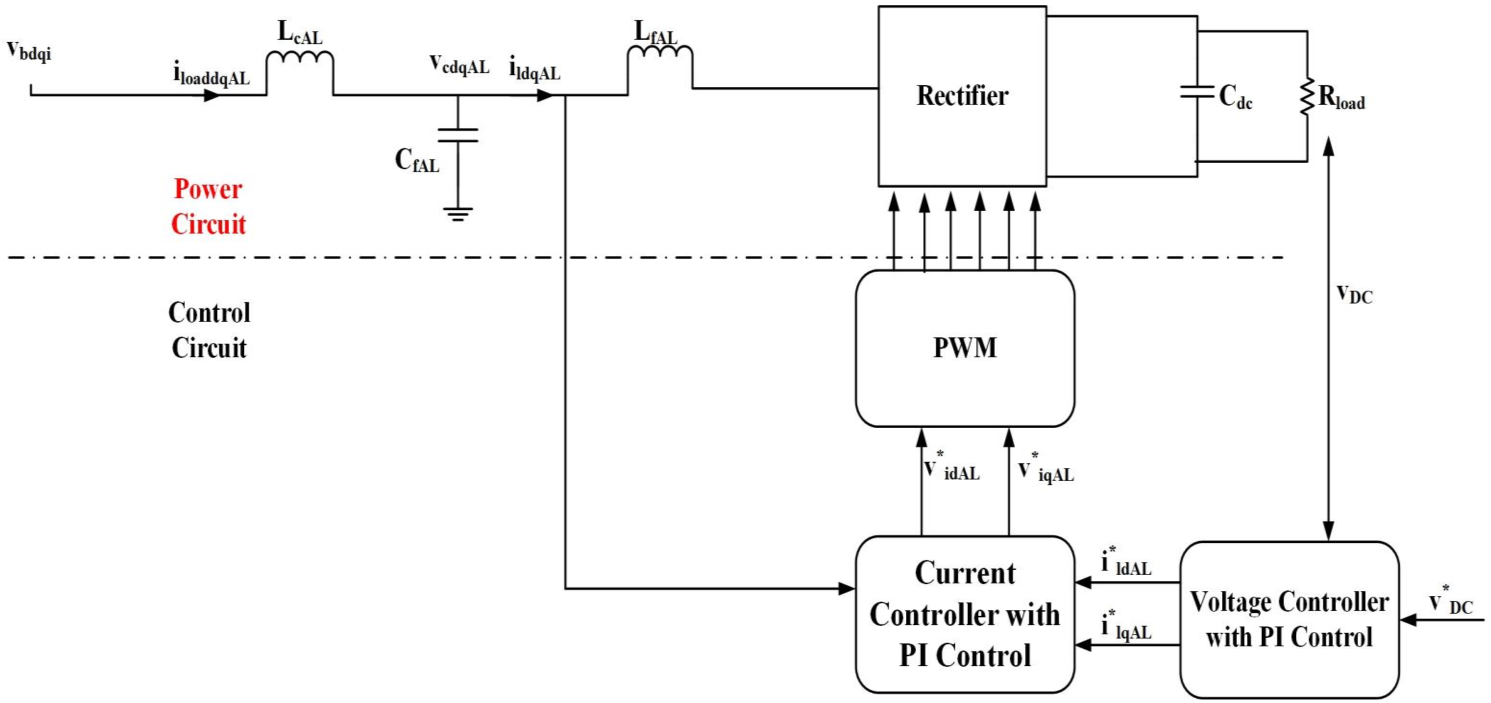


Fig.12 RIAL Load

Modelling is same as IIDG module consisting filter modelling then converter and resistance load at DC end.
Control parts include voltage controllers followed by current controllers.

Droop Control

In a conventional power system, synchronous generators will share any increase in the load by decreasing the frequency according to their governor droop characteristic.

Similarly, reactive power is shared by introducing a droop characteristic in the voltage magnitude.

The real power sharing between inverters is obtained by introducing an artificial droop in the inverter frequency and in voltage for reactive power sharing.

One great advantage of droop control is that it does not need internal communication between different converter units connected in parallel to carry out proper sharing of power absorbed by the load.

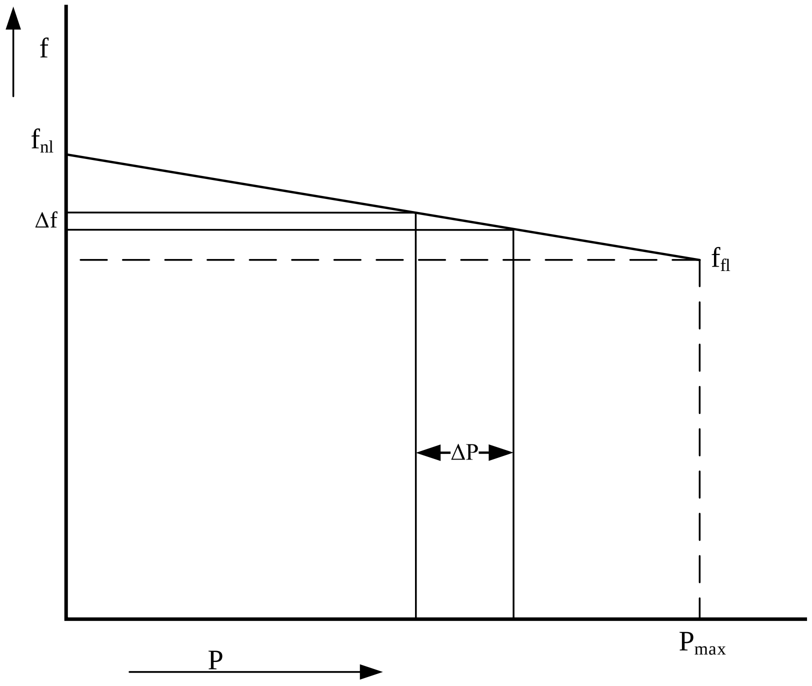
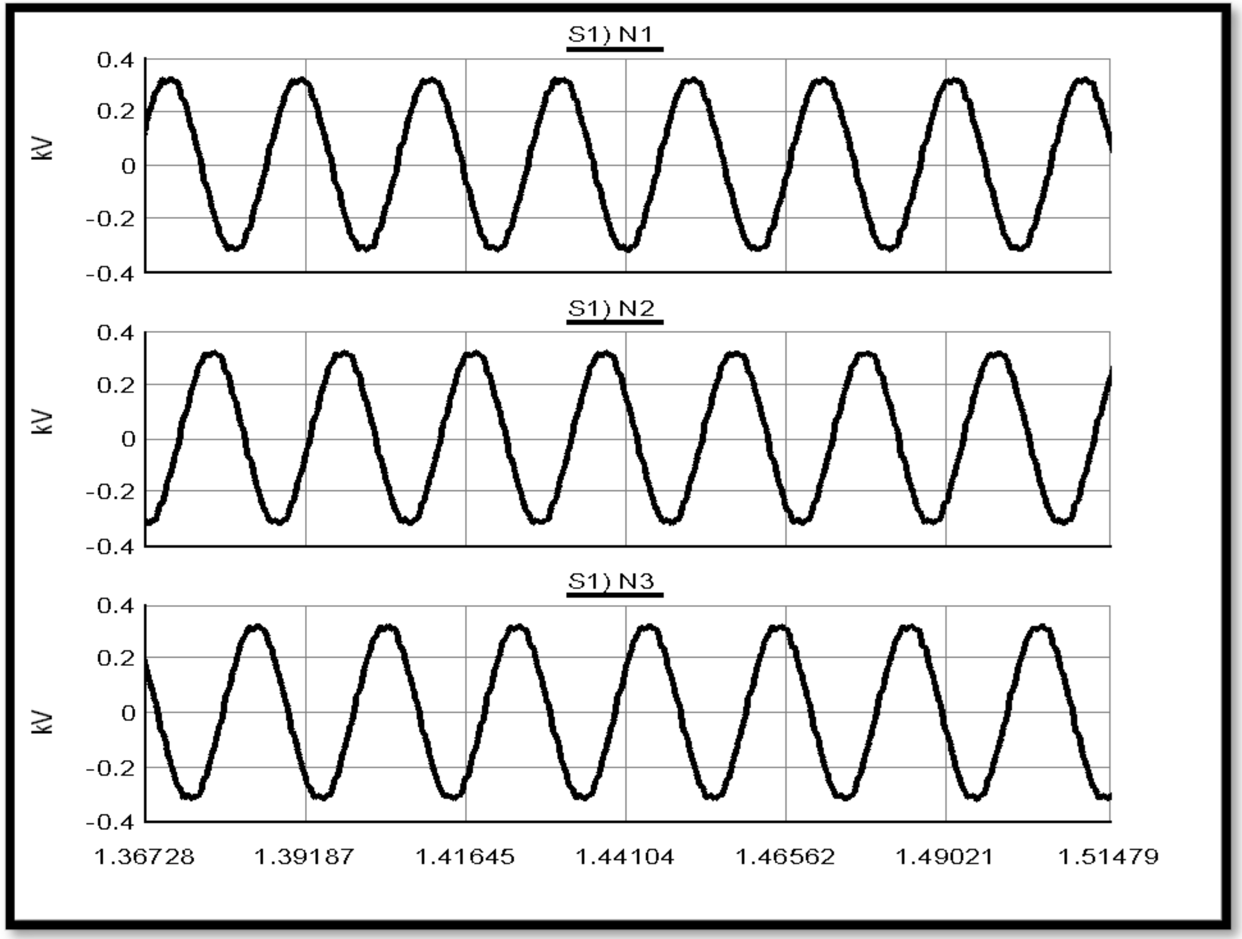


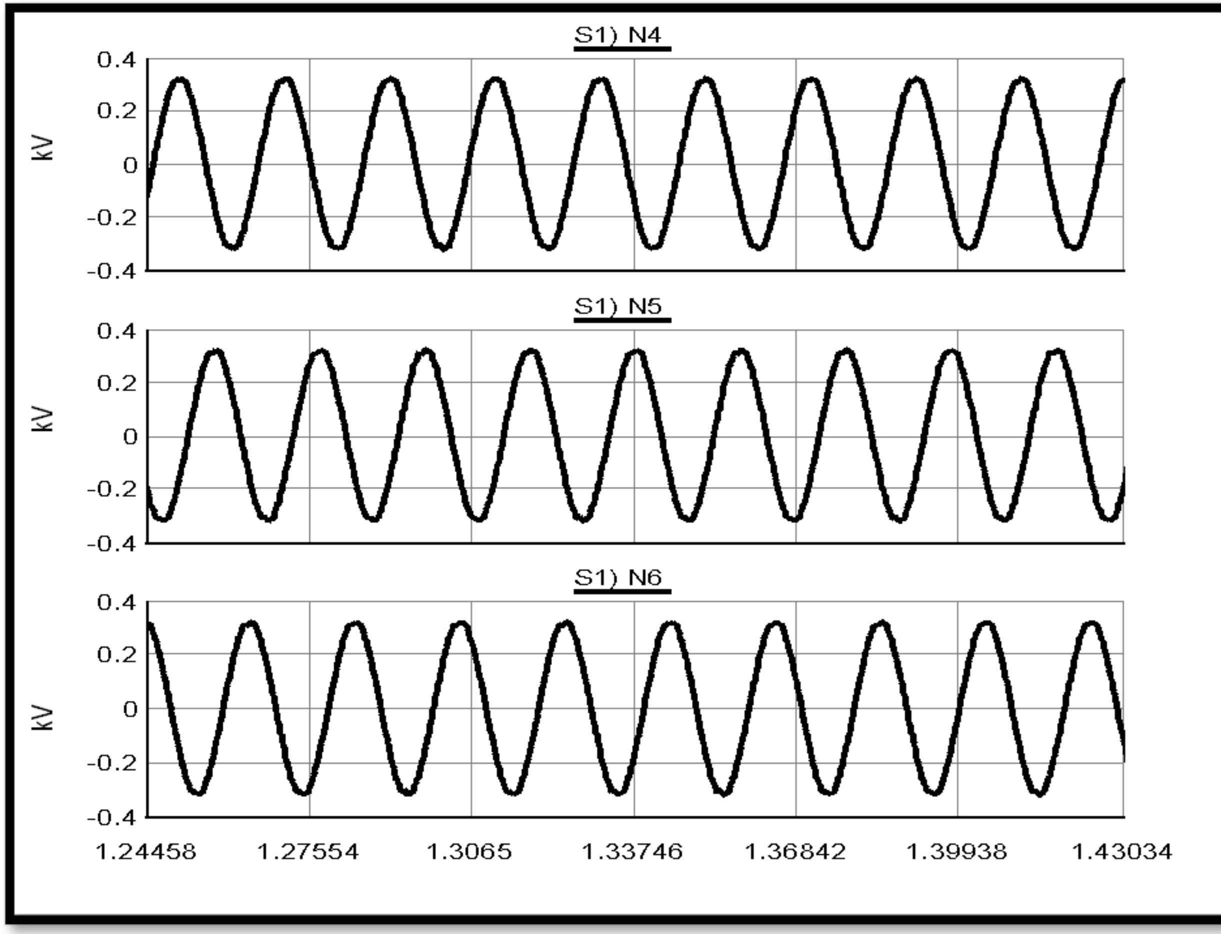
Fig.13 Active power droop Char.

Test System Parameters

Static Active Power Droop Gains for Unequal ratings
m_{P1}=3.142*10-4 rad/sec/W m_{P2}=1.5708*10-4 rad/sec/W
Static Reactive Power Droop Gains for Unequal ratings
n_{Q1}= 8.33*10-4 V/VAR n_{Q2}= 5.00*10-4 V/VAR
Inverter Parameters
f_{sw}=10 kHz, ωc=500 rad/s,, F=0.75, f_{nl}=50.5 Hz
Filter Parameters
L_f=1.35 mH, C_f=50 µF, r_f=0.1Ω
Controller Parameters
K_{pv}=0.05, K_{iv}=390,K_{pi}=10.5, K_{ii}=16*10^3
Coupling Inductor Parameters
r_c=0.3Ω , L_c= 0.35 mH.
Line Parameters
R_{line1}= 0.30Ω L_{line1}= 1.5 mH
RIAL Parameters
L_{fAL}=2.3mH, C_{fAL}=8.8 µF, R_{fAL}=0.1Ω, f_{swAL}=10 kHz, wc=31.41 rad/s, R_{cAL}=0.03Ω, L_{cAL}= 0.93 mH, K_{pvAL}=0.05, $K_{ivAL=}$390,K_{piAL}=10.5, K_{iiAL}=16*103
Load Parameters
RL Load 8KVA Z_{RLload} = (16.21 + j11.70) Ω/phase
CPL 12 KVA r_{CPL} = 13.224Ω cosα=0.85
RIAL Load 12KW R_{RIAL}=40.833Ω
R Load 25kW R_{Rload} = 6.347Ω/phase

Simulation Results



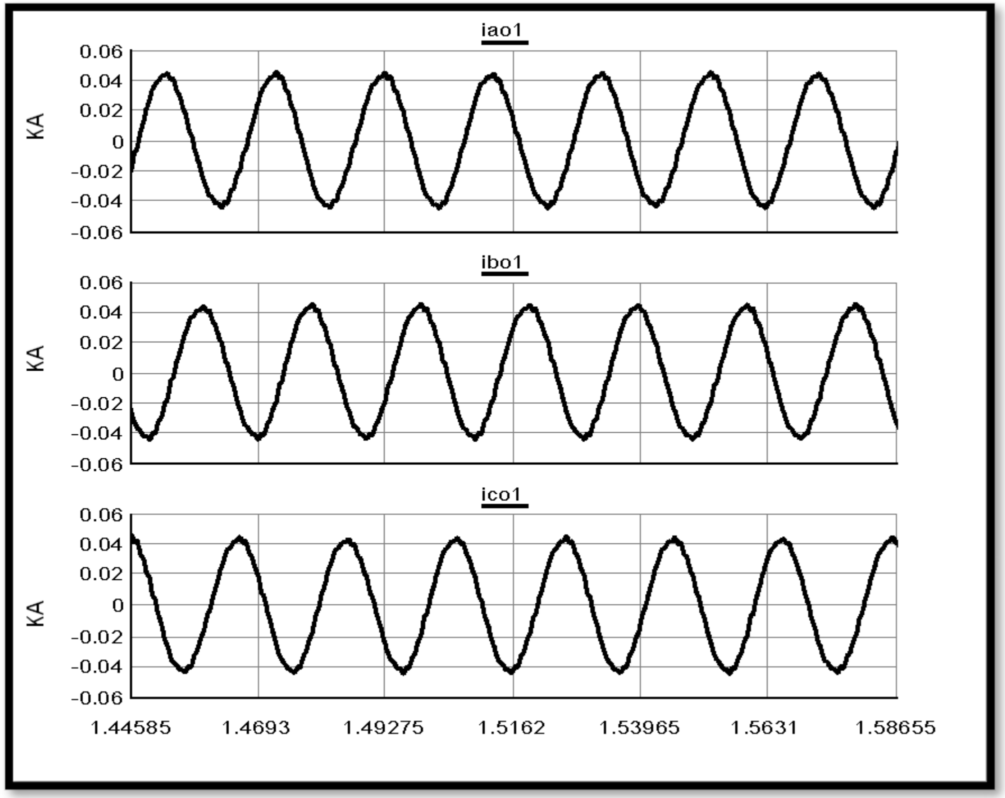


227.87 V per phase

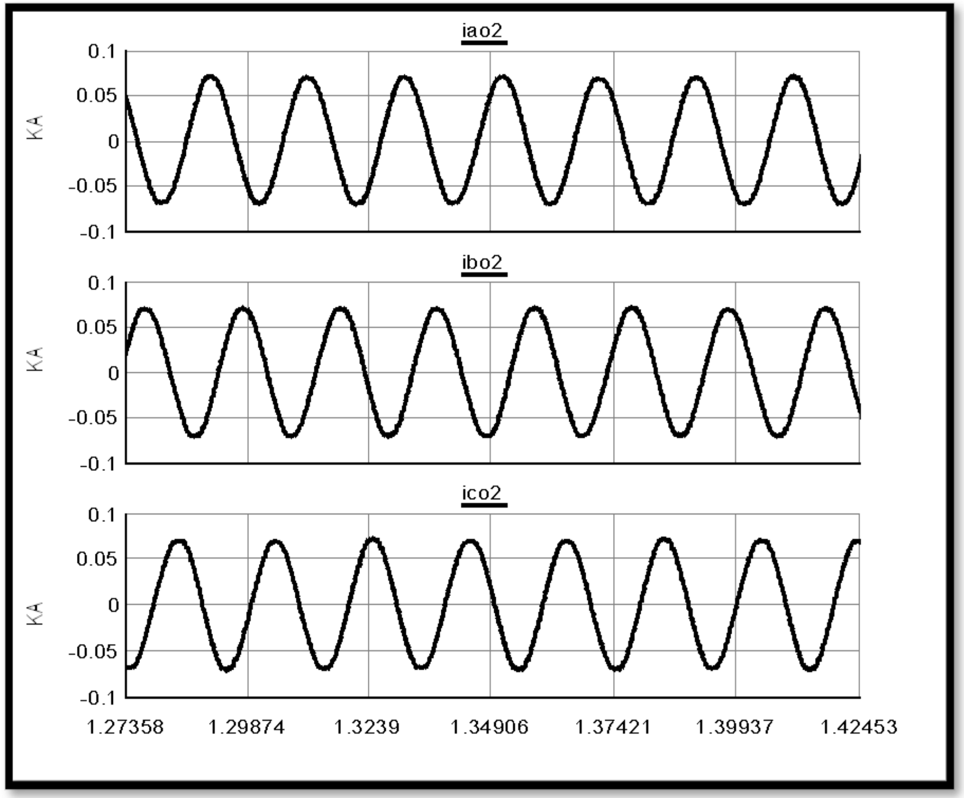
Bus Voltages

228.27 V per phase

Results



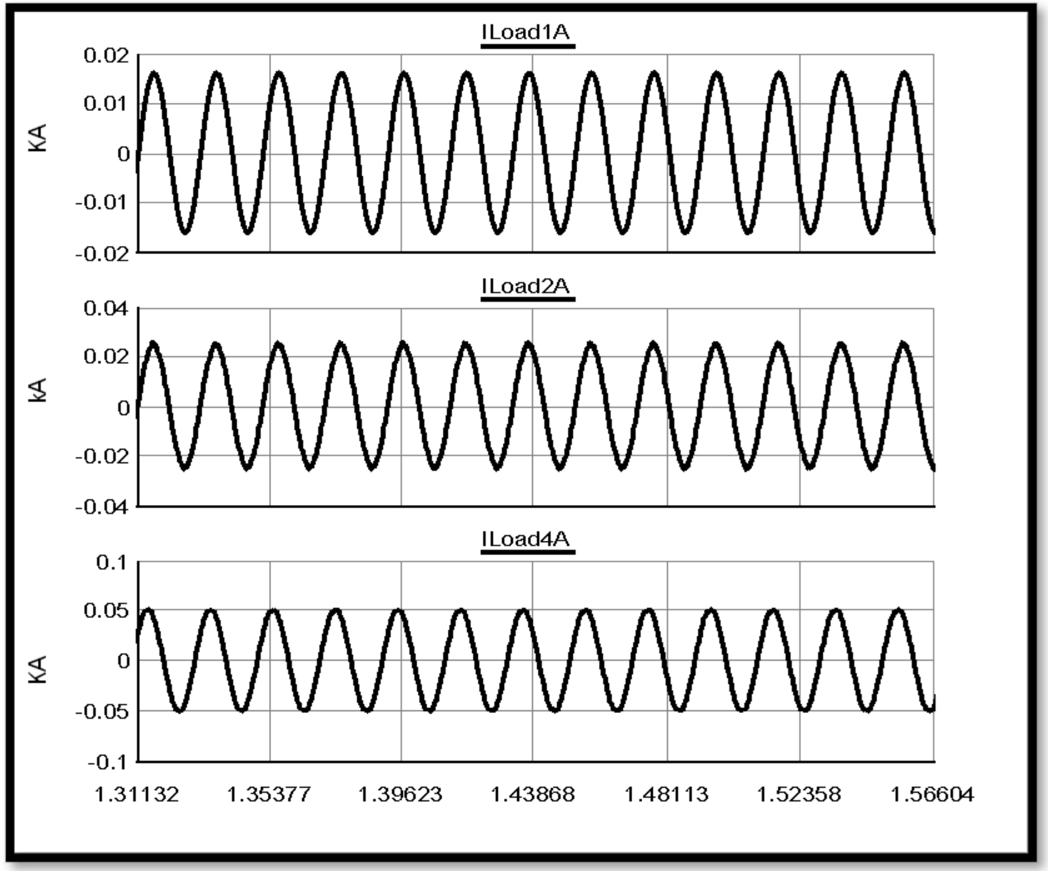
30.64 A

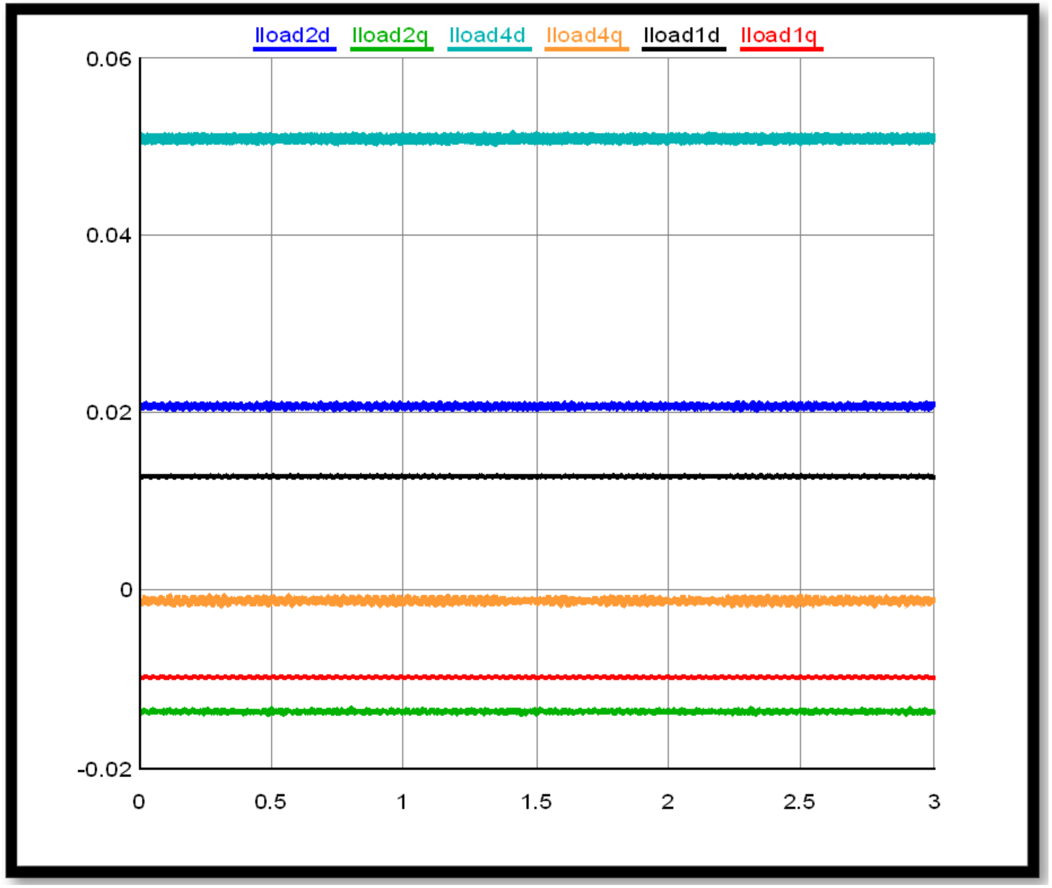


50.11A

IIDG units Output Currents

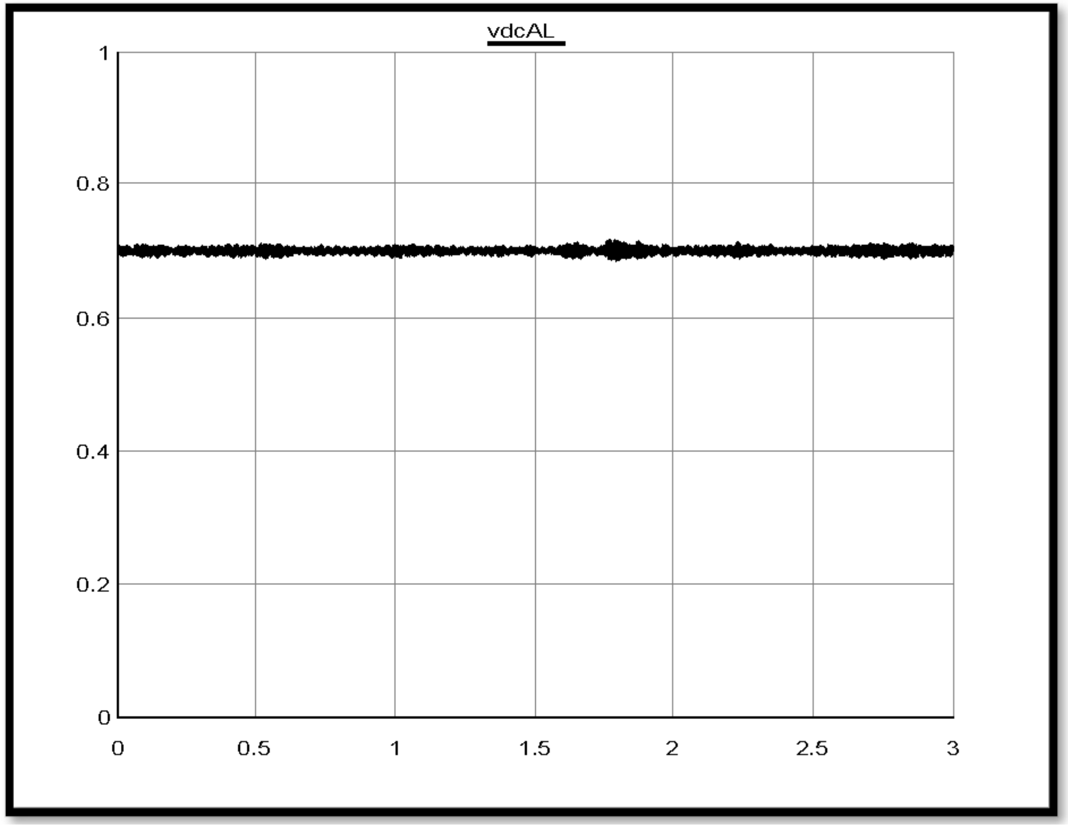
Results

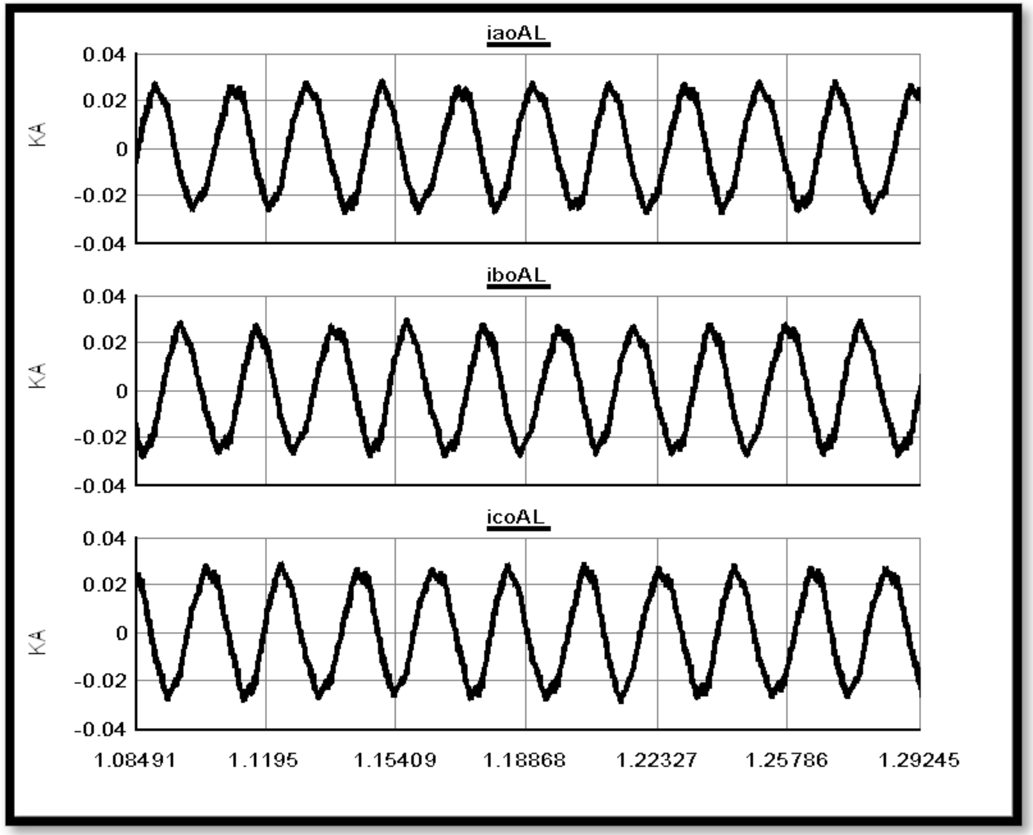




Load Currents in abc and dq frame of reference

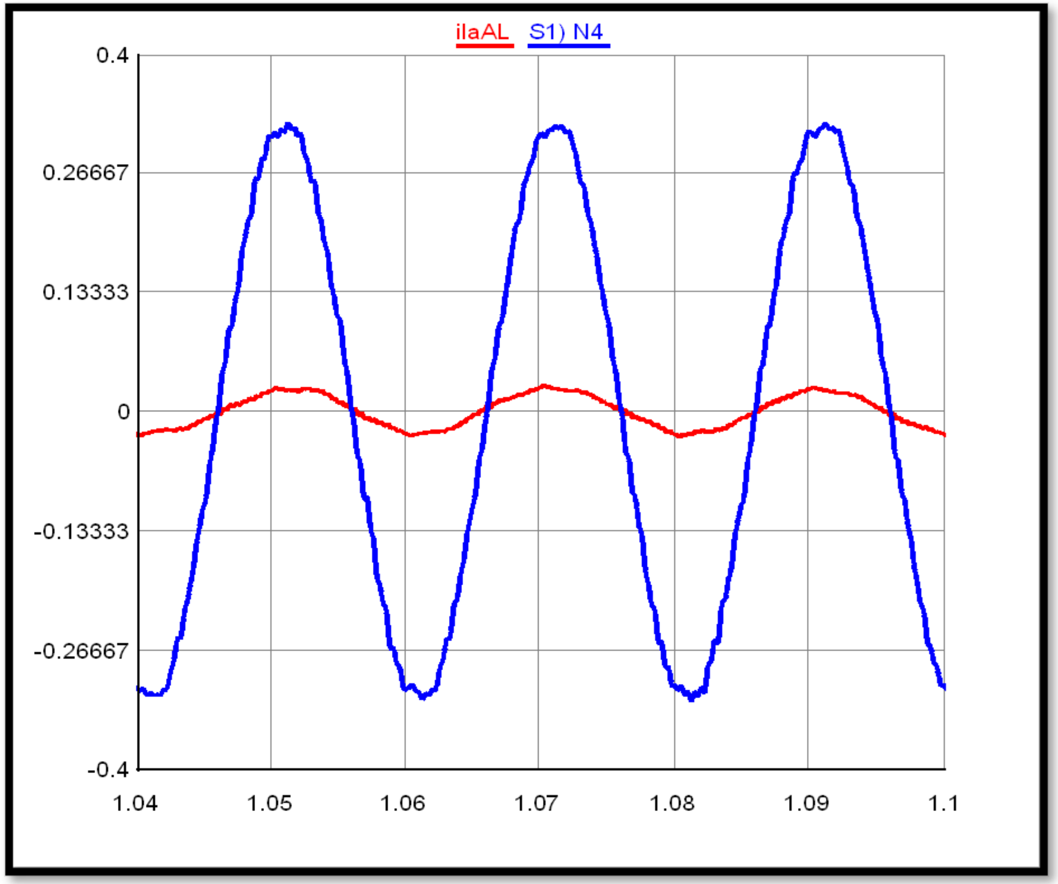
Results

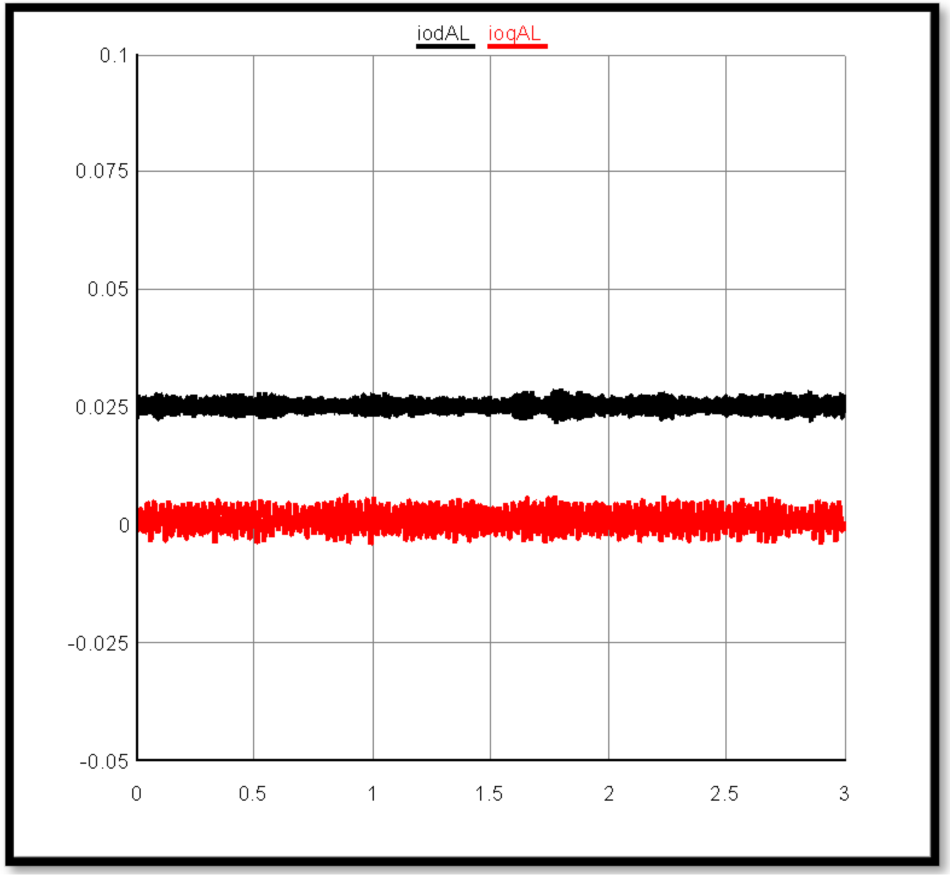




Load Currents in abc and dq frame of reference

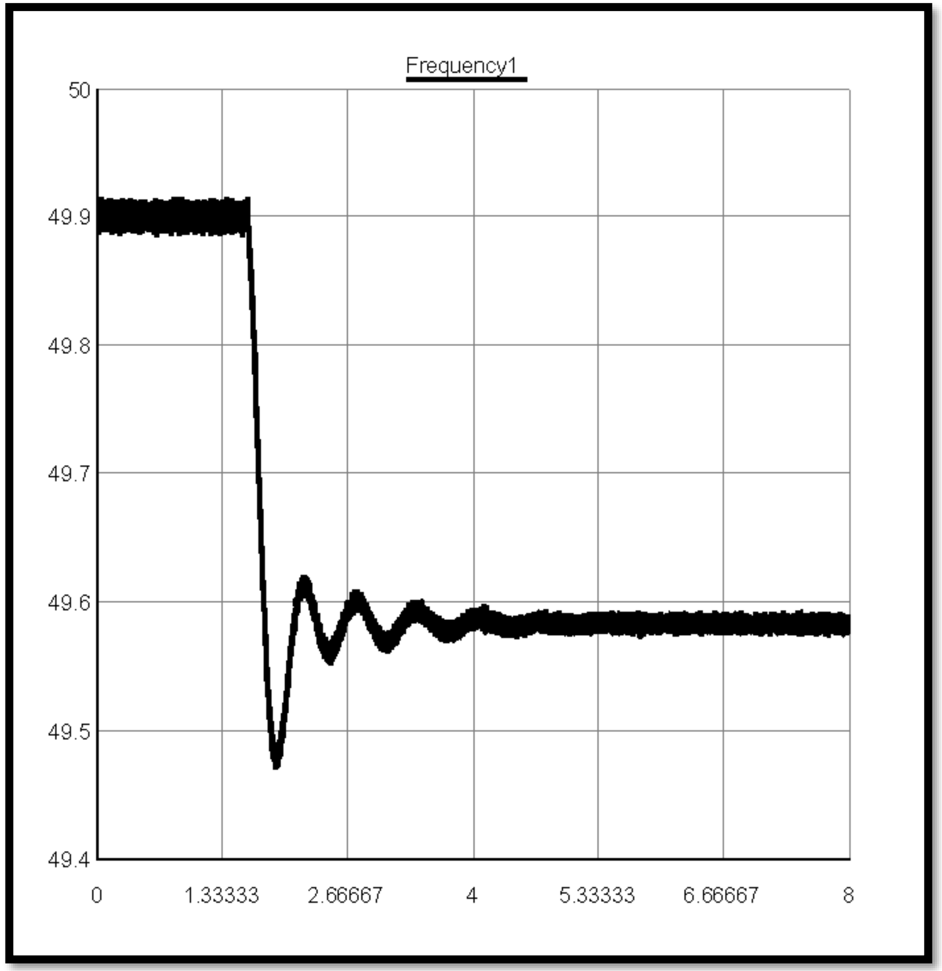
Results





Load Currents in abc and dq frame of reference

Results



Frequency response for disturbance

Load Before disturbance = 36kW

Frequency according to droop gain

$$= 50.50 - \frac{36 * 1}{60} = 49.9\ Hz$$

Load After disturbance = 56kW

Frequency according to droop gain

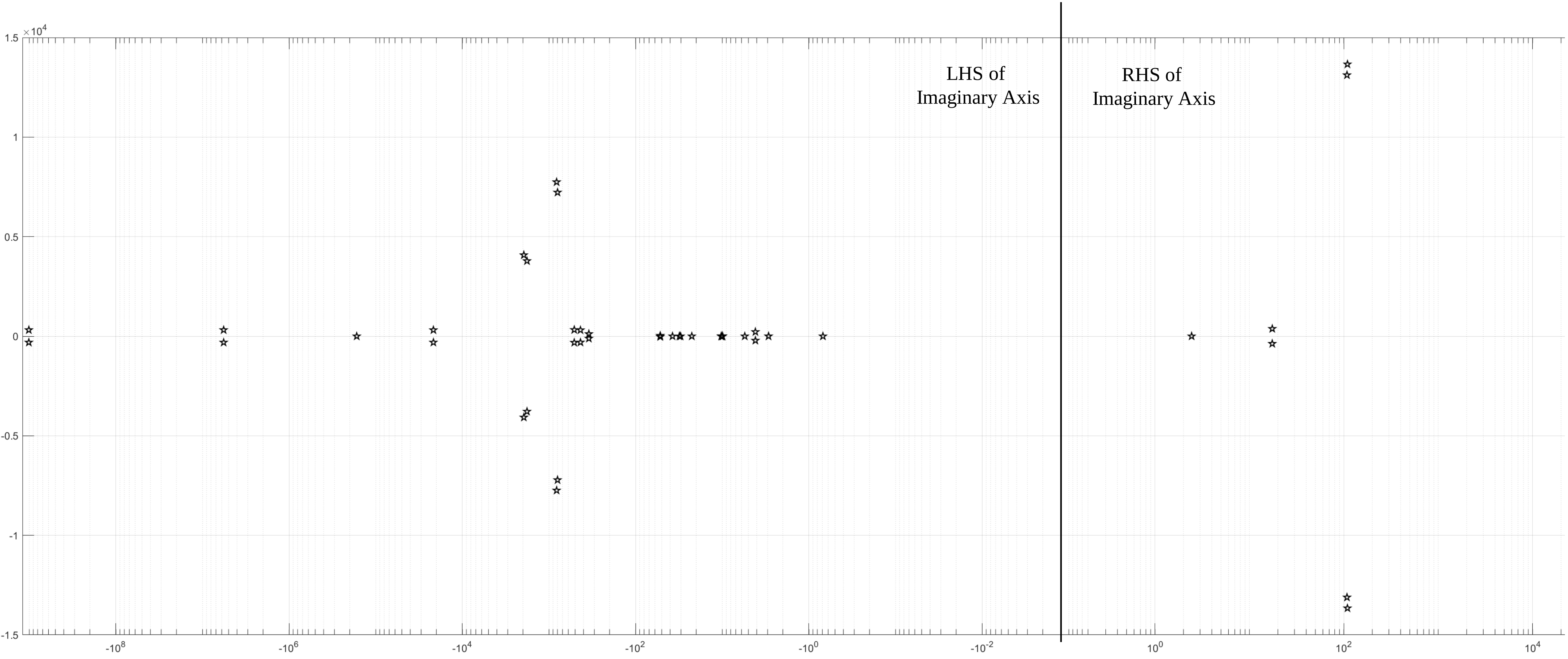
$$= 50.50 - \frac{56 * 1}{60} = 49.567\ Hz$$

Steady State Parameters

Parameter	IIDG units and RIAL	
	[IIDG1 IIDG2]	**[RIAL]**
Internal Parameters		
V_{oD}/V_{cDAL}	[325.26 325.26]	[321.87]
V_{oQ}/V_{ocQAL}	[0 0]	[-4.98]
I_{oD}/I_{gDAL}	[39.21 70.66]	[25.12]
I_{oQ}/I_{gQAL}	[-18.46 -5.49]	[0.909]
I_{lD}/I_{lDAL}	[39.00 70.44]	[25.52]
I_{lQ}/I_{lQAL}	[-13.35 -0.38]	[0.0]
δ_o/δ_{AL}	[0 0.011]	[0.322]
External Parameters		
V_{bD}/V_{gDAL}	[322.14 322.58]	[322.58]
V_{bQ}/V_{gQAL}	[-8.8 -12.65]	[-12.65]
Steady state parameters of RL, CPL and R Loads		
I_{loadD}	[12.81 20.70 50.84]	
I_{loadQ}	[-9.78 -12.65 -1.19]	
Steady state parameters of Transmission Line		
I_{lineD}	[5.386]	
I_{lineQ}	[4.34]	

Steady-state Initial Operating Conditions for unequal droop values

Results



Eigen value plot for various types of load

Stability Analysis

Eigenvalues or modes having higher frequencies (typically greater than 1kHz) are related to filtering parameters since the filter is used to eliminate higher frequencies.

Eigenvalues or modes having Mid-frequencies (typically between 100Hz to 1kHz) are related to Current and voltage parameters since they are designed for higher bandwidth.

Eigenvalues or modes having Lower frequencies (typically less than 100Hz) are related to the power Controller.

Eigenvalues present at the right-hand side of the imaginary axis, i.e., unstable modes correspond to rectifier interfaced active load.

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Thank You….