# B. TECH. PROJECT REPORT

**On**

# Implementation of Synchronverter on Real Time Digital Simulator(RTDS) with CHIL


BY

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**DISCIPLINE OF ELECTRICAL ENGINEERING**

**INDIAN INSTITUTE OF TECHNOLOGY INDORE**


**December 2019**

# Implementation of Synchronverter on Real Time Digital Simulator(RTDS) with CHIL

**A PROJECT REPORT**

*Submitted in partial fulfillment of the*

*requirements for the award of the degrees*

***of***

**BACHELOR OF TECHNOLOGY**

**in**

**ELECTRICAL ENGINEERING**

*Submitted by:*

**Shrayanti Bharat Korwate (160002025)**

*Guided by:*

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**INDIAN INSTITUTE OF TECHNOLOGY INDORE**

**December 2019**

## CANDIDATE’S DECLARATION

We hereby declare that the project entitled **Implementation of Synchronverter on real time digital simulator with CHIL** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in **ELECTRICAL ENGINEERING** completed under the supervision of **Dr. Amod C Umarikar, Associate Professor, Electrical Engineering Department,** IIT Indore is an authentic work.

Further, we declare that we have not submitted this work for the award of any other degree elsewhere.

**Signature and name of the student(s) with date**

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## CERTIFICATE by BTP Guide(s)

It is certified that the above statement made by the students is correct to the best of my knowledge.

**Signature of BTP Guide(s) with dates and their designation**

## Acknowledgements

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## Abstract

The share of electrical energy in distributed energy sources is steadily increasing in economical,technical and environmental reasons. Electrical power system is undergoing a change from centralized to distributed generation sources which results in connection of more and more inverters in the grid. As DGs are integrated in the grid, the overall inertia of the system decreases which also decreases the stability. So to overcome this disadvantage, synchronverter is implemented which emulates the characteristics of synchronous generator. A real time digital simulator RTDS has been used to successfully implement the synchronverter.

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# 1. Introduction

The share of electrical energy produced by distributed energy sources, such as combined heat and power (CHP) plants, and renewable-energy sources such as wind power, solar power, wave and tidal power, etc.is steadily increasing due to economical , technical and environmental reasons. The European Union has set a 22% target for the share of renewable-energy sources and a 17.5% target for the share of CHP in electricity generation by 2020. The electrical power system is currently undergoing a dramatic change from centralized generation to distributed generation.

Most of these distributed generators comprise variable-frequency ac sources, high-frequency ac sources or dc sources, and hence, they need dc–ac converters, also called inverters to interface with the public-utility grid. For example, wind turbines are most effective when they are free to generate at variable frequency, small gas turbines operate at high frequency and also require ac to dc to ac conversion, photovoltaic arrays require dc–ac conversion. This means that more and more inverters will be connected to the grid and will eventually disturb the power generation. When renewable power generators will provide the majority of the grid power, such irresponsible behaviour will become unsupportable. Thus, the need will arise to operate them in the same way as conventional power generators or at least to imitate certain aspects of the operation of conventional generators. The key problem here is how to control the inverters in distributed power generators.

## Distributed Generation System

Distributed generation refers to a variety of technologies that generate electricity at or near where it will be used, such as solar panels and combined heat and power. Distributed generation may serve a single structure, such as a home or business, or it may be part of a microgrid, such as at a major industrial facility, a military base, or a large college campus. When connected to the electric utility’s lower voltage distribution lines, distributed generation can help support delivery of clean, reliable power to additional customers and reduce electricity losses along transmission and distribution lines. In our system we have not connected any energy storage device because we have connected the system to an infinite grid (which is an infinite energy source).

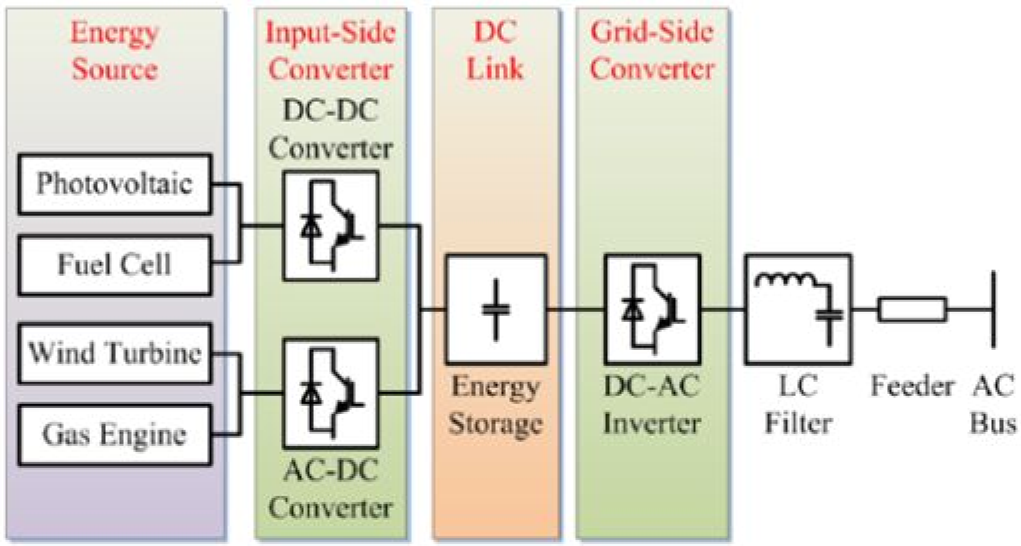


**Figure 1.1 A Typical Distributed Generation system**

Now, role of the power electronics in distributed energy system. You see these are the distributed energy sources. It depends if it is a wind then it is AC and if it is a battery it is DC. If it is a solar it is DC. So it can be AC to DC or DC to DC converter. AC to DC converter if the input is your variable AC for this you need to convert into the DC and if the input is variable DC for example, your solar it will change output voltage and current depending on the radiation and the temperature.

So for this reason we require to have a DC to DC or AC to DC converter. Thereafter, essentially you require a DC to regulated AC converter. And generally these are PWM converter and thus you will be injecting your harmonics into the system and their topological advancement here also there instead of this two level inverter we go for the multilevel inverter and thereafter you will have that filter to filter out those harmonics, high frequency harmonics, and ultimately you have a point of common coupling. And these are the area of the utility where it will interact with the grid and you may have a local load also and you can dispatch power in bidirectional way.

So this is something the overall role of the power electronics. This block is the power electronics. So power electronics interface accepts power from DERs and converters. It is required for maintaining voltage or variable voltage and frequency. The generalized block diagram shown in figure 1.1 is the representation of the power electronics interface with distributed system is shown in the figure. So input can be of different voltage and frequency and make it in a standardized we require the power electronics.

## Different Conventional Control Technique

Many industrial processes are controlled using conventional controllers like PI, PD, and PID etc. The PI controller is very popular because of their robust performance over a wide range of operating conditions and functional simplicity. There are two types of conventional control techniques-

1) Voltage Control Technique
2) Current Control Technique

The voltage control loop of the grid-forming power converter will be enabled only when the microgrid is disconnected from the main network and works in the island mode.On the other hand, the inner current loop regulates the current supplied by the power converter, tracking the reference current provided by the outer voltage loop. The voltage controller is utilized to control the capacitor voltage, and the current controller is utilized to control the inductance current. The voltage-mode control is simple and has a low number of control loops. Both the voltage controller and current controller are PI controllers. Other advantages of the current-mode control include robustness over variations of parameters, superior dynamic performance and higher control precision.

As we work on a grid connected system, we have implemented current control technique.

## Current Control Technique

In order to control the real and reactive power in voltage source converter (VSC), the VSC line current is tightly regulated by a dedicated current-control method which is performed in d-q frame. Thus, $P_s$ and $Q_s$ are controlled by the line current components $i_d$ and $i_q$. The feedback and feed-forward signals are first transformed to the dq-frame and then processed by compensators to produce the control signals in dq-frame. Finally, the control signals are transformed back to the abc-frame and fed to the VSC as shown in figure 1.2.

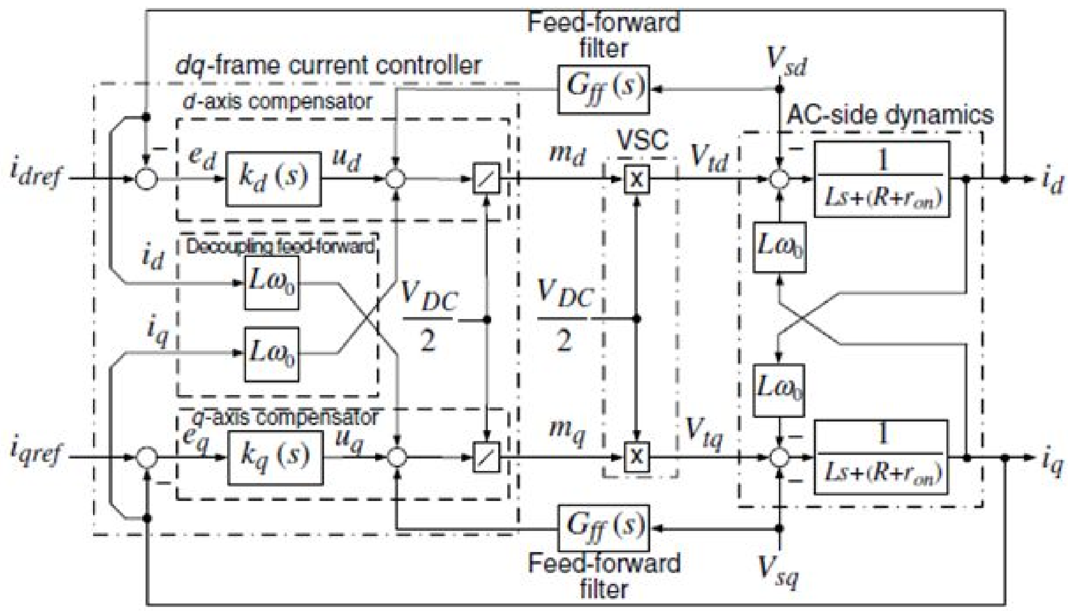


**Figure 1.2. Control block diagram of a current-controlled VSC system**

In this chapter, we have been introduced by the concept of distributed generation system and various conventional current control techniques. In the next chapter we are going to introduce Synchronverter and the motivation behind it.

# 2. Synchronverter

An inverter which can be operated to mimic as a synchronous generator i.e. the dynamic equations are kept the same, only the mechanical power exchanged with the prime mover is replaced with the power exchanged with the dc bus. Such an inverter and the associated controller with it is altogether called as synchronverter. Precisely, synchronverter is nothing but a synchronous generator with a small capacitor bank connected in parallel to the stator terminals.

## Why Synchronverter?

As DGs are integrated with grid, the overall inertia of the system decreases which also decreases the stability. So, to overcome this disadvantages synchronverter is implemented which emulates the characteristics of synchronous generators by implementing swing equations. An advantage is that we can choose the parameters, such as inertia, friction coefficient, field inductance and mutual inductances. We can also choose not to have magnetic saturation and eddy currents. Synchronverters can also be operated as synchronous machines using same mathematical derivations.

A synchronverter is divided into two parts-

1) Power part of synchronverter.
2) Electronic part of Synchronverter.

## Power part of synchronverter

The power part mainly consists of three phase inverter which includes LC filters. LCL filters are used to reduce harmonics and ripples caused by the switching. In grid connected system, the impedance of the grid should be included in the impedance of the inductors Lg and then we may consider infinite bus after a circuit breaker.

## Electronic part of synchronverter

It is basically a Digital Signal Processor (DSP) which controls the switches. The two parts of synchronverter interact via i and e (from power part) The various voltage and current sensors and the signal conditioning circuits come under electronic part.

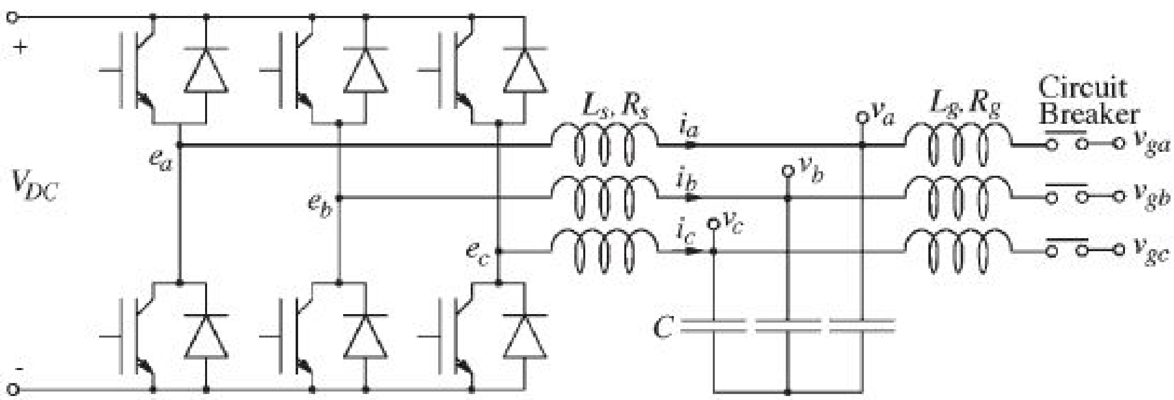


**Figure 2.1 Power part of the Synchronverter**

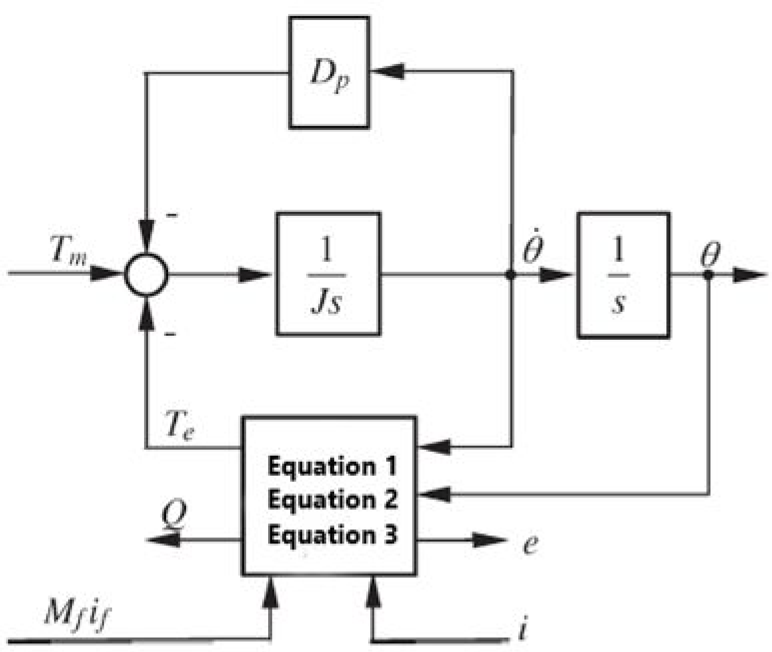


**Figure 2.2 Electronic part of Synchronverter**

Where, Equation 1: $e = \theta' M_f\, i_f$

Equation 2: $T_e = 3/2 M_f\, i_f\, i_d$

Equation 3: $Q = -3/2\, \theta' M_f\, i_f i_q$

(these are called the swing equations which are explained in detail in Chapter 3)

# Why RTDS?

We have carried out the following simulation on RTDS (Real time digital simulator). Some of the major advantages of using RTDS are -

1. The RTDS Simulator is the leading real time power system simulator which allows us to validate the performance of power system devices.
2. The RTDS Simulator runs electromagnetic transient type simulations in real time.
3. The physical devices such as power system protection and control devices or power electronics devices, can be connected to the system in the closed loop.


**Figure 2.3 RTDS (Real time digital simulator**

# 3.Implementation

## 3.1 Current Controller :

Figure 3.1 shows the current controller implemented. Assuming a steady state operating condition, the equation are as follows-

$$Ldi_d/dt = L_{\omega o}i_q - (R + r_{on})i_d + V_{td} - V_{sd} \tag{3.1.1}$$

$$Ld_{iq}/dt = -L_{\omega 0}i_d - (R + r_{on})i_q + V_{tq} - V_{sq} \tag{3.1.2}$$

We get,

$$V_{td}(t) = V_{DC}/2m_d(t) \tag{3.1.3}$$

$$V_{tq}(t) = V_{DC}/2m_q(t) \tag{3.1.4}$$

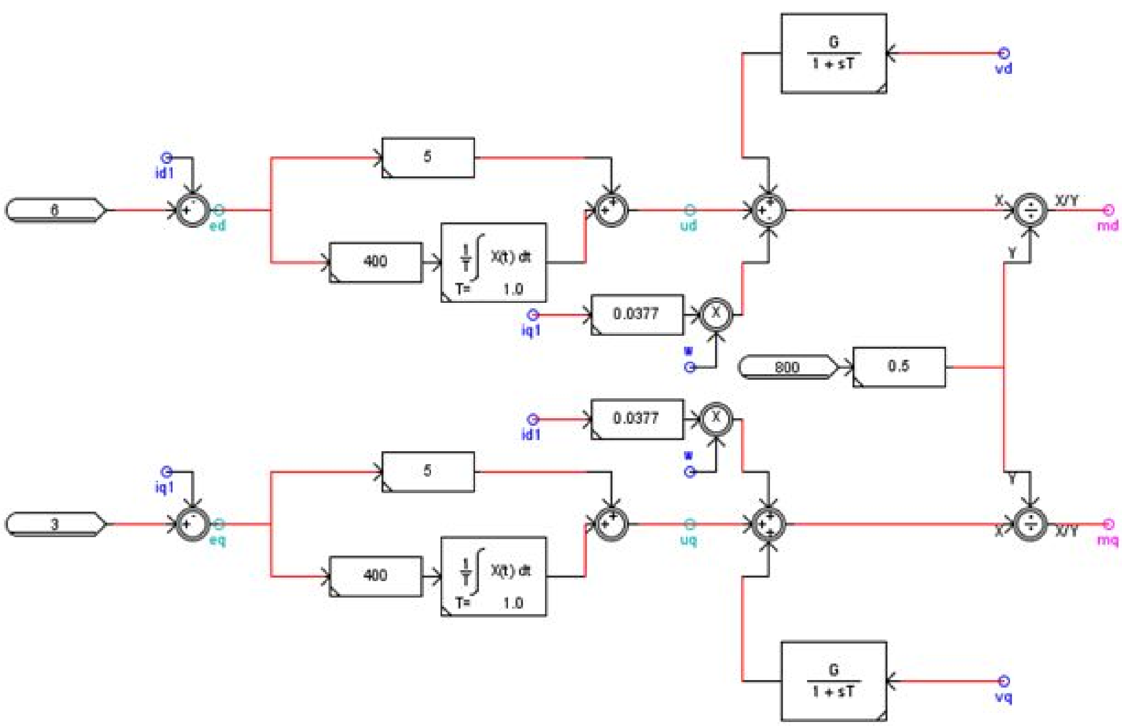


**Figure 3.1 A current controller**

We get the equations of $m_d$ and $m_q$ after substituting the values of $V_{td}$ and $V_{tq}$ from equations 3.3 and 3.4 in equation 3.1 and 3.2 as,

$$m_d = 2V_{DC}u_d - L_{\omega 0}i_q + V_{sd} \tag{3.1.5}$$

$$mq = 2V_{DC}u_q + L_{\omega 0}i_d + V_{sq} \tag{3.1.6}$$

Let

$$k_d(s) = k_p/s + k_i s \tag{3.1.7}$$

where $k_p$ and $k_i$ are proportional and integral gains, respectively.

if

$$k_p = L/\tau_i \tag{3.1.8}$$

$$k_i = (R + r_{on})/\tau_i \tag{3.1.9}$$

where $\tau_i$ is the time constant of the resultant closed-loop system .If $k_p$ and $k_i$ are selected based on equations of 3.1.8 and 3.1.9, the response of $i_d(t)$ to $i_{dref}$ (t) is based on a first-order transfer function whose time constant $\tau_i$ is our choice.

## Results

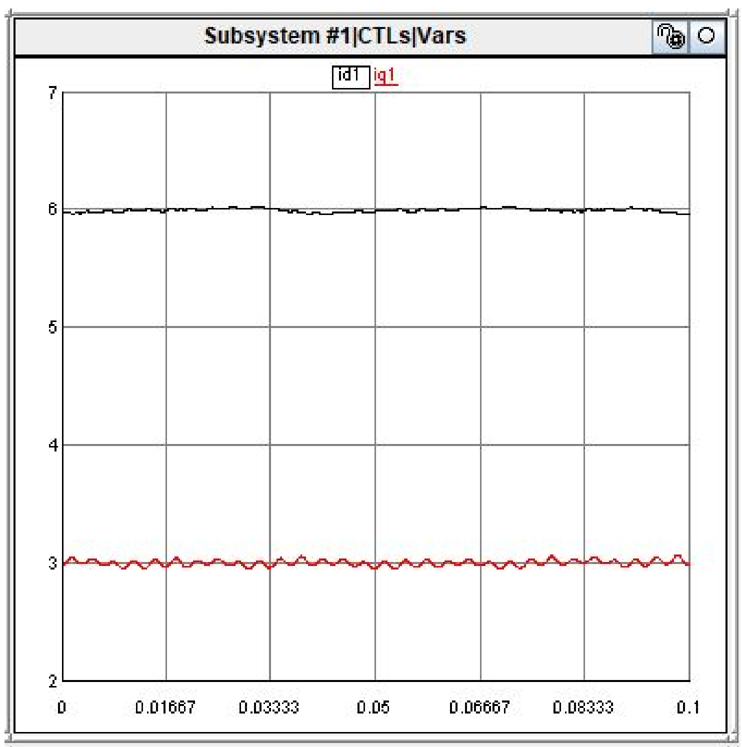


**Figure 3.2(a)**

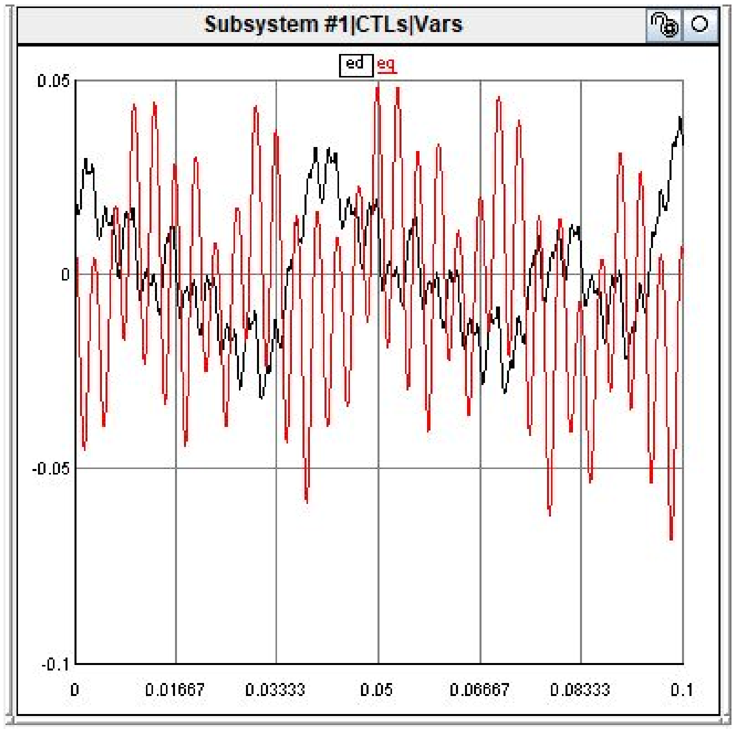


**Figure 3.2(b)**

**Figure 3.2. Simulation Results (a) The value of $i_{dref}$ and $i_{qref}$ is set approximate to 6 and 3 (equal to value of $id_1$=6A and $iq_1$ =3A) (b) This graph shows the error ($e_d$ and $e_q$ )minimized to a scale of +0.05 to -0.05.**

## 3.2 Synchronverter:

### Swing Equations

Assume that the resistance of the stator windings is $R_s$; then the phase terminal voltages

$$v = [v_a \; v_b \; v_c]^T \tag{3.2.1}$$

and

$$e = [e_a \; e_b \; e_c]^T \tag{3.2.2}$$

is the back electromotive force (EMF) due to the rotor movement given by

$$e = M_f \, i_f \, \theta' \sin\theta - M_f di_f dt \cos\theta \tag{3.2.3}$$

Where $M_f$ is mutual inductance, $i_f$ is field current and θ’ is angular frequency.

The mechanical part of the machine is governed by

$$J\theta'' = T_m - T_e - D_p\,\theta' \qquad (3.2.4)$$

From simple energy considerations we have

$$T_e = \partial E/\partial\theta|_{\Phi,\Phi f\ \text{constant}}$$

$$T_e = M_f\, i_f\, i_0 \langle \sin\phi, \sin\theta \rangle$$

Where $T_e$ is electrical torque, $\Phi,\Phi_f$ are flux and $\langle \sin\phi, \sin\theta \rangle$ represents the inner product of the two quantities. The above equation reduces to

$$T_e = 3/2 M_f\, i_f\, i_d \qquad (3.2.5)$$

$i_d$ is the current in d-frame.

The switches in the inverter should be operated so that the average values of $e_a$, $e_b$, and $e_c$ over a switching period should be equal to e given in (3.2.4). This can be achieved by the usual PWM technique.

It is advantageous to assume that the imaginary field (rotor) winding of the synchronverter is fed by an adjustable dc current source if instead of a voltage source $v_f$ . Then, the terminal voltage $v_f$ varies, but this is irrelevant. As long as $i_f$ is constant, the generated voltage from (3.2.4) reduces to

$$e = \theta' M_f\, i_f \qquad (3.2.6)$$

Define the generated real power P and reactive power Q (as seen from the inverter legs) as P = $\langle i, e \rangle$ Q = $\langle i, eq \rangle$ where $e_q$ has the same amplitude as e but with a phase delayed from that of e by π/2, i.e.,

$$e_q = \theta' M_f\, i_f \sin(\theta - \pi/2) = -\theta' M_f\, i_f \cos\theta$$

Then, the real power and reactive power are, respectively

$$P = \theta' M_f\, i_f \langle i, \sin\theta \rangle \qquad (3.2.7)$$

$$Q = -\,\theta' M_f\, i_f \langle i, \cos\theta \rangle$$

$\langle i, \cos\theta \rangle$ denotes $i_q$ so the equation reduces to

$$Q = -3/2\ \theta' M_f\, i_f i_q \qquad (3.2.8)$$

Equations (3.2.5),(3.2.6) and (3.2.8) are called the swing equations of a synchronous generator. These three equations of e, $T_e$ and Q are fed to the electronic part of the synchronverter.

## 3.3 Operation of Synchronverter

**1) Frequency drooping and regulation of real power**

To share the load evenly in synchronous generators, we need to vary the real power delivered to the grid according to the grid frequency, which is a control loop called "frequency droop". The prime mover maintains the rotor speed and the damping factor is due to mechanical friction.When the real-power demand increases, the speed of the SGs drops due to increased $T_e$. The power regulation system of the prime mover then increases the mechanical power. According to the IEEE standards, the frequency droop are a 100% increase in power for a frequency decrease between 3% and 5%.

Thus, denoting the change in the total torque acting on the imaginary rotor by ΔT and the change in angular frequency by $\Delta\theta'$, we have

$$D_p = -\Delta T/\Delta\theta' \tag{3.3.1}$$

The time constant of the frequency-droop loop is $\tau_f = J/D_p$. Hence, if we have decided upon $\tau_f$ , then J should be chosen as

$$J = D_p\tau_f \tag{3.3.2}$$

Because there is no delay involved in the frequency-droop loop, the time constant $\tau_f$ can be made much smaller than for a real SG.

**2) Voltage Drooping and Regulation of reactive power**

The regulation of reactive power Q flowing out of the synchronverter can be realized similarly. Define the voltage drooping coefficient $D_q$ as the ratio of the required change of reactive power ΔQ to the change of voltage Δv, i.e.,

$$D_q = -\Delta Q\Delta v \tag{3.3.3}$$

The inner loop is the (amplitude) voltage loop, and the outer loop is the reactive-power loop. The time constant $\tau_v$ of the voltage loop can be estimated as

$$\tau_v = K\theta' D_q \tag{3.3.4}$$

The difference between the reference voltage $v_r$ and the amplitude $v_m$ is fed to the voltage drooping coefficient $D_q$, $v_m$ is given as

$$v_a v_b + v_b v_c + v_c v_a = -3/4 vm^2$$

.

## Calculations:

1) $D_p = -\Delta T/\Delta\theta'$

As $T=P/\theta'$

where P=10kW(rated) and

$\theta'=314.16$ T=31.83 N-m

$\Delta\theta' = 0.5\%$ frequency drop

So, $\Delta\theta' = 1.57$

Therefore, $D_p = 20.27$

2) $D_q = -\Delta Q/\Delta v$

As initial reactive power is 0 Var , $\Delta Q$= 10kW ,

Grid Voltage =325V (from inverter) $\Delta v$ = 5% of voltage (IEEE standards).

Therefore, $D_q = 615.38$

From the above values of $D_p$ and $D_q$ , we find

J= 0.04054 (from equation 3.3.2)

K=386.65 (from equation 3.3.4)

for time constant of 0.002s

### 1) Power part

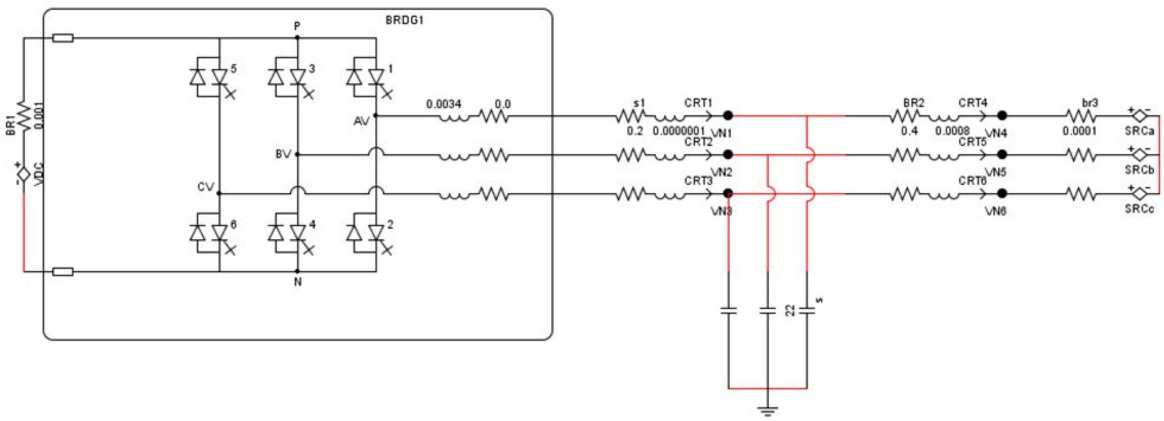


**Figure 3.3 Power part (An inverter with LCL filters)**

### 2) Electronic part

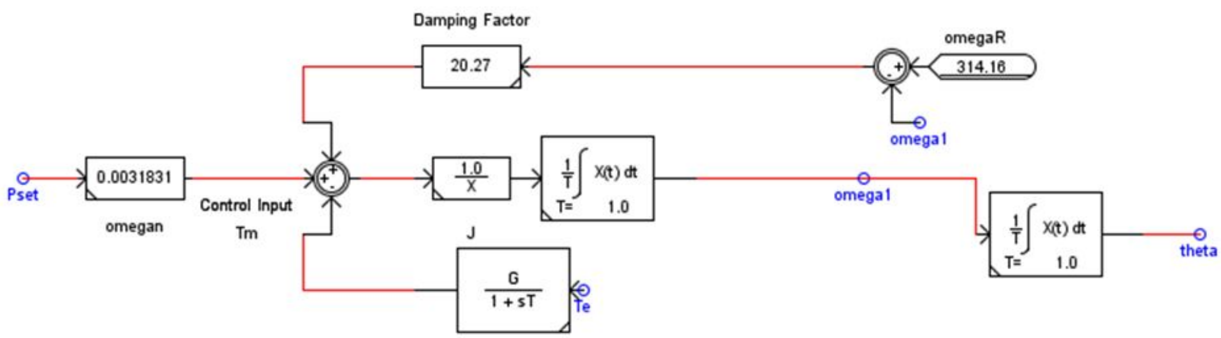


**Figure 3.4 Active Power Loop**

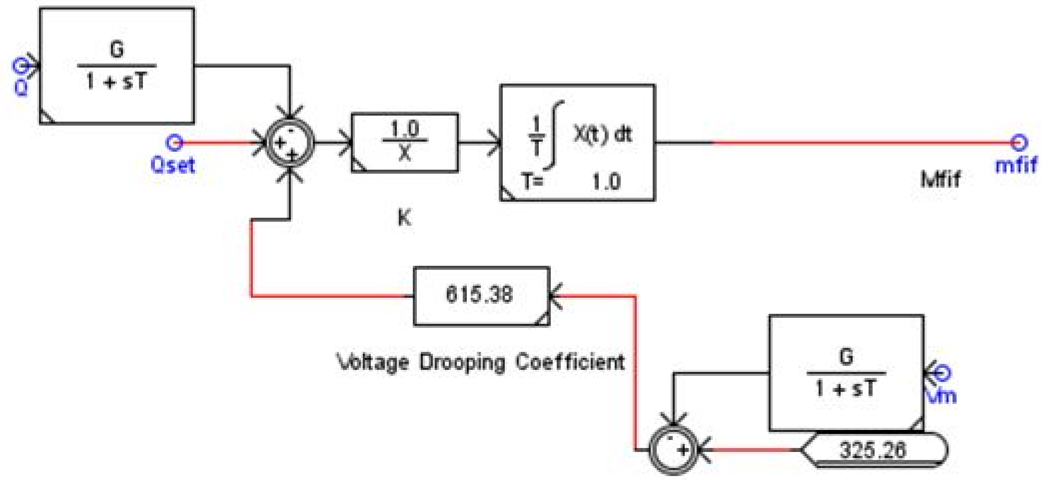


**Figure 3.5 Reactive Power Loop**

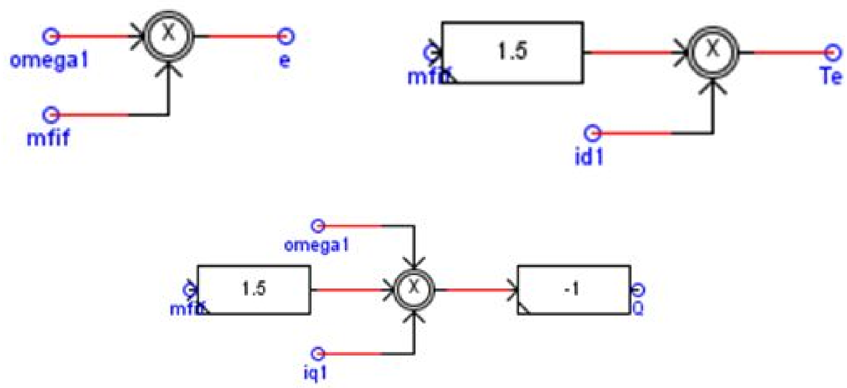


**Figure 3.6- Swing Equations (a) back emf (b) Electrical Torque (c) Reactive Power**

## Results

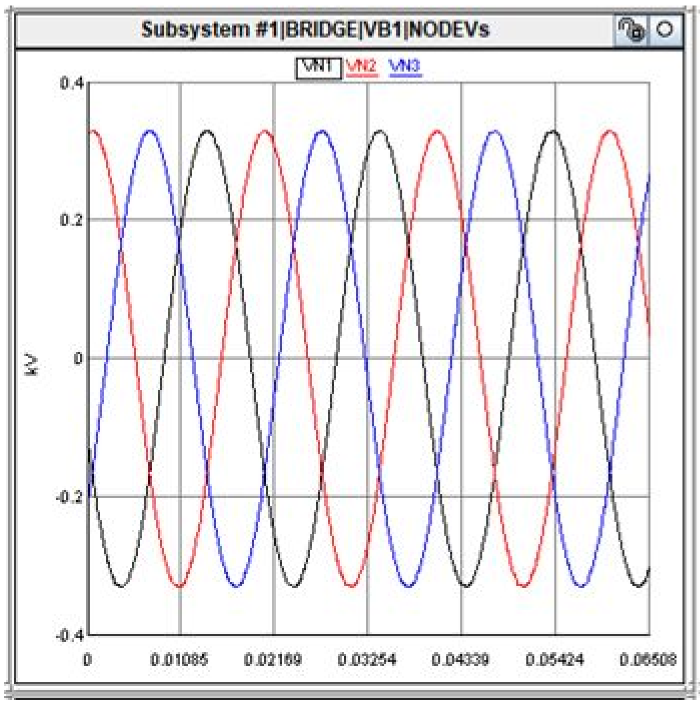


**Figure 3.7 Output AC voltage obtained from inverter**

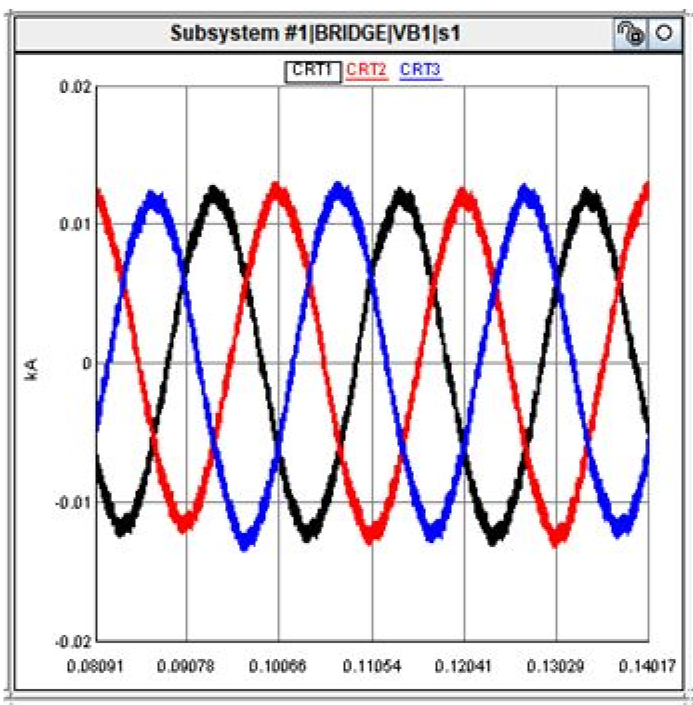


**Figure 3.8 Output Current Wave**

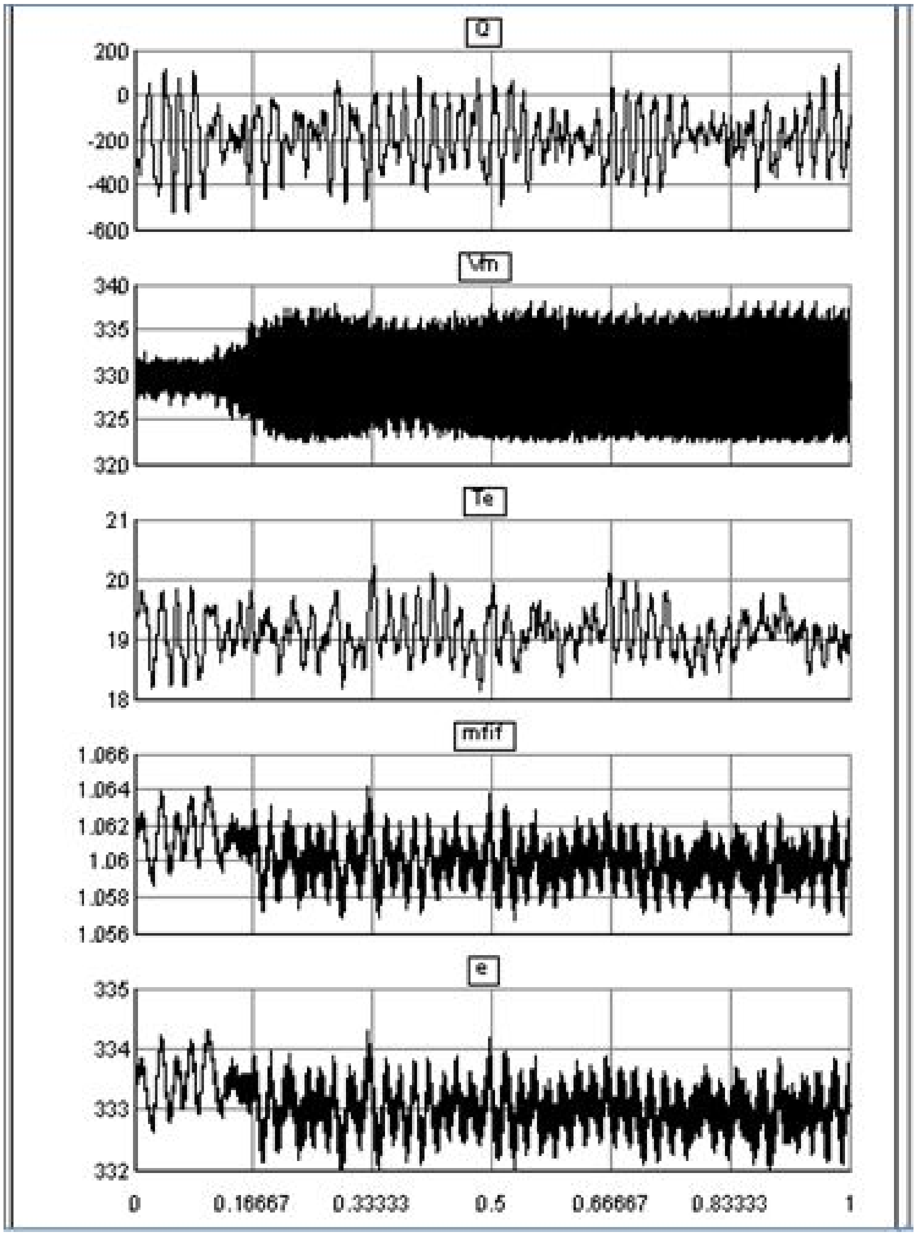


**Figure 3.9 The graphs of Q, $V_m$,$T_e$, mfif and e**

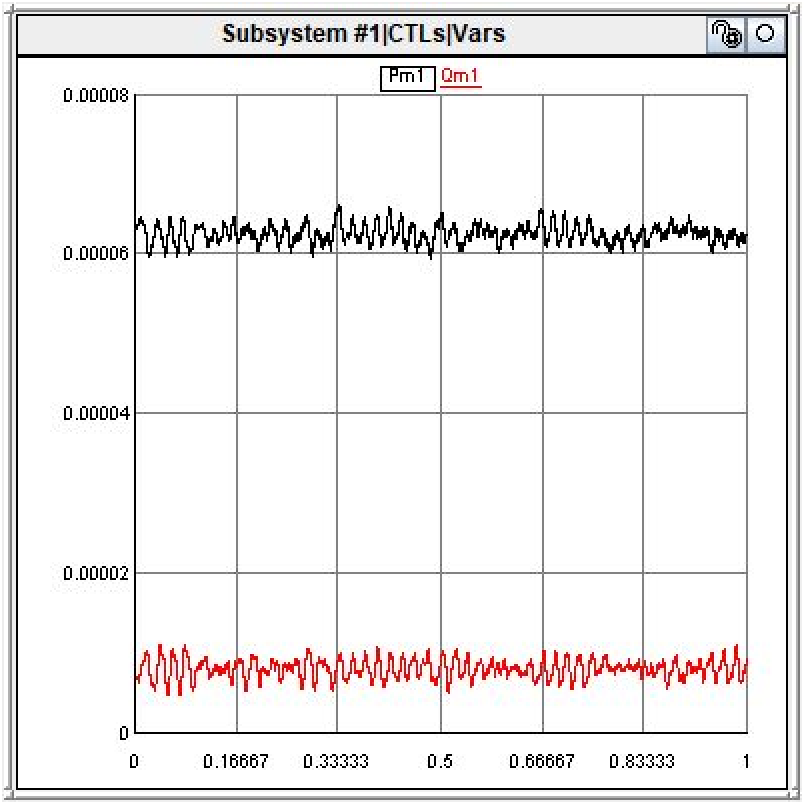


**Figure 3.10 The obtained active and reactive power values are equal to the set values. i.e. $P_{set}$ =6000 W and $Q_{set}$ = 500 W**

In this chapter, we have implemented current controller and synchronverter. We have implemented PI controller in current controller. We have also implemented swing equations in a synchronverter and noted the results. In the next chapter, we are going to plot the data in MATLAB and look for the various advantages of synchronverter over current controller and also account for inertia and damping factor.

# Experimental Results

To verify our observation, we considered the results implemented from the MATLAB. To account for the inertia, on changing P (active power) from 6000 W to 8000 W. As the value of J increases from 0.02 kgm^2 to 0.06 kgm^2 we have seen a slight decrease in transient response.We can say that as the value of J (Inertia) increases there is decrease in the transient response.

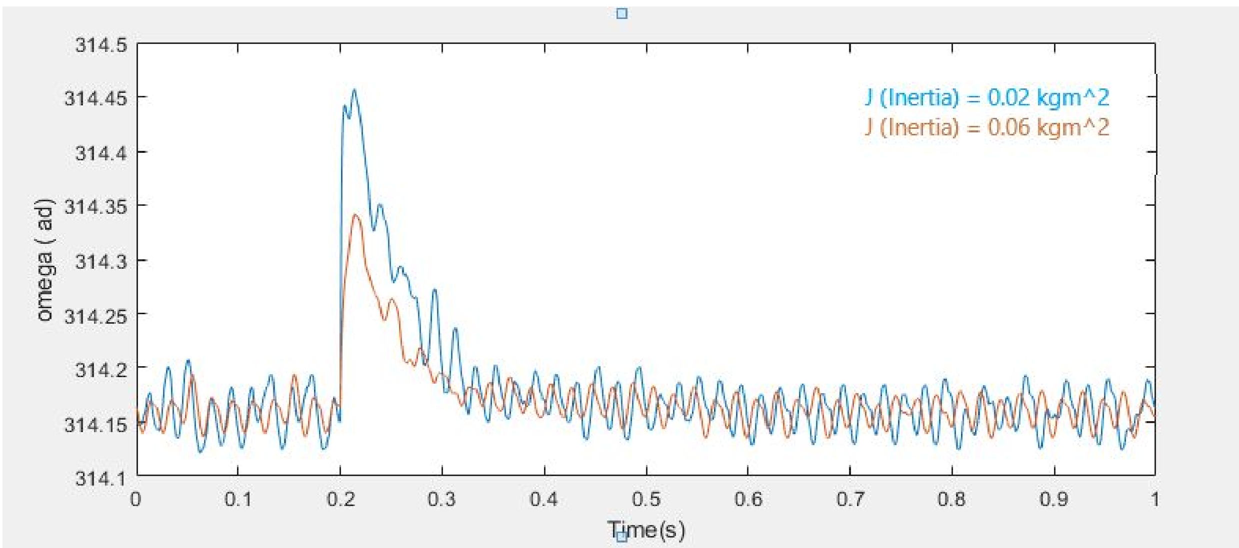


**Figure 4.1 Plot of omega vs time for different values of inertia.**

For damping factor, as we change P from 6000 W to 8000 W , we observe that as the value of $D_p$ increases the system is showing overdamping nature.It should be noted here that the load is connected in the above system. For $D_p$= 15 , the system is critically damped and for $D_p$ = 30 and 50 the system is more inclined towards overdamping nature.

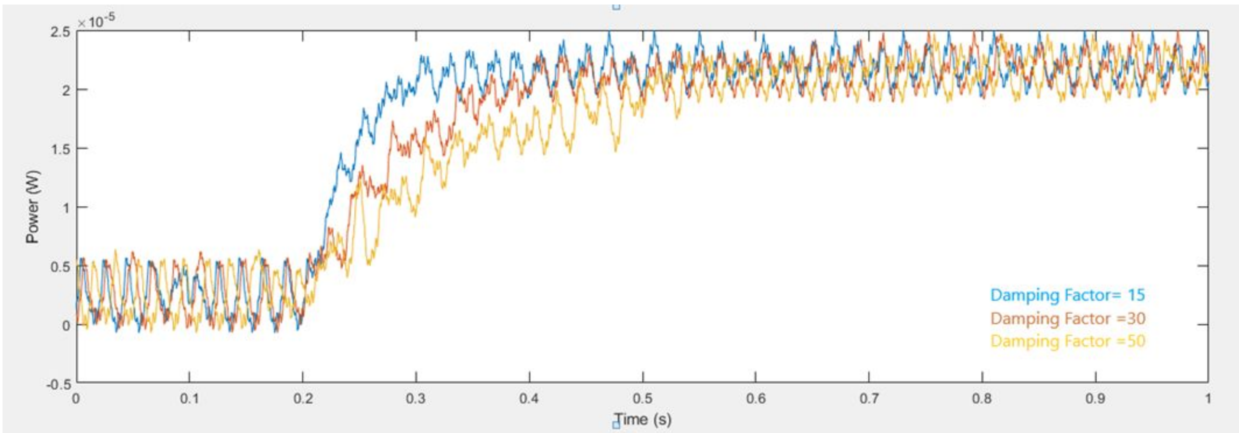


**Figure 4.2 Plot of Power(W) vs time(s) for different values of damping factor**

## Comparison

On comparing current controller with synchronverter, we have made certain observations.We have kept reference active power as 10kW for synchronverter. In case of current controller, we have set the value of $i_{dref}$ such that the power is also 10kW. In both the cases we have varied the load from 0-5kW , on getting all the values we have plotted the data on MATLAB. We have observed that transient response for synchronverter is better than current controller for such change which makes synchronverter more stable than current controller.

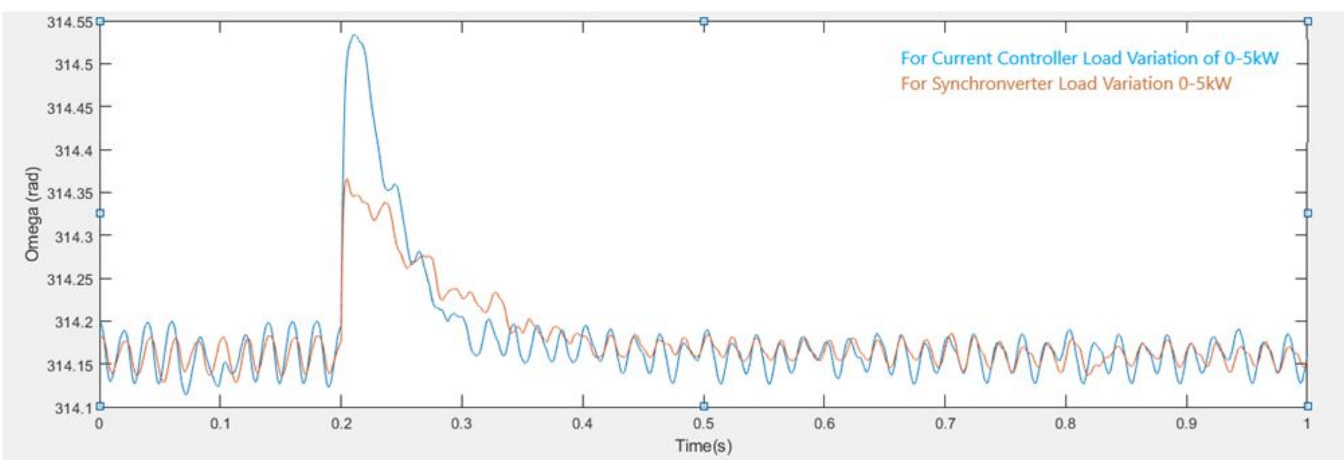


**Figure 4.3 Plot of omega vs time(s) for different controller (current controller and synchronverter) for a reference active power of 10kW.**

# Conclusion

An attempt has been made to simulate an inverter which will emulate the characteristics of synchronous generator.

We have chosen $D_p$ such that the frequency drop of 0.5% causes the torque to increase by 100% and the voltage drooping coefficient $D_q$ such that when grid voltage drops by 5% Q increases by 100%. (IEEE standards)

We have observed the system changes when there is observed a change in damping ratio and inertia. Later on, we have compared current controller with synchronverter.

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