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Controlling of three phase single stage grid connected PV system

1.Introduction:

Renewable energy, especially photovoltaic (PV) power generation, is a promising alternative to traditional energy sources. PV systems convert solar energy into direct current using semiconductor materials and consist of solar panels with multiple solar cells. They use Maximum Power Point Tracker (MPPT) algorithms for efficient power output but integrating power electronic devices generates harmonics that require filters to reduce Total Harmonic Distortion (THD). Fuzzy Logic Controllers (FLCs) are effective for inverter control in PV systems due to their fast response and robustness. This paper explores a new fuzzy logic control strategy for grid-connected three-phase PV inverter systems, achieving acceptable THD levels under varying conditions. Renewable energy accounts for about 33% of global electricity, with PV contributing 60% of green energy. Research focuses on improving PV system efficiency, economic viability, and control strategies. The report proposes a Fuzzy PI controller strategy for Single Stage Three Phase (SSTP) grid-integrated PV applications, discussing methodology, results, and conclusions.

2. Operating principle of fuzzy PI controller in three phase single stage grid connected PV system:

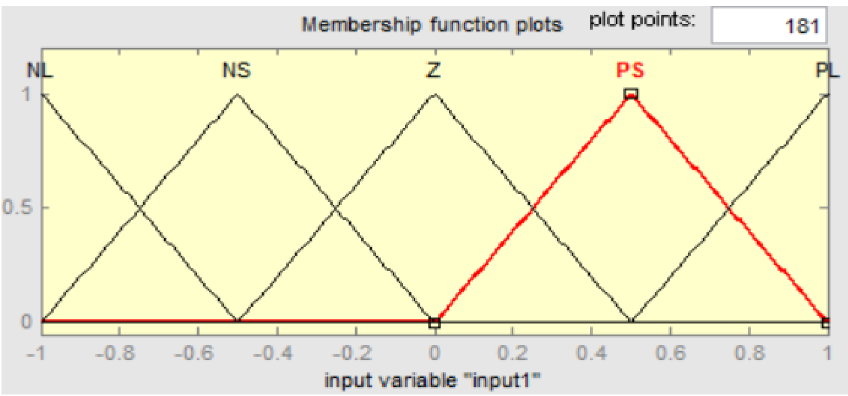
1. **Fuzzifier Unit:** Converts crisp input data into fuzzy values at the input terminal.
2. **Knowledge Base and Inference Engine:** Includes a rule base and an inference engine that processes fuzzy inputs to generate fuzzy outputs.

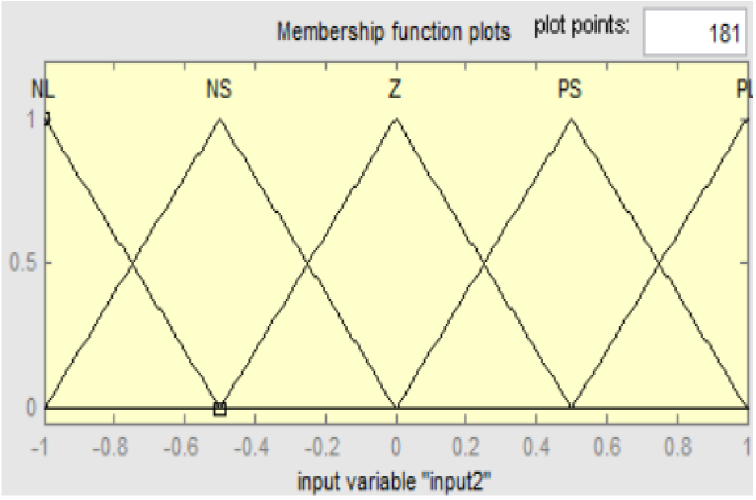
3. **DE fuzzifier Unit:** Converts fuzzy outputs back into crisp values at the output terminal.

In an FLC-based control system, the essential variables are inputs and outputs.

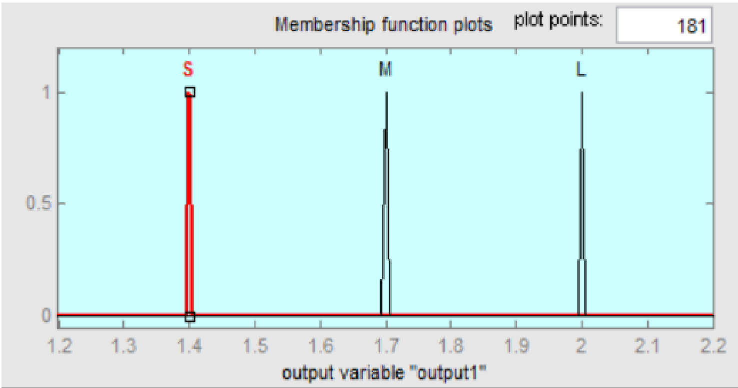
1. **Inputs:** Parameters or variables of the process to be controlled, depending on the application. Typically, an error and its rate of change are chosen as input variables.
2. **Outputs:** Usually the changes in gains.

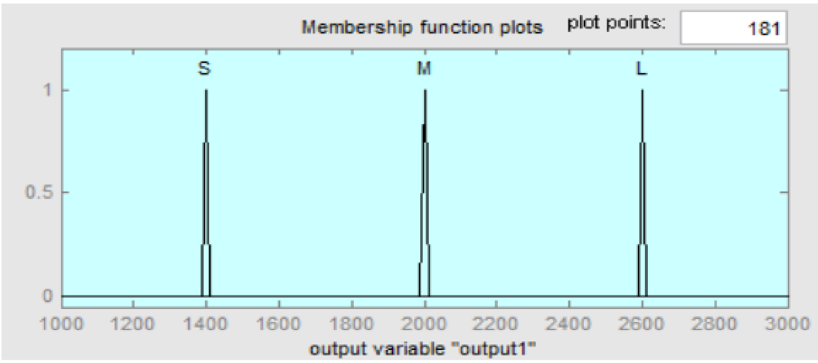
s' s	NB	NM	NS	Z	PS	PM	PB
PB	Z	PS	PM	PB	PB	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PS	NM	NS	Z	PS	PM	PB	PB
Z	NB	NM	NS	Z	PS	PM	PB
NS	NB	NB	NM	NS	Z	PS	PM
NM	NB	NB	NB	NM	NS	Z	PS
NB	NB	NB	NB	NB	NM	NS	Z





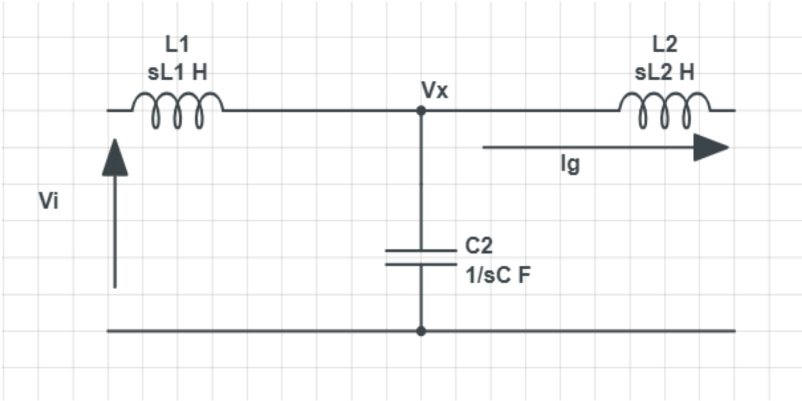
Input membership functions of e & Δe.





Output Membership functions of Kp and Ki

Design of LCL filter:



RLC Circuit Single Phase

$$\frac{\mathrm{V_i - V_X}}{\mathrm{SL1}} = \frac{\mathrm{I_g + V_X}}{\frac{1}{\mathrm{SC}}} --- 1$$

$$\mathrm{V_x = I_g SL2} \qquad --- 2$$

By Solving equation 1 and 2,

$$\frac{\mathrm{I_g}}{\mathrm{V_I}} = \frac{1}{S^3 L1L2C + S(L1 + L2)} \quad --- 3$$

Let us assume that

$$L1 + L2 = L \qquad L_P = \frac{L1L2}{L1 + L2}$$

Then it becomes,

$$\frac{I_g}{V_I} = \frac{1}{SL(1 + S^2 CL_P)} --- 4$$

$$\omega_{res} = \frac{1}{\sqrt{CL_P}}$$

Selection of Switching frequency

$$\mathrm{F_{sw} = 10khz}$$

Selection of resonant frequency

$$F_{res} = \frac{F_{sw}}{10} = 1000\ Hz$$

Value of capacitance,

Reactive power requirement = 5% of rated power(s)

$$Q = \frac{V^2}{\frac{1}{2 * \pi * f * c}} = \quad 5\ \%\ of\ s$$

For 100 kva , 50Hz,230 $V_{p\text{-}p}$

$$\mathrm{c} = \frac{0.05 * (\frac{100 * 10^3}{3})}{230 * 2 * \pi * 50} = 100.28\ micro\ F$$

Value of Inductance,

$$\frac{I_g}{V_I} = \frac{1}{SL(1 + S^2 CL_P)}$$

$$\omega_{res} = \frac{1}{\sqrt{CL_P}}$$

$$\frac{I_g}{V_I} = \frac{1}{SL(1 + \frac{S^2}{{\omega_{res}}^2})} \qquad s \longrightarrow j\omega$$

$$\frac{I_g}{V_I} = \frac{1}{j\omega_{s\omega} L(1 - \frac{{\omega_{s\omega}}^2}{{\omega_{res}}^2})}$$

$$\left|\frac{I_g(s\omega)}{V_I(s\omega)}\right| = \left|\frac{1}{\omega_{s\omega} L(1 - \frac{{\omega_{s\omega}}^2}{{\omega_{res}}^2})}\right|$$

$$L = \left| \frac{1}{\omega_{s\omega} \frac{I_g(s\omega)}{V_I(s\omega)} (1 - \frac{{\omega_{s\omega}}^2}{{\omega_{res}}^2})} \right|$$

For 100 kva , 50Hz,230 V_{p-p}

Current, $I_g = \frac{100}{\frac{3}{230}} = 144.92\ A$ F_{sw} =10KHz

F_{res} = 1000Hz

$I_g(s\omega)$ = 0.3% of $I_g(s\omega)$ = 0.434

$V_i(s\omega)$ = 0.9% of $V_i(s\omega)$ =207V

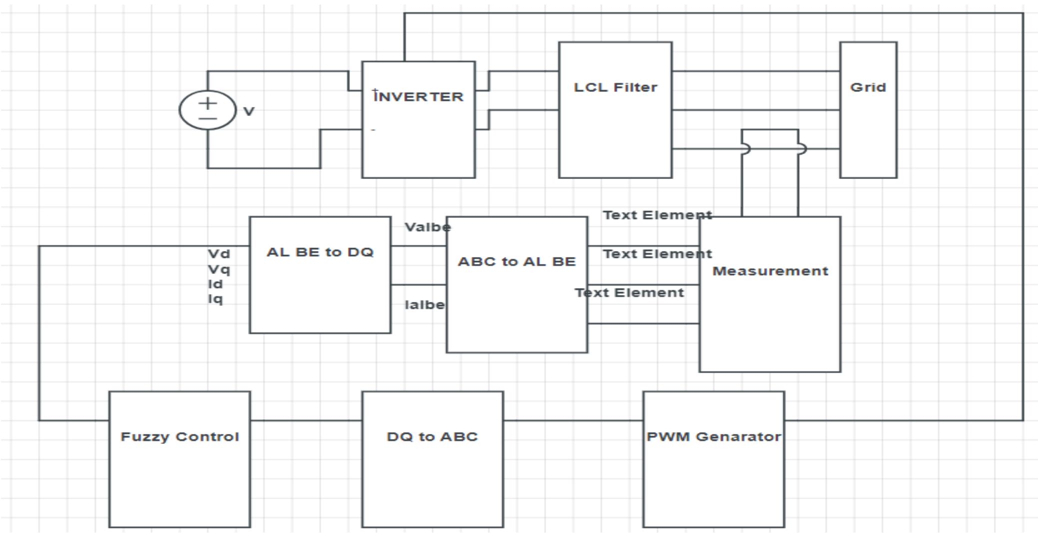
$$L = \frac{1}{2 * \pi * 10000(\frac{0.434}{207})(1 - \frac{2 * \pi * 10000^2}{2 * \pi * 1000^2})} = 76.68uH$$

L1=L2= 76.68/2= 38.34uH

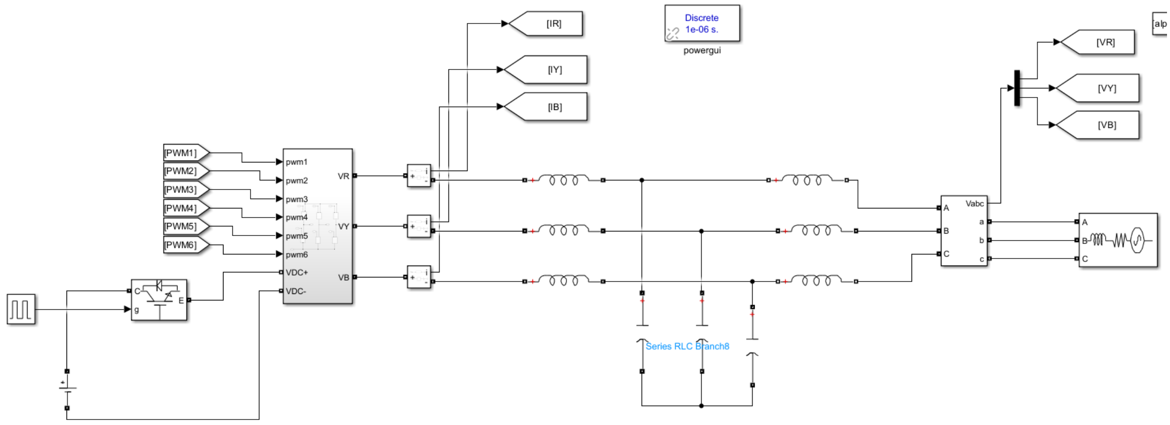
$$L_{max} = \frac{0.2 * V_{grid}}{2 * \pi * 50 * I} = 1mH$$

L1=L2= 1mH/2= 500u

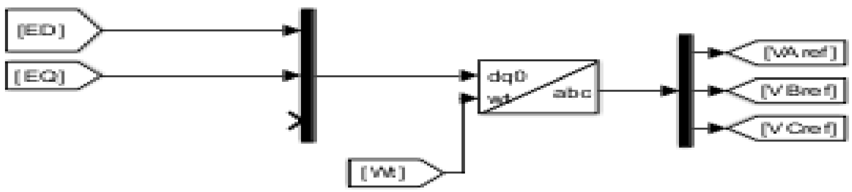
Operating principle:



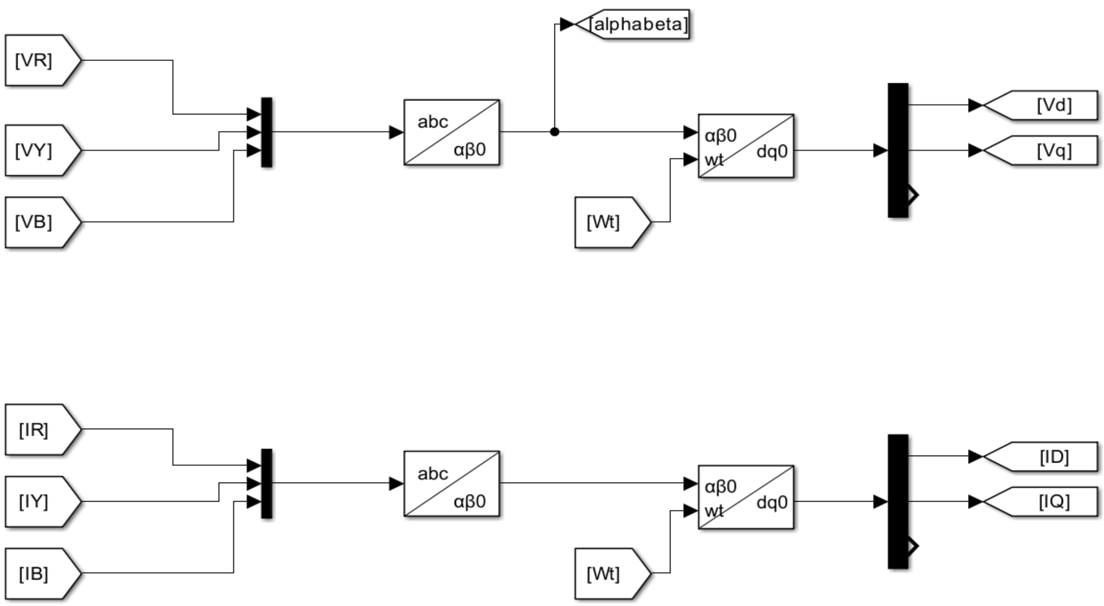
3.Simulink Designing:



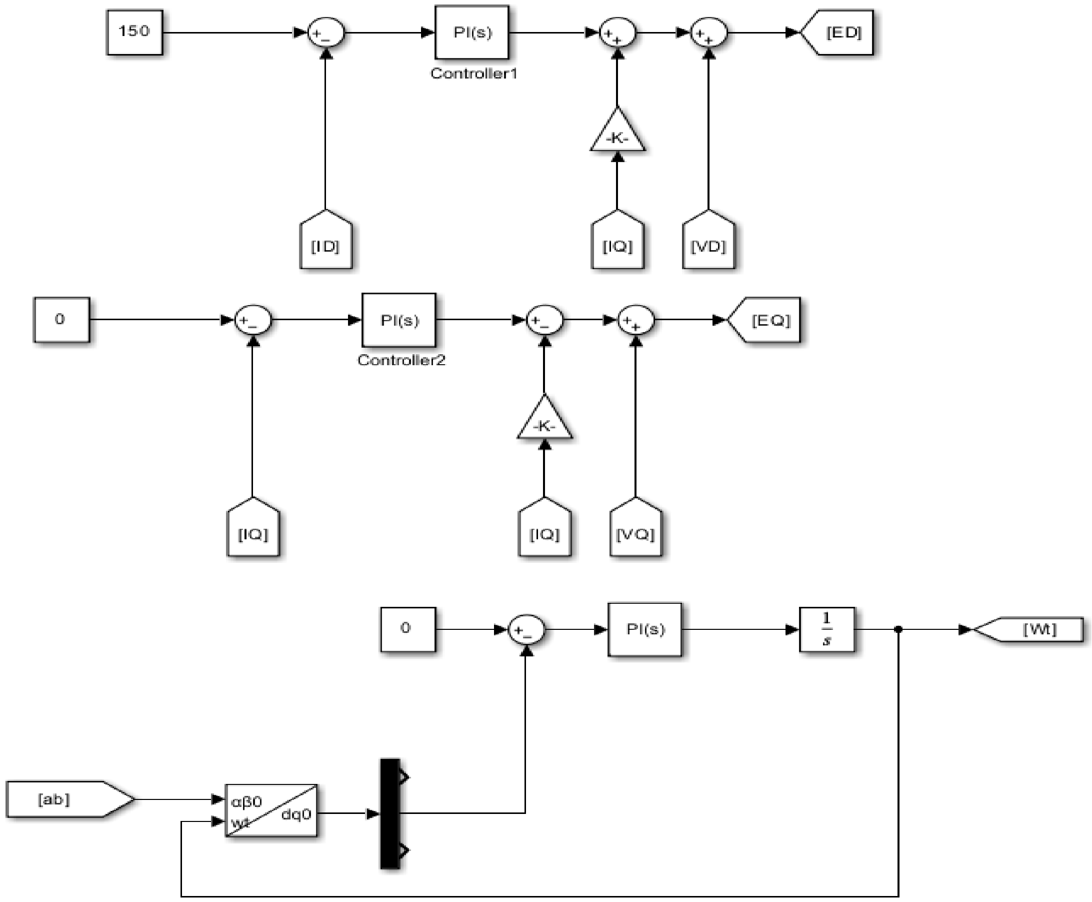
Inverter and grid with lcl filter



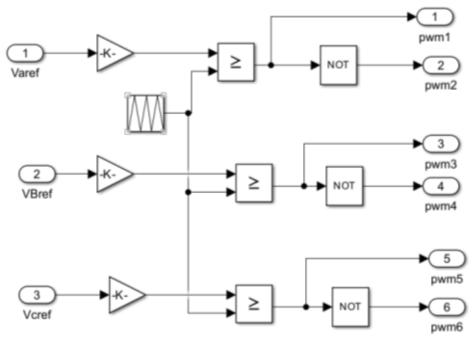
DQ to ABC conversion



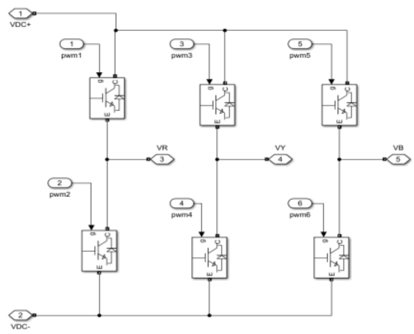
ABC to DQ



Fuzzy PI controller



PWM generator

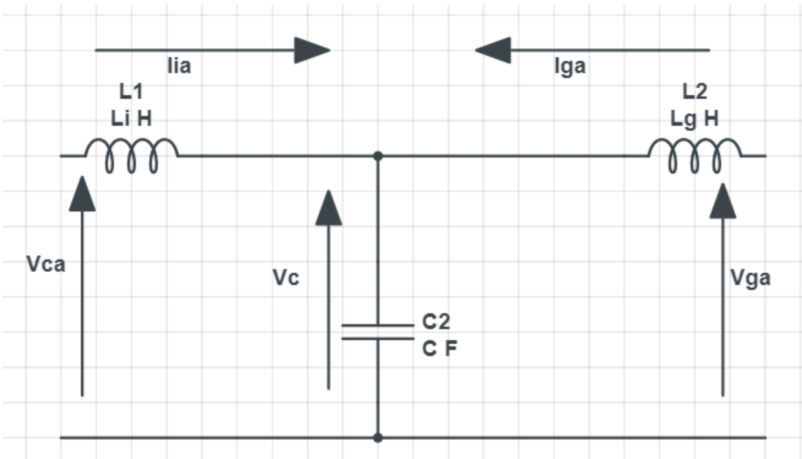


Inverter Design Subsystem

By changing the pulse width in pulse generator, we can modify the input.

4. State-Space Model:

Modelling of a Three Phase grid connected inverter with LCL Filter



By using Kirchhoff law

We get,

$$L_I \frac{dI_{ia}}{dt} = V_{ia} - V_{ca} \quad ----5$$

$$L_g \frac{dI_{Ga}}{dt} = V_{Ca} - V_{ga} \quad ----6$$

$$C_a \frac{dV_{ca}}{dt} = I_{ia} - I_{ga} \quad ----7$$

In this the variables are,

V_{ga} is the grid voltage for phase 'a' which has the value of $V_{ga}=V_m\sin(wt)$

V_{ia} is the inverter voltage for phase 'a'

V_{ca} is the voltage across the capacitor.

Let us take the,

$I_a = x_1$, $I_{ga} = x_2$, $V_{ca} = x_3$

So while we differentiate wrt t,

$$\dot{x_1} = \frac{dI_{ia}}{dt}, \dot{x_2} = \frac{dI_{ga}}{dt}, \dot{x_3} = \frac{dV_{ca}}{dt}$$

We got our state variables

Then When we substitute the variables in our 3 equations

We get

$$L_I \dot{x_1} = mV_{dc} - x_3 \quad ----8$$

$$L_g \dot{x_2} = x_3 - \mathrm{Vmsin(wt)}$$

Then, substituting $V_m = \sqrt{2}\, V_{dc}$ in above equation

$$L_g \dot{x_2} = x_3 - \sqrt{2}\mathrm{V}_{dc}\mathrm{sin(wt)} \quad ---9$$

$$C_a \dot{x_3} = x_1 - x_2 \quad ----10$$

By the state equations in equation 4,5,6

The matrix form is,

$$\begin{bmatrix} \dot{X}_1 \\ \dot{X}_2 \\ \dot{X}_3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & \frac{-1}{L} \\ 0 & 0 & \frac{-1}{L} \\ \frac{-1}{C_a} & \frac{-1}{C_a} & 0 \end{bmatrix} \begin{bmatrix} X_1 \\ X_2 \\ X_3 \end{bmatrix} + \begin{bmatrix} \frac{m}{L_I} \\ \frac{\sqrt{2}\mathrm{sin(wt)}}{L_g} \\ 0 \end{bmatrix} [Vdc]$$

$$\dot{X} = Ax + Bu$$

5. Analysis and result:

Stability Analysis through Bode Plot:

By the above derived expression

i.e., in the equation 4

The transfer function of the lcl filter is given by,

$$\frac{I_g}{V_I} = \frac{1}{SL(1 + S^2 C L_P)}$$

When we substitute the values we designed,

L=L1+L2

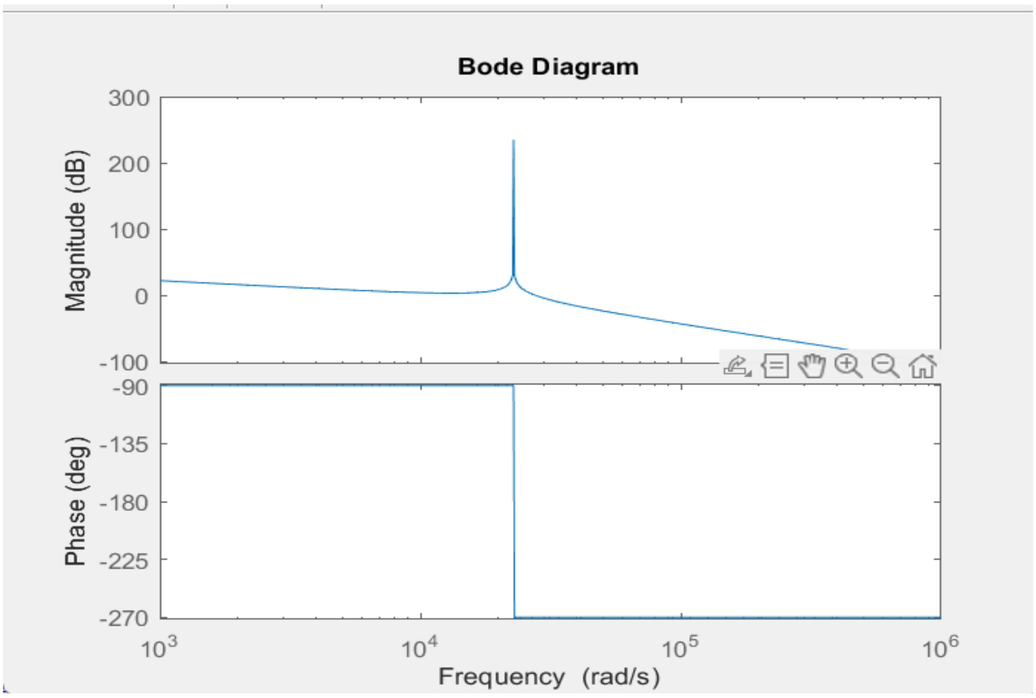
L1=500uH   L2 = 500uH

L=1mH

C=100.28uH

$$G(s)=\frac{1}{S(500)*10^{-6}(1+S^2(100.28)(500)*10^{-12})}$$

Bode Plot:



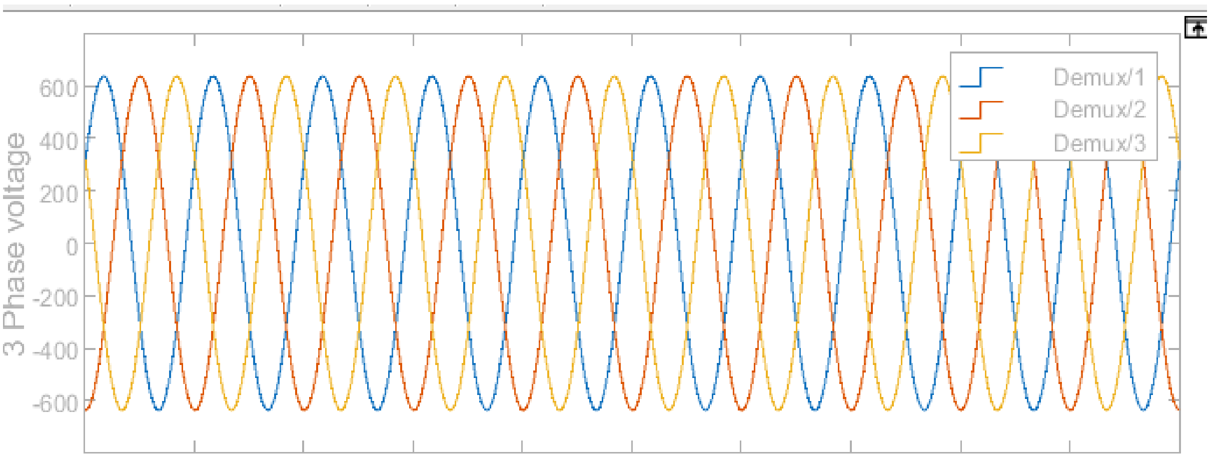
This is the bode plot without damping resistance.

Simulation Results:

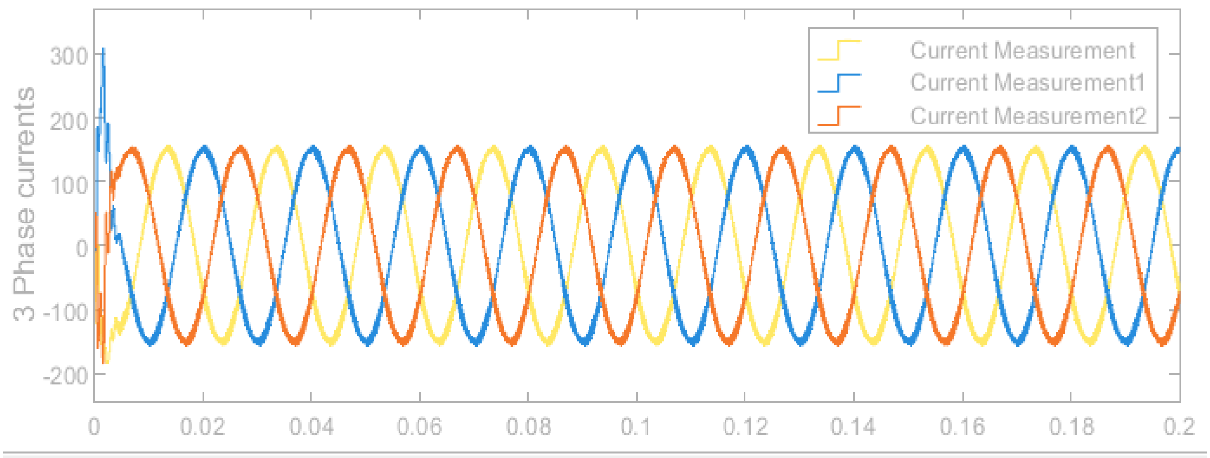
Simulation Parameters:

Parameter	Value
Input voltage	800V
Reference voltage	415V
Inductor	500e-6H
Capacitor	100e-6 F

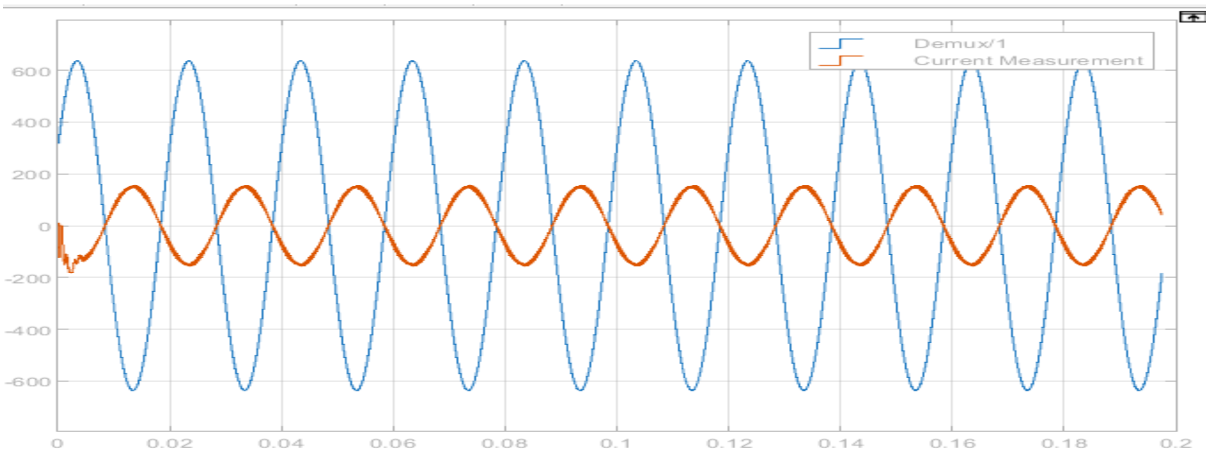
Output Graphs of Simulink model By Keeping Grid Voltage as 450 V



Output Voltages with fuzzy pi controller



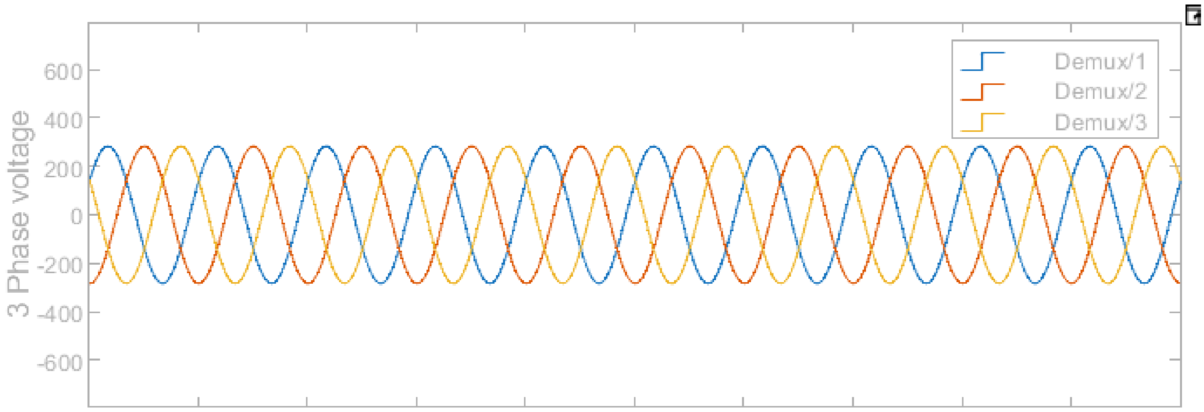
Output Currents with fuzzy pi controller



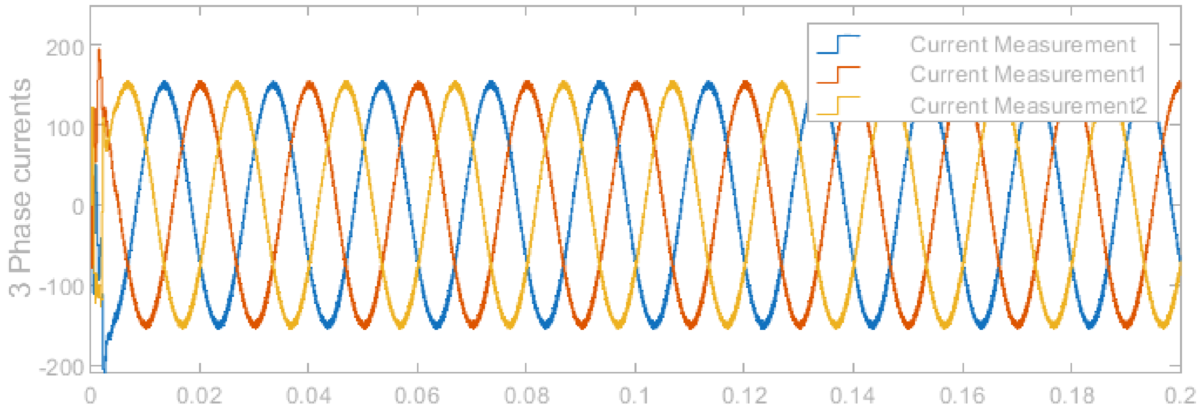
Current and voltage comparison graph

Checking Synchronisation checking with grid:

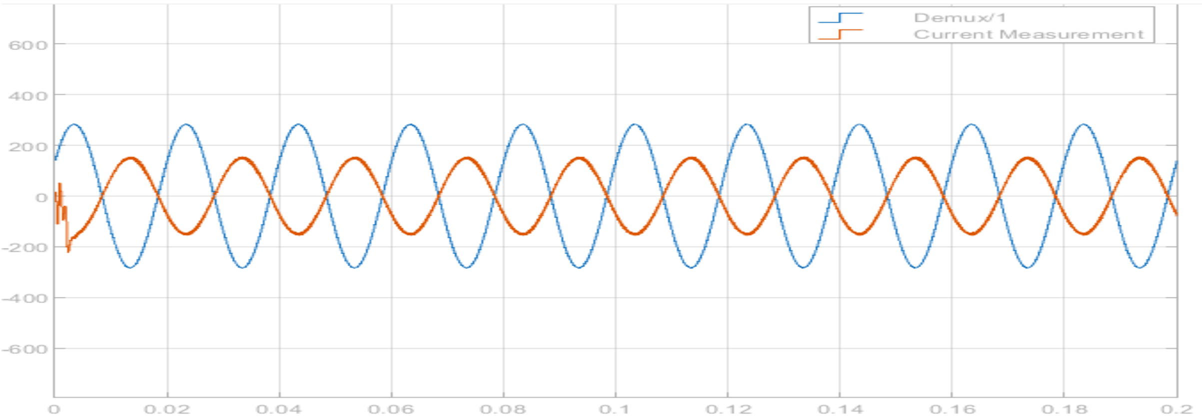
We can check the grid synchronisation by keeping the grid voltage as 200V



Output Voltages



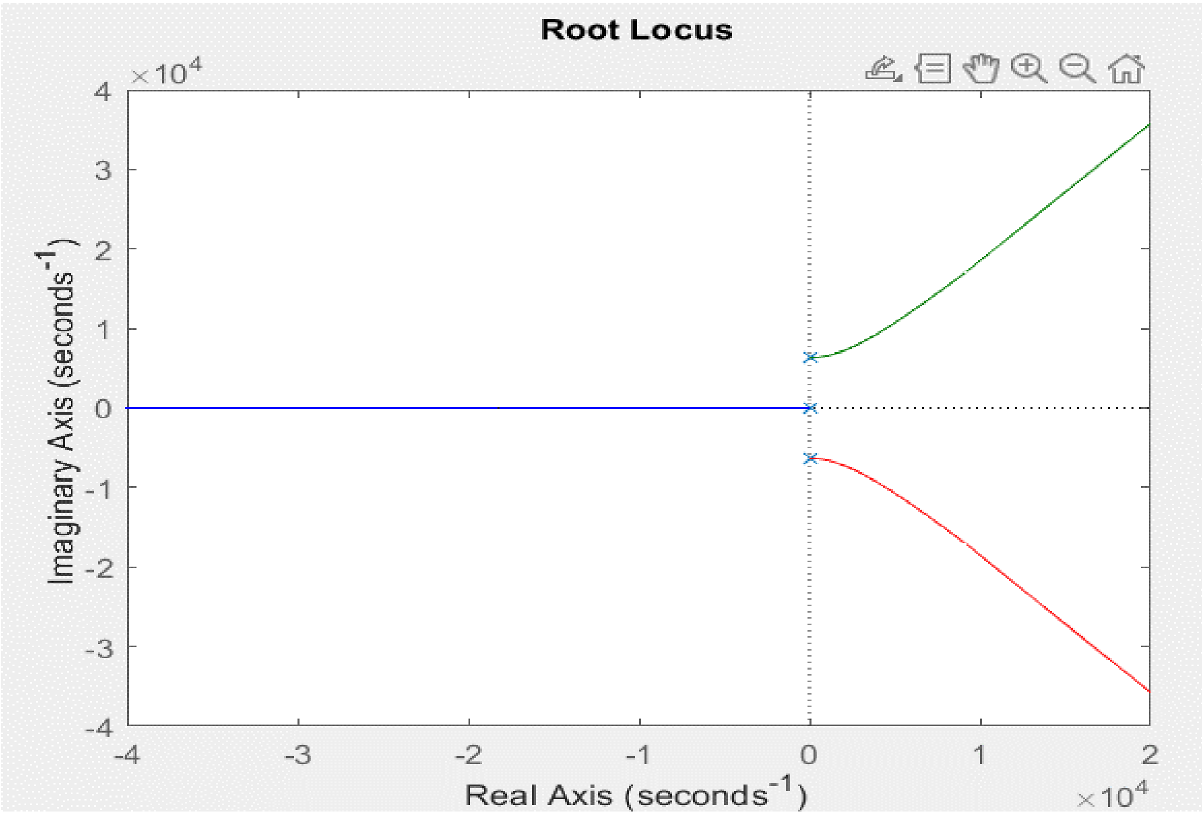
Output Currents



Voltage and Current comparison

As we reduced the grid reference voltage the output voltage also has been reduced. Therefore, the Grid Synchronisation is done.

Checking stability of LCL filter using R-locus Plot:



Number of poles and zeros: 3 poles and 0 zeros.

The value of poles is 0, 6.3157194e+03i, 6.3157194e+03i