Controlling of three phase single stage grid connected PV system using fuzzy PI Controller

Summer Internship Report

Submitted By:

P. Pranesh Kumar

2nd year B.Tech. - EEE

Vellore Institute of Technology -Vellore.

Submitted To:

Dr. S. Mageshwari

Assistant Professor

EEE Department

National Institute of Technology – Trichy.

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING NATIONAL INSTITUTE OF TECHNOLOGY TIRUCHIRAPALLI-620015

JUNE 2024

ACKNOWLEDGEMENT

I would like to express my deepest gratitude to my mentor Dr. S. Mageswari, Assistant Professor, Department of Electrical and Electronics Engineering, National Institute of Technology, Trichy, for her invaluable guidance, support, and encouragement throughout the duration of my summer internship. Her expertise and insightful feedback greatly enhanced my learning experience and contributed significantly to the completion of this project.

I am thankful to the faculty and staff of the EEE Department for providing the necessary resources and creating an environment that is favourable to research and education. Their assistance and cooperation were crucial for successful completion of my internship.

I also want to express my heartfelt appreciation to my colleagues and friends for their continuous support and collaboration, which made this journey both productive and enjoyable.

Thank you all for your support and encouragement.

Sincerely,

P. Pranesh Kumar

Bonafide Certificate

This is to certify that **Mr. P. Pranesh Kumar**, Roll Number **22BEE0105**, student of the Department of Electrical and Electronics Engineering, Vellore Institute of Technology, Vellore, has successfully completed the summer internship on the topic **"Controlling of three phase single stage grid connected PV system using fuzzy PI Controller"** under the mentor **Dr. S Mageshwari,** assistant professor National Institute of Technology, Trichy.

This work is an authentic record of research carried out by them during the period from 30 May 2024 to 28 June 2024 in partial fulfilment of the requirements for the summer internship program.

Pranesh Kumar. P have shown great enthusiasm and dedication in undertaking this project, and the findings of this work have significant potential in the field of battery management and charging applications.

I wish them to be successful in their future endeavours.

Dr. S. Mageswari

Assistant Professor

Department of Electrical and Electronics Engineering

National Institute of Technology, Trichy

Date:

TABLE OF CONTENTS

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:

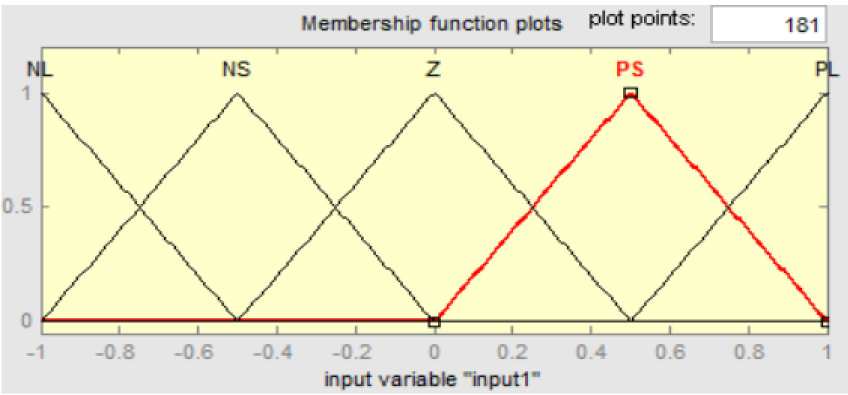
1. **Fuzzifier Unit:** Converts crisp input data into fuzzy values at the input terminal.
2. **Knowledge Base and Inference Engine:** Includes a rule base and an inference engine that processes fuzzy inputs to generate fuzzy outputs.

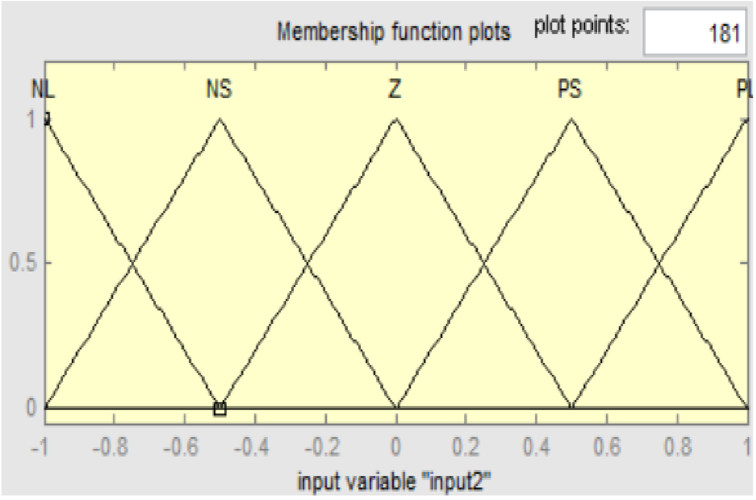
3. **DE fuzzifier Unit:** Converts fuzzy outputs back into crisp values at the output terminal.

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

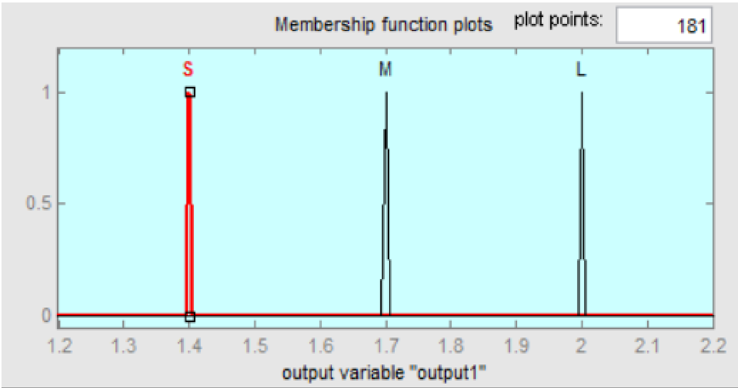
1. **Inputs:** Parameters or variables of the process to be controlled, depending on the application. Typically, an error and its rate of change are chosen as input variables.
2. **Outputs:** Usually the changes in gains.

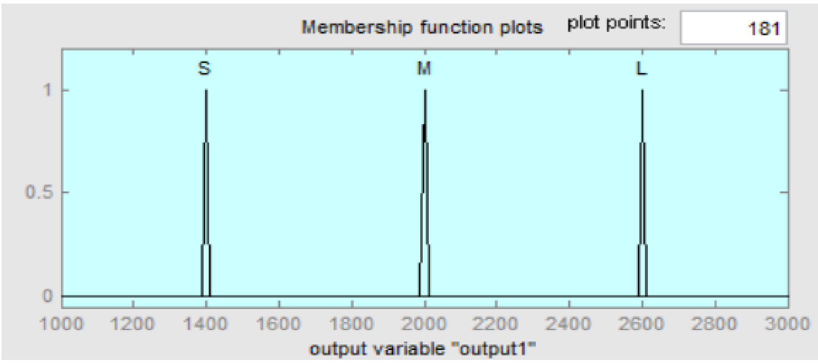
s' s	NB	NM	NS	Z	PS	PM	PB
PB	Z	PS	PM	PB	PB	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PS	NM	NS	Z	PS	PM	PB	PB
Z	NB	NM	NS	Z	PS	PM	PB
NS	NB	NB	NM	NS	Z	PS	PM
NM	NB	NB	NB	NM	NS	Z	PS
NB	NB	NB	NB	NB	NM	NS	Z





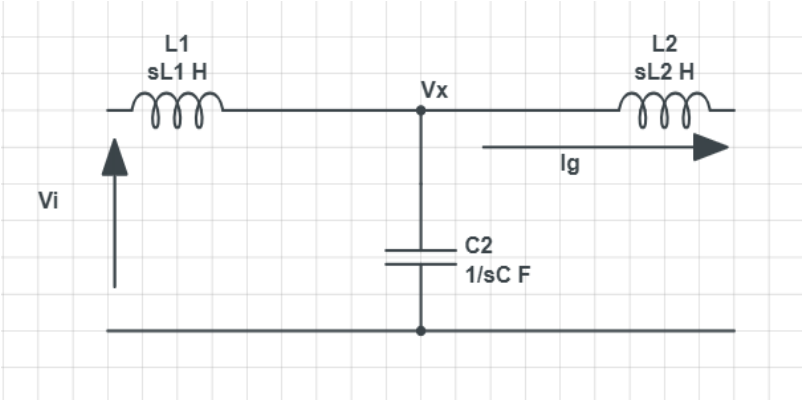
Input membership functions of e & Δe.





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,

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

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

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,

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

$$\omega_{res} = \frac{1}{\sqrt{C L_P}}$$

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

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

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

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

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

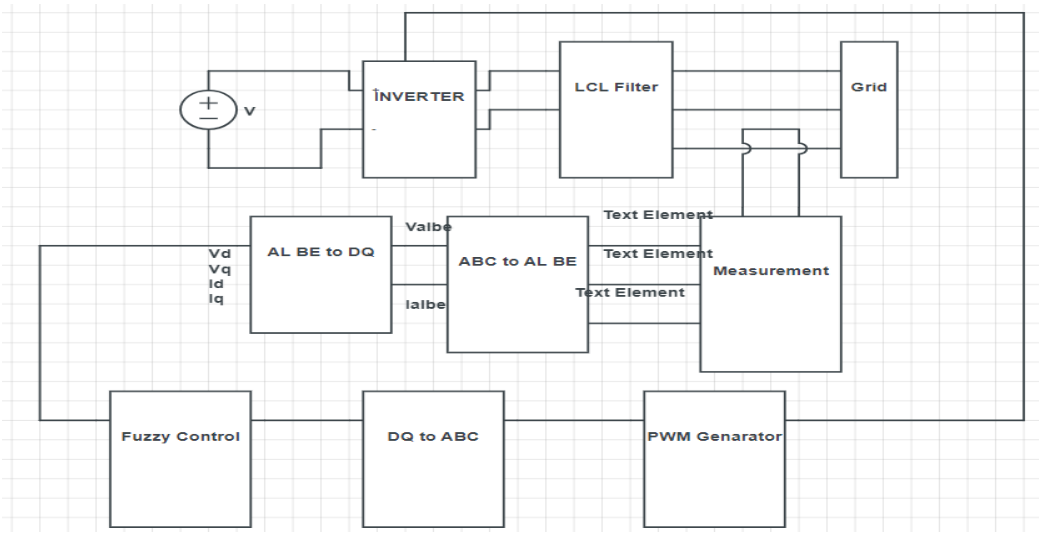
$$L = \frac{1}{2 * \pi * 10000(\frac{0.434}{207})(1 - \frac{2 * \pi * 10000^2}{2 * \pi * 1000^2})} = 76.68uH$$

L1=L2= 76.68/2= 38.34uH

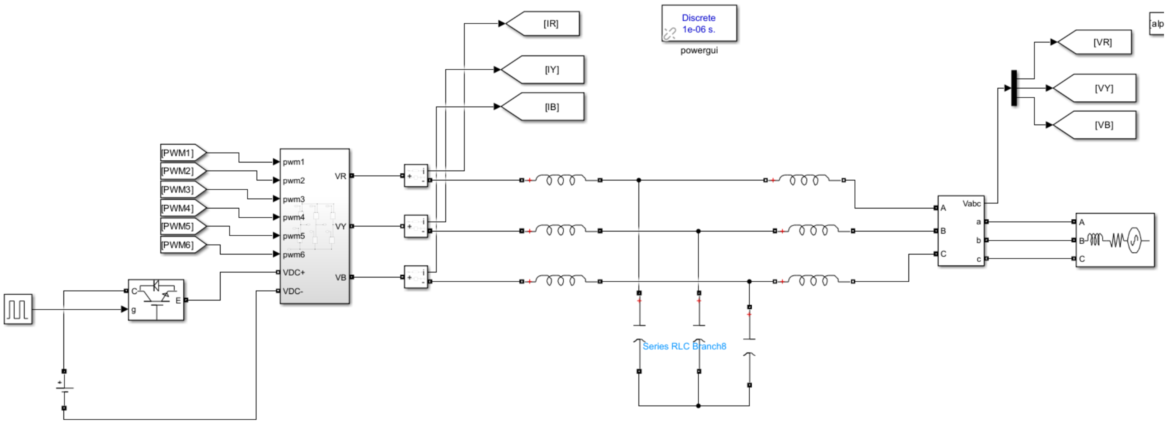
$$L_{max} = \frac{0.2 * V_{grid}}{2 * \pi * 50 * I} = 1mH$$

L1=L2= 1mH/2= 500u

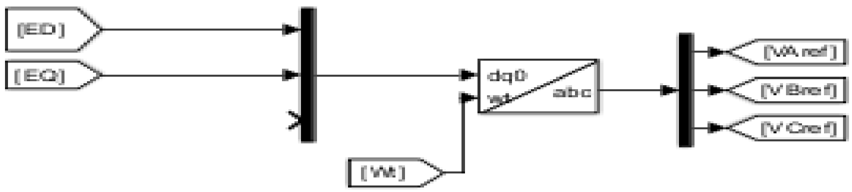
Operating principle:



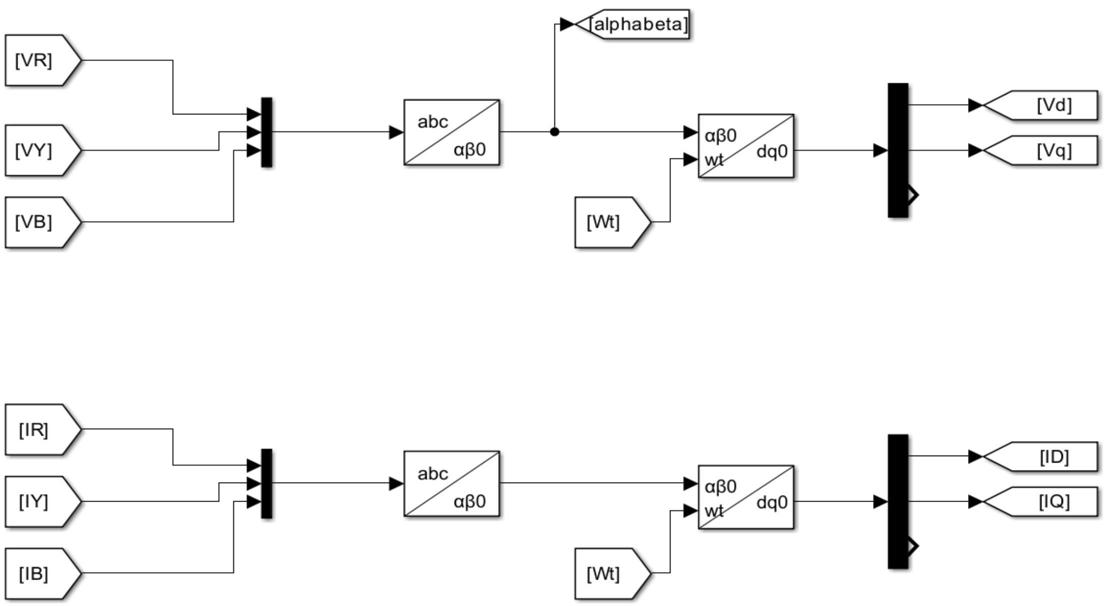
3.Simulink Designing:



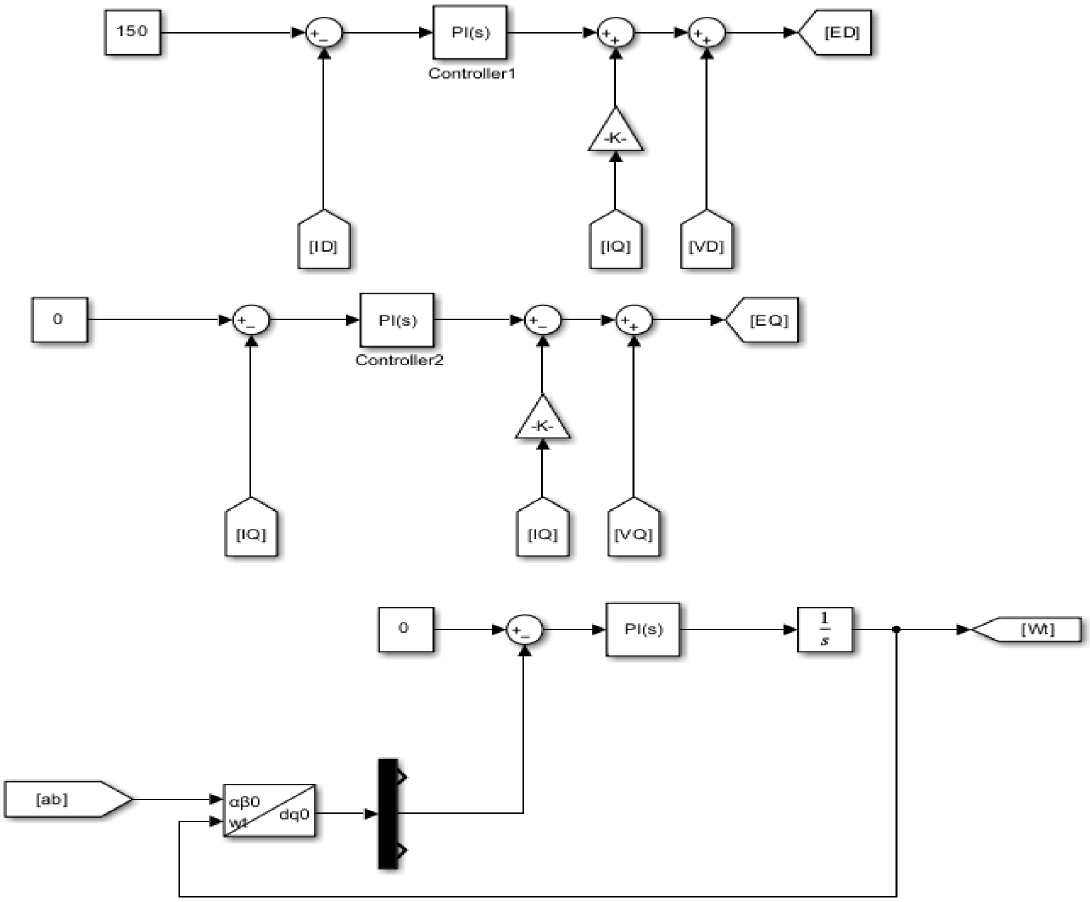
Inverter and grid with lcl filter



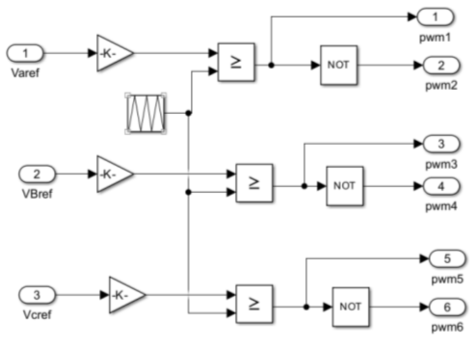
DQ to ABC conversion



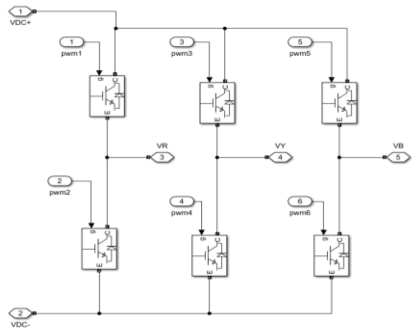
ABC to DQ



Fuzzy PI controller



PWM generator

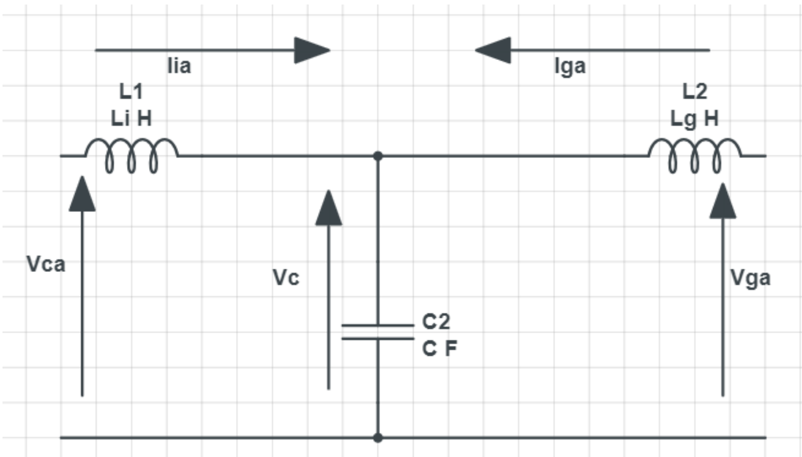


Inverter Design Subsystem

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

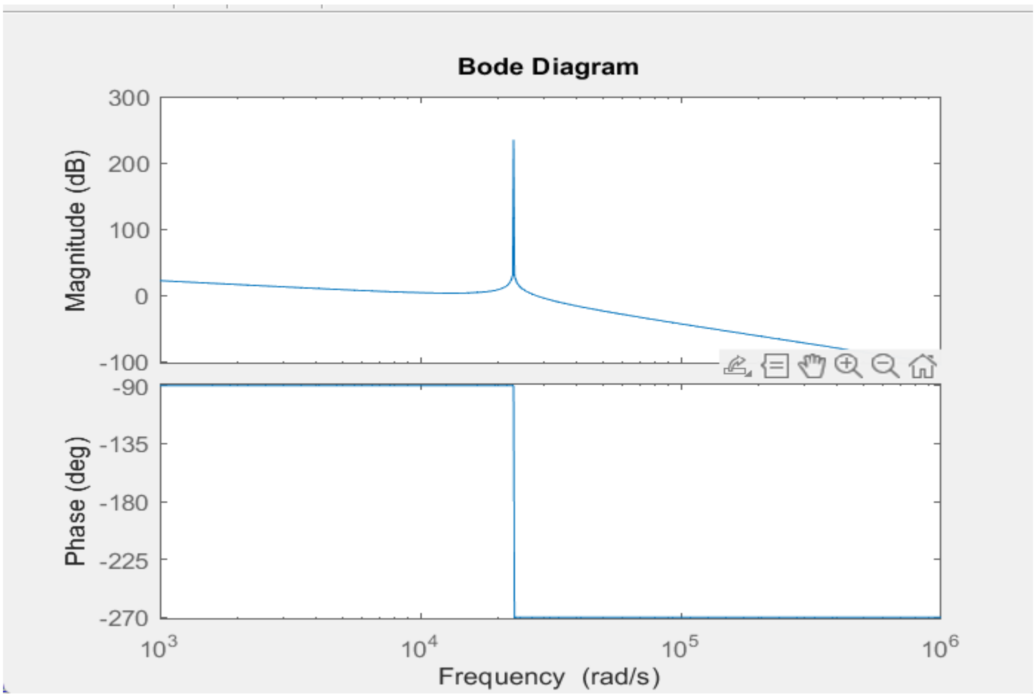
L1=500uH   L2 = 500uH

L=1mH

C=100.28uH

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

Bode Plot:



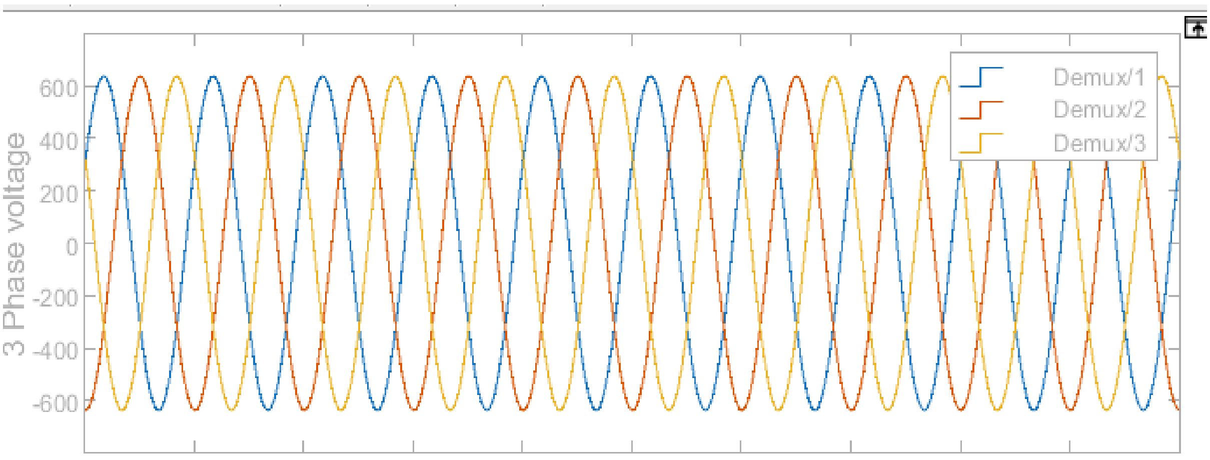
This is the bode plot without damping resistance.

Simulation Results:

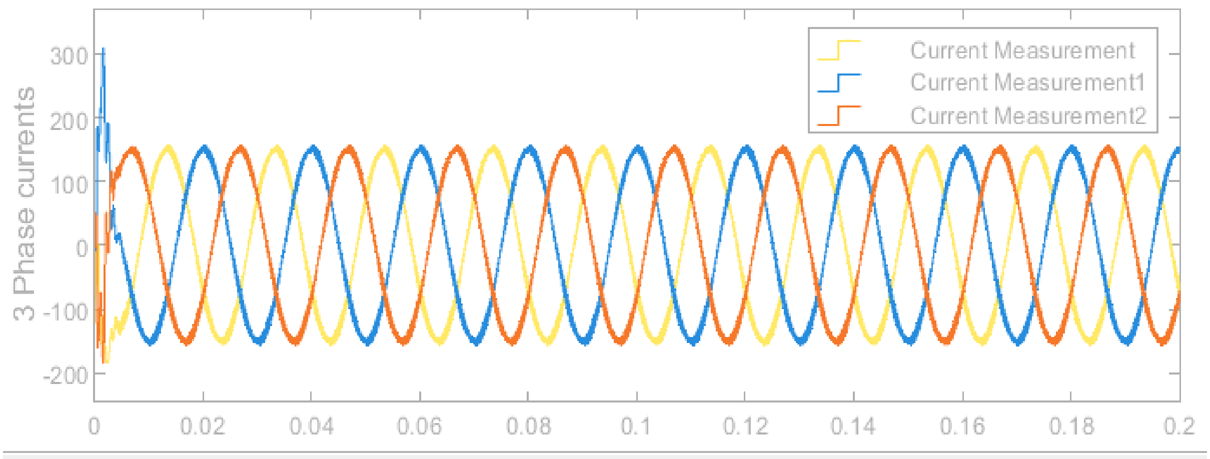
Simulation Parameters:

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

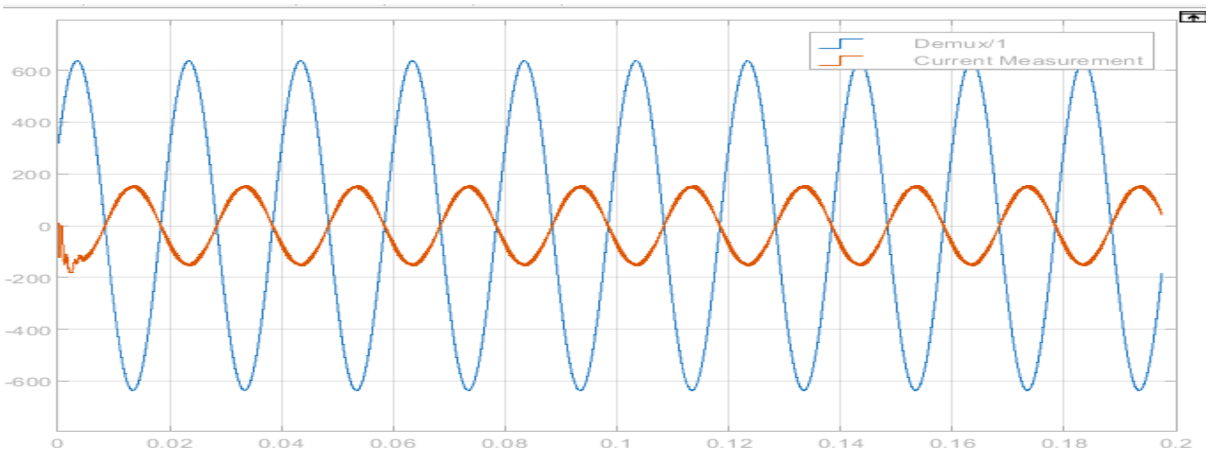
Output Graphs of Simulink model By Keeping Grid Voltage as 450 V



Output Voltages with fuzzy pi controller



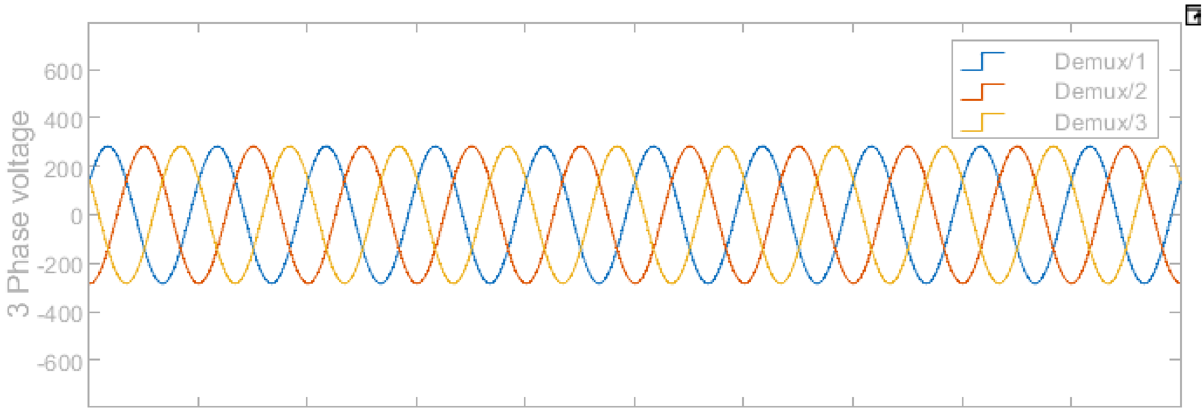
Output Currents with fuzzy pi controller



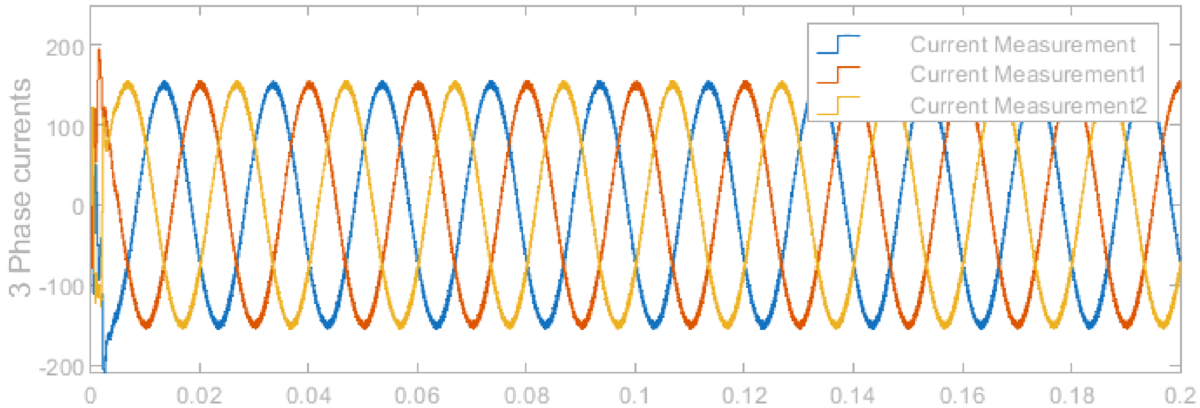
Current and voltage comparison graph

Checking Synchronisation checking with grid:

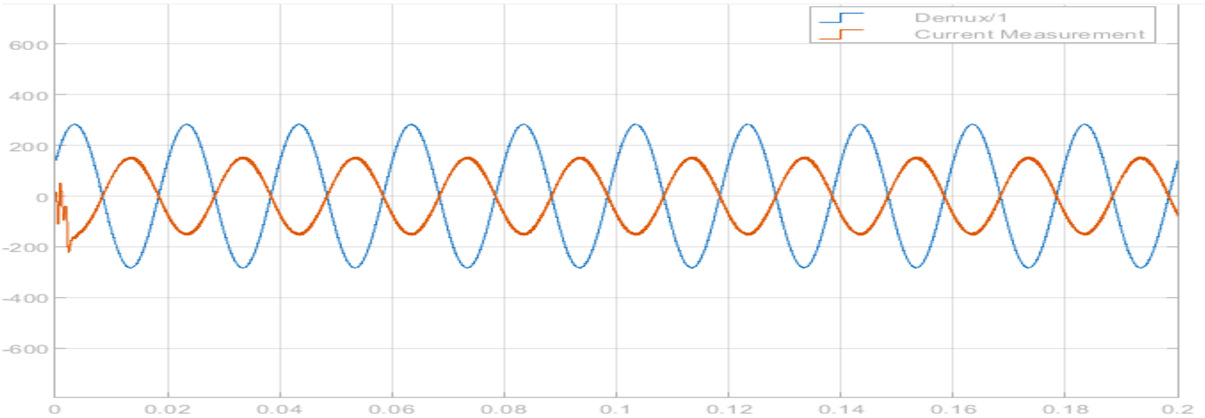
We can check the grid synchronisation by keeping the grid voltage as 200V



Output Voltages



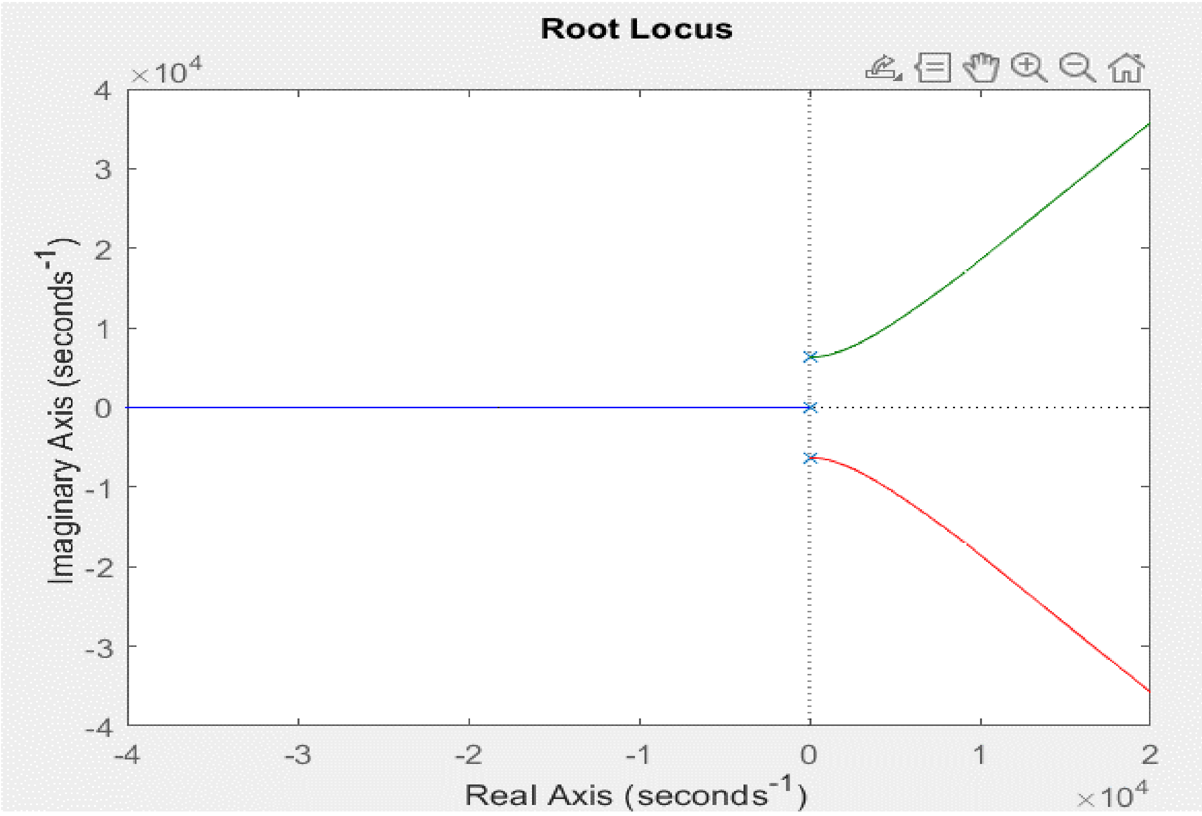
Output Currents



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

6.Conclusion:

Design of a fuzzy PI controller is designed for three phase single stage grid connected PV system. The output voltage is regulated for different reference values. The simulation results are observed and tabulated. The output voltage, current are plotted, and results are included. The state equations of the lcl filter have been derived also with the transfer function. Also have checked the synchronisation with the grid. Then bode and root locus plots have been plotted for the stability analysis.

7.Inference:

Learned about the Simulink modelling in MATLAB. Improved my knowledge on the deriving of state space equations. Learned about how the fuzzy pi controller works.

8.References:

1.Sankar, Ronanki, J.S.V. Kumar, and M.G. Rao. (2018). "Adaptive Fuzzy PI Current Control of Grid Interact PV Inverter." International Journal of Electrical and Computer Engineering, vol. 8, pp. 472-482. doi:10.11591/ijece.v8i1.pp472-482.

2.Li, H., Wang, K.D., Zhang, W.R. (2007). "Improved performance and control of hybrid cascaded h-bridge inverter for utility interactive renewable energy applications." IEEE Power Electronics Specialists Conf., Orlando, USA, June 2007, pp. 2465–2471.

3. Nur Mohammad, "Improved Solar Photovoltaic Array Model with FLC Based Maximum Power Point Tracking," International Journal of Electrical and Computer Engineering (IJECE), vol. 2, no. 6, pp. 717-730, Dec. 2012.

4. K. Arulkumar, D. Vijayakumar, and P. Kaliannan, "Design of Optimal LLCL Filter with an Improved Control Strategy for Single Phase Grid Connected PV Inverter," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 9, pp. 114-125, 2018. doi:10.11591/ijpeds.v9.i1.pp114-125.