**Coursework 1: Average Design and Modelling**

1. **LR Filter Design**

The RL filter should be developed first before the controller design. To obtain the value of inductor, the maximum current ripple across the inductor should be identified first. As the frequency of the inverter’s output voltage is , the maximum switching ‘ON’ time would be , when the duty cycle can be approximated by 0.5. The expression of current ripple could be given by:

*Eqn.1*

Thus, the value of inductor L could be calculated by:

*Eqn.2*

In realistic, the inductor has parasitic resistance, which will cause loss within it.

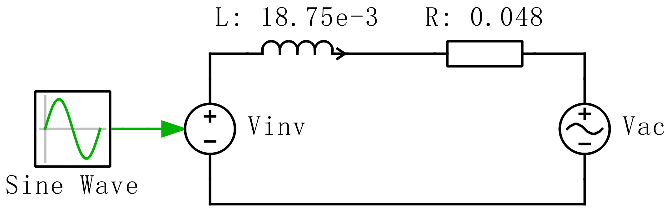
*Eqn.3*

*Eqn.4*

Thus, the value of the parasitic resistance could be given by:

*Eqn.5*

The simplified schematic diagram and phasor diagram are shown in the **Figure 1** below.



**Figure 1.** Simplified Schematic and Phasor Diagram

The phasor expression of RL impedance could be given by:

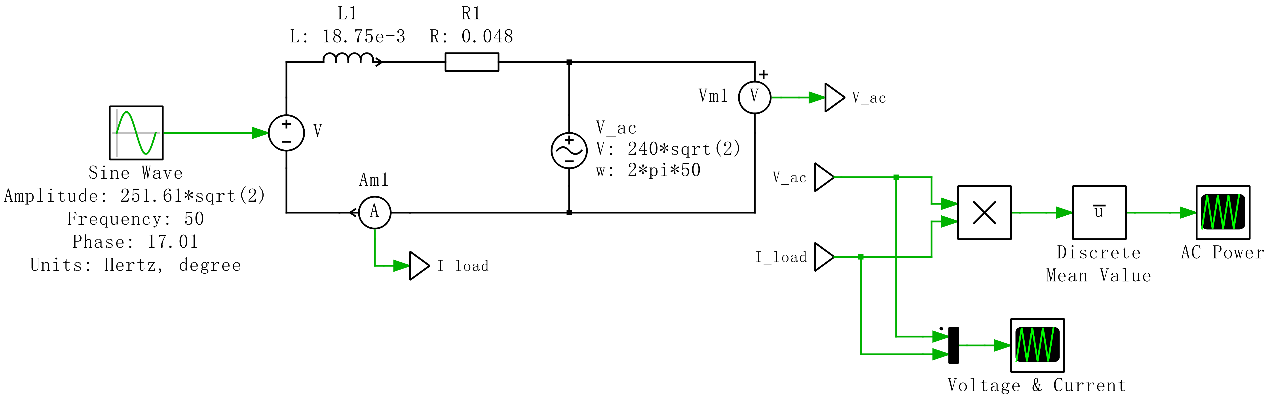
*Eqn.6*

Thus, the phasor expression of inverter output voltage could be given by:

*Eqn.7*

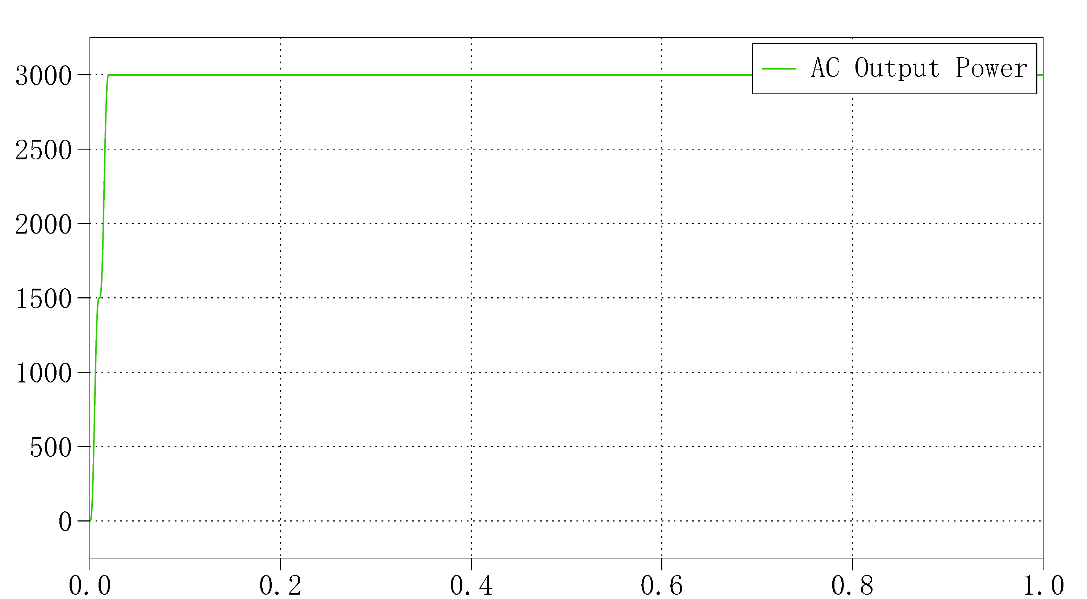
*Eqn.8*

Verifying the above parameters in simulation, the schematic is shown in **Figure 2** below.

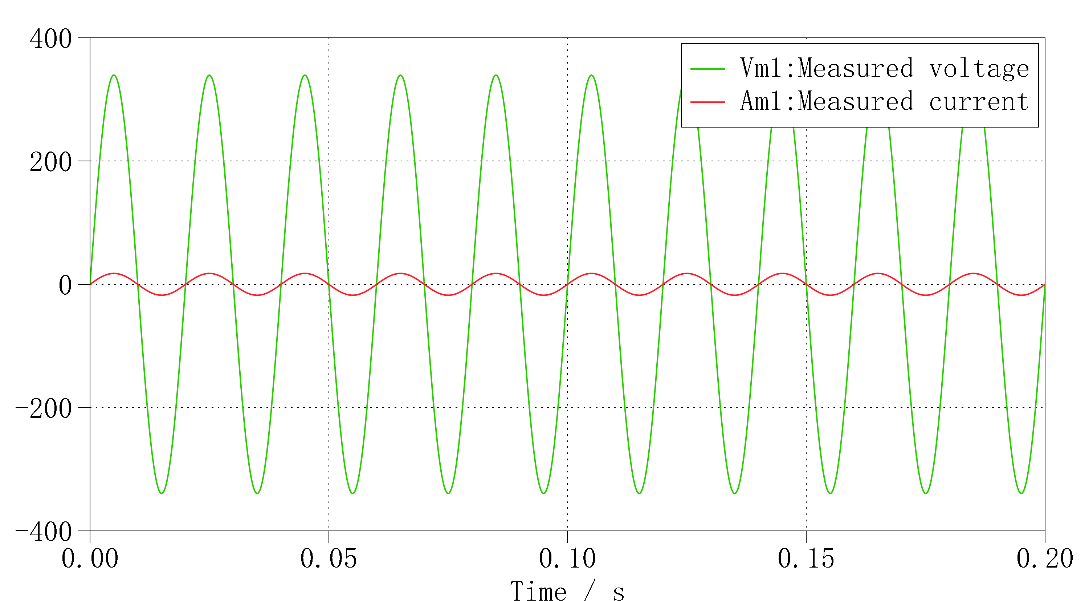


**Figure 2.** Verification Circuit of RL Filter

A ‘Discrete Mean Value’ module has been used to obtain the averaged AC power, the ‘sample time’ has been set to be 0.0002 and ‘number of samples’ has been set to be 100 to ensure the fundamental frequency is 50 Hz. The waveform output power to the AC grid is shown in **Figure 3**, and the waveform of AC voltage and current are shown in **Figure 4**.



**Figure 3.** Waveform of AC Output Power (to the grid)



**Figure 4.** Waveform of AC Voltage and Current

It can be observed from **Figure 3** that the cursor reading of the AC output power at steady state is 2998.96 W, which is quite closed to the required 3 kW. The reason for the power reading is slightly lower than 3 kW could be due to the decimal rounding error of calculated inverter output voltage . In addition, the cursor reading of AC voltage and current in **Figure 4** are 339.411 V and 17.6722 A respectively, which is almost equal to the required voltage peak of and current peak of .

1. **Current Controller Design**

According to the required settling time of inverter , specification of controller design could be given in *Eqn.9*, where the damping ratio determines the degree of overshoot in a step response, and natural frequency determines the speed of response.

*Eqn.9*

The transfer function of RL filter could be given by:

*Eqn.10*

It can be seen that the RL filter is a 1st order type 0 plant, so PI controller could be used as the current controller. The transfer function of current controller could be given by:

*Eqn.11*

The control diagram could be represented in **Figure 5** below.

图示

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**Figure 5.** Control Diagram of Current Controller (Closed Loop)

The open loop transfer function could be given by:

*Eqn.12*

Thus, the expression of the above closed loop system could be represented by:

*Eqn.13*

As the general transfer function of 2nd order system could be represented by:

*Eqn.14*

Comparing *Eqn.13* and *Eqn.14*, expression of PI controller’s parameter ( and ) could be obtained as below.

*Eqn.15*

According to the design specification identified in *Eqn.9,* the values of PI controller’s parameter could be given by:

*Eqn.16*

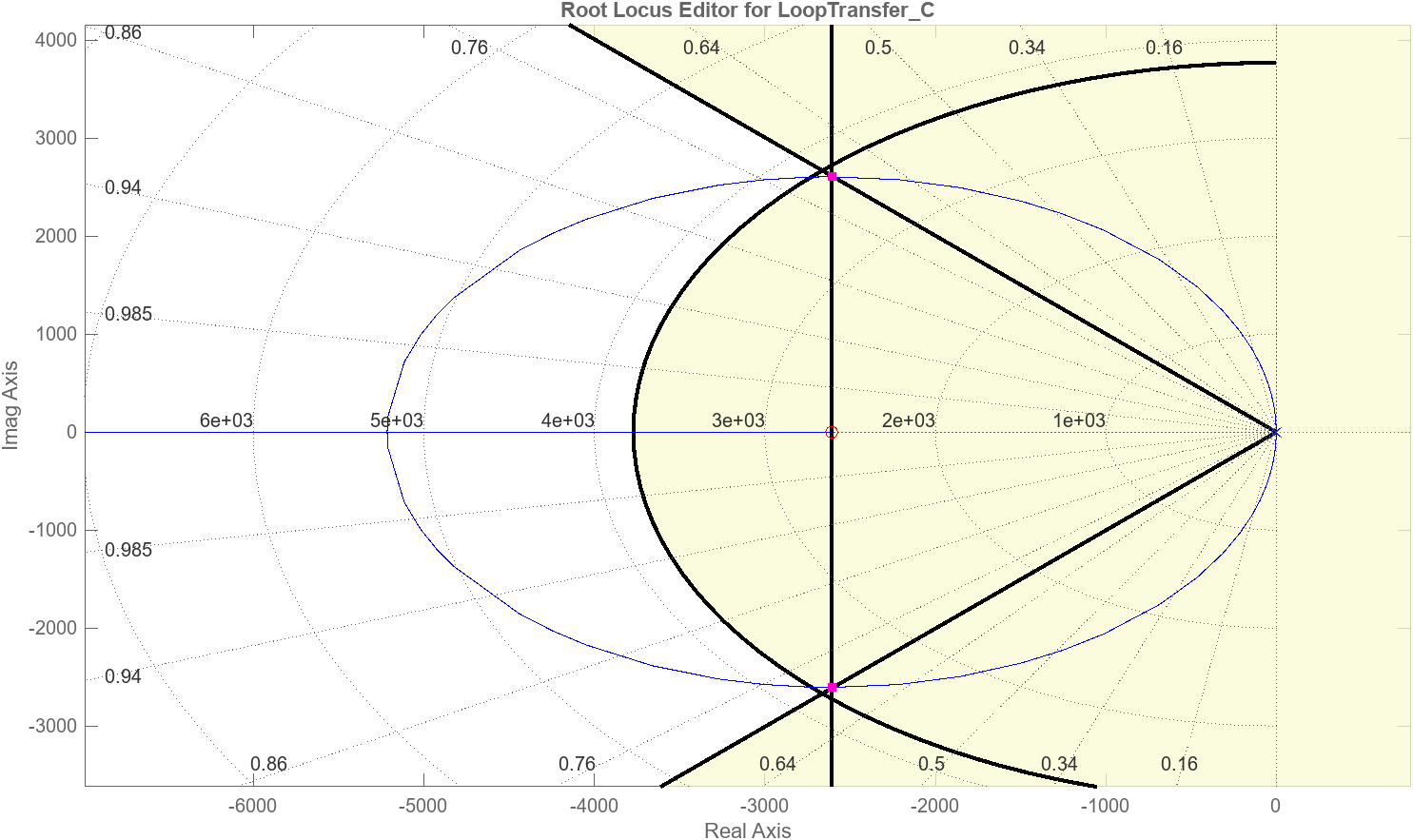
Thus, the current controller could be given by:

*Eqn.17*

Use ‘sisotool’ in MATLAB to verify the current controller parameters, the procedure could be divided into four steps:

1. Enter the transfer function of the plant as parameter of ‘sisotool’.
2. Add an integrator and a real zero to form a PI controller.
3. Specify the design specifications (damping ratio, natural frequency, settling time).
4. Move the zeros and poles to obtain the transfer function of designed controller.

Then, the root locus of the current controller could be given, which is shown in **Figure 6** below.



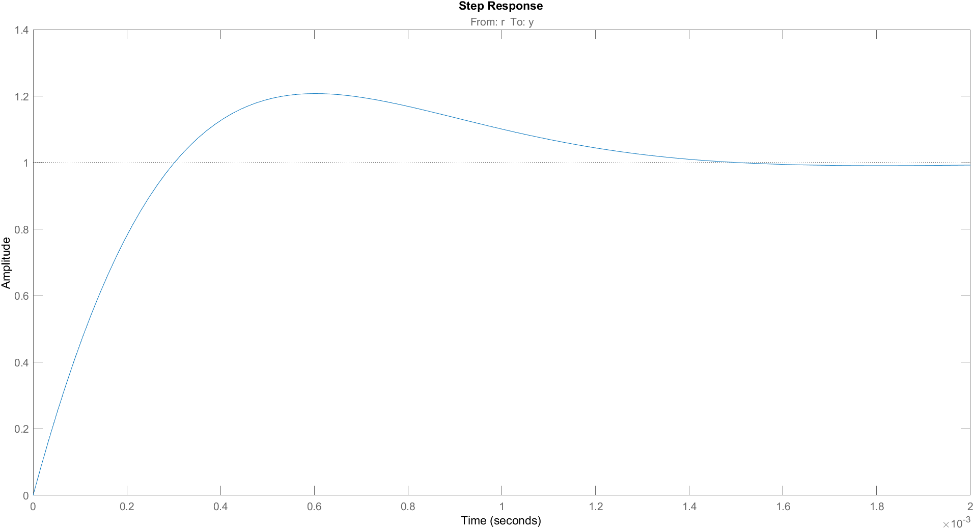
**Figure 6.** Root Locus of the Designed Current Controller

According to the result in MATLAB, the transfer function of current controller could be expressed by:

*Eqn.18*

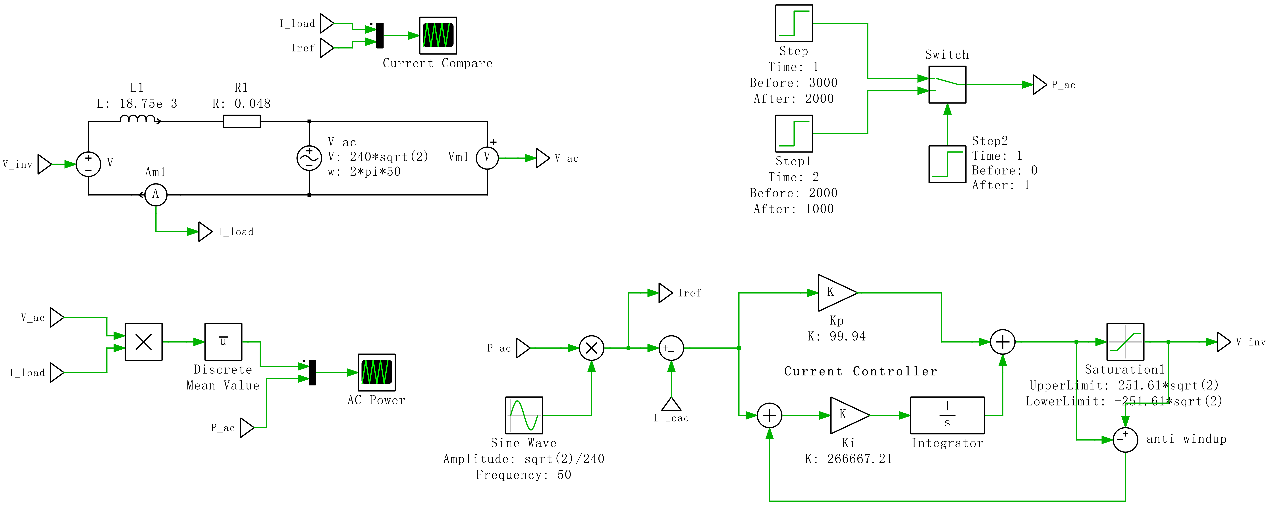
The reason why the obtained result is slightly different from the calculated value could be due to

The step response of current controller is shown in the **Figure 7**, which meets the design requirement of settled within 1.5 ms.



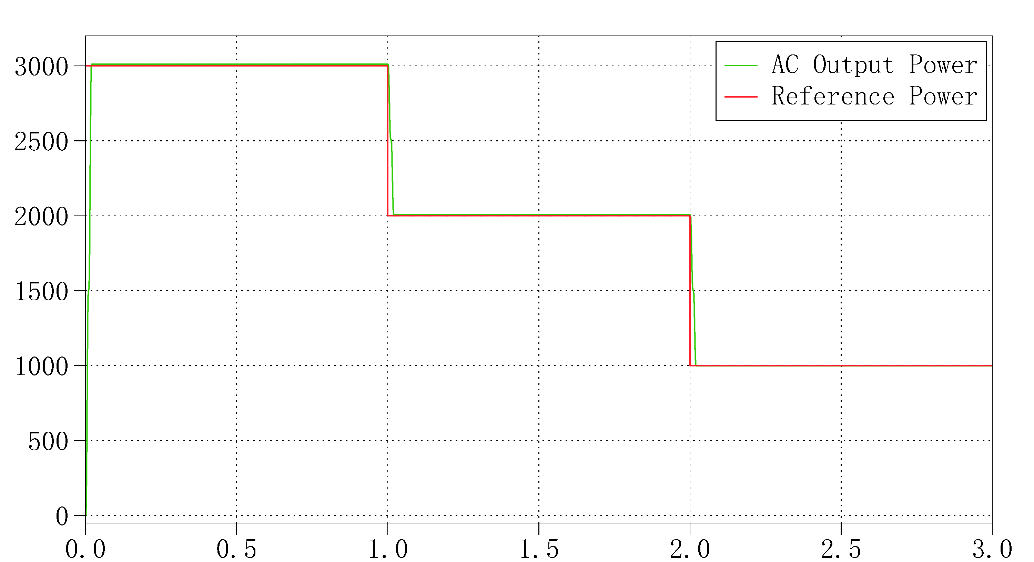
**Figure 7.** Step Response of Current Controller

To verify the performance of current controller, the inverter was tested under different power levels, ranging from 1 kW to 3kW. The overall testing schematic of current controller is shown in **Figure 8** below.



**Figure 8.** Verification Circuit of Current Controller

The RMS value of reference current is derived from the rated active power divided by the AC voltage RMS value (240 V). The difference value between and AC current can be referred as ‘error’, which is also the input of current controller. A ‘saturation’ module is used to set limit to the output (the inverter voltage, limited within to ). A ‘anti-windup’ feedback loop is also added to the integrator to prevent closed-loop instability. The waveform of reference active power and AC output power are compared in **Figure 9** below.



**Figure 9.** Comparison between Reference Active Power and AC Output Power

The waveforms of AC current under different power level are presented in **Figure 10**.