MITIGATION OF HARMONICS USING TUNED FILTERS

A Skill Test Report

submitted by

BACHELOR OF ENGINEERING in

ELECTRICAL AND ELECTRONICS ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

University College of Engineering, Anna University-BIT Campus,

Trichy-620 024

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CONTENT

STAFF SIGNATURE

EXPERIMENT-5

Mitigation of harmonics using tuned filters

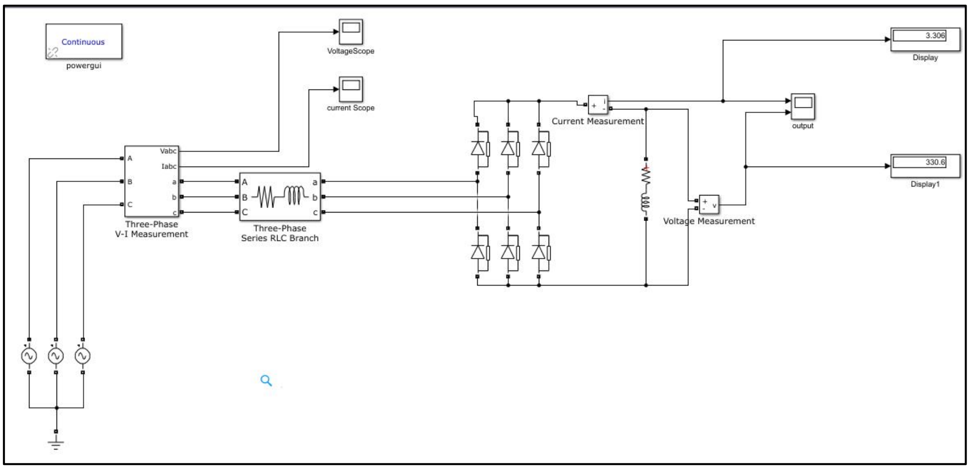
Objective:

To mitigate the harmonics using filters such as single tuned and double tuned filters.

Software Required:

MATLAB R2017a.

Circuit Diagram:

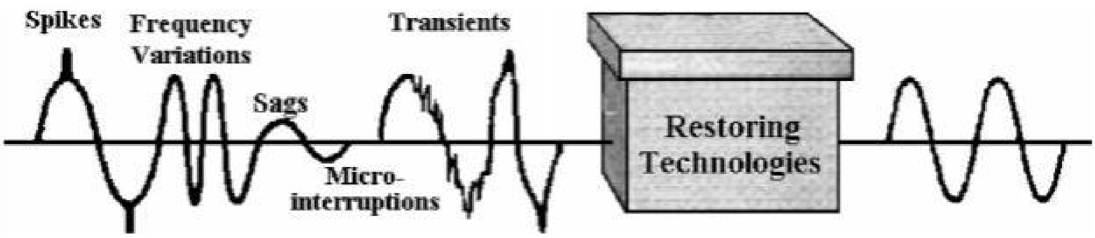


Theory:

Introduction:

Harmonic signal can be described as a signal whose frequency is the integer multiple of the fundamental /reference frequency. Mathematically, it is described as the ratio of the frequency of such a signal to the frequency of the reference signal . Power distribution system is designed to operate with sinusoidal voltage and current waveform at constant frequency. However, when non linear load like thyristor drives, converters and arc furnace are connected to the system, excessive harmonic currents are generated and this causes both current and voltage distortions. These harmonics pollute the PS and produce many adverse effects like malfunction of sensitive equipment, reduced power factor, overloading of capacitor, flickering lights, overheating of equipment's, reduced system capacity, etc. Few of the other reported harmonic effects include: excessive current in neutral wire, overheating of the motor, microprocessor problem and unexplained computer crash. Its more effect can be found at distribution grid stations as well as industrial sectors where it causes higher transformer losses, line losses, reactive power and resonance problems, untoward protection system activations, harmonic interactions between customers or between the utility and the load. Basically, the common source of harmonic signal is nonlinear load. It is due to the fact that current does not vary smoothly with voltage. Nonlinear load such as fluorescent lamp, electric welding machine and three-phase rectifier generates primarily 5th and 7th current harmonic and some of higher order harmonics.

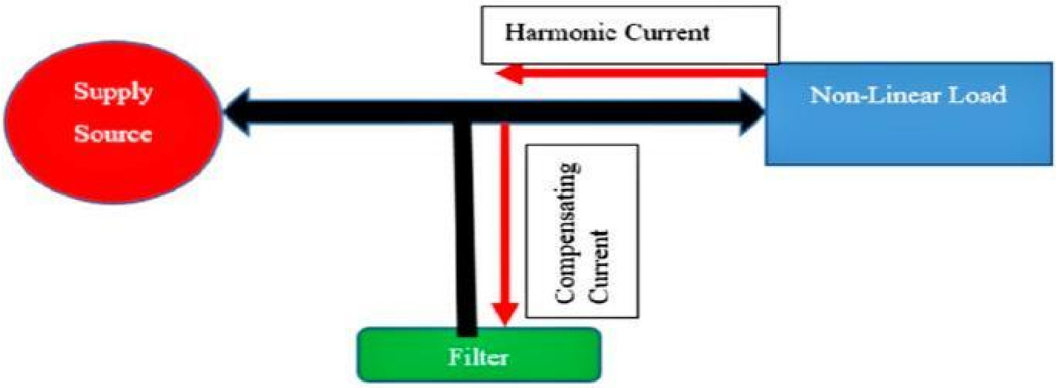
The harmonic signal cannot be totally mitigated, but it can be reduced by several ways, such as by using active filters, passive filters and hybrid filters. The common practice for harmonic mitigation is the installation of passive harmonic filters due to many advantages. Passive filters are the simplest, no power supply required and exhibit the best relationship cost-benefit among all other mitigation techniques when dealing with low and medium voltage rectifier system.



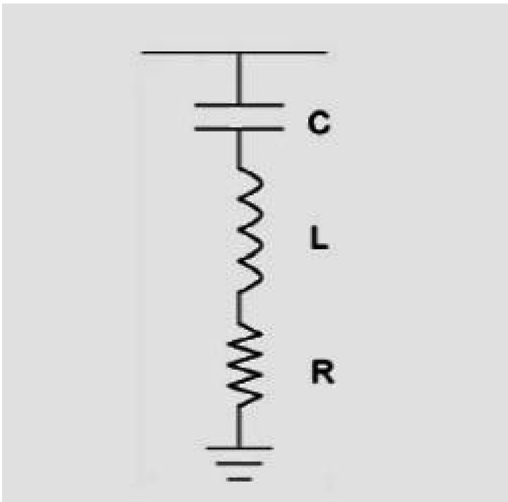
Single Tuned Filter:

The single tuned filter is the most common type of filter which is used in industry for mitigating the harmonic. This filter is inexpensive and simplest compared with other filters for mitigating the harmonic problems.

Harmonic current flowing due to non-linear load:



Single Tuned Filter:



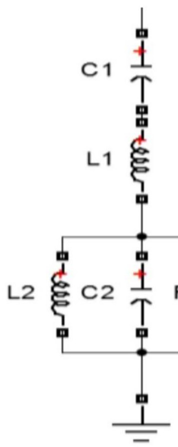
This filter is connected in shunt with the distribution system and it will offer low impedance to current through which harmonic current will tend to divert in the system. A very simple arrangement of the single tuned passive filter is shown in the above figure For designing the single tuned passive filter, it is important to calculate an appropriate resistor, capacitor and inductor values that enable to mitigate harmonics in power frequency.

Double Tuned Filter :

The double tuned filter can be designed by either equivalent method or parametric method. In this proposed research paper, equivalent method has been used. The conventional double tuned filter is as shown . It is having a series resonant and shunt resonant circuit . Double tuned passive filter & equivalent single tuned passive filters It can filter two lower order (3rd, 5th, 7th etc.) harmonics with a single circuit whereas for single tuned, it requires two separate parallel circuits. The series circuit gives series resonant frequency (sw) and parallel circuit gives parallel resonant frequency (pw).

These two resonance frequencies can filter two dominant lower order current harmonics from the power system with single circuit. Double tuned passive filter gives better performance when compared to the two single tuned passive filters .In this proposed research, by using parameters of two single tuned filters, the double tuned filter was designed. At resonant frequencies, the reactance of inductor is equal to the reactance of a capacitor. The double tuned passive power filter provides low impedance path to the two lower order current harmonics

Double tuned filter:



Configure the POWERGUI Block for FFT Analysis:

The PowerGUI block is necessary for performing FFT and other power system analyses in
Simulink. Follow these steps:
1) Add a PowerGUI block to your Simulink model.
2) Double-click the PowerGUI block and select Configure Simulation Parameters.
3) Ensure the solver is set to Discrete with a small-time step (e.g., 1e-5 seconds).
Once the simulation runs, this block allows you to analyse the waveform and calculate
harmonics using FFT.

Perform FFT Harmonics Analysis:

Now, we'll use the FFT tool in the PowerGUI block to analyse the harmonics of the output voltage waveform.

Step 1: Double-click the PowerGUI block.

Step 2: From the PowerGUI menu, select FFT Analysis.

Step 3: In the FFT Analysis window:

Select the signal to analyse, which is the output voltage waveform. Set the Fundamental frequency to 50 Hz (assuming a 50 Hz system). Set the Start Time for the analysis. Choose a time after transients have settled, for example, 0.04 seconds to ensure steady tate conditions. Set the number of cycles to analyse. For accuracy, analyse at least 3 cycles (set this to 3).

Step 4: Click Display to generate the FFT plot.

Derivation for Tuned Filters:

Capacitor can design to trap a certain harmonics by employing a tuning reactor whose inductive reactance is equal to capacitive reactance of the capacitor at tuned frequency.

Parallel resonance involving a capacitor and a source inductance it can be achieved

$$\boxed{Xcr = Xc1/h_r = Xsr = h_r X s1}$$

where,

- Xcr = capacitor reactance at resonance
- Xc1 = capacitor reactance at fundamental frequency
- h_r = harmonic order activating resonance
- Xsr (or) Xl1 = source inductive reactance
- Xs1 = source inductive reactance at fundamental frequency
- fr = resonance frequency (fr = hrf1)
- f1 = fundamental frequency (50 Hz)
- Qc = capacitor rating per unit

$$\boxed{Q_c = 1/ Xc1 \text{ pu}}$$

- Scc - Short Circuit Capacity of the bus in MVA

$$\boxed{Scc = 1/Xs1 \text{ pu}}$$

At resonant frequency [ωr or h_r]

$$\omega r = hr\omega 1 = 1/\sqrt{(L_{s1}C_{1})} \text{ rad/sec}$$

Or

$$f_r = h_r f1$$

The above equation can be rewritten as ,

$$\boxed{fr = fr/f1 = 1/ w1 \sqrt{(L_{S1}C1)} \text{ Hz}}$$

The above equation the capacitor with a reactance

$$\boxed{Xc1 = h_r^2 Xs1}$$

It excites resonance at h_r^{th} harmonic frequency .

Turning the capacitor for a certain harmonic alternatively designing the capacitor to trap a certain harmonic it requires addition of reactor .

At the tuned harmonic ,

$$\boxed{X_{ln} = h_n X_{L1}}$$

$$\boxed{X_{Ln} = h_n X_{L1} = Xcn = X_{c1}/h_n = X_n}$$

- Xn = characteristics reactance,

$$\boxed{Xn = X_{Ln} = X_{nc}}$$

- X_{Ln} = reactor inductive reactance at tuned frequency
- X_{L1} = Inductive reactor at fundamental frequency
-
- X_{cn} = Capacitor reactance at tuned frequency

$$\boxed{Xcn = \sqrt{L1/C1}}$$

- h_n = tuning order alternatively harmonic order to which capacitor is tuned are which is to be filter
-
- fn tuning frequency

$$\boxed{f_n = h_n f1}$$

from above equation characteristics equation

$$\boxed{X_n = \sqrt{(X_{l1} X_{c1})} = \sqrt{(L1 / C1)}}$$

Now tuned frequency is

$$\boxed{\omega = h_n\,\omega 1 = 1/\sqrt{(L1\ C1)}\ \text{rad/sec}}$$

or

$$\boxed{f_n = h_n\,f1 = 1/2\pi\sqrt{(L_1\ C_1)}\ \text{Hz}}$$

The reactor inductive reactance can be found as

$$\boxed{X_{l1} = Xc1/\ h_n = (h_r^2/\ \ h_n^2\ )X_{s1}}$$

The capacitor tuned to the harmonic activating resonance

The equation reduced by $\boxed{X_{l1} = Xs1}$

Now, $h_n = fn/f1 = 1/\ \omega 1\sqrt{(\ L1\ C1)} = \sqrt{(Xc1/X_{l1})}$

$= hr\ \sqrt{(Xs1/\ X_{l1})}$

Mathematical calculation for single tuned filter model:

11th harmonic order tuned filter : A 33kv,6.2MVA capacitor bank is to be installed at bus where the short circuit capacity is 750MVA.Design the capacitor bank to trap the 11th harmonic by adding a reactors and plot the impedance graph for the 33kv bus system

Solution:

Harmonic order, $h_n = fr/f1$

$= \sqrt{(Xc/Xs)}$

$= \sqrt{(scc/Qc)}$

$= \sqrt{(750MVA/6.2MVA)}$

$= 10.998$

$\boxed{\mathbf{h_n=11th\ harmonic}}$

Capacitive Reactance, $Xc= (kv^2/Qc)$

$= ((33\times10^3)^2/(6.2\times10^6))$

$\boxed{\mathbf{Xc\ \ = 175.6\ \Omega}}$

Inductive Reactance, $X_l= (Xc/h_n^2)$

$= (\ 175.6/11^2)$

$\boxed{\mathbf{X_l= 1.452\Omega}}$

Now, assume that Q = 60(Quality factor)

Q lies between $30 < Q > 100$

The reactor would have resistance of,

Characteristics reactance, $X_n = \sqrt{(X_l . X_c)}$

$= \sqrt{(1.45 \times 175.6)}$

$\boxed{\mathbf{X_n = 16\ \Omega}}$

$R = X_n/Q$

$= 16/60$

$= 0.2667$

$\boxed{\mathbf{R = 0.3\ \Omega}}$

The filter impedance plotted using this formula,

$Z_F(h) = [\ R + j((h.X_L)-(X_c/h))\ ]$ ohm

$= [\ 0.266 + j((11 \times 1.452)-(175.6/11))]$

$= [\ 0.266 + j(15.972-15.96)\ ]$

$\mathbf{Z_F(h) = 0.266 + j0.012\Omega}$

$\boxed{\mathbf{Z_F(h) = 0.266 < 2.5\Omega}}$

The rating of filter is sizing by

$Q_{filter} = ((kv^2)/(X_c-X_l))$

. $= ((hn^2)/((h^2)-1)).Q_c$

$= (11^2)/((11^2)-1)$

$= 1.0083 \times 6.2$

$\boxed{\mathbf{Q_{filter} = 6.252\ MVAr}}$

Mathematical calculation for double tuned filter model:

Design a double tuned filter to eliminate the 11th and 13th harmonic with a 33Kv, 6.2 MVA, ,a capacitor bank is to be installed at a bus where the short circuit capacity is 750MVA.

Solution:

For 11^{th} harmonics,

Harmonic order, $h1 = fr/f1$

$= \sqrt{(X_{c1}/X_s)}$

$= \sqrt{(scc/Q_{c1})}$

$= \sqrt{(750MVA/6.2MVA)}$

$= 10.998$

$\boxed{\mathbf{h_1 = 11th\ harmonic}}$

Capacitive Reactance, $X_{c1} = (kv^2/Q_c)$

$= ((33 \times 10^3)^2/(6.2 \times 10^6))$

$\boxed{\mathbf{X_{c1} = 175.6\ \Omega}}$

Inductive Reactance, X_{l1}= $(Xc1/h1^2)$
= $(175.6/11^2)$

$\boxed{\mathbf{X_{l1}= 1.452\Omega}}$

Now, assume that Q = 60(Quality factor)

Q lies between 30 < Q > 100

The reactor would have resistance of,

Characteristics reactance, $Xn_1 = \sqrt{(X_{l1}.Xc_1)}$
$= \sqrt{(1.45\times175.6)}$

$\boxed{\mathbf{Xn_1 = 16\ \Omega}}$

For 13th harmonics,

$fr/f2=\sqrt{(Scc/Q_{c2})}$

$13=\sqrt{(750/Qc_2)}$

$13^2=(750/Qc_2)$

Q_{c2} =750/169

$\boxed{\mathbf{Q_{c2} = 4.4\ MVA}}$

Capacitive reactance, $X_{c2} = Kv^2/Qc_2$
= (33 x10^3)^2/(4.4 x 10^6)

$\boxed{X_{c2}= \mathbf{247.5\Omega}}$

Inductive reactance, $X_{l2} = X_{c2}/h2^2$

X_{l2} = 247.5/13^2

$\boxed{\mathbf{X_{l2} = 1.47\ \Omega}}$

Here Quality factor is ,Q = 60

Characteristics reactance, $Xn2=\sqrt{(Xl2Xc2)}$

$X_{n2} = \sqrt{(1.47 \times 247.5)}$

X_{n2} = 19

$R = X_{n1}/Q= Xn2/Q$

R_1 = 16/60

$\boxed{\mathbf{R_1 = 0.3\ \Omega}}$

R_2 =19/60

$\boxed{\mathbf{R_2=0.3\Omega}}$

Therfore, $\boxed{\mathbf{R = 0.3\Omega}}$

Impedance plotted using this formula,

Impedance at 11th harmonics

$Z_F(1) = [R + j((h_1.X_{L1})-(Xc_1/h_1))]$ ohm

$= [0.266 + j((11\times1.452)-(175.6/11))]$

$= [0.266 + j(15.972-15.96)]$

$\mathbf{Z_F(1) = 0.266 + j0.012\Omega}$

Impedance at 13th harmonic ,$Z_F(2) = R + j ((h_2X_{l2}) - (X_{c2}/h_2))$

$= 0.3 +j (13 \times 1.47) - (247.5/ 13))$

$\boxed{\mathbf{Z_F(2) = 0.3 + j\ 0.08\Omega}}$

Total Impedance $Z_F = 1/([1/Z_F(1)]+[1/Z_F(1)])$

$1/ Z_F(1) = 3.75 - j0.16$

$1/ Z_F(2) = 3.11 - j0.83$

$Z_F = 1/(3.75 - j0.16 +3.11 - j0.83)$

$Z_F = 0.142 + j0.021$

$\boxed{\mathbf{Z_F = 0.143<8.4\Omega}}$

The rating of filter is sizing by

$Q_{filter1}$ = h1^2/(h1^2 -1)

$= (11^2)/((11^2)-1)\ 6.2$

$= 1.0083\times6.2$

$\boxed{\mathbf{Q_{filter1} = 6.252\ MVAr}}$

$Q_{filter2} = h_2^2/(h_2^2 -1)$

$= 13^2/(13^3 - 1)$

$= 1.005$

$= 1.005 \times 4.4$

$\boxed{\mathbf{Q_{filter2} = 4.42\ MVAR}}$

$Q_{efffilter} = (Q_1Q_2)/(Q_1+Q2+(2Q_1Q_2))$

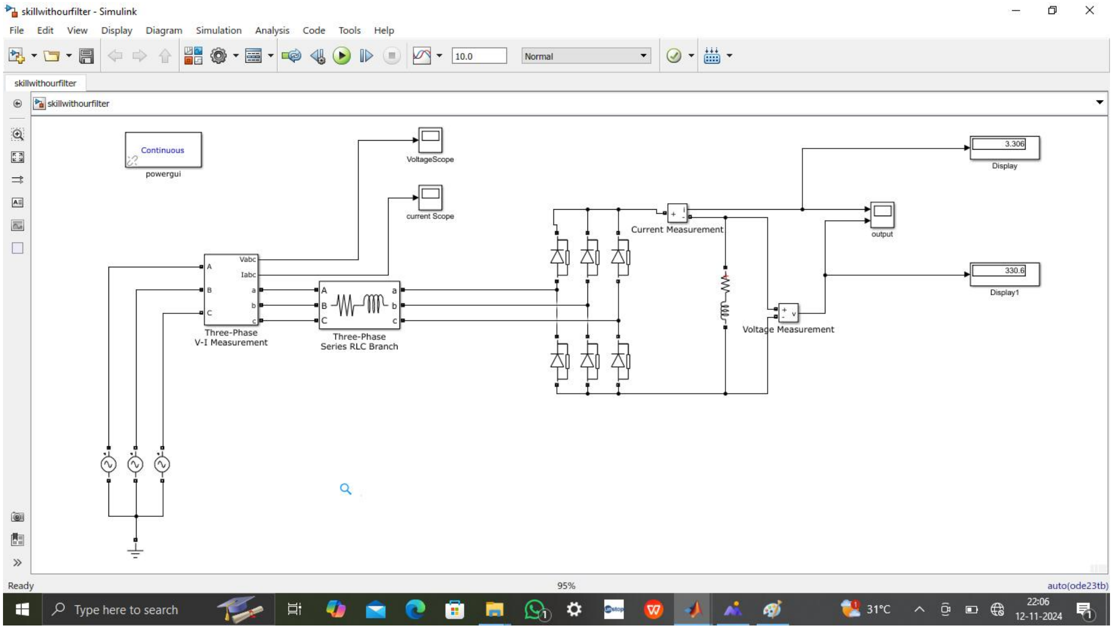
$= (27.625)/(6.252+4.42+(2*5.255))$

$\boxed{\mathbf{Q_{efffilter} = 1.3641\ MVAR}}$

SIMULATION:

1. SIMULATION OF GRID WITHOUT FILTER

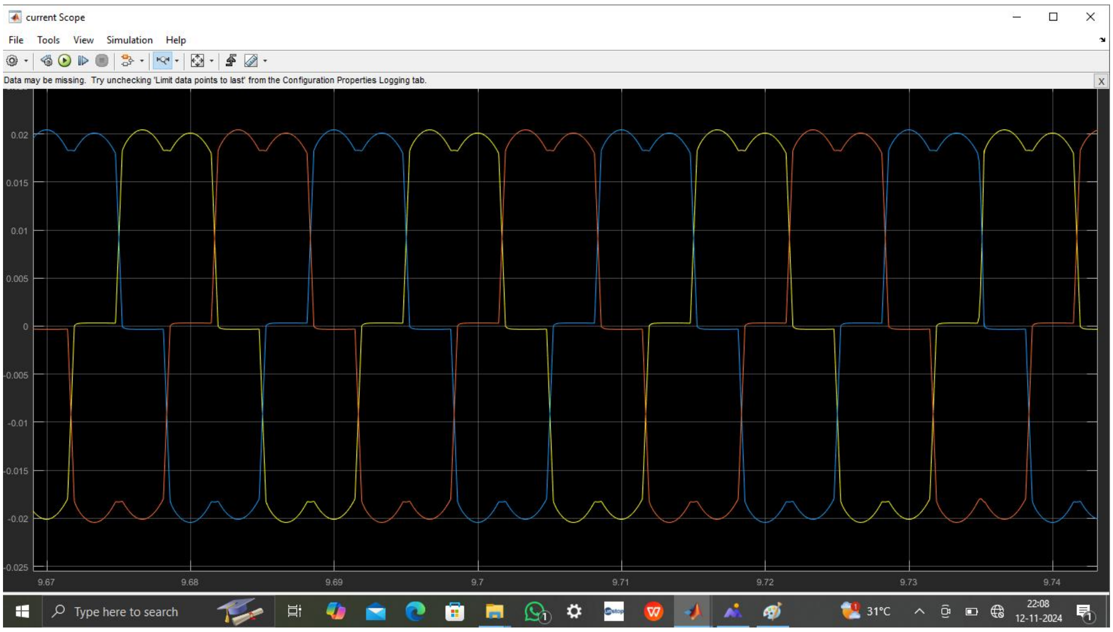
MODEL:



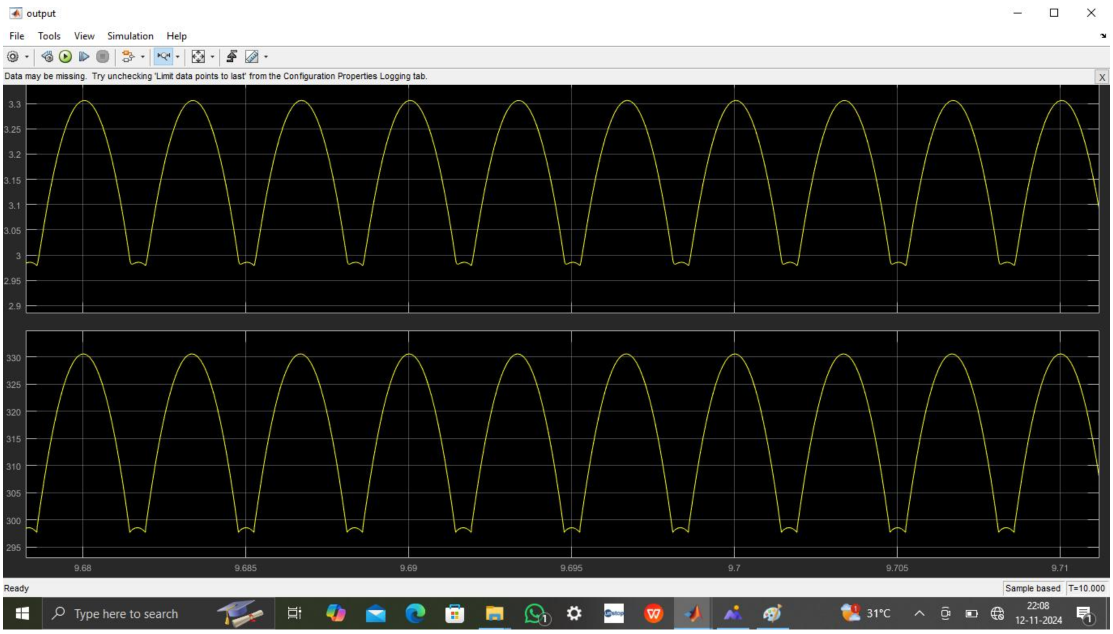
OUTPUT:

VOLTAGE SCOPE:

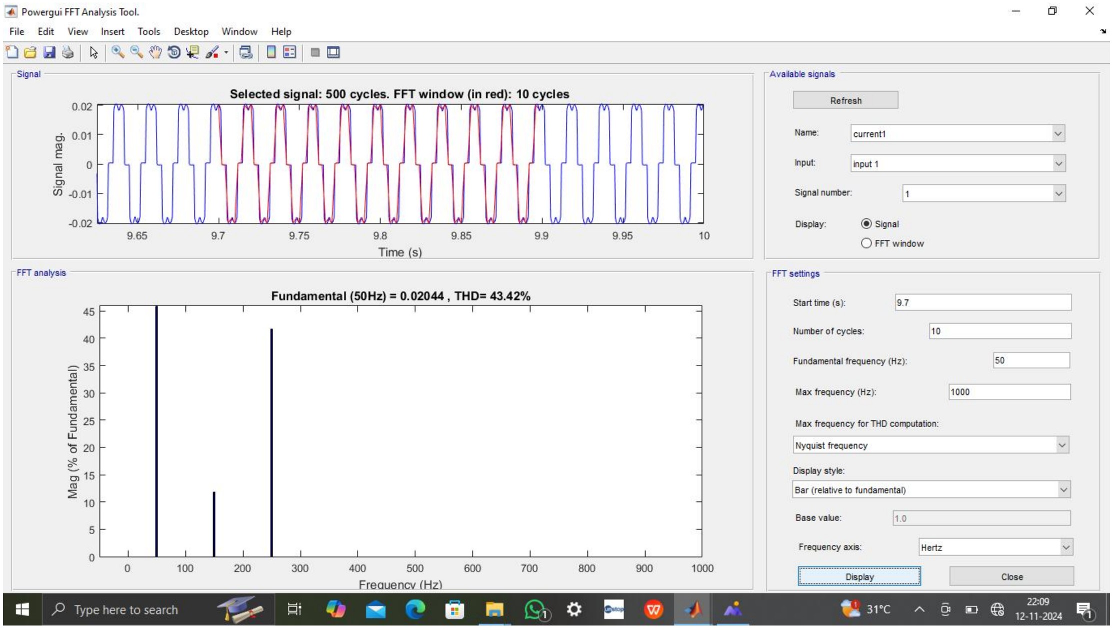
CURRENT SCOPE:



OUTPUT SCOPE:

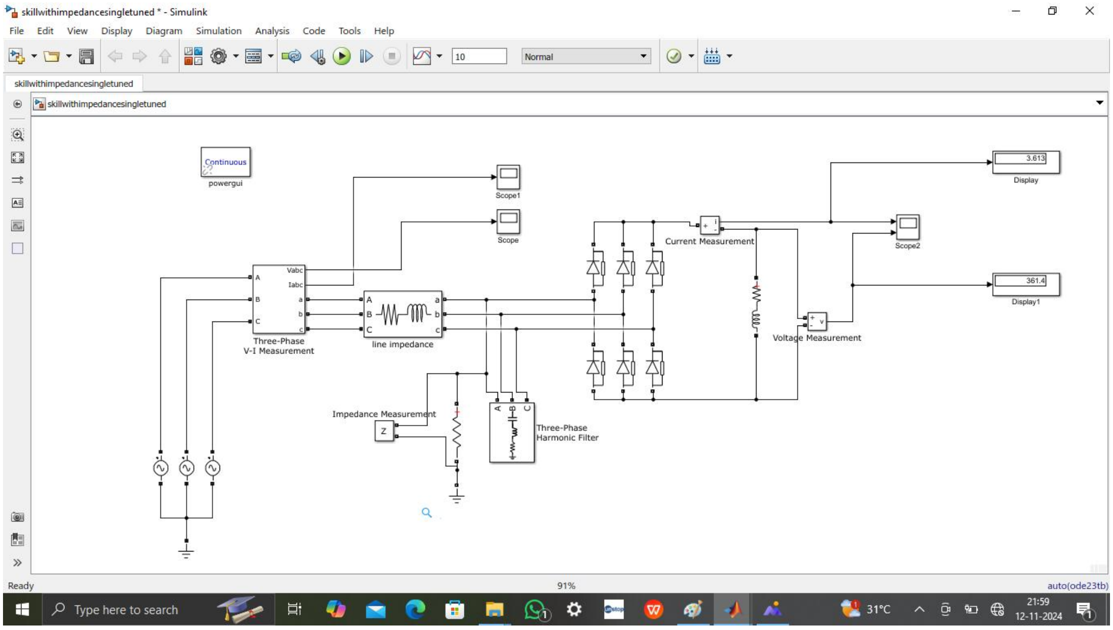


FFT ANALYSIS:



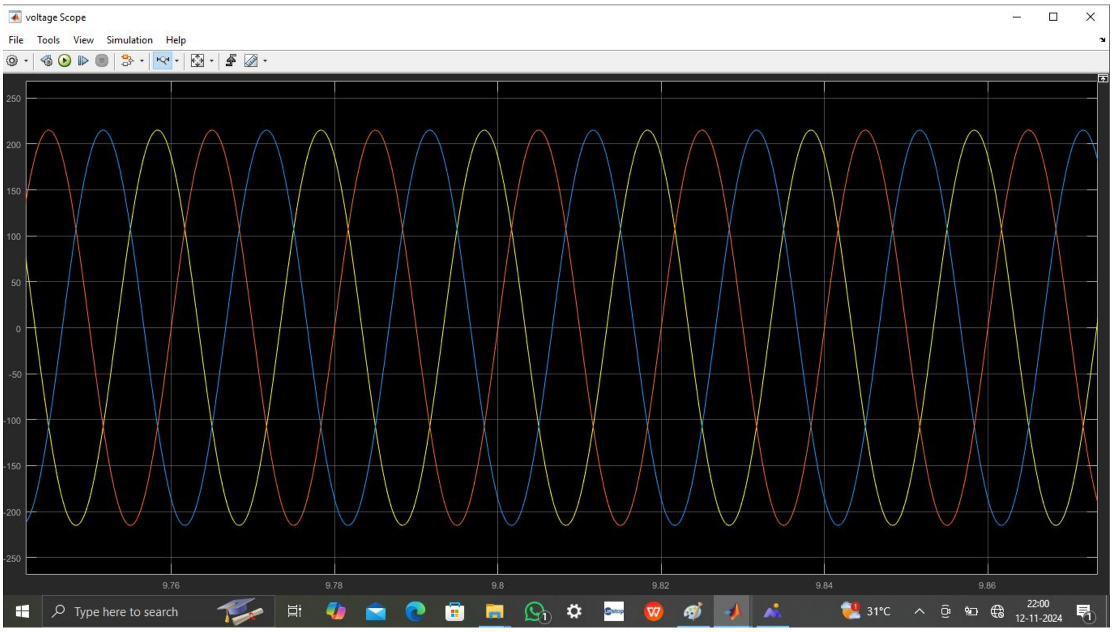
2.SIMULATION OF GRID WITH SINGLE TUNED FILTER:

MODEL:

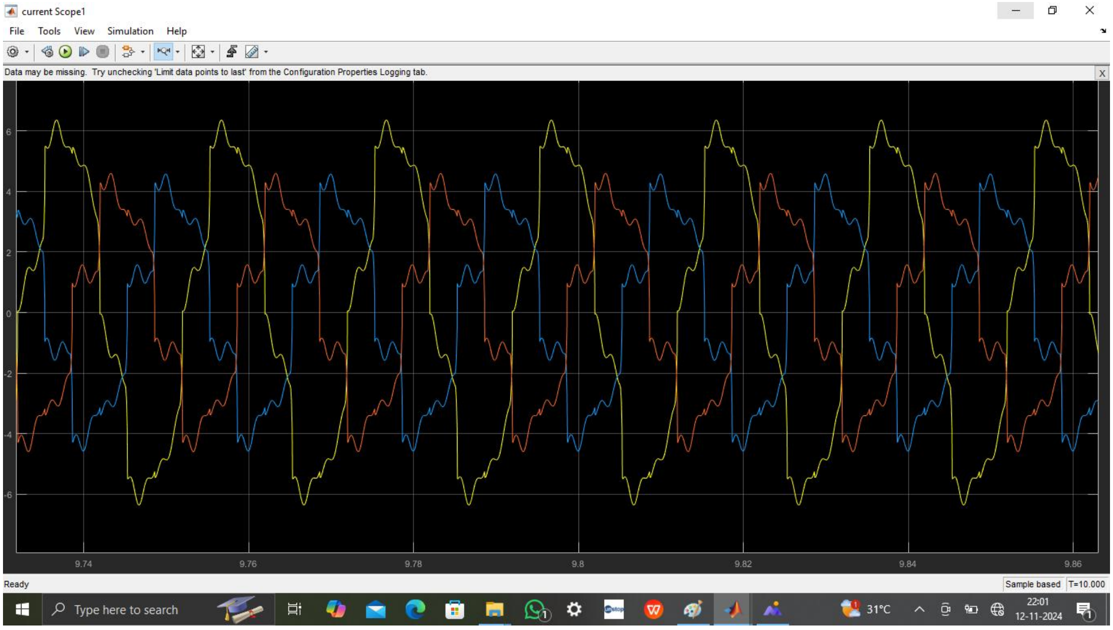


OUTPUT:

VOLTAGE SCOPE:

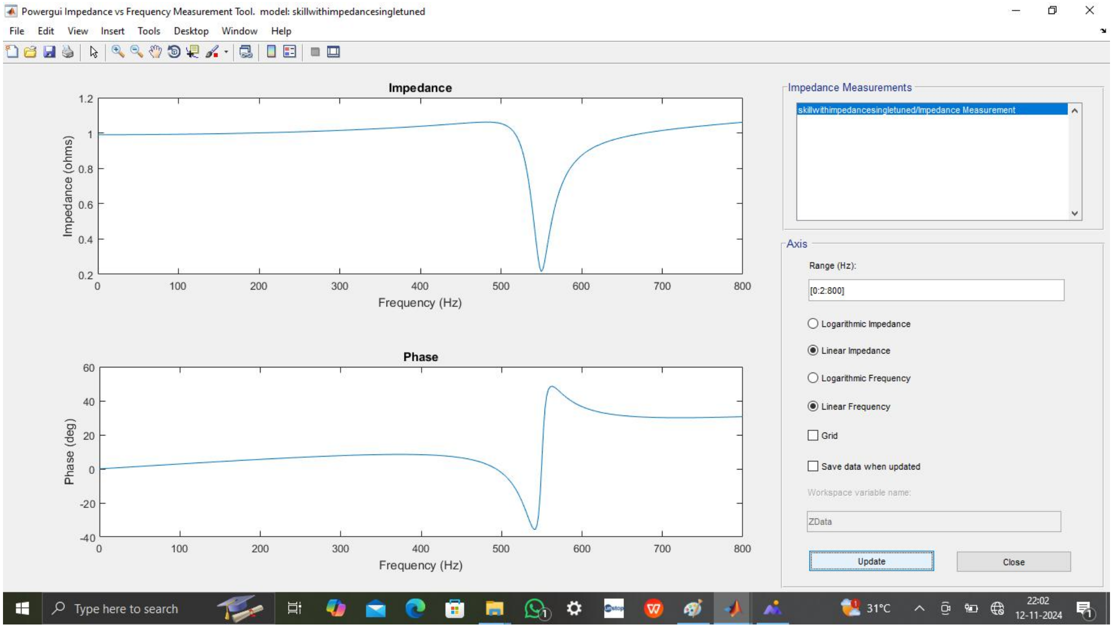


CURRENT SCOPE:

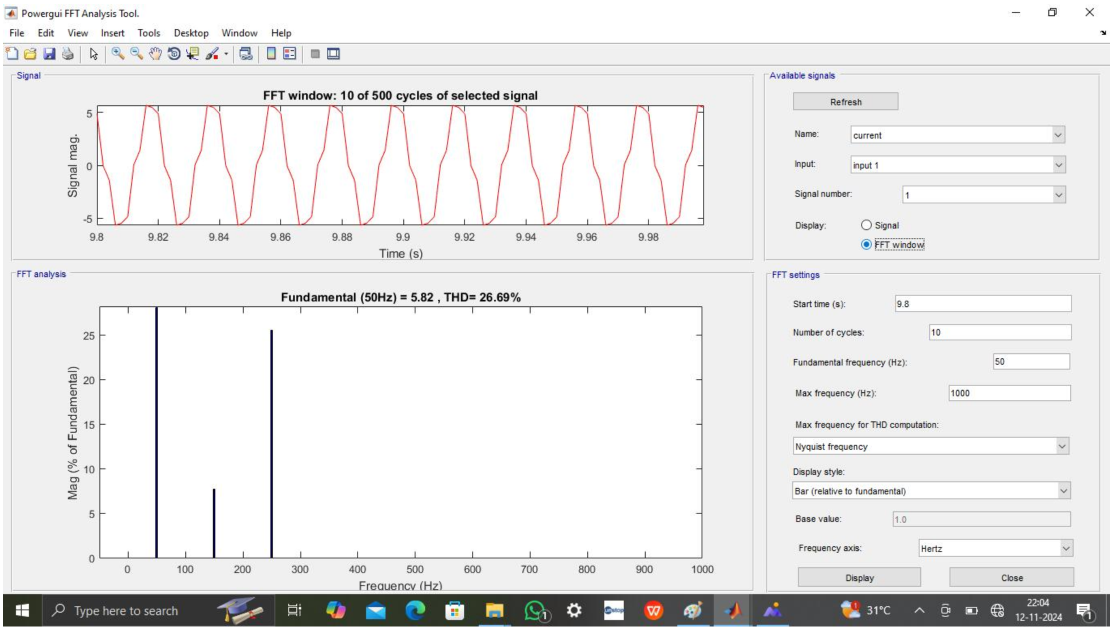


OUTPUT SCOPE:

IMPENDANCE ANALYSIS:

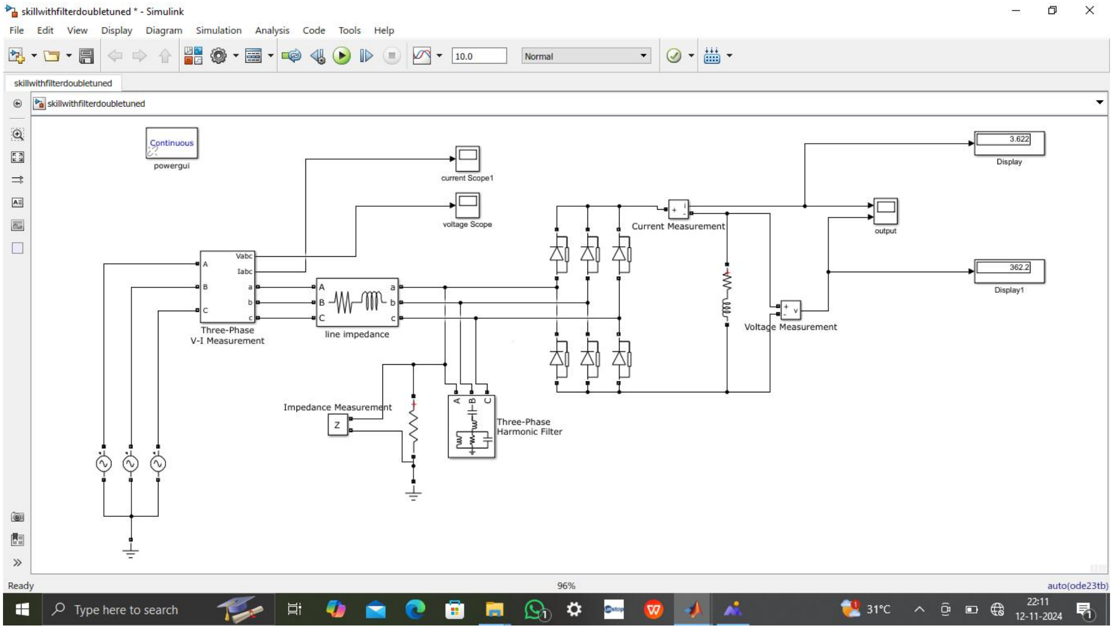


FFT ANALYSIS:



3.SIMULATION OF GRID WITH DOUBLE TUNED FILTER

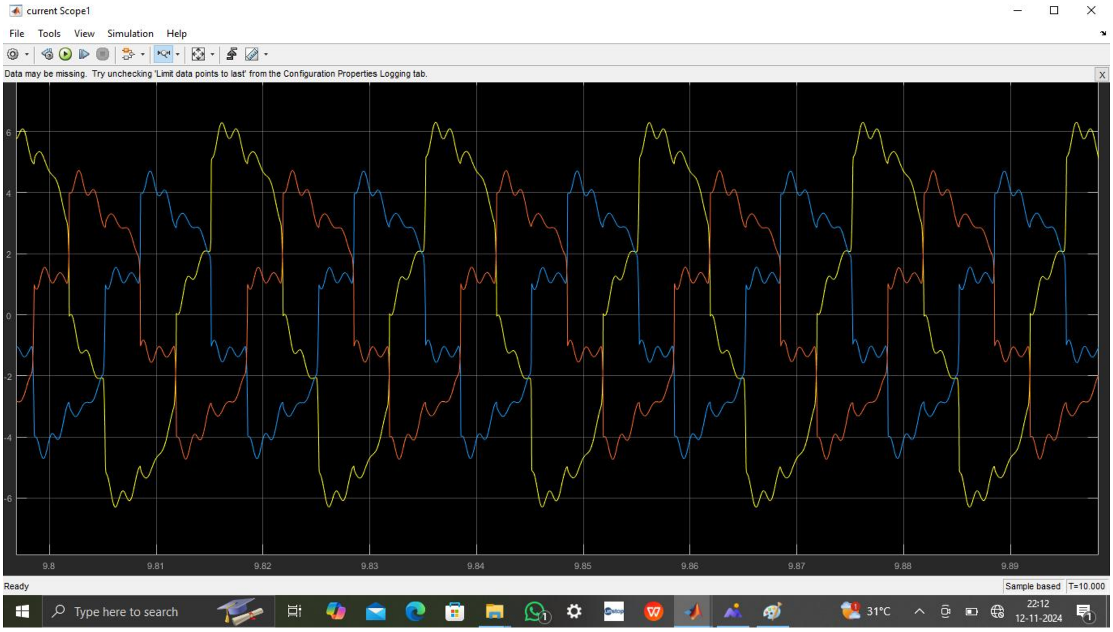
MODEL:



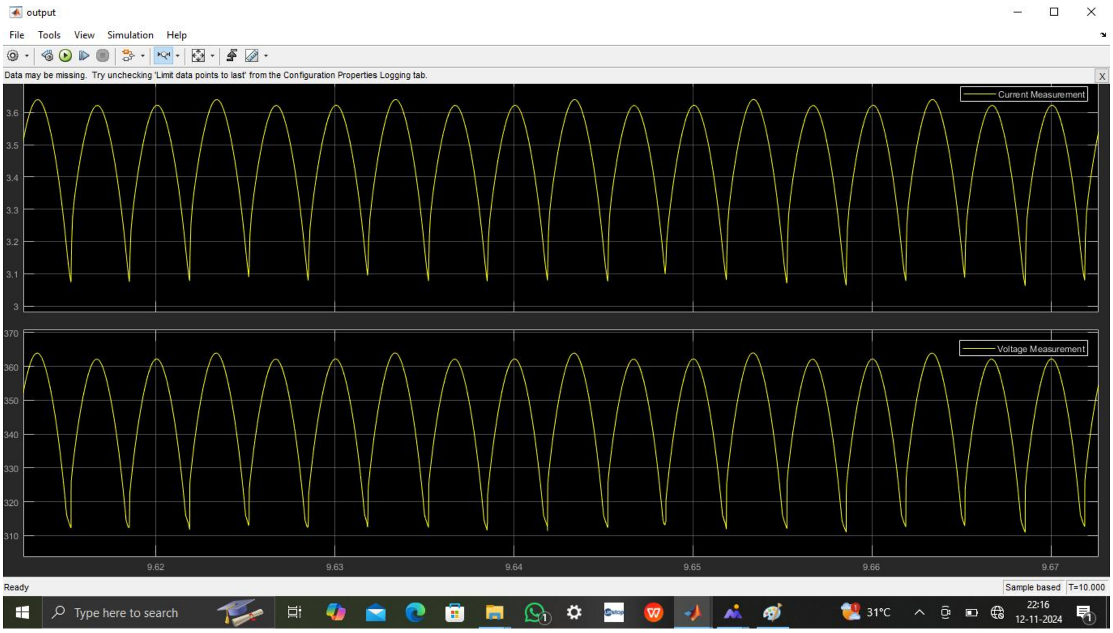
OUTPUT:

VOLTAGE SCOPE:

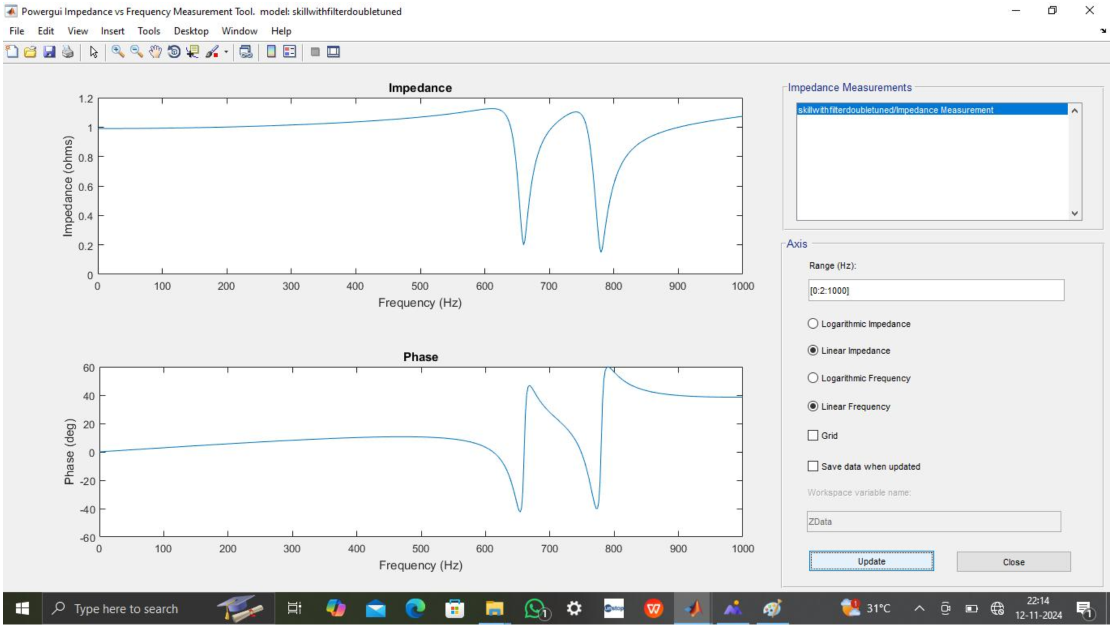
CURRENT SCOPE:



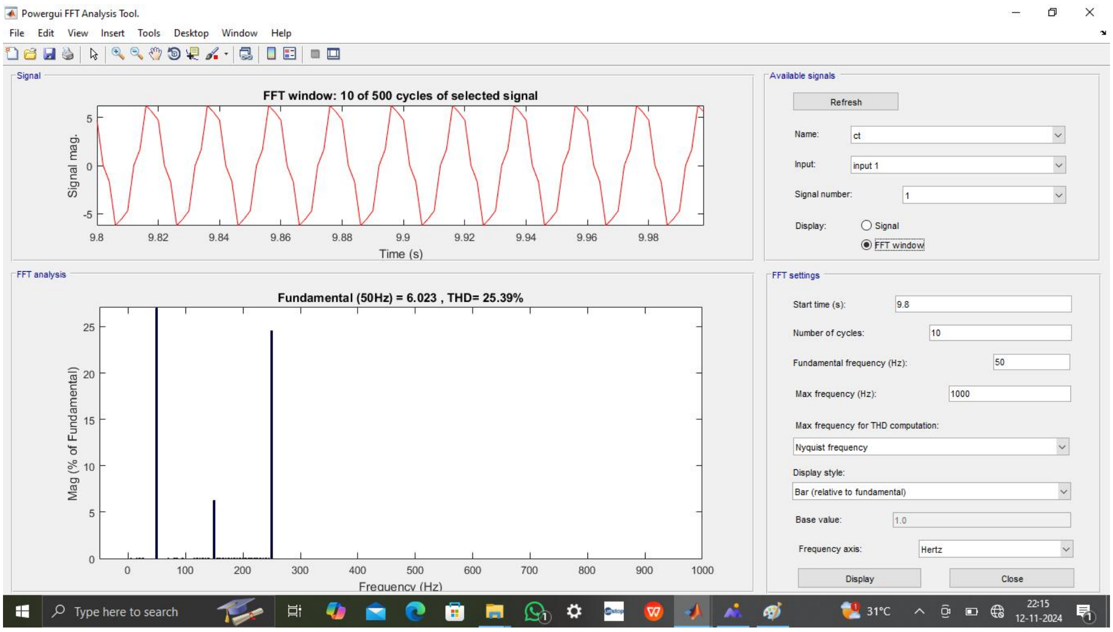
OUTPUT SCOPE:



IMPEDENCE ANALYSIS:



FFT ANALYSIS:



RESULT:

Thus the simulation for mitigation of harmonics using single and double tuned filter is done successfully and theoretical and practical results are verified.