NTP based Frequency Measurement

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Problem Statement

A power system is continually subject to disturbances in the form of load and generation changes, faults and equipment tripping. These disturbances give rise to electromechanical transients like inter-machine oscillations and system frequency changes. They can be observed in the frequency measurements at various locations in the grid. To study these transients, a wide area frequency measurement setup is implemented. The measurements are done at different locations in the NEW grid and time synchronized using the internet based Network Time Protocol (NTP). The measured frequency is time stamped and sent via the internet to a server. This system is low-cost, easy to implement and is a viable tool for tracking and studying system transients

Introduction

In modern power systems, maintaining stability amidst dynamic conditions is crucial. Wide area frequency measurement (WAFM) setups offer real-time monitoring across the grid, providing insights into power transmission dynamics. Leveraging advancements in measurement technology and Network Time Protocol (NTP) synchronization, WAFM setups are cost-effective tools for studying system transients.

Frequency stability is vital for power systems, ensuring steady frequency despite disruptions. Network Time Protocol (NTP) plays a pivotal role, enabling precise time synchronization among measurement devices. NTP-based monitoring empowers operators to promptly detect and respond to frequency deviations, enhancing grid resilience and reliability. Additionally, accurate frequency measurements facilitated by NTP optimize equipment performance, ensuring devices operate within designated frequency ranges and aiding regulatory compliance.

Technologies like Phasor Measurement Units (PMUs) and GPS further advance wide area frequency monitoring. Despite challenges in mitigating system transients, WAFM setups coupled with NTP offer a promising solution, revolutionizing grid monitoring and management. This setup holds the potential to enhance stability and reliability while providing a low-cost, easily deployable tool for tracking and analyzing power system dynamics.

Methodology

We had created a MATLAB model with FLL to generate frequency from grid waveforms, integrating a ZCD to handle noise. Frequency data is saved in CSV. Then python code is developed to read and send this data from a CSV file to a Google server. The server-side app processes and plots the data for analysis. We monitor for voltage sag, frequency drift, and harmonics to detect grid disturbances. By correlating frequency changes with external factors, we optimize the system for better reliability.

Procedure we have followed:

1. MATLAB Simulation Model Development:
    - Develop a MATLAB simulation model to generate frequency using the Frequency-Locked Loop (FLL) algorithm.
    - Include a pre-filter stage to handle noise in the input waveform.
    - Implement the FLL algorithm, incorporating a Zero Crossing Detector (ZCD) to estimate the fundamental frequency. The ZCD compares the filtered grid voltage with zero to obtain a square wave, from which positive and negative zero crossings are extracted.

2. Data Collection and Storage:
    - Record the frequency changes over time using the MATLAB simulation model.
    - Store the frequency data in a CSV file format for further processing and analysis.

3. Python program from Client PC:
    - Python program is configured to read the CSV file and sends the frequency data to a google server using appropriate communication protocol.

4. Data Transmission and Server Setup:
    - Set up a google sheet to receive and process the transmitted frequency data.
    - We are sending 1000 frequency data per 0.5 second. Hence, it uploads the data every 0.5 second and it reset the frequency graph plot every 0.5 sec.

5. Data Visualization and Analysis:
    - Monitor the plotted data to observe changes such as voltage sag, frequency drift, phase shift, DC offset, and harmonics at any particular time instant.

6. Interpretation and Troubleshooting:

- Analyze the observed changes in frequency to identify potential disturbances or anomalies in the power grid.
- Investigate the root causes of disturbances by correlating frequency variations with external factors such as load fluctuations, equipment failures, or grid disturbances.

By following this methodology, you can effectively implement an NTP-based frequency measurement device capable of monitoring and analyzing grid dynamics in real-time, thereby enhancing grid stability and reliability.

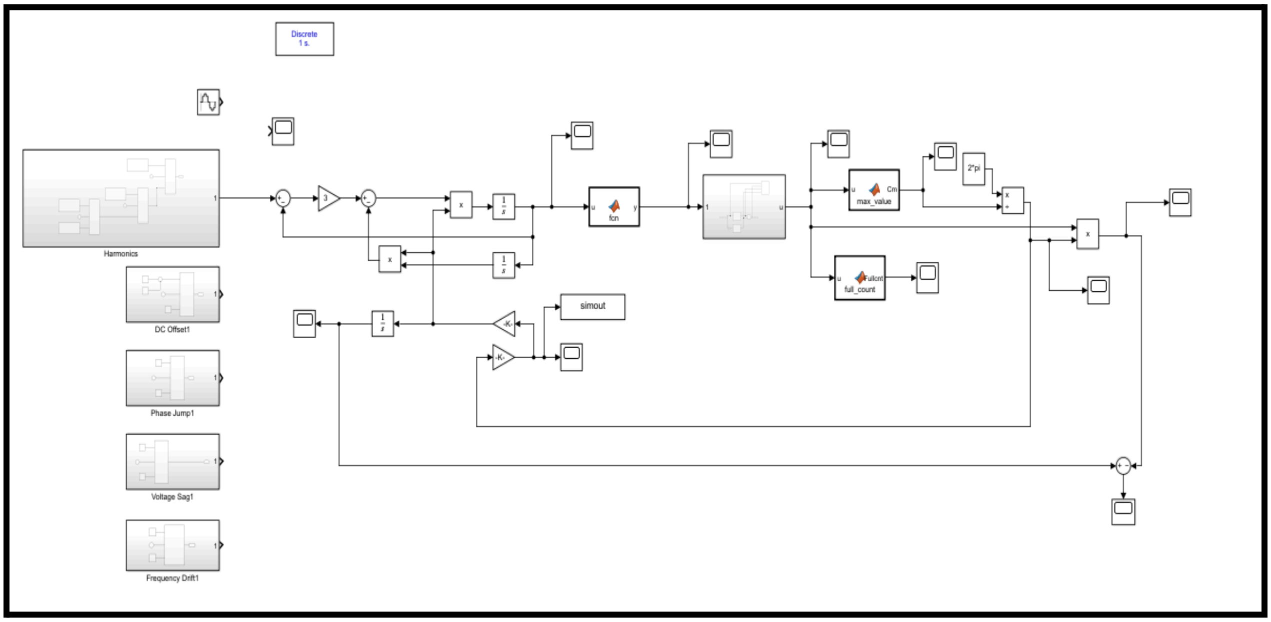


Fig.1: The Block diagram of FLL algorithm

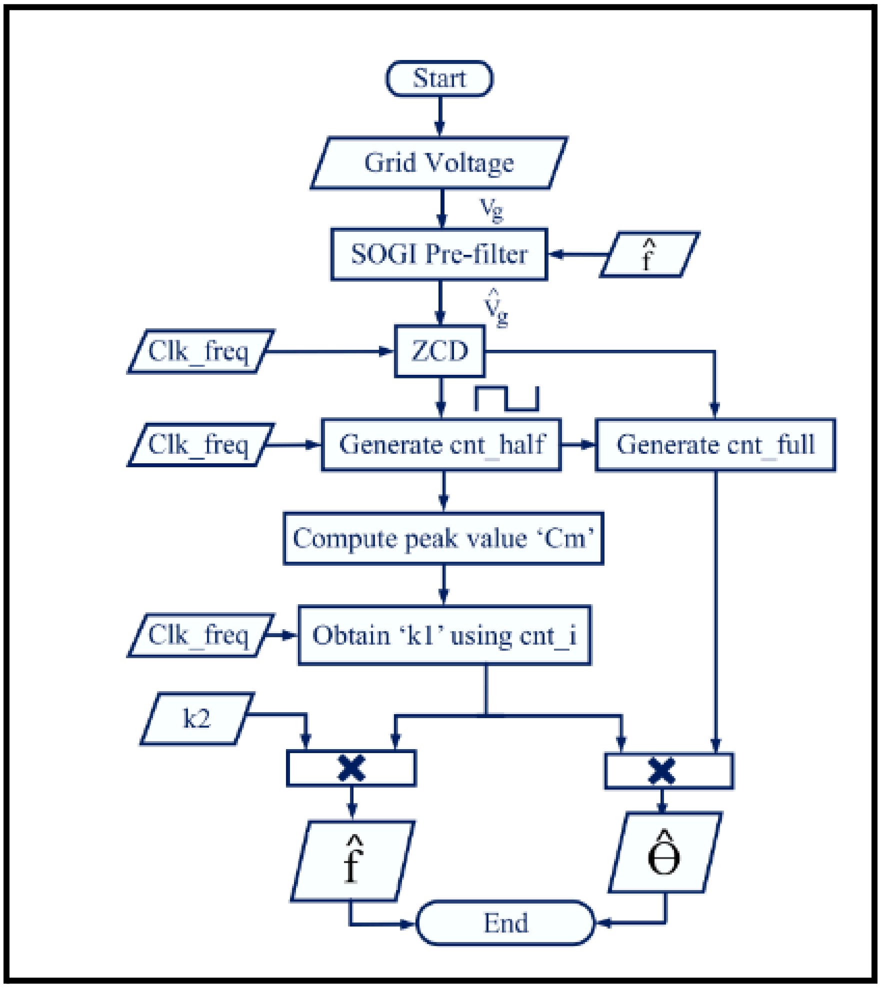


Fig.2: Flowchart of the proposed algorithm to generate frequency.

We have two stages to implement the FLL algorithm in which one is the pre-filter stage and another is the frequency locking stage which includes ZCD, half counter and basic algo. After this stage we measured the frequency. Further explanation will be given below of these two stages.

The pre-filter selection for the proposed FLL should address the elimination of DC offset, effective rejection of high-frequency noise, and attenuation of harmonics from the grid voltage. This objective can be met by implementing a pre-filter with a bandpass characteristic.

The frequency locking stage of the system focuses on accurately determining both frequency and phase for synchronization. This stage is divided into three parts: Zero Crossing Detection (ZCD), estimation of grid frequency (f), and phase angle determination. ZCD operates by comparing the filtered grid voltage (Vg), devoid of DC-offset and noise, with zero to generate a square wave. Positive and negative zero crossings are then identified from the transitions in this square wave. The grid frequency (f) is estimated using a digital counter (cnt_half) that increments with a predefined high-frequency digital clock and resets at every zero crossing instant provided by the ZCD.

Observation:

MATLAB Observation of generated frequency:

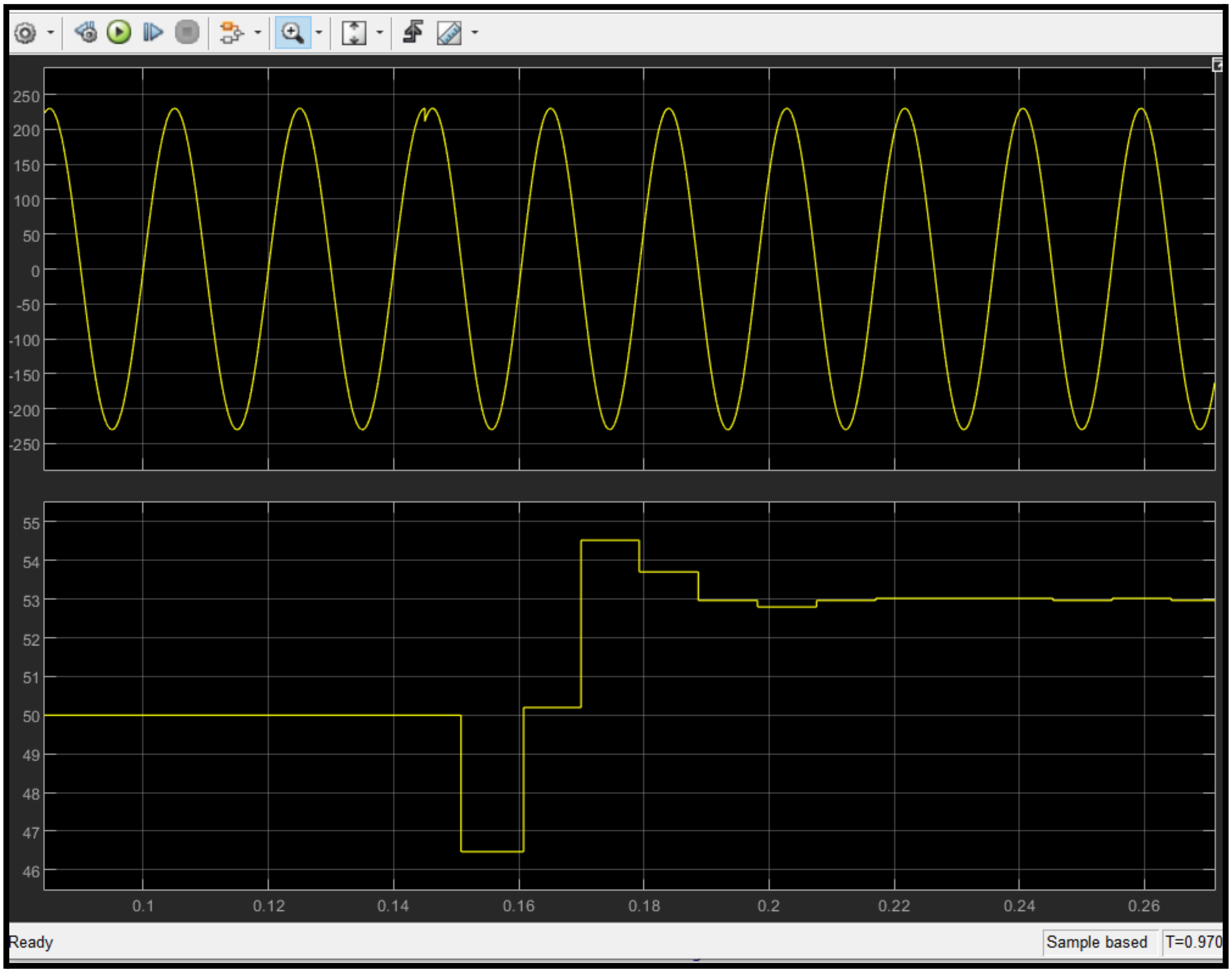


Fig.3: Frequency drift

Frequency Drift: The grid is given a frequency drift of +3 Hz at 0.145 s as shown in Fig.3 and we observed fluctuation in frequency .

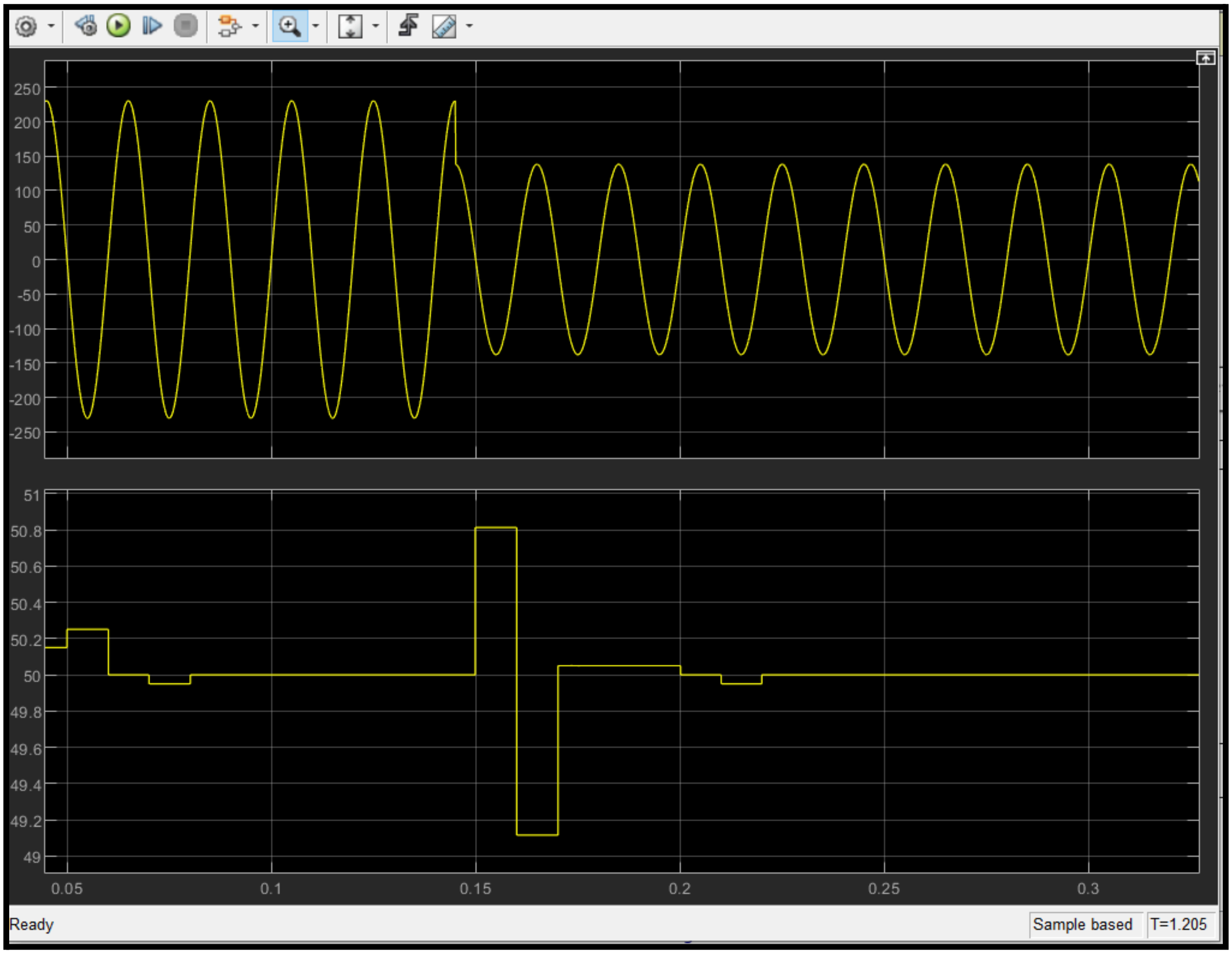


Fig.4: Voltage sag

Voltage Sag : A voltage sag of 138V is introduced into the grid voltage at 0.145 s. The frequency estimates of the proposed algorithm are presented in Fig.4 . From the results, it is observed that the proposed algorithm has frequency deviation.

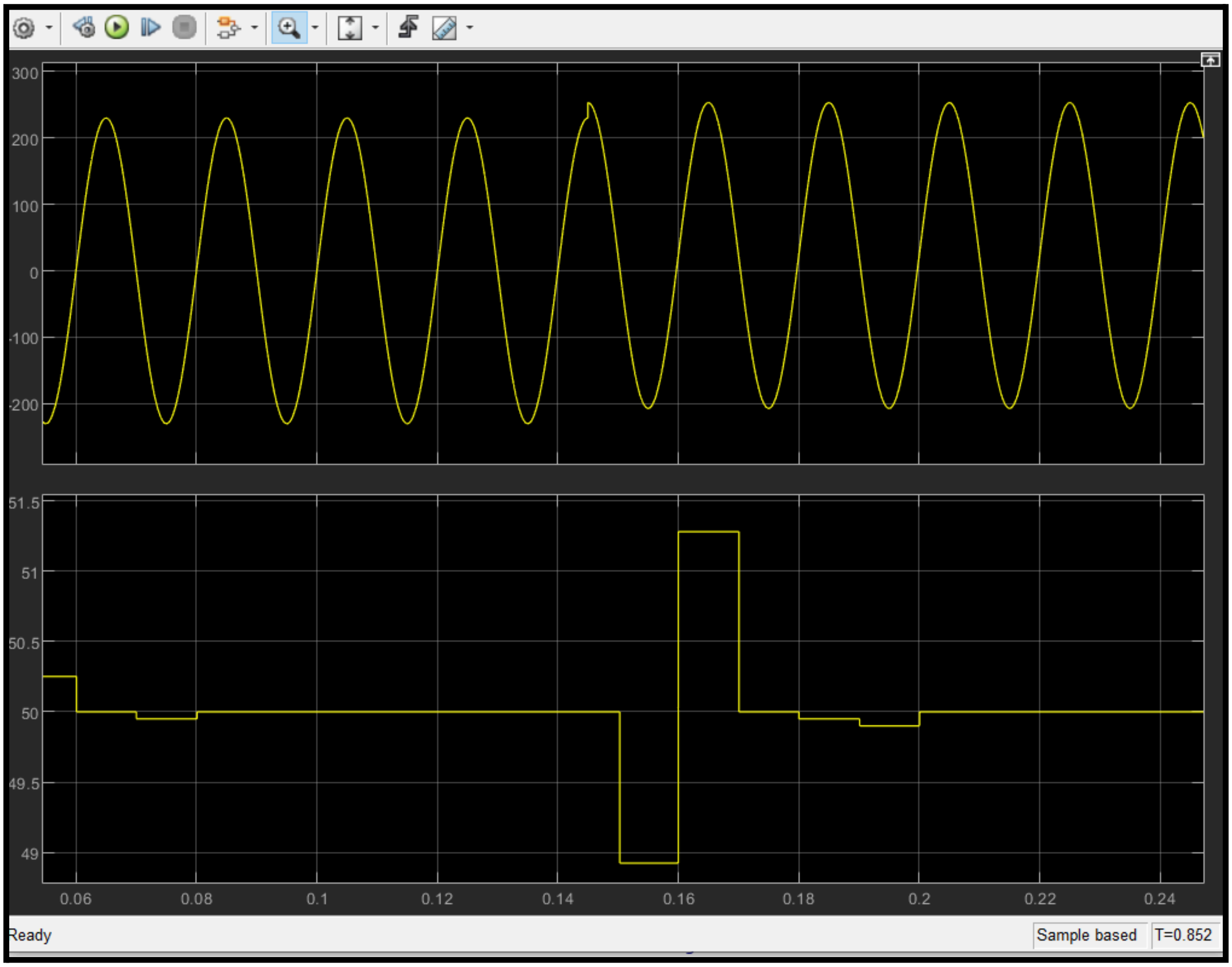


Fig.5: DC offset

DC offset : The grid is given a dc-offset of 23V at 0.145 s From the results, it is observed that the proposed algorithms have shown deviation in frequency as shown in fig.5.

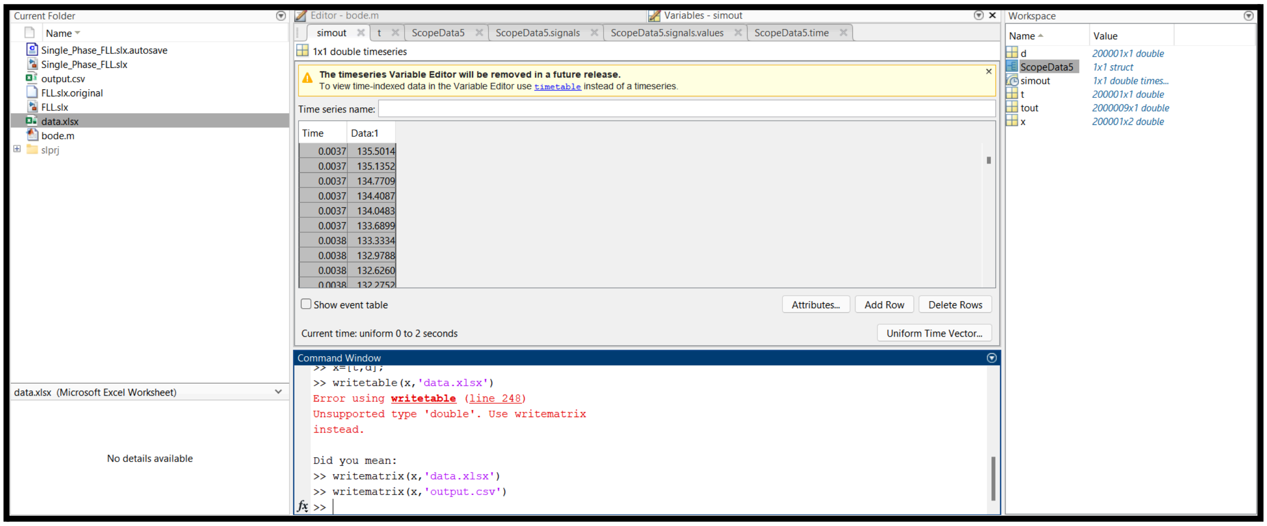


Fig.6: The MATLAB plot recorded as the csv file to transfer it to the Client.

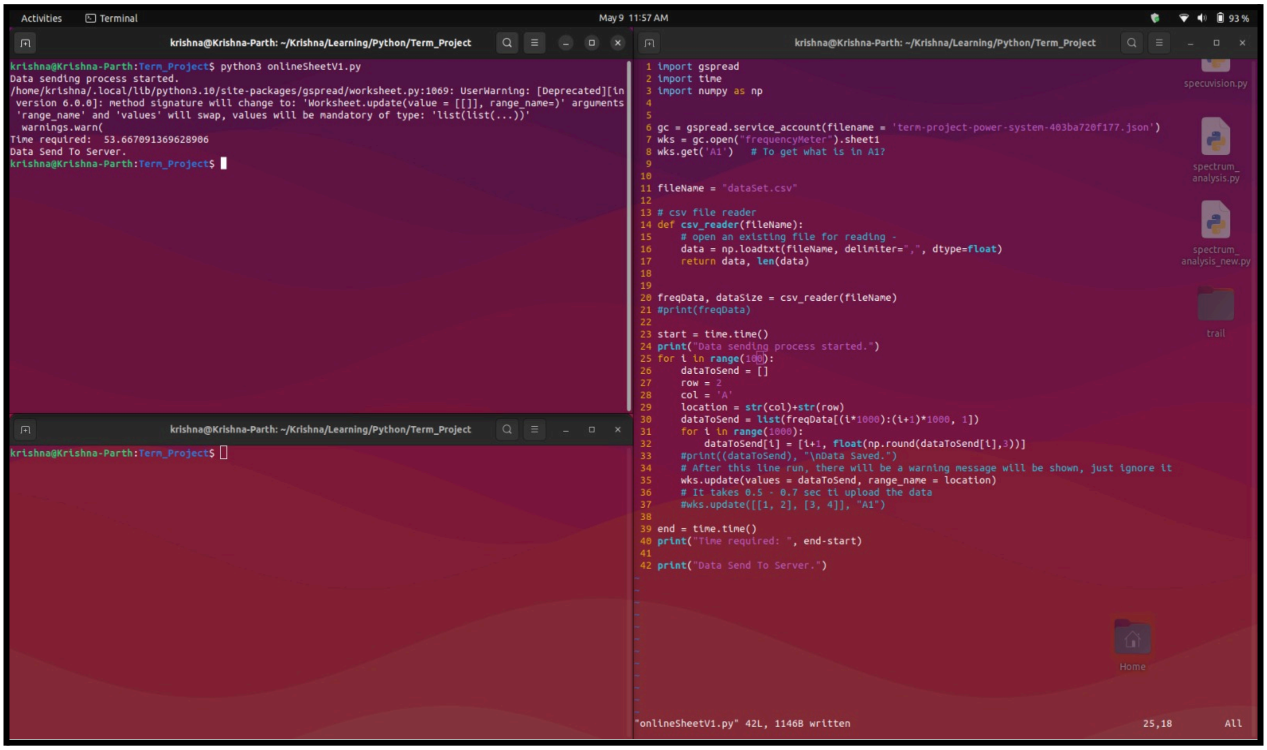


Fig.7: Python code, on client side computer, to upload the real time data with speed of 100*1000 sample rate per minute

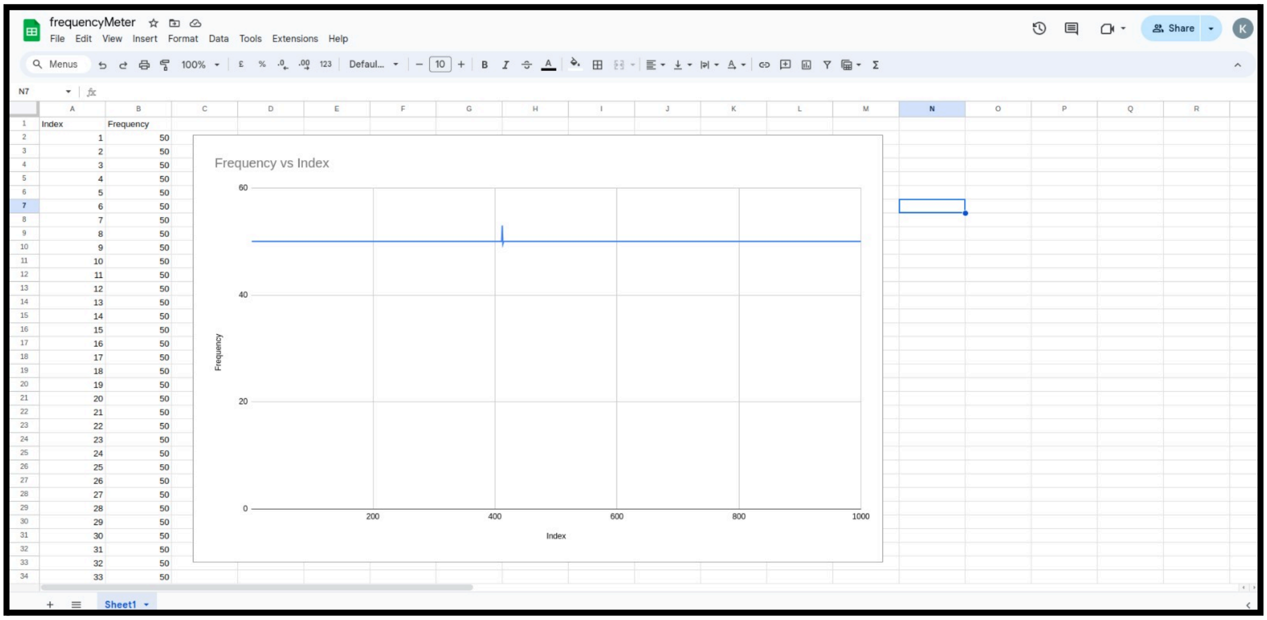
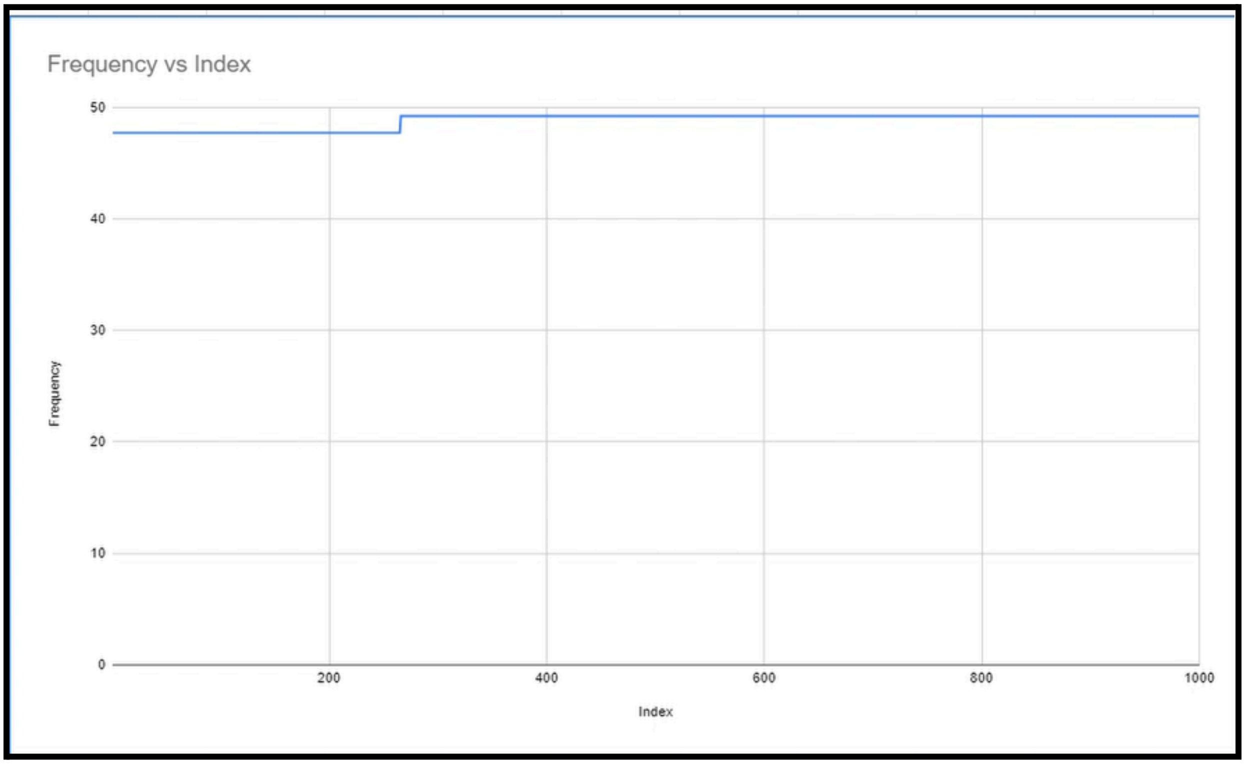

frequencyMeter
File Edit View Insert Format Data Tools Extensions Help
Index
Frequency
Frequency vs Index
60
40
20
0
200
400
600
800
1000
Index
Sheet1

Fig.8a


Frequency vs Index
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40
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Frequency
200
400
600
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Fig.8b

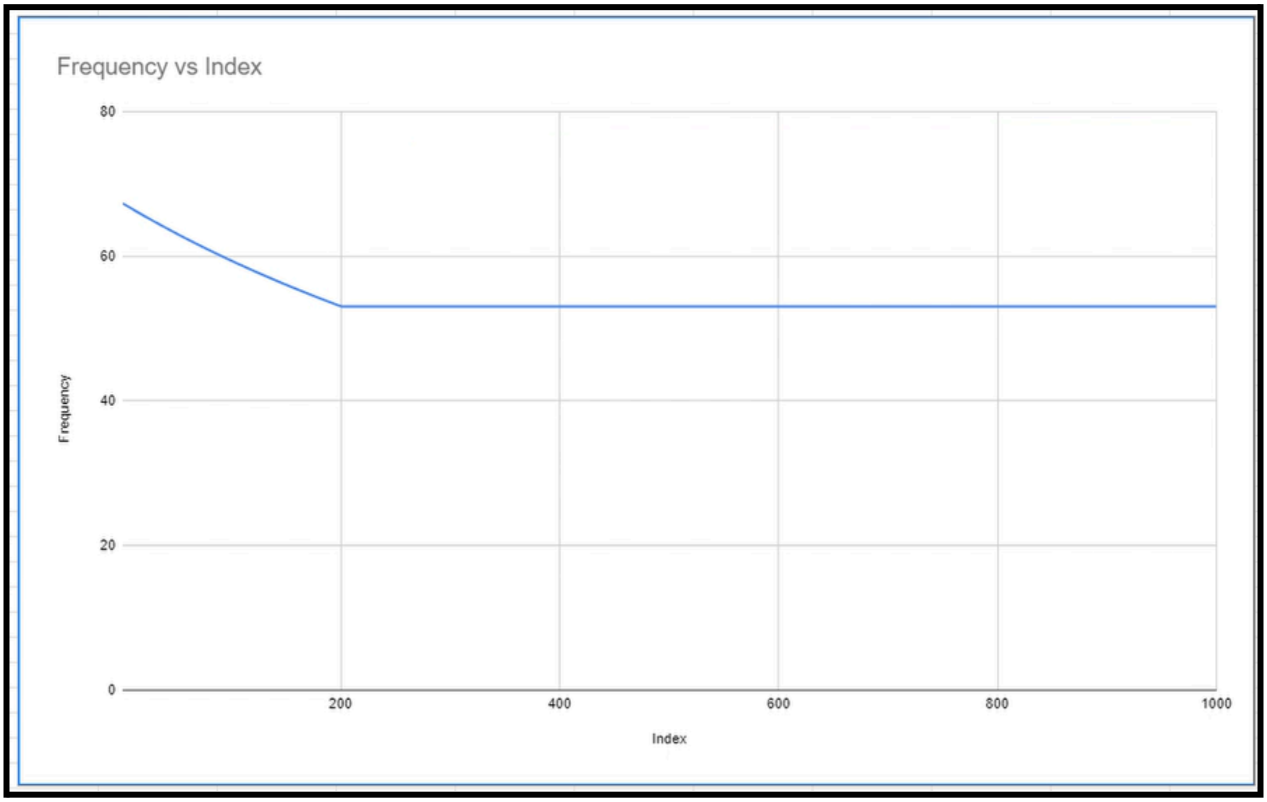

Fig.8c

The graphs in fig. 8a,8b and 8c, we plotted on server computer from our dataset after running from python code

Future Implementation Part:

In the future, we will work on a Frequency measuring system according to our base paper. The system combines hardware, software, and networked synchronization to provide accurate frequency measurements for single-phase AC power and this system sends the data to the server and synchronizes the time using NTP. Also we have to make a real time interface so that we can display the frequency deviation plot w.r.t. Time.

Detailed explanation of the approach:

The frequency measurement system consists of following components: Frequency Measurement Device (FMD), NTP synchronized client side computers with a Real Time

Application Interface on a Linux platform, A server side computer with the Linux operating system.

Frequency Measuring Device:

The 230 V AC supply is stepped down to 12 V passed through an RC filter to the ZCD circuit, which comprises an OP AMP and a diode. The negative half-cycle of the square-wave is clipped and an output at 3.3 V is generated, then it is fed directly to the general purpose input/output (GPIO) pin on ESP32. A program is written to detect the rising edges on the GPIO pin.

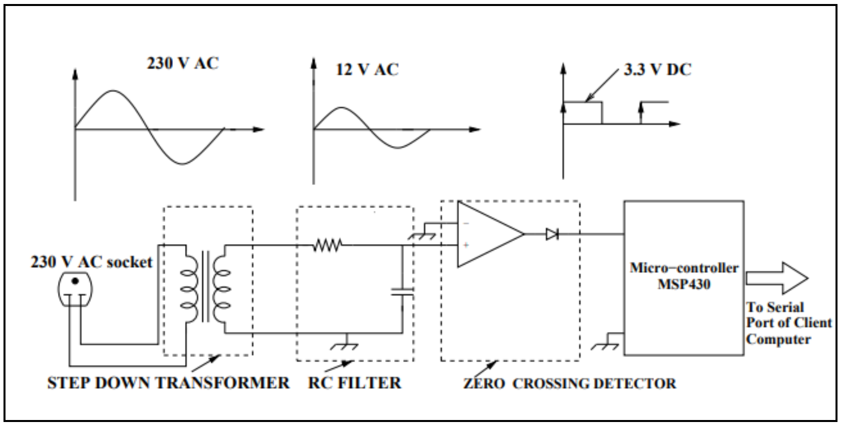

Fig.9: Block diagram of Frequency Measurement Device

The time at every rising edge is noted and the time difference between two consecutive rising edges when inverted gives the value of the frequency. The count obtained from the FMDs is transferred to the client computer. The client computer should take this data the moment it is on its serial port and get it time stamped at the same instant.

Client Side Computer:

There are four tasks to be performed by the client side computer-

1. Keep the computer synchronized with the others using NTP.
2. Capture the measurement being sent at the serial port of the computer.
3. Time Stamp it using a NTP synchronized clock (realtime task).
4. Communicate the time-stamped measurement to the server.

Server Side Computer:

Once data reached the server with time NTP stamped from client computer, we have following features:

1. Data saved at server for wide range access
2. Pictorial view of data available on real-time
3. Analysis to find reason of faults
4. Provide assistance in Power grid management

Conclusion:

This report outlines the development of a wide-area synchronized frequency monitoring system that leverages Network Time Protocol (NTP) synchronization. Although GPS-based systems offer superior synchronization accuracy compared to NTP, the latter's accuracy is sufficient for detecting slow transients in frequency variations. This capability enables the system to monitor electro-mechanical transients caused by grid disturbances. The system has been utilized to analyze several disturbances within the NEW grid, demonstrating its effectiveness as a valuable tool for monitoring and post-disturbance analysis.

We are planning to implement a NTP based Frequency Meter which includes three major portions: Frequency Measurement Device, Client Side Computer and Server Side Computer. In this report, we had implemented the last two parts successfully and in place of FMD, we are using the Matlab Simulink model to generate a time varying frequency dataset which includes 2 million frequencies. Then we sent those frequency values to Server Computer using Client Computer and Network protocol in real-time.

Furthermore, it significantly reduced manufacturing and installation costs, which will facilitate large-scale deployment of a wide area frequency monitoring system. The NTP-based synchronized sampling control method was proposed and implemented, compensating the sampling time error caused by local time drift and eliminating the GPS reliance.

Further work includes making of Frequency Measurement Device using Zero Crossing Detector, improving the NTP time synchronization accuracy by latency calibration, system simplification, field tests, and integrating more functionality such as phasor measurement and power quality monitoring.

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