Design and Development of a Cost-Effective M-Class Phasor Measurement Unit for Power System Monitoring

DEPARTMENT OF ELECTRICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY ROPAR

SHUBHAM RAJ
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Under the supervision of
Asst. Prof. Dr. BIBHU PRASAD PADHY

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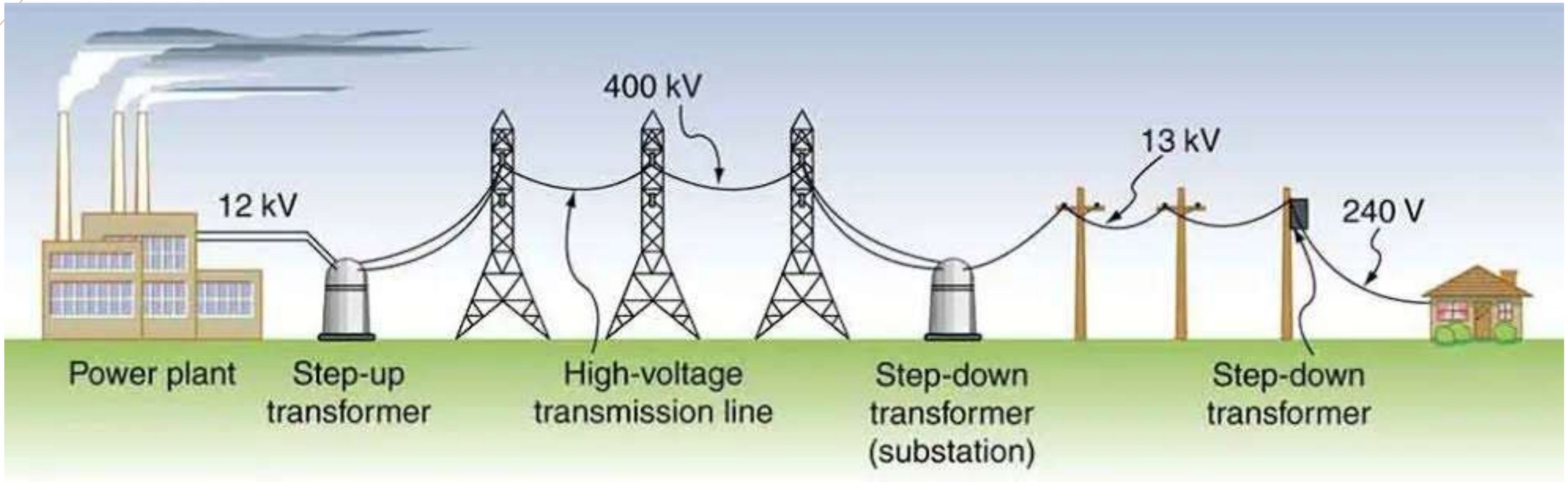
INTRODUCTION



Generation Level → Transmission Level → Sub-Transmission Level → Distribution Level

TSO

TSO : Transmission System Operation involves managing and coordinating high-voltage power lines, substations, and equipment to transmit electricity from generation to distribution networks.

1

RTU (Remote Terminal Unit) is a hardware device used to collect data from sensors, through CTs (Current Transformers) and PTs (Potential Transformers), which measure RMS values of voltage and current signals. The RTU sends this data to a control center, and this entire monitoring and control system is known as SCADA (Supervisory Control and Data Acquisition) system.

2

The 2003 blackout in the northeastern U.S. and central Canada its took a week to restore the power system. Investigations revealed that the lack of real-time monitoring of the power system was a key cause, so there is a need of real time monitoring or near real time monitoring.

3

A new measuring device called the phasor measurement unit (PMU) has been introduced. It captures data from current transformers (CTs) and potential transformers (PTs), also measuring the phasor information of electrical signals. Thus, traditional SCADA systems has been replaced by wide area monitoring systems (WAMS).

4

RTUs update their measurements every minutes at the control center, while PMUs updates their measurements every 20 milliseconds, enabling near real-time monitoring. Additionally, PMUs are synchronized with GPS, which gaves precise time-tag information.

OBJECTIVES

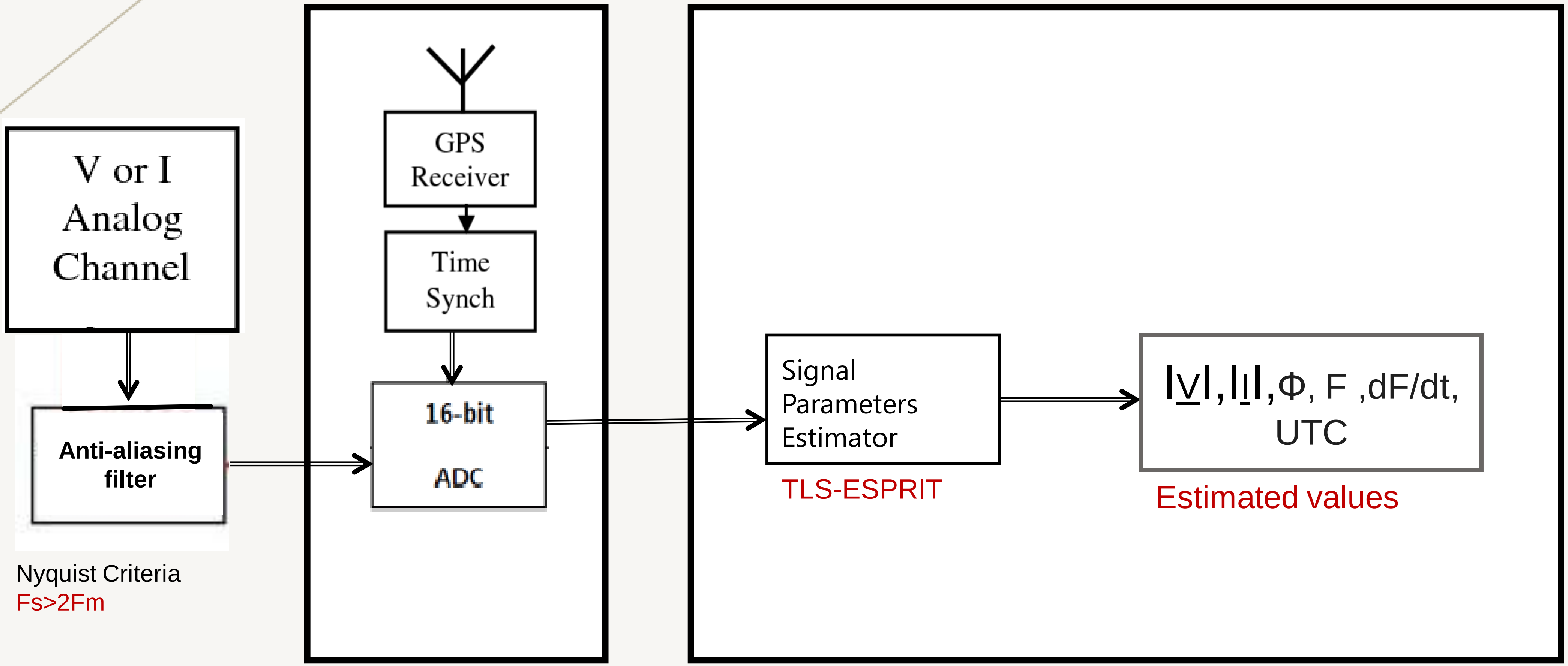
1

To develop a low-cost PMU, focus on minimizing hardware implementation costs by using affordable components, optimizing circuit design and utilizing open-source software for data processing.

2

Implementation of TLS-ESPRIT estimation technique for more accurate and fast measurements.

Block Diagram of Phasor Measurement Unit :



Micro-controller
DSP-TMS320F37289D

MATLAB-Software + DSP-TMS320F37289D

1

An **Anti-aliasing filter** makes sure that the signal being sampled doesn't have frequencies higher than half the sampling rate called Nyquist rate ($F_s > 2F_m$). If higher-order harmonics are present, they can show up as lower-order harmonics, further distorting the signal.

2

As PMUs are Geographically spread across the power grid, **GPS** provides a common reference for sampling and sends information with a time tag. The GPS offers a highly accurate 1 pulse-per-second (PPS) signal, allowing PMUs to synchronize their internal clocks to UTC, which is essential for real-time monitoring.

3

The **TLS-ESPRIT** (Total Least Squares Estimation of Signal Parameters via Rotation Invariance Technique) is a time-frequency domain method used for signal parameter estimation. It should follows the updated IEEE standard, IEEE std C37.118.1a-2014, which specifies the permissible limits for maximum frequency error, maximum magnitude error, and Total Vector Error (TVE) for various test conditions.

LITERATURE REVIEW

Paper Title	Author Details	Year	Inference
ESPRIT-Estimation of signal Parameters Via Rotational Invariance Technique	Richard Roy and Thomas Kailath	1989	1.Detail analysis of ESPRIT method
Performance Analysis of Total Least squares ESPRIT Algorithm	Bjorn Ottersten and Mats Viberg	1991	1. Traditional ESPRIT assumes noise only in the signal subspace and that the measurement matrix is clean, using least squares estimation. 2. TLS-ESPRIT accounts for noise in both the signal and measurement matrices, providing more robust parameter estimation. 3. TLS-ESPRIT performs better in high-noise or highly correlated signal environments compared to traditional ESPRIT. 4. This results in improved accuracy, especially when both signal and measurement spaces are noisy.
New ESPRIT based method for an efficient assessment of Waveform distortions in power system	L.Alfieri, G. Carpinelli , A. Bracale	2015	1. The method relies on calculating the frequencies of spectral components a limited number of times and assumes damping factors remain nearly constant across the analyzed waveform.
Development of a Micro- Phasor Measurement Unit for Distribution System Applications	Hari Prasanna Das and Ashok Kumr Pradhan	2016	1.Detail analysis of Design and Development of PMU.

ESTIMATION TECHNIQUE:

1.Time Domain

Least-Squares method:

Limitation:

- It is unable to determine the signal's available frequency component.
- It uses an inversion approach, which increases the computational burden.
- It's possible that the inversion is not achievable. that is, creating a singular matrix.

2.Frequency Domain

DFT method:

Limitation:

- Its converts time domain information to frequency domain so that time domain information should be lost.
- They are extremely sensitive to frequency deviation; as soon as the frequency deviates from their nominal value, they will begin to produce inaccurate results.
- Its estimates the frequency components of both stationary and non-stationary signals. However, it does not indicate the specific time when an event occurs in non-stationary signals.
- Spectral Leakage Problem.

3.Time-Frequency Domain

TLS-ESPRIT method:

Advantages:

- Better frequency resolution i.e clearly distinguish between nearby frequency.
- No Spectral leakage problem.
- More Robust to noise.
- TLS-ESPRIT provide high resolution estimation for both statiionary signals, and non-stationary signals, it is able to track time-varying frequencies.

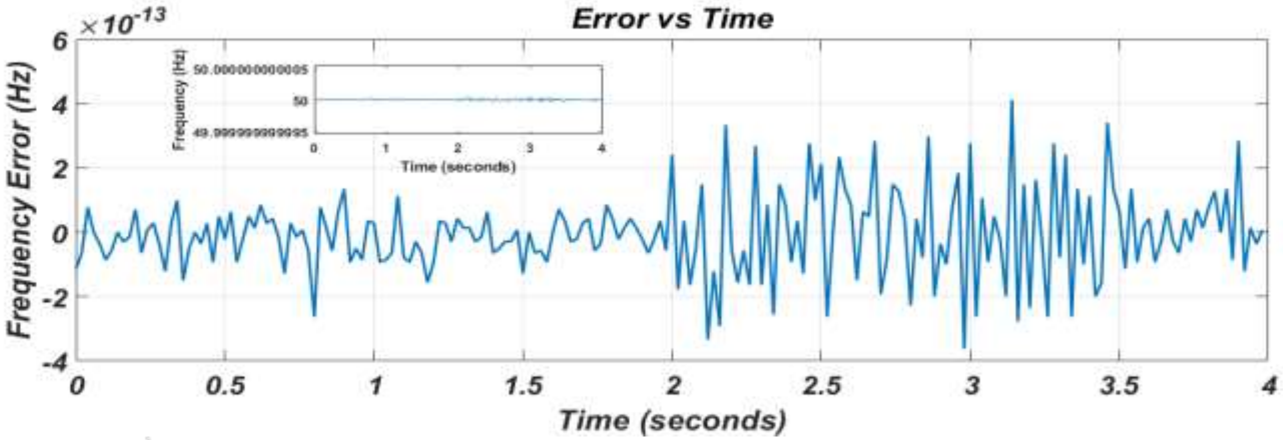
TLS-ESPRIT ALGORITHM:

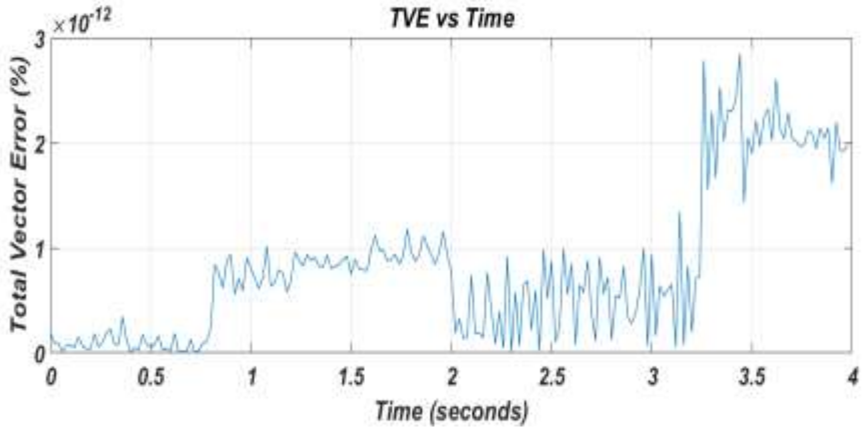
Input Data → Estimation of covariance matrix → Eigen Value Decomposition (SVD) → Construct the Signal sub-space → Total Least Squares → Frequency and Damping estimated → Amplitude and phasor estimation

WORK SO FAR:

Test Scenarious:

Case 1: **Steady state Test (only fundamental frequency) : Y(t)=230cos(2*pi*50*t + phi)**

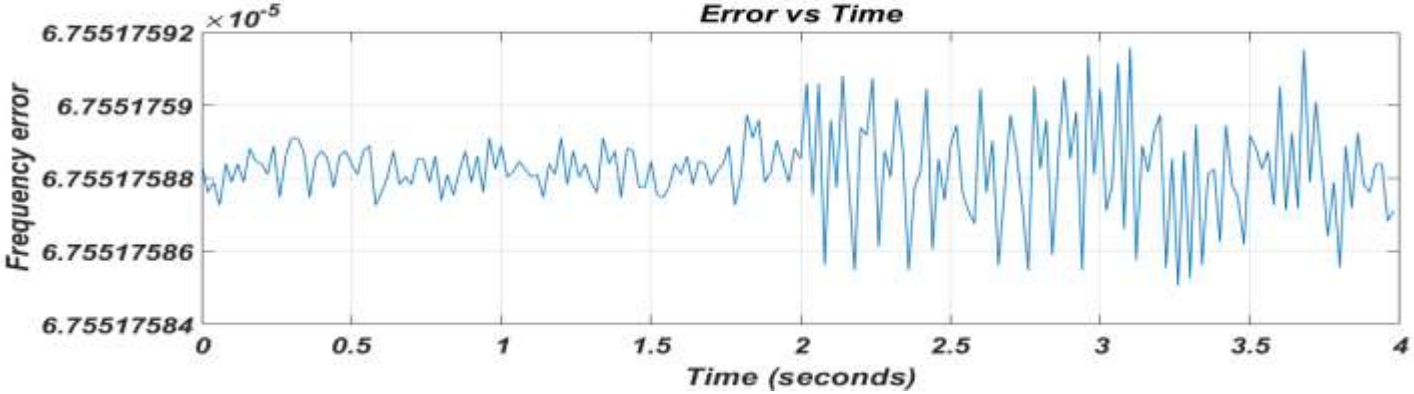


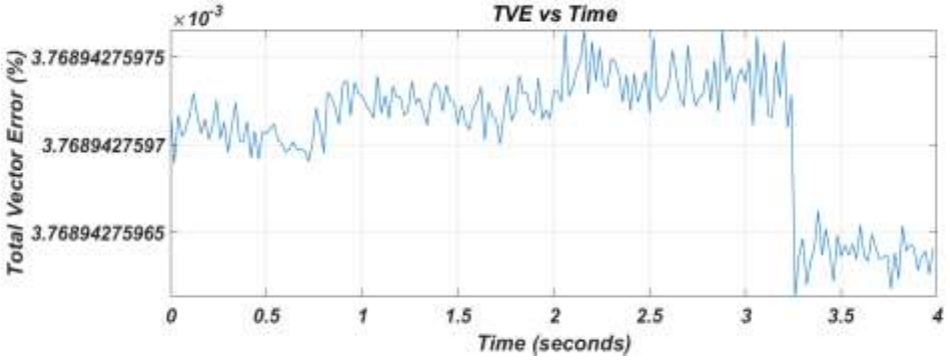


IEEE std c37.118.1a-2014: Max TVE =1%

Case 2: **Harmonic Distortion Test (Fundamental Frequency with 3rd , 5th and 7th harmonics) :**

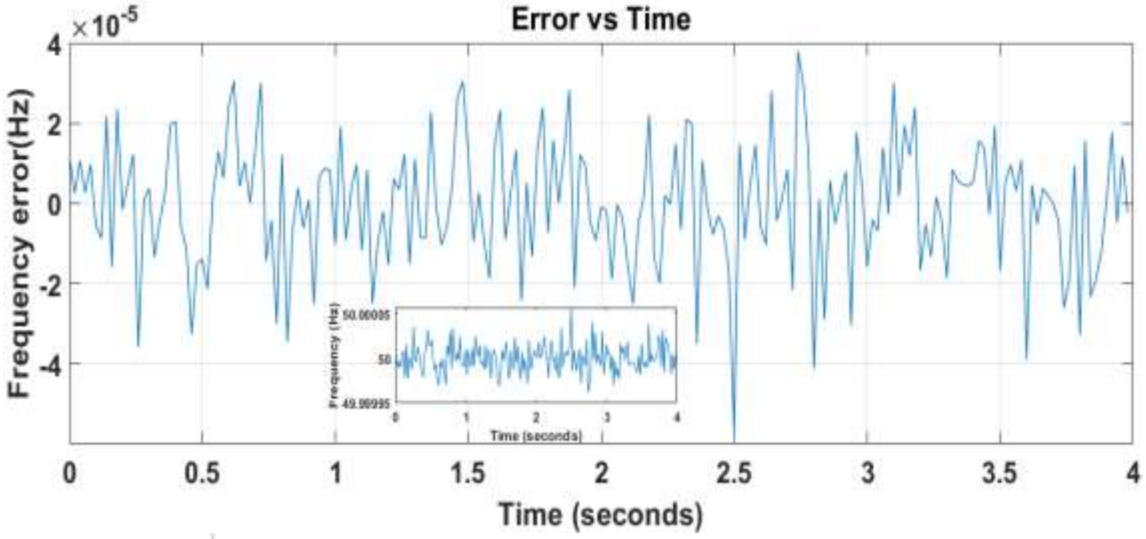
Y(t)=230cos(2*pi*50*t + phi)+ 10cos(3*2*pi*50*t + phi)+ 2cos(5*2*pi*50*t + phi)+ 1cos(7*2*pi*50*t + phi)

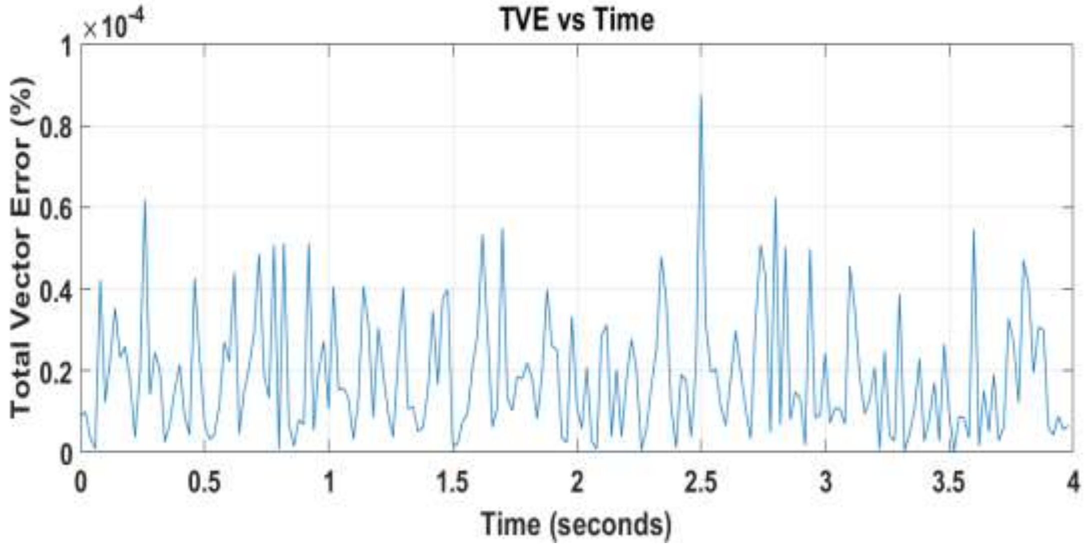




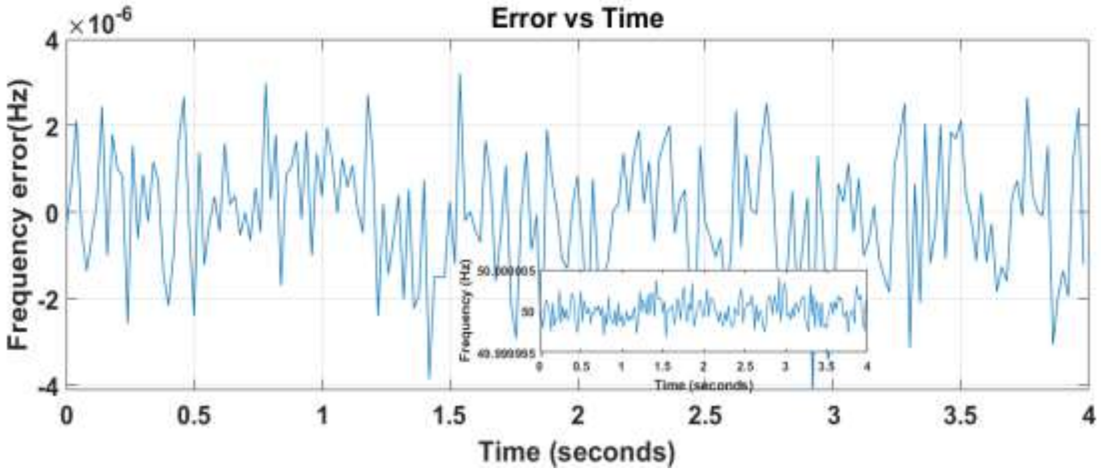
IEEE std c37.118.1a-2014 : Max FE=0.005Hz and Max TVE=1%

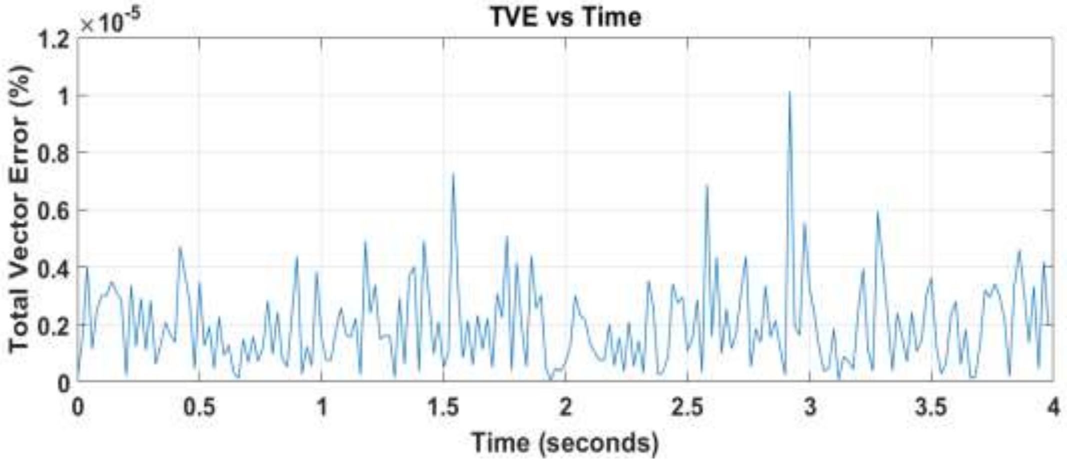
Case 3(a): Fundamental Signal with White noise(60db): Y(t)=230cos(2*pi*50*t + phi)+ 60db noise



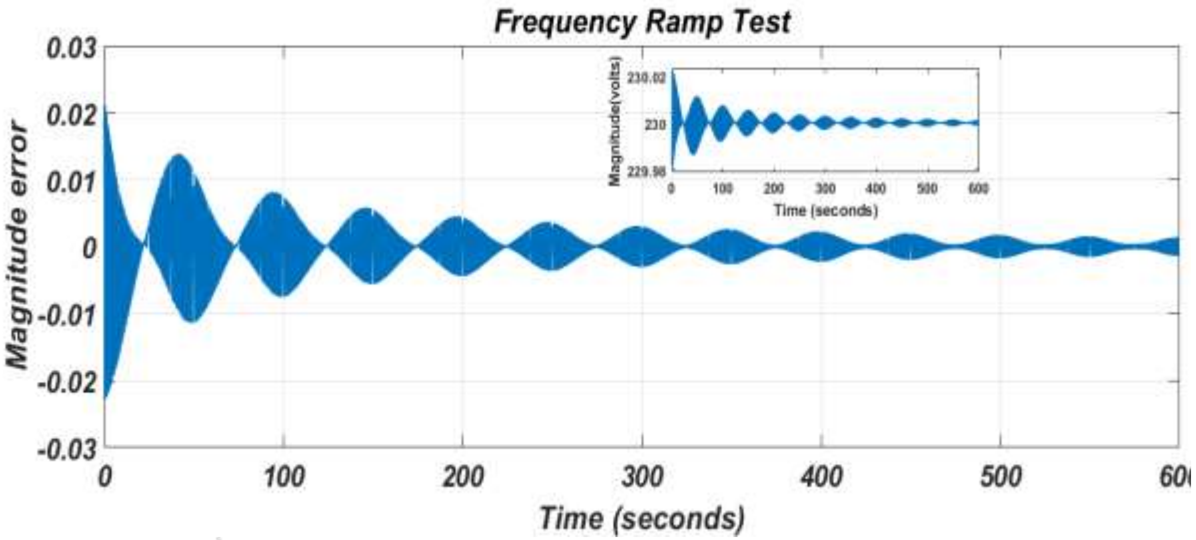


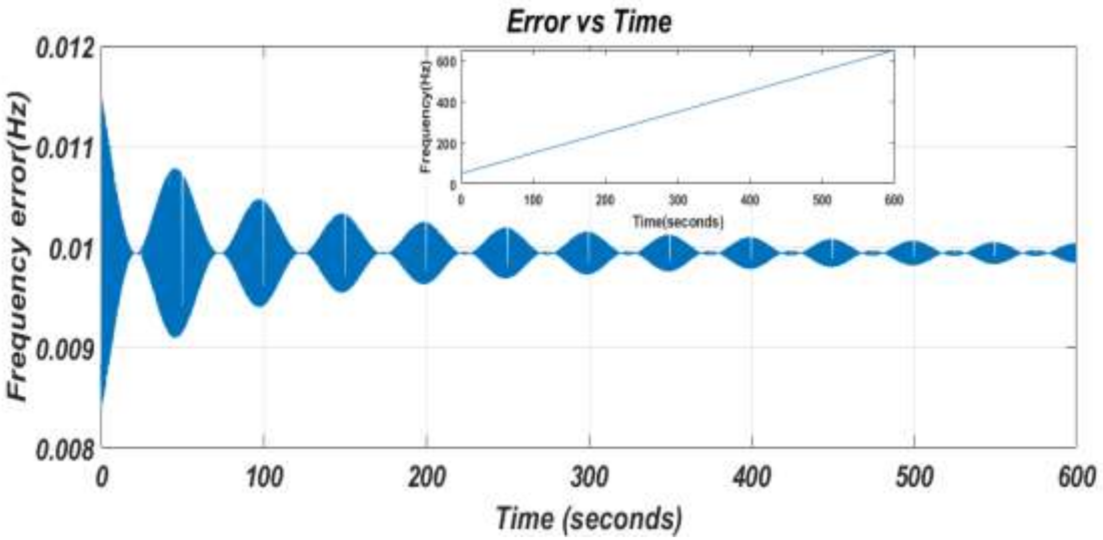
Case 3(b): Fundamental Signal with White noise(80db): Y(t)=230cos(2*pi*50*t + phi)+ 80db noise





Case 4: Frequency Ramp Test



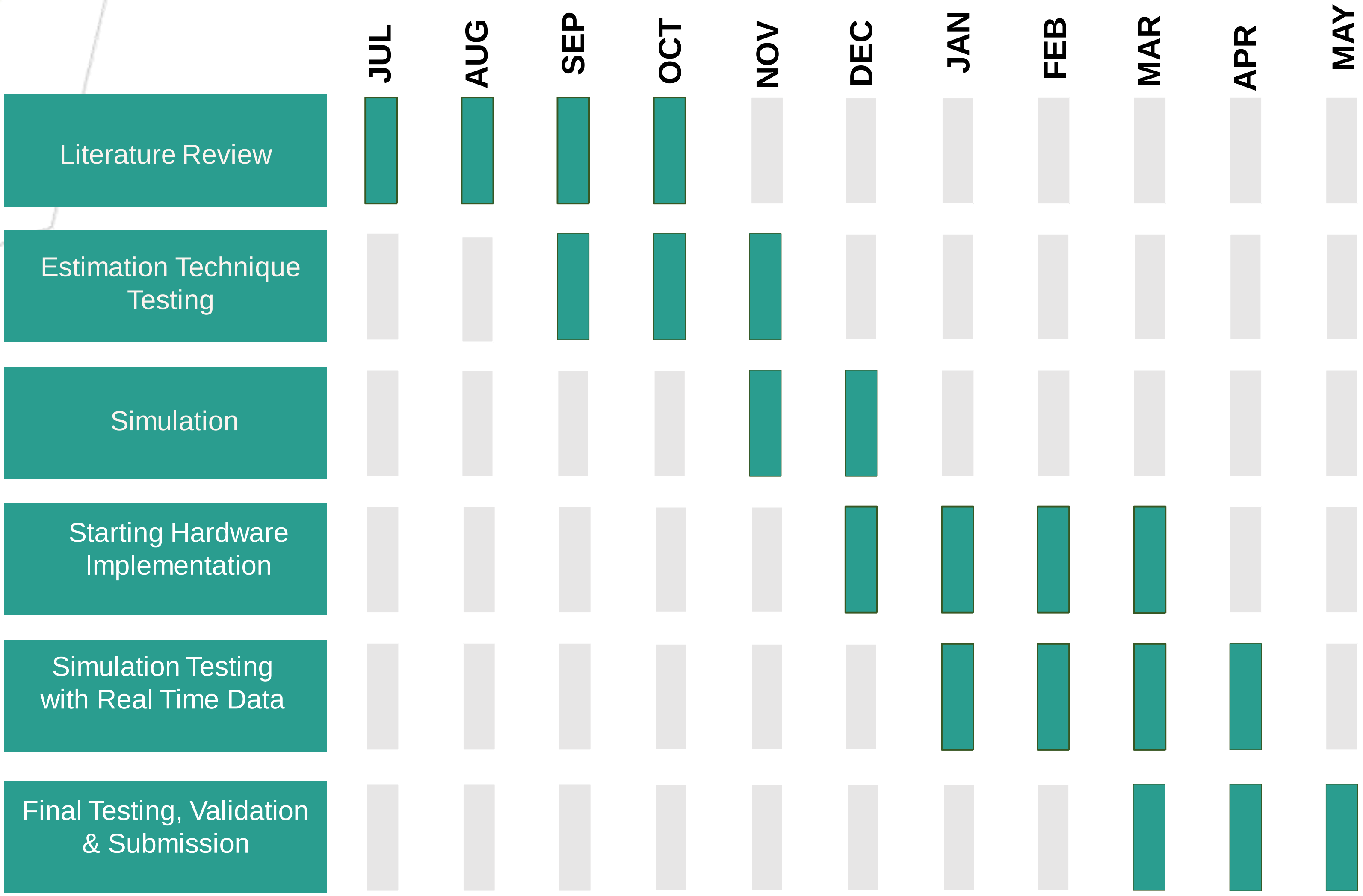


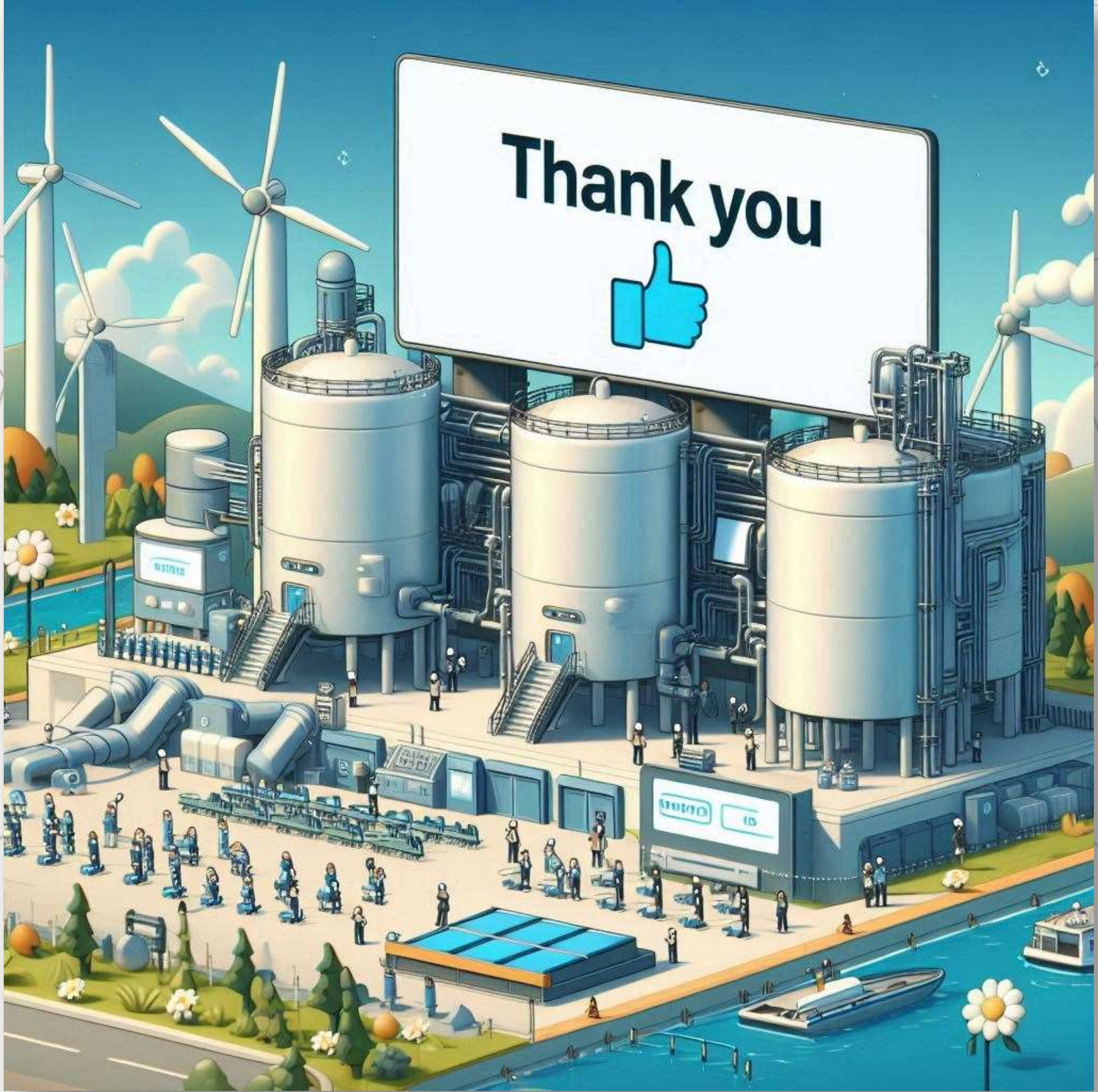
IEEE std c37.118.1a-2014 : Max FE=0.01Hz and Max TVE=1%

1

I am encountering an issue during the Ramp Frequency Test where the frequency error exceeds the maximum limit at the start but decreases over time. I need to resolve this problem and ensure the algorithm performs correctly under other testing conditions as well.

PROJECT TIMELINE




Thank you