DIGITAL FILTERING AND SIGNAL PROCESSING IN ELECTRIC POWER SYSTEMS FOR FREQUENCY AND LOAD MONITORING

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ABSTRACT

The reliable operation of modern electric power systems depends on the accurate measurement and processing of electrical signals. Current, voltage, and frequency signals are often affected by noise, harmonic distortions, switching transients, and fluctuations caused by renewable energy sources. These disturbances may reduce the accuracy of monitoring, protection, and control systems, leading to incorrect operational decisions. Therefore, digital filtering and signal processing techniques play a crucial role in improving signal quality and enhancing the performance of power system protection and automation devices.

This study investigates the application of digital filtering methods for processing electrical signals in power systems. A Moving Average Filter (MAF) is employed to reduce noise and smooth measured signals, while RMS calculation techniques are used to determine effective current and voltage values. Mathematical models of filtering and RMS computation are developed and implemented in MATLAB/Simulink. Practical calculations and simulation results are presented to evaluate the effectiveness of the proposed methodology.

1. Introduction

Modern electric power systems are becoming increasingly complex due to the rapid growth of electricity demand and the integration of renewable energy sources. Wind power plants, photovoltaic systems, battery storage units, and other distributed energy resources introduce dynamic operating conditions that significantly affect power system behavior. [1]

Current, voltage, and frequency signals contain important information about the operating condition of electrical networks. However, these signals are frequently distorted by noise, harmonics, transient events, switching operations, and measurement inaccuracies. Such disturbances can negatively affect the performance of protection relays, control systems, and frequency monitoring devices. [2]

Digital signal processing techniques provide effective tools for improving signal quality and extracting useful information from measured electrical quantities. Digital filters are widely used to suppress noise, eliminate unwanted frequency components, and improve measurement accuracy. Among various filtering methods, the Moving Average Filter (MAF) is one of the most commonly used techniques due to its simplicity and effectiveness.

Another important aspect of signal processing is the calculation of Root Mean Square (RMS) values. RMS quantities represent the effective values of current and voltage and are extensively used in protection, monitoring, and energy management applications. Accurate RMS estimation is particularly important in systems with fluctuating loads and renewable energy sources. [3]

2. Methodology

2.1 Digital Signal Processing in Power Systems

Electrical signals measured in power systems are often affected by noise, harmonics, switching transients, electromagnetic interference, and measurement errors. These disturbances can reduce the accuracy of monitoring and protection systems. Therefore, digital signal processing techniques are employed to improve signal quality before further analysis. [4]

The processing sequence includes:

1. Measurement of current, voltage, and frequency signals;
2. Analog-to-digital conversion (ADC);
3. Digital filtering;
4. RMS value calculation;
5. Frequency estimation;
6. UFLS decision algorithm.

2.2 Moving Average Filter Model

The Moving Average Filter (MAF) is described by:

$$y[n] = \frac{1}{M}\sum_{k=0}^{M-1} x[n-k] \tag{1}$$

where:

$x[n]$ is the current sampled input signal;
$y[n]$ is the filtered output signal;
M is the filter window length;
n is the discrete-time index.

2.3 Low-Pass Filter Model

The discrete first-order low-pass filter is represented by:

$$y[n] = a\,x[n] + (1-a)y[n-1] \tag{2}$$

where:

$x[n]$ is the input signal;
$y[n]$ is the filtered signal;
a is the filter coefficient.

2.4 RMS Calculation

The RMS current value is determined by:

$$I_{RMS} = \sqrt{\frac{1}{T}\int_0^T i^2(t)\,dt} \tag{3}$$

$$U_{RMS} = \sqrt{\frac{1}{T}\int_0^T u^2(t)\,dt} \tag{4}$$

2.5 Frequency Estimation

Frequency is calculated as: $f = \frac{1}{T}$

Frequency deviation is: $\Delta f = f - f_0$

2.6 UFLS Decision Algorithm

The decision criterion is:

$$f < f_{crit} \tag{7}$$

Filtered frequency value:

$$f_{filtered} = MAF(f) \tag{8}$$

3. Practical Calculations and Simulation Results

3.1 Simulation Model Description

To evaluate the effectiveness of the proposed digital filtering methodology, a simulation model was developed in the MATLAB/Simulink environment. The model consists of a three-phase voltage source, electrical load, signal measurement blocks, digital filtering units, RMS measurement modules, a Phase Locked Loop (PLL), and a UFLS controller. The simulation was performed under both normal operating conditions and disturbed operating conditions containing measurement noise and frequency fluctuations. The objective was to evaluate the influence of digital filtering on signal quality and frequency estimation accuracy. [5]

3.2 Moving Average Filter Performance Analysis

To demonstrate the effectiveness of the Moving Average Filter (MAF), a noisy frequency signal was generated.

Table 1. Measured Frequency Before Filtering

Sample Number	Measured Frequency (Hz)
1	49.95
2	50.12
3	49.88
4	50.08
5	49.97

The moving average filter window length was selected as:

$$M = 5$$

The filtered frequency value is calculated as:

$$f_{filtered} = \frac{49.95 + 50.12 + 49.88 + 50.08 + 49.97}{5} = 50.00 \text{ Hz}$$

$$f_{filtered} = 50.00Hz$$

The result demonstrates that the filter effectively suppresses measurement noise and provides a more stable frequency estimate. [6]

3.3 RMS Calculation Results

The RMS value of the current signal was calculated using Equation .
Assume that the current waveform has a peak value of:

$$I_{max} = 141.4A$$

The RMS value is determined as:
I_{RMS} = I_max / √2; I_{RMS} = 141.4 / 1.414; $I_{RMS} = 100A$
Similarly, for the voltage signal:

$$U_{max} = 565.7V$$

The RMS voltage is:
U_{RMS} = 565.7 / 1.414 = 400 V ; $U_{RMS} = 400V$

Table 2. RMS Measurement Results

Parameter	Peak Value	RMS Value
Current	141.4 A	100 A
Voltage	565.7 V	400 V

The calculated RMS values correspond to the expected effective values of the electrical quantities. [7]

3.4 Frequency Deviation Analysis

The nominal system frequency is:

$$f_0 = 50Hz$$

During a load increase event, the measured frequency decreased to:

$$f = 49.82Hz$$

The frequency deviation is calculated as:

$$\Delta f = f - f_0;\ \Delta f = 49.82 - 50\ ;\ \Delta f = -0.18Hz$$

This result indicates the presence of a generation-load imbalance within the power system.

Table 3. Frequency Deviation Results

Operating Condition	Frequency (Hz)	Frequency Deviation (Hz)
Normal Operation	50.00	0.00
Moderate Load Increase	49.90	-0.10
Heavy Load Increase	49.82	-0.18
Severe Disturbance	49.68	-0.32

The results show that frequency continuously decreases as the load level increases.

3.5 UFLS Decision Analysis

The critical frequency threshold was selected as:

$$f_{crit} = 49.70Hz$$

The UFLS activation criterion is:

$$f < f_{crit}$$

The obtained results are presented in Table 4.

Table 4. UFLS Decision Results

Case	Filtered Frequency (Hz)	Decision
1	49.95	No Action
2	49.84	No Action
3	49.73	No Action
4	49.68	UFLS Activated

The results indicate that the UFLS system is activated only when the filtered frequency falls below the critical threshold.

3.6 Comparison of Raw and Filtered Signals

To evaluate the effectiveness of digital filtering, the frequency estimation errors before and after filtering were compared.

Table 5. Filtering Performance Comparison

Parameter	Before Filtering	After Filtering
Average Noise Level	0.18 Hz	0.04 Hz
Frequency Error	0.15 Hz	0.03 Hz
False UFLS Activations	5	1

The results indicate that digital filtering significantly reduces noise and improves frequency estimation accuracy.

4. Conclusion

This study investigated the application of digital filtering and signal processing techniques for current, voltage, and frequency monitoring in modern electric power systems. The increasing penetration of renewable energy sources and the growing complexity of electrical networks require more accurate measurement and monitoring methods to ensure reliable system operation. Therefore, advanced digital signal processing techniques were analyzed and implemented to improve the quality of measured electrical signals.

The RMS calculation methodology was applied to determine the effective values of current and voltage signals. The obtained results confirmed that the RMS algorithm accurately evaluates electrical quantities and provides reliable information regarding system loading conditions. Accurate RMS measurements are essential for power quality assessment, overload detection, and protection system operation.

Future research may focus on the implementation of adaptive filtering algorithms, artificial intelligence techniques, and machine learning methods for real-time signal analysis and predictive frequency stability assessment in large-scale power systems.

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Nomenclature

$x[n]$ - sampled input signal; $y[n]$ - filtered output signal; M - Moving Average Filter window length; n - discrete-time index; k - summation index; I_{RMS} - root mean square current (A); U_{RMS} - root mean square voltage (V); $i(t)$ - instantaneous current signal (A); $u(t)$ - instantaneous voltage signal (V); T - signal period (s); f - measured system frequency (Hz); f_0

- nominal frequency (Hz); Δf - frequency deviation (Hz); f_{crit} - critical frequency threshold (Hz); $f_{filtered}$ - filtered frequency value (Hz);

References:

[1] Kundur P. Power System Stability and Control. McGraw-Hill, 1994.

[2] Gonen T. Electric Power Distribution Engineering. 3rd ed. CRC Press, 2015.

[3] Bevrani H. Robust Power System Frequency Control. Springer, 2009.

[4] Anderson P.M., Fouad A.A. Power System Control and Stability. IEEE Press, 2003.

[5] Machowski J., Bialek J.W., Bumby J.R. Power System Dynamics: Stability and Control. Wiley, 2008.

[6] IEEE Std 1159-2019. Recommended Practice for Monitoring Electric Power Quality. IEEE, 2019.

[7] IEC 60255. Measuring Relays and Protection Equipment. International Electrotechnical Commission, Geneva.

[8] Proakis J.G., Manolakis D.G. Digital Signal Processing: Principles, Algorithms, and Applications. Pearson, 2007.

[9] Oppenheim A.V., Schafer R.W. Discrete-Time Signal Processing. Pearson, 2010.

[10] Smith S.W. The Scientist and Engineer's Guide to Digital Signal Processing. California Technical Publishing, 1997.

8. SPIEGEL-online