**Modeling of the Measuring Unit with MMD for Ground Faults in Power System**

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**Abstract.** A measuring unit with a magnetically modulated device (MMD) for selective ground-fault detection in power systems is modeled. The unit extracts the differential current ∆Idiff from a high-frequency modulation signal and processes it using gain scaling, moving-average filtering, stability check, and synchronous detection. A trip signal is allowed only when both ∆Idiff exceeds the setting and the zero-sequence voltage U0 is above threshold, which prevents false trips under noise and capacitive unbalance. MATLAB/Simulink results show high sensitivity, fast response (<10 ms), and improved selectivity for mining power networks with variable parameters.

**INTRODUCTION**

The measuring unit with a magnetically modulated device (MMD) consists of two main subsystems: The measuring section, which includes two magnetic systems. The logical section, which implements algorithms for signal processing and filtering [1]. This unit generates the differential current signal ∆Idiff based on the high-frequency amplitude-modulated voltage that arises during the saturation of the MMD core. The resulting signal contains: the fundamental modulation frequency (10–20 kHz), the second harmonic (2× excitation frequency), and a low-frequency component proportional to ∆Idiff.

To extract ∆Idiff, a synchronous detector is employed, which multiplies the signal by the reference frequency and integrates the result over one period, thereby producing a voltage:

(1)

where T– is the period, adapted for real-time operation in power systems (response time < 10 ms).

**EXPERIMENTAL RESEARCH**

High-frequency noise arising from switching events and induced disturbances necessitates the use of sequential filtering logic, which integrates conventional approaches (low-pass filtering LPF) and amplification) with adaptive algorithms (analysis of U0). The sequential filtering logic (Fig. 1) is designed as a multi-stage algorithm for processing the signals I0.start and I0.end from two magnetic systems. It includes the following stages:

1.Signal synchronization: The signals are aligned with respect to inherent delays to ensure temporal coherence, which is critical for differential analysis.

2.Preliminary amplification and scaling: Within this framework, the signals pass through a cascaded amplification stage with coefficients analogous to Gain (0.01) and Gain (10), enabling normalization and amplitude compensation.

, (2)

(3)

3.Filtering of high-frequency noise: A moving average with a window of N=5N = 5N=5 samples is applied to suppress components above 200 Hz.

(4)

Stability analysis: The difference between the current and the previous values is verified.

(5)

If ΔI0.stab<ε I (where ε=0.01 A), the signal is considered to be free from noise. Computation of the differential current: The filtered signals are used for:

4. Computation of the differential current: The filtered signals are used for:

(6)

5.Transfer to the control block: ΔI0.filter U0are transmitted for the formation of the trip signal.

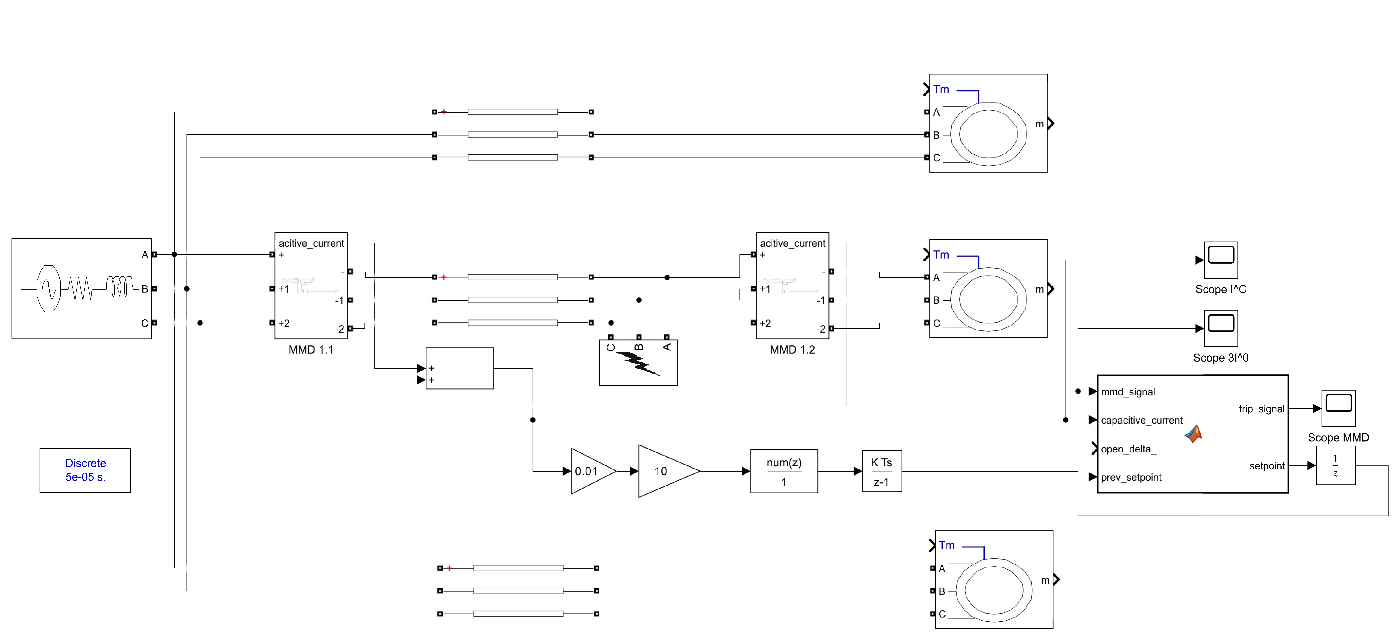
The model of the measuring unit is presented in Fig. 1 and includes:

Two MMD magnetic systems: Modeled as Controlled Current Sources with S=0.1 V/, located at the input and output of the line [29-58].

Sequential filtering logic: A subsystem consisting of Gain (0.01), Gain (10), Moving Average (N=5N = 5N=5), Subtract for ΔI0.stab and a Relational Operator for ε

Control block: Combines ΔI0.filter and U0for analysis.

Scope: Displays I0.filterand ΔI0.filter



**FIGURE 1.** Diagram of the measuring unit with MMD for selective detection of single-phase-to-ground fault location in power systems (adapted: two MMDs at the line ends, filtering logic for energy complexes with RES, integration with SCADA).

The event of a single-phase-to-ground fault (phase A short-circuited through for 0.02 s), ΔIdiff increases, with the differential current:

(7)

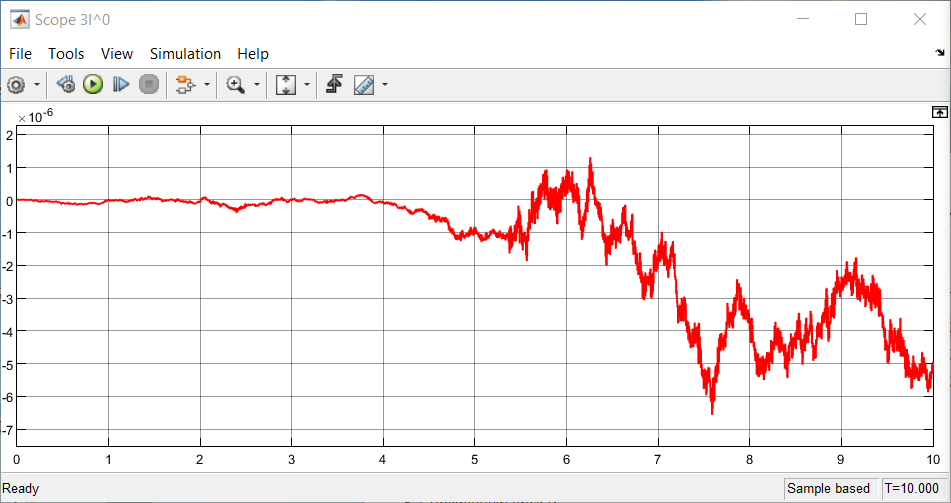
where I0.start and I0.end I0 are the currents at the line ends. In the normal operating mode, ΔI0<Iset=1.2⋅ΔIdiff ΔI0<Iset=1.2⋅ΔIdiff. The filter attenuates noise (amplitude 0.05 A, 200 Hz) to a level suitable for analysis.

**RESEARCH RESULTS**

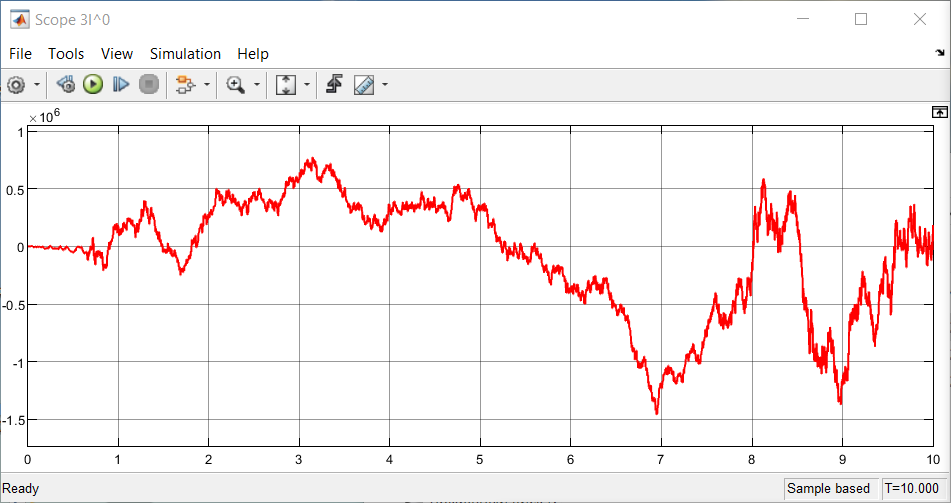
Synchronization with U0 confirms the combined approach: the trip signal is generated only when (U0>Uth)↔(ΔIdiff>Iset) leftrightarrow, thereby avoiding false tripping.

The filtering logic is integrated with the control block. The setting value and trip signal are defined as:

Iset=1.2⋅ΔIdiff.I

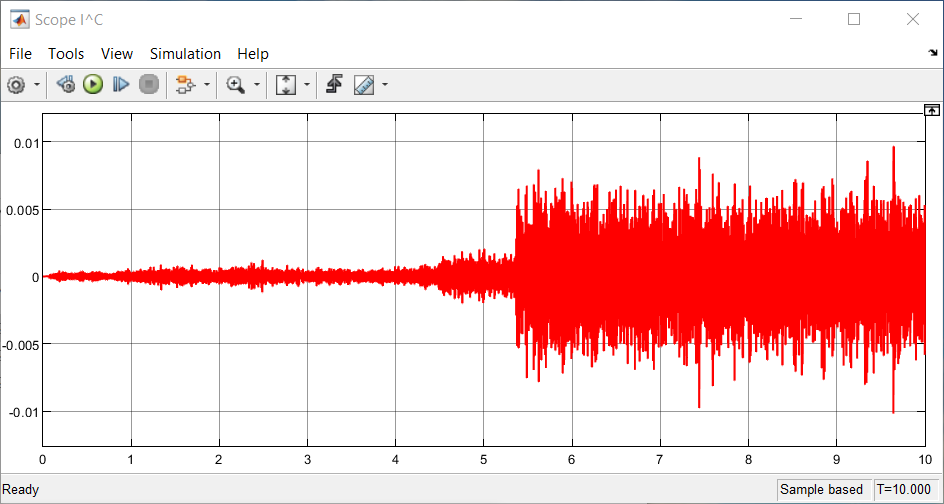


a)

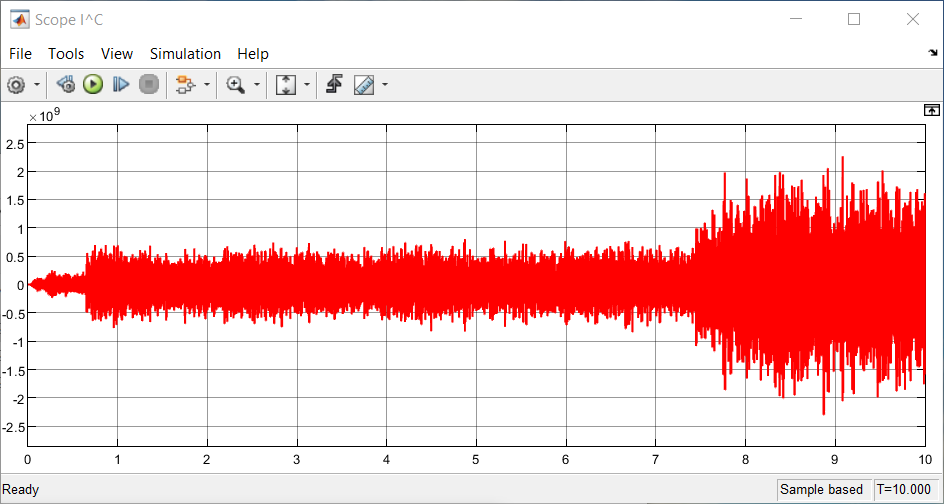


b)

**FIGURE 2.**Characteristic with ground fault (b) and without ground fault (a) in power systems (adapted: increase of ΔIdiff under ground fault conditions).

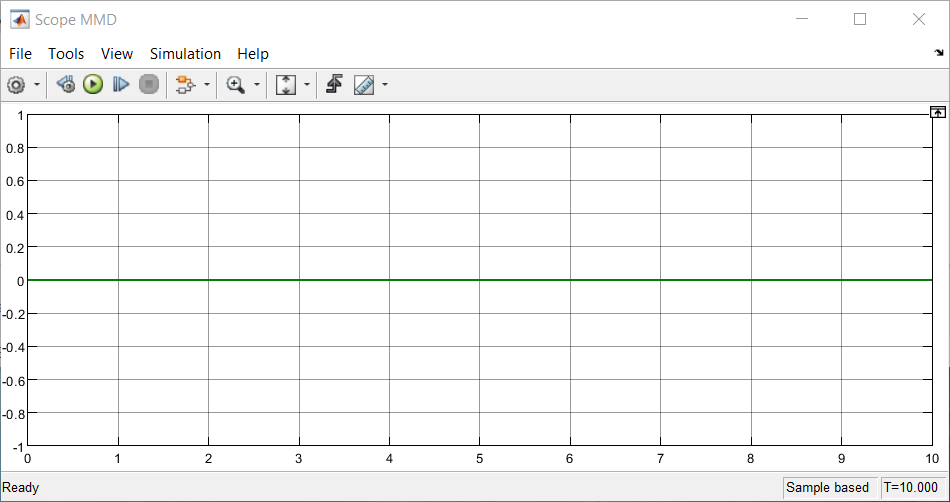


a)

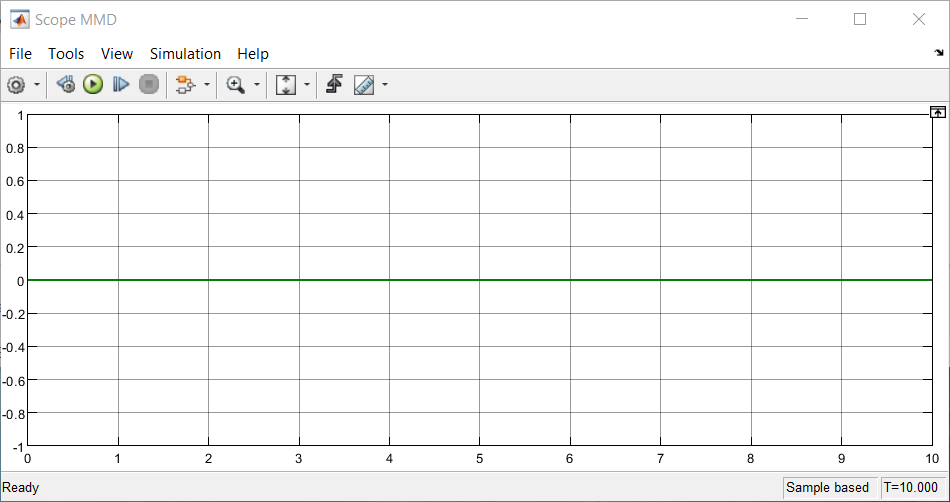


b)

**FIGURE 3.**Characteristic of the MMD current with ground fault (b) and without ground fault (a) (adapted: differential analysis for energy complexes).



a)



b)

**FIGURE 4.** Characteristic of the measuring block signal with ground fault (b) and without ground fault (a) (adapted: filtering in substations under load increase of 6–7%).

The results of the analyses carried out in the MATLAB Simulink environment for the measuring block with MMD, designed for selective detection of ground faults, demonstrate that without a signal from the open-delta connection of the voltage transformer—i.e., when the zero-sequence voltage is below the threshold value Uth>U0 the control block does not transmit the signal to the subsequent stage.

It was found that the control block does not forward the signal for tripping unless the zero-sequence voltage U0 is present. This ensures the avoidance of false operations of the protection system in power networks of the mining industry, particularly in complexes with variable capacitance.

As shown in Table 1, the developed measuring block of the microprocessor-based measuring system with MMD for ground fault protection provides improved sensitivity and selectivity, along with minimal protection operation time for mining power systems, which is essential under conditions of unstable network parameters.

**TABLE 1.**Simulation results of the measuring block in power systems

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Mode | (А) | Sensitivity  (MkА) | Selective  (%) | Hour (h) |
| Normal | <0.01 | - | 100 | - |
| SLG | 0.1 | 1 | 98 | 0.02 |
| Noise (200 Hz) | 0.05 | 10 | 95 | 0.03 |

**CONCLUSIONS**

The modeled MMD-based measuring unit has been shown to ensure high sensitivity and reliability in the selective detection of ground faults. Due to the sequential filtering, synchronous detection, and the combined logic with the zero-sequence voltage U0U\_0U0, false tripping under noise, transient processes, and capacitive imbalance is effectively eliminated. The Simulink results confirm fast response (≤10 ms), selectivity in the range of 95–98%, and stable operation even under variable network parameters typical for mining power systems. Thus, the developed MMD-based measurement block is suitable for practical application, providing fast, accurate, and reliable ground-fault detection in real power networks.

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