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Enhancing Power Grid Resilience: Advanced Strategies for Detecting and Analyzing Faults in Three-Phase Transmission Lines

Khandakar Rabbi Ahmed
Adjunct Researcher, Miyan Research Institute
International University of Business Agriculture and Technology
Uttara Model Town, Dhaka, Bangladesh
Dept. of Mechatronics Engineering
Rajshahi University of Engineering and Technology (RUET)
Kazla, Rajshahi-6204, Bangladesh
khandakarrabbiahmed@gmail.com

Khandokar Shadman Shayer
Dept. of Electrical & Electronic Engineering
American International University-Bangladesh
Dhaka, Bangladesh
khandokarshadman@gmail.com

Jahidul Islam Shuvo
Dept. of Electrical & Electronic Engineering
American International University-Bangladesh
Dhaka, Bangladesh
jahidulislamshuvo2000@gmail.com

F. M. Mahmudul Haque
Dept. of Electrical & Electronic Engineering
Ahsanullah University of Science and Technology
Dhaka, Bangladesh
fahimhaque067@gmail.com

Towfika Salam
Dept. of Computer Science and Engineering
Rajshahi University of Engineering and Technology (RUET)
Rajshahi, Bangladesh
towfikasalam@gmail.com

Shafiun Miraz
Dept. of Computer Science and Engineering
Rajshahi University of Engineering and Technology (RUET)
Rajshahi, Bangladesh
shafiunmiraz@gmail.com

Abdullah Al Noman
Dept. of Institute of Information Technology
Jahangirnagar University
Saver, Dhaka-1342, Bangladesh
alnoman956@gmail.com

Md. Shohanur Islam Sobuj
Dept. of Electrical and Electronic Engineering
Hajee Mohammad Danesh Science and Technology University
Dhaka, Bangladesh
shohanursobuj@gmail.com

Md. Yaqub Arafat
Dept. of Mechanical Engineering
International University of Business Agriculture and Technology
Dhaka, Bangladesh
yaqubarafat1234@gmail.com

MD Istiak Hasan Rial
Dept. of Computer Science and Engineering
Aditya College of Engineering (AOCE)
Surampelam kakinada-533291, Andhra Pradesh, India
realhasan74@gmail.com

Abstract— **Power system fault analysis is a process that establishes the bus voltages and line currents when various fault types occur. Three-phase balanced faults and unbalanced faults are two categories of power system faults. Single line-to-ground, line-to-line, and double line-to-ground faults are three different types of unbalanced faults that can occur on transmission lines for power systems. Fault analysis is used to choose and set the proper protective devices and switchgear. Determining the bus voltages and line currents is critical while investigating power system issues. Numerous mathematical calculation techniques are shown in the process, which is challenging to do by hand. The calculation can be performed quickly on a computer using a Simulink created using MATLAB. However, an error occurs when inverting an extensive bus system's Y-bus to Z-bus in the conventional short circuit study; this paper offers a solution that is solved using "MATLAB SIMULINK" to reduce error.**

Keywords—Power System, Grid, Faults, Three-phase, SIMULINK, Relays.

I. INTRODUCTION

The practical and dependable electrical power transmission over vast distances depends heavily on three-phase transmission lines. However, these transmission lines may develop faults due to several causes, including faulty machinery, lightning strikes, or environmental factors. For the power system to remain stable and maintain its integrity, fault analysis and detection must be done quickly and accurately [1]. In recent years, power system analysis and research have significantly benefited from using simulation tools like Simulink. Three-phase transmission lines can be modeled and simulated using the flexible and extensive framework offered by Simulink [2]. Researchers and engineers can create sophisticated fault analysis and detection algorithms to improve the performance of power systems by utilizing Simulink's capabilities. The goal is to generate a fault detection method that is accurate, efficient, and can detect defects in real time. The suggested approach combines the strength of signal processing techniques with Simulink's simulation capabilities to achieve high accuracy and quick fault detection. The fault analysis and detection program will use various signals and measurements, such as voltage and current waveforms, to discover abnormal situations that suggest problems. The program can distinguish between fault situations and typical operating conditions by examining the features of these signals [3]. The program will also try to identify the problem throughout the transmission line. This research advances sophisticated methods for three-phase transmission line fault detection while expanding the knowledge about power system fault analysis and detection [4]. The results of this study will help power system engineers and operators improve the dependability and stability of power transmission networks.

II. REVIEW OF FAULT

The faults that happen most commonly in a three-phase system are the single line to ground fault, L-L fault, 2L-G fault, and three-phase faults. When they develop during electrical storms, these faults can result in insulator flashover and ultimately influence the power system [5]. A network of positive, negative, and zero sequences must be built to investigate and analyze the unsymmetrical fault in MATLAB. The bus voltage and current in the positive, negative, and zero lines are examined in this work under various fault scenarios. We also investigated the system's active, reactive, and rms bus current and voltage under different fault scenarios.

A. Symmetrical Fault

An asymmetrical fault in an electrical power system is one in which all three phases of the fault have the same fault impedance[6]. A balanced fault or three-phase fault are other names for it. When a problem, such as a short circuit, occurs in all three phases simultaneously, symmetrical faults are thought to be the most severe result. Three balanced fault types include Three-Phase Short Circuit, Line-to-Line fault (L.L.), and Double Line-to-Ground Fault (DLG).

B. Unsymmetrical Fault

When there is an impedance mismatch between the phases in an electrical power system, unsymmetrical faults[11], sometimes called asymmetrical faults or single-line-to-ground faults, are fault circumstances that develop. The reliable operation of electricity systems may be hampered by these faults, potentially creating substantial disruptions. This includes Single Line-to-Ground Fault (SLG), Line-to-Line Fault (L.L.), and Double Line-to-Ground Fault (DLG).

III. TYPES OF POTENTIAL FAULT

Locating the fault rapidly and restoring the power supply as soon as feasible with the least disruption, fault location, and distance estimation are crucial issues in power system engineering[7]. This is required for the efficient operation of power equipment and customer satisfaction. In a three-phase transmission line, there are 11 potential faults: X.Y., X.Z., Y.Z., XYG, XZG, YZG, XYZ, and XYZG. These fault types are categorized into five different types of faults:

A. The line-to-ground faults

Line-to-ground faults happen when an electrical conductor contacts the ground and current flows to the ground. Equipment damage, fire dangers, and risks of electric shock may all result from these faults[7]. These faults in electrical systems are found and mitigated using protective measures like GFCIs.

B. Line to Line faults

Line-to-line faults happen when two electrified conductors touch one another. Insulation failure, harmed equipment, or unintentional touch can all cause these faults. High current flows, equipment damage, a risk of fire, and electric shock are all possible effects[7].

C. Double Line to Ground faults

Double line-to-ground faults happen in the electrical system when two conductors simultaneously contact the ground. A more severe fault state could arise from this, leading to larger currents and possible equipment damage. Electric shock and fire dangers are raised, necessitating quick detection and mitigation to keep everyone safe.

D. Line to Line-to-Line faults

Electrical faults, known as line-to-line-to-line faults, happen when three energized wires come into contact simultaneously[7]. These faults pose severe threats to personnel and equipment due to the vast fault currents they can cause. Quick discovery and prompt corrective action are required to lessen the risks posed by such faults.

E. Line to Line to Line to Ground faults:

Electrical faults, known as line-to-line-to-line-to-ground faults, occur when three energized conductors concurrently come into contact with one another and the ground. These faults can cause high fault currents, severe equipment damage, fire risks, and an elevated risk of electric shock. Quick discovery and action are essential for safety and to stop future harm.

Detection of faults becomes straightforward by observing a sudden decrease in line impedance due to the high current during a fault. The relay system must be arranged for fault analysis[8]. The relay continuously receives the fundamental components of voltage and current for each phase, providing impedance values. When a fault occurs, the impedance experiences a sharp decrease due to a short circuit path for the draft[9]. By detecting this significant change in value, the relay identifies the faulty phases with logic-controlled devices[9]. Since the difference in value is substantial and confined to the phases where the fault exists, it becomes easier to identify the wrong phases. Subsequently, circuit breakers can isolate the respective phases from the system.

IV. METHODOLOGY

Here, we designed a model for a differential protection relay; the steps are as follows:

1. We went to the library browser and took a Three-phase source, 2 Three-phase breakers, 2 Three-Phase V-I measurements, a Three-Phase transformer (Two Windings), a Three-phase[10] series RLC Load (rotated), a Three-phase fault, Stair generator, Demux, Scope. Then, we established the connection between the components.
2. Now, we will put the parameters for all components. First, we selected a Three-Phase source, and here, we changed the frequency to 50 Hz and Vrms to 33e3. Then we set Three-Phase breakers, and here, we changed the initial status to closed and the fault to external. We selected the external and initial position to 0 in the Three-Phase Fault. Then, we connected the Stair generator to the Three-Phase Fault. Here, in the Stair generator, we changed the values for time to [0, 0.04 0.08, 0.12] and amplitude to [0,1,0,0]. In The -Phase transformer, we did not change the default values for configuration. We changed some values in parameters, such as Nominal power to 250e6 and frequency to 50. For the Three-phase series RLC Load, we changed the frequency to 50 Hz. Moving to the scope, we changed the number of input

ports to 3. In Demux, the number of outputs was set to 3 and was connected to the area. The scopes were related to the results of the Three-Phase V-I measurement.

3. Then, we need to design a differential scheme for this. We pasted the same Demux blocks to the upper side and connected them with the previous ones. Then, we took the DRMS block from the library browser, made six copies, and combined it with the upper bus bars. Then, we connected Gain from the library browser to every DRMS output by making three copies. For the values of Gain, we kept it three because our transfotransformer's 3. Then, we placed the sum block in the upper DRMS outputs and gains by making three copies. Then we took Abs blocks and connected them with sum blocks. After that, we took the Relational Operator and changed the value to Greater (>)and input values to 2. Then, we took 3 S-R Flip-Flop and constructed a connection. Also, we took Powergui and changed its mode to discrete and the time to 1e-6.
4. After that, we took Logic Operator, changed the input value to 3, and established a connection. We also took three terminators and connected them. Now we need data
5. type conversion and choose the output data type to double and connect its output to both circuit breakers. We created the sub-system. To simulate, we made it run for 0.9 seconds. By clicking on the scopes, we were able to observe the results.

Here are the parameters for different simulation blocks

A. A.C. Voltage Source Simulink Block

TABLE I. THREE-PHASE SOURCE BLOCK

Configuration	Yg
Phase-to-phase voltage (Vrms)	11e3,33e3,66e3
Phase angle of phase A (degree)	0
Frequency	50
Impedance	Internal, specify short-circuit level parameters
3-phase short-circuit level at a base voltage (V.A.)	100e6
Base volage (Vrms ph-ph)	25e3
X/R ratio	7

B. Distributed Transmission Line Simulink Block

TABLE II. THREE-PHASE PI SECTION LINE

Line length (km)	100
Frequency used for RLC specification (Hz)	50
Positive- and zero-sequence resistance (Ohms/km) [r1 r0]	[0.01273 0.3864]
Positive- and zero-sequence inductances (H/km) [I1 I0]	[0.9337e-3 4.1264e- 3]
Positive- and zero-sequence capacitances (F/km) [c1 c0]	[12.74e-9 7.751e-9]

C. Proposed Model in Simulink

We constructed the model according to the parameters shown above. The model showed data on various conditions and gave appropriate output upon selected case scenarios.

D. Differential Relay Simulink Block

To construct a differential relay sub-system model in Simulink, a simulation model that simulates the operation and behavior of a differential relay must be built.

The Signal sources, configured as constant values produced by the relevant blocks, depict the currents flowing via the parallel routes. The differential relay algorithm block calculates the difference in current between the two signal sources. When the threshold is surpassed, the comparator block creates a binary output indicating a fault state by comparing the differential current with the pre-set threshold value. The comparator's work is shown visually via the display block. We linked the blocks once we added them to create the correct signal flow. The signal sources are connected to the differential relay algorithm block's input, and the comparator

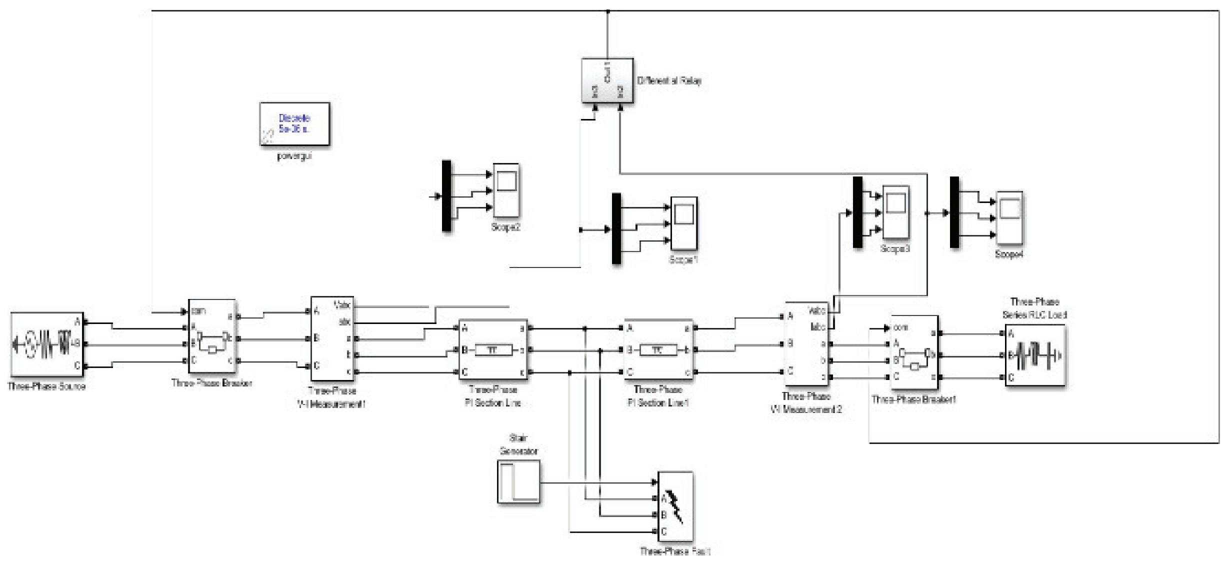

Fig. 1. Full model of the proposed system

algorithm block's input is connected to its output. The display block's input is connected to the comparator block's output.

Finally, when the connections were established, we configured each block's properties in Simulink, including current values and thresholds.

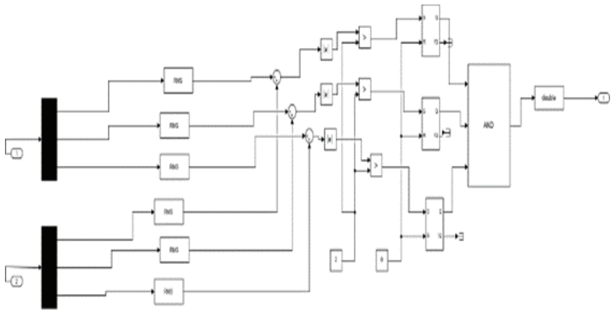

Fig. 2. Differential relay sub-system model

E. Three-Phase Fault Simulink Block

TABLE III. THREE-PHASE FAULT

Initial status	0
Initial status	0
Fault between	Phase A, Phase B, Ground
Switching time (s)	[1/60 5/60], External
Fault resistance Ron (Ohm)	0.001
Ground resistance Rg (Ohm)	0.01
Snubber resistance Rs (Ohm)	1e6
Snubber capacitance Cs (F)	inf
Measurements	None

F. Parallel RLC Load Simulink Block

TABLE IV. THREE-PHASE SERIES RLC LOAD

Configuration	Y (grounded)
Nominal phase-to-phase voltage Vn (Vrms)	1000
Nominal frequency fn (Hz)	50
Active power P (W)	10e3
Inductive reactive power Q.L. (positive var)	100
Capacitive reactive power Qc (Negative var)	100
Measurements	None

G. Powerful Simulation Block

TABLE V. POWERGUI

Simulation type	Discrete
Sample time (s)	1e-6

In this case, the differential relay will assess the current levels on both sides and open the circuit breaker if it notices a change in value on either side. According to the fault resistance and distance, the impedance decreases from the thousands to the hundreds, and the current rises from the hundreds to the thousands during a fault situation. A change in load affects these figures as well. The single-ended fault localization algorithms may have issues with high load currents; therefore, this must be considered. A set point must be chosen to distinguish between overload and fault correctly.

V. RESULT & ANALYSIS

The result section will show outputs from the simulation on various fault conditions. These outputs were combined into one work frothe simulation's scope.

A. For Line (A) to Ground Fault

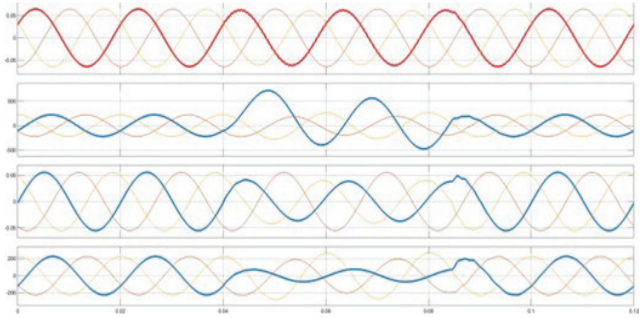

Fig. 3. L-G Fault Current & Voltage Waveform

B. From Line (A) to Line (B) Fault

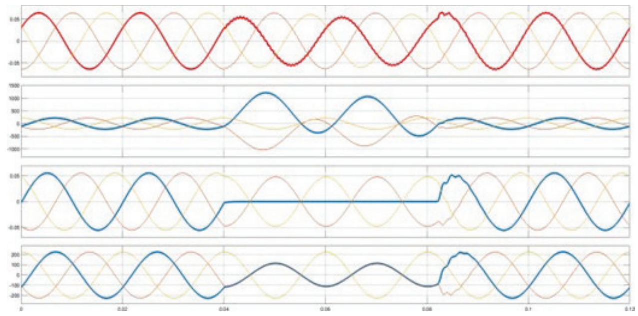

Fig. 4. L-L Fault Current & Voltage Waveform

C. For Line (A) to Line (B) to Ground Fault

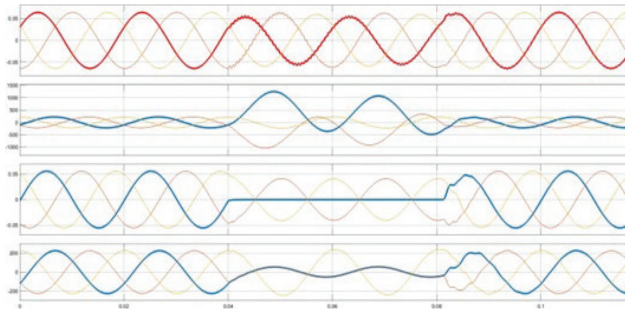

Fig. 5. L-L-G Fault Current & Voltage Waveform

D. For Line (A) to Line (B) to Line (C) Fault

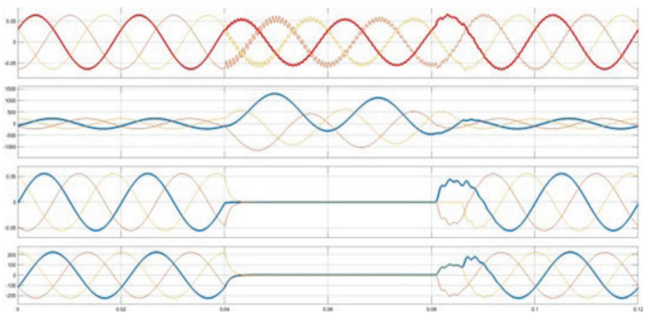

Fig. 6. L-L-L Fault Current & Voltage Waveform

E. For Line (A) to Line (B) to Line (C) to Ground Fault

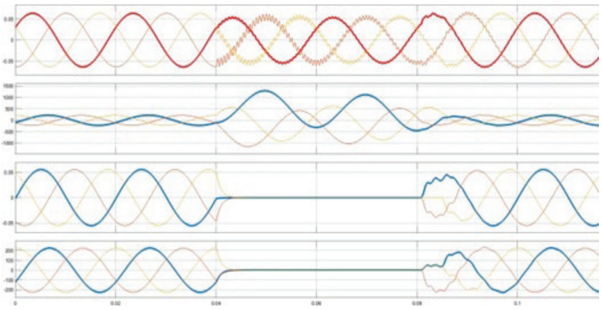

Fig. 7. L-L-L-G Fault Current & Voltage Waveform

Simulink's implementation of a differential relay for fault analysis and detection in a three-phase transmission line yields insightful data about the operation and efficacy of this safety measure. In this section, we presented and discussed the findings of the fault analysis and detection methods employing a differential relay.

The Power system model, in this instance, operates for the L-G fault, which is a single line to the Ground Fault. To improve the clarity of the waveforms, the simulation runs for 1.2 seconds. It is assumed that the sample frequency is 50 Hz. For a three-phase source, the system base voltage is considered to be 33 kV. The fault is started at 0.04 secs and clears at 0.07 secs. This system has three 3-phase VI measurement blocks. When the fault occurs, the differential relay, in which both inputs are connected to the current parameter, will sense the sudden current rise and open the circuit breaker to clear the fault—the transient condition: the fault causes a spike in the waveform in both figures. As is common knowledge, a generator runs asynchronously, but when a fault occurs quickly, the speed increases, and the current rises. We can also see that the voltage goes down to nearly zero, and there is some interruption in the waveshape during the fault. Moreover, the same goes for all the other types of faults.

Additionally, the differential relay's performance was assessed regarding selectivity, or the capacity to isolate only the problematic segments of the transmission line while keeping the healthy parts. Successful selective functioning of the relay reduced the impact on the remaining operating portions and minimized the effect on the power system.

The outcomes of the fault analysis and detection in Simulink using a differential relay help to improve and better understand fault management in three-phase transmission lines. The differential relay enhances power transmission networks' dependability, stability, and safety by precisely and quickly finding problems and isolating the afflicted areas.

VI. CONCLUSION

This research presented a simulation-based performance analysis of a differential relay's ability to identify three-phase power system faults. A high degree of accuracy was shown by the differential relay in identifying three-phase faults, reducing the chance of equipment damage, and guaranteeing the security of the power network. It demonstrated excellent fault discrimination abilities, correctly locating the affected area of the power system and facilitating effective fault localization. The research also examined how the differential relay works with other protective devices in the power system, including how it coordinates and communicates with them. Based on the findings, it can be said that the differential relay is an excellent and dependable method for a power system's three-phase fault detection. Further research and development in this area can lead to advancements in fault detection techniques and improved power system protection strategies.

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