ADAPTIVE STABILITY DETECTION ALGORITHM FOR MODERN PROTECTION RELAYS

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ABSTRACT

This paper presents an adaptive relay algorithm for Out-Of-Stability (OOS) detection that can be implemented in modern distance, line differential, and generator protection relays. The algorithm based Synchro-Phasor Measurement Units (SPMUs) for detecting the online system frequency used for calculating the online system angular speed. The algorithm is angular frequency-based for detecting the OOS condition for instant of tripping and normal power swing that could be used for blocking the distance function from the abnormal tripping. Also, the algorithm is considered a remote breakers monitoring as it can detect fault clearing instant without any tele-communications between local and remote end substations. Single machine infinite bus (SMIB) test system is employed for validating the effectiveness of the proposed relay algorithm by making a comparative analysis between the Conventional Time Domain Method (CTDM) and the proposed relay algorithm.

I. INTRODUCTION

Modern power systems networks require a continuous monitoring, control, remedial actions in real-time events. OOS for interconnected power systems networks is a great computation challenge due to non-linear differential equations used in system simulation [1, 4-7]. So that, conventional protection relays detect the OOS using blinder characteristics with two steps or three steps either QUAD or MHO shape [2, 3]. Some manufacturers using the rate of change of impedance with respect to time that intersects the blinders for detecting the OOS like Siemens Company. Whereas, other manufacturers employed some timers that guarantee that the impedance stayed inside the blinders for certain time which means OOS and instant tripping should be happened like General Electric Company. The blinder characteristics method requires complex setting for drawing the adequate regions for power swing that blocks the distance function from abnormal tripping, and OOS that trips the associated circuit breakers [2, 3]. Thus, any setting error from user side could cause mal operation for the protection relay. Also, the blinders setting for generator protection and Over Head Transmission Lines (OHTLs) must be coordinated to trip the associated circuit breakers by selectivity. According to the above reasons an adaptive online monitoring and tripping algorithm is presented in this paper that can be implemented in modern protection relays equipped with Phasor measurement Units (PMUs).

The algorithm is adaptive and online since it is based on the online measurements via SPMUs for detecting system OOS. No settings are adjusted by the user and in turn no errors from user side that could make mal operation as in the case of the blinder characteristics method. Also, the presented algorithm can detect the tripping actions by the remote end circuit breakers without any tele-communications as depicted in the following sections. The algorithm comprises of five stages for detecting the normal power swing and OOS that will be highlighted in the following sections.

II. MODERN PROTECTION RELAY ALGORITHM

The modern protection relays algorithm presented in this paper comprises of five stages as depicted in the following subsections.

The *first stage* is for detecting the disturbances in system angular frequency and producing an output operand denoted (W_{DD}) which stands to angular frequency Disturbance Detector. The W_{DD} detects the sudden increment or decrement in the system angular frequency. Figure.1 depicts the first stage of the algorithm. The Discrete Fourier Transform (DFT) soft filter is used to filter the input frequency signal from any other injected harmonics due to switching heavy loads.

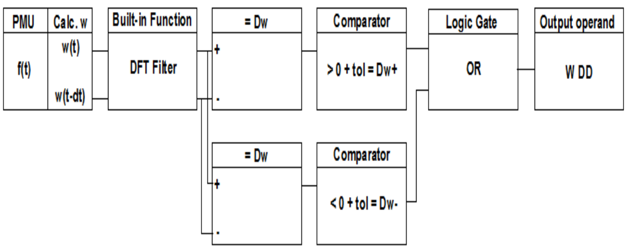

Figure.1: First stage of the modern protection relay algorithm

Second stage is for detecting a fault condition in the power system network as depicted in figure.2. Fault occurrence is detected by a signal from the disturbance detector AND a signal from the internal logic operand that detects an increment in the angular frequency Dw+. An OFF-delay timer with two power cycles is used for sealing-in (latching) the output operand of this stage.

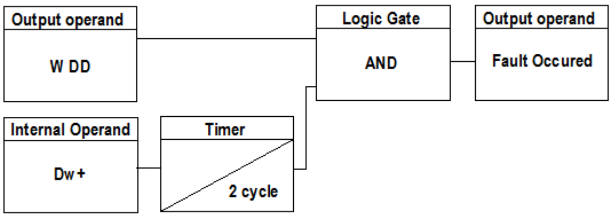

Figure.2: Second stage of the modern protection relay algorithm

Third stage is for detecting the instant of fault clearing. The output operand "Fault Cleared" is activated by a signal from the fault occurrence operand and a decrement in the angular frequency by the operand Dw- as shown in figure.3. An OFF-delay timer with two power cycles is used for sealing-in (latching) the output operand of this stage. Relay at local end in the substation can detect if the fault is cleared or tripped by remote end circuit breakers.
The issue is, although a fault clearing is occurred from remote end circuit breaker as it is the location of fault, the local generating unit could loss-of-synchronism if the tripping action exceeds the system critical clearing time. So that, a continuous monitoring for system stability due to internal or external faults should be employed in the presented adaptive modern algorithm. Figure.3 depicts the third stage of the algorithm.

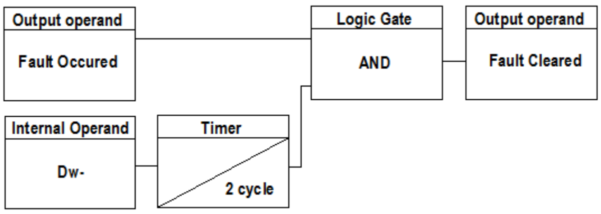

Figure.3: Third stage of the modern protection relay algorithm

Figure.4 depicts the *fourth stage* of the presented OOS algorithm of normal power swing detection resulting from small disturbances like line connection, line disconnection, or auto-reclosure actions. Output operand should be used for blocking the distance protection function preventing the abnormal tripping in that case. This part of the logic resets by the produced output operand after two power cycles delay time i.e. the function seal-in time is equals two cycles for more reliable and stable operation for the algorithm. This stage detects a stable system by tracking the angular frequency signal. After fault occurrence, the angular frequency increases reaches to a maximum value. Then a decrement in angular frequency will be happened. If the angular frequency decreases to the value of the synchronous angular frequency or below, the algorithm considers a stable swing and produces an output operand used to block the protection relay from mal-operation.

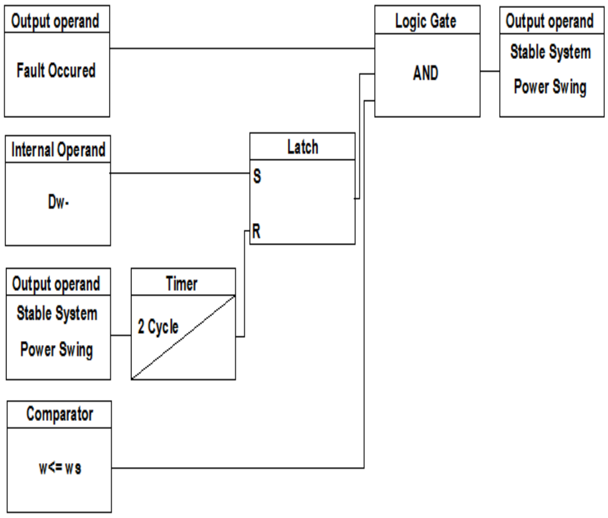

Figure.4: Fourth stage of the modern protection relay algorithm

Figure.5 depicts the *fifth stage* of the presented OOS algorithm. This stage is implemented for detecting the OOS events in the system due to system faults. The algorithm produces an output operand for instant tripping which in turn should be assigned for relay outputs to trigger the associated tripping circuits. Also, This part of the logic is Reset by the produced output operand after two cycle delay time i.e. the function seal-in time is equals two cycles for more reliable operation and dependable algorithm.
Also, this stage detects unstable system by tracking the angular frequency signal. After fault occurrence, the angular frequency increases reaches to a maximum value. Then a decrement in angular frequency will be happened. If the angular frequency decreases to a value greater than the synchronous angular frequency then increases again, the algorithm considers unstable swing and produces an output operand to trip the associated circuit breakers.

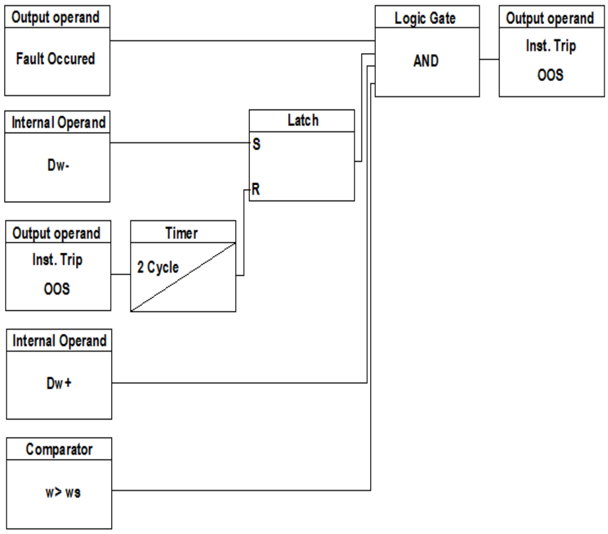

Figure.5: Fifth stage of the modern protection relay algorithm

Figure.6 shows an overall logic diagram for the Modern Protection Relay (MPR) algorithm for easy tracking.

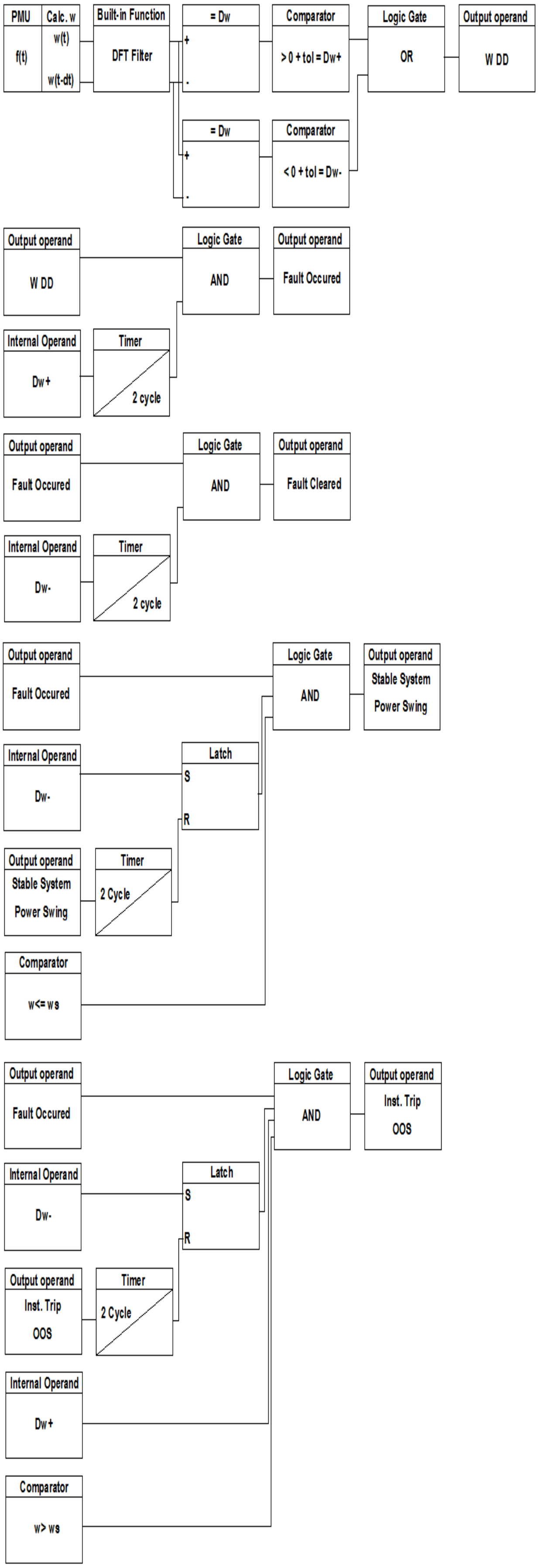

Figure.6: The MPR algorithm for OOS

III. Simulation Results

The power test system used in this paper is the Single Machine Infinite Bus (SMIB) with two parallel lines as shown in figure.7 with system data in [4]. A three phase short circuit is simulated at the beginning of one of the two Over Head Transmission Lines (OHTLs). Off-line simulation –using Matlab M-files created by the authors- is made for obtaining the frequency response to be used as the online measurements of the PMU. More details about PMUs and SPMUs and their applications in stability detection and control are in [8, 9, 10].

The internal clock of the protection relay used for time-tagging can be synchronized with an IRIG-B signal or via the SNTP protocol over the Ethernet port to have a synchronized phasor as shown in figure.7 by the SPMU.

According to the MPR algorithm the CT and PT analogue signals are connected to the SPMU which in turn are employed by the Modern MPR algorithm as shown in figure.6. The MPR logic is simulated -by Matlab M-files created by the authors- to result the depicted results in this section.

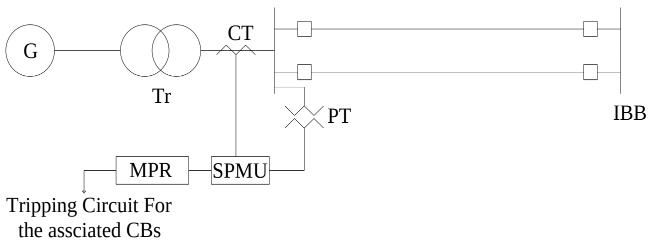

Figure.7: SMIB test system

Figure.8 shows an alarm message by the MPR algorithm for a stable case with normal power swing events. Also, at the same time a signal will be used for blocking the protection relay from tripping during this power swing preventing the mal-operation. Whereas, figure.9 depicts the system response for stable power swing disturbances which is dealt by stage four of the MPR logic.

Figure.10 shows an alarm message by the algorithm for unstable case with normal power swing events. Whereas, figure.11 depicts the system response for unstable disturbances which is dealt by stage five of the MPR logic.

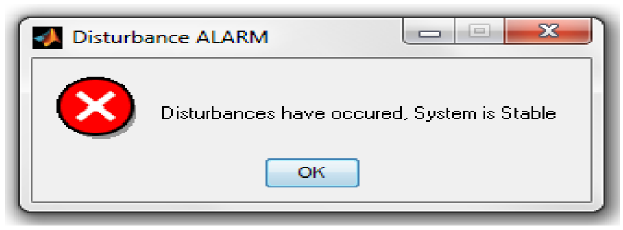

Figure.8: Alarm message for stable system

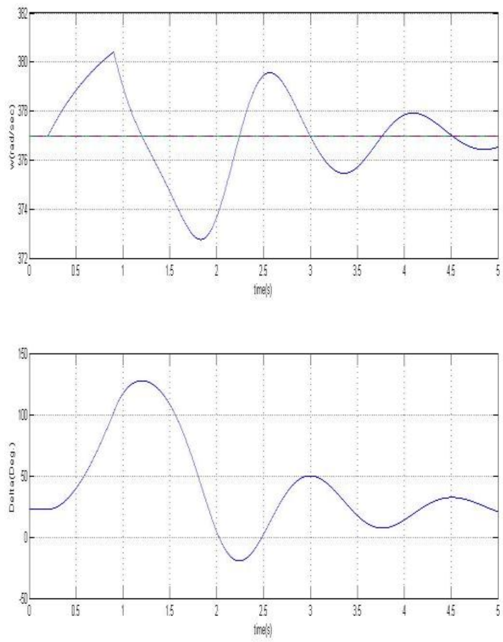

Figure.9: System responses for stable case

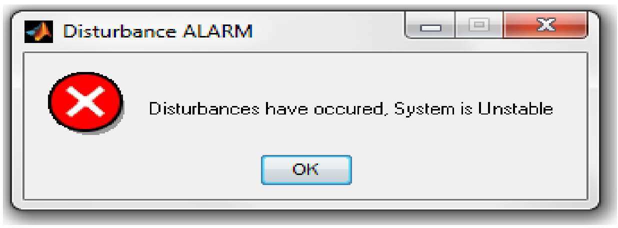

Figure.10: Alarm message for unstable system

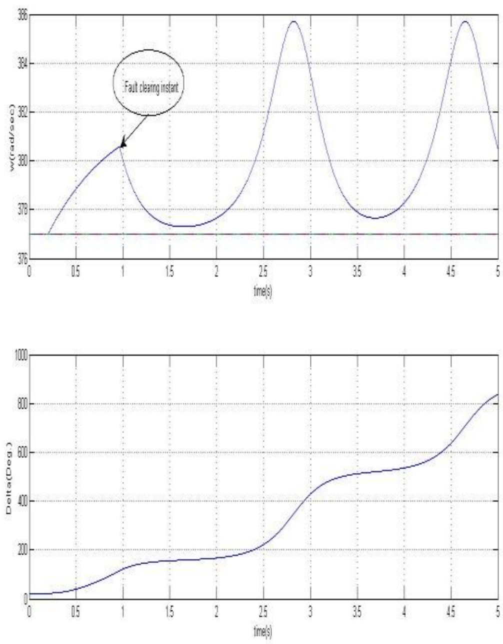

Figure.11: System responses for unstable case

Figure.6 depicts the overall modern MPR algorithm that can be implemented in modern protection relays for a more reliable and secure power systems networks. The overall algorithm is programmed via Matlab script file and tested by SMIB test system for several cases shown in table.1.

A comparative analysis is made between Conventional Time Domain Method (CTDM) and the modern algorithm for OOS as shown in table.1. The two methods show identical results but, the MPR algorithm is a real-time one and adequate to be embedded into protection relay algorithm as discussed into this paper.

Table 1: Validating the modern OOS MPR algorithm

Case No.	***Fault Time (ms)***	***CTDM*** *(Off-line)*	***Modern Algorithm*** *(Real-time)*	***Remarks on the algorithm***
1	100	Stable	Stable	Distance Block
2	200	Stable	Stable	Distance Block
3	300	Stable	Stable	Distance Block
4	400	Stable	Stable	Distance Block
5	500	Stable	Stable	Distance Block
6	600	Stable	Stable	Distance Block
7	700	Stable	Stable	Distance Block
8	750	Unstable	Unstable	Trip
9	800	Unstable	Unstable	Trip
10	900	Unstable	Unstable	Trip

IV. CONCLUSIONS

Out-of-stability and normal power swing can be detected using the adaptive MPR algorithm presented in this paper. The algorithm can be implemented in modern protection relays such as generator, distance, and line differential protection relays that need a blocking during normal power swing events. The algorithm detects the OOS via the online measurements of SPMUs that reflects the real state of the system and doesn't require any off-line simulations. No need for tele-communications (pilot signals) between local and remote end substation as the tripping actions by the remote end circuit breakers can be monitored via the algorithm as described through the paper.

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