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Smart Fault Detection Algorithm for Transmission Networks

Fady Wadie[1, *]

[1]*Mechatronics and Robotics Engineering Department, Faculty of Engineering, Egyptian Russian University, Badr City, Cairo, Egypt*

*Corresponding author: Fady Wadie, E-mail: fady-wadie @eru.edu.eg, Tel:+201222705643

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ABSTRACT

In this paper, a new smart fault detection algorithm was proposed that was employed in the protection system of electrical power transmission systems. The proposed algorithm uses phasor measurement units (PMUs) located at the terminals of the transmission lines. The measurements from the PMUs are used to compute the rate of change of delta reactive power or RPCQ for each line. The value of RPCQ is used to detect the occurrence of faults and define the faulty line. The algorithm was tested using a bench mark testing system WSCC 9-bus system. The testing included different types faults including single line to ground, line to line, double line to ground and three phase faults at different locations. The results showed the robustness and reliability of the proposed algorithm in fault detection. The fault location was changed to be in different positions of the line, and the proposed scheme still succeeded in detecting the faulty line correctly. The main contributions of this paper is the proposal of the smart fault detection algorithm that succeeds in providing high confidence results while using simple procedures.

Keywords: phasor measurement units; adaptability; backup protection.

1. Introduction

The continuous expansion of electrical power systems has challenged the reliability of conventional protection systems [1]. Smart protection systems have emerged to overcome such problems through enhanced algorithms of detection and the utilization of communication links in the detection process [2, 3]. In addition, the advances in measuring devices as interpreted through Phasor Measurement Unit (PMU) has allowed a further leap in the performance of smart protection algorithms [4, 5].

The literature survey showed that within this field, there three different paths that researchers have undertaken. The first path was characterized by using measuring devices to detect abnormal measuring patterns and possible faults. [5 - 9]. The second path gathers the information of the status of different protective relays across the network and analyzes the possible faulty elements [10 - 17]. The third path uses a hybrid approach of both previous paths by including both electrical measurements and the status of protective devices [18 – 21]. Further progress in this field in included the usage of time domain analysis to detect faults [22]. Superimposed impedance was based on the first path scenario was used in [23]. Negative sequence of zero current during faults was used in [24]. Travelling wave based fault detection was introduced in [25]. Real time fault detection was proposed in [26]. Artificial intelligence based algorithm that integrates machine learning and neural networks techniques within the algorithm was used in [27 – 29].

This paper proposes a smart fault detection algorithm that is intended to detect faults within transmission systems and avoids the drawbacks of previous schemes even in the presence of series compensated transmission lines. The algorithm gathers the measurements of positive sequence voltage and currents from PMUs at the terminals of the protected transmission line. The data are sent using dedicated communication links to the control room. The measured data are used to compute the positive sequence reactive power at both terminals of the transmission line and that comparison would be used for fault detection. The proposed protection algorithm was tested upon the Western System Coordinating Council (WSCC) 9-bus system using MATLAB/Simulink software packages.

A comparison is provided in table 1 that evaluates the literature paths in comparison to the proposed algorithm.

Table 1. Comparison between literature and proposed algorithm

	Path 1 Ref. [5 -9, 22 - 24, 26]	Path 2 Ref. [10 - 17, 27 - 28]	Path 3 Ref. [18 - 21, 25, 29]	Proposed Algorithm
Required Measuring Devices	PMUs	Conventional measuring devices	Conventional measuring devices	PMUs
Level of Complexity	Low	High	Medium	Very Low
Source of Delays	Communication links only	Computational time only	Communication and computational	Communication links only
Certainty of final decision	high	low	medium	high

The table shows that the proposed algorithm inherits most of the advantageous of the first path avoiding drawbacks from path 2 and path 3. In addition, the proposed algorithm provides a simpler fault detection than that of path 1 algorithms.

The contribution of this paper mainly relies on introducing a smart fault detection algorithm that avoids complicated procedure and provides a high level of confidence in the final decision. The remaining sections of the paper are organized as follows. Section 2 provides the main concept of the proposed algorithm. Section 3 presents the modeling of the testing system. Section 4 presents the simulation results for the performance of the proposed smart algorithm. Finally; conclusions are derived in section 5.

2. Main Concept of the Proposed Algorithm

The main concept upon which the smart algorithm was based, is that faults tend to absorb a significant portion of reactive power while the remaining un-faulty lines drop to negligible value. To transform that concept into a fault detection algorithm, a PMU is installed at the terminals of each transmission line of the network. The PMU measure the positive sequence currents and voltages at the terminals of each line. The measured values are sent via dedicated communication links to the control room. The smart algorithm computes the difference of the reactive power for each line ΔQ_n where "n" is the identifying number of each transmission line. Then the rate of periodical change of the ΔQ_n is computed for each line (RPCQ) according to (1)

$$RPCQ_n = \frac{\Delta Q_n(t) - \Delta Q_n(t-T)}{T} \quad (1)$$

Where $RPCQ_n$ is the rate of periodical change of the ΔQ_n for transmission line "n". $\Delta Q_n(t)$, $\Delta Q_n(t-T)$ are the difference of reactive power at terminals of transmission line "n" at two successive instants separated by one electrical periodic time T. The RPCQ is nearly zero in normal operations as the transmitted and received reactive powers at the terminals of the line are nearly constant and hence, the difference between them is constant and the rate of change will be zero. In faulty conditions, that condition is disrupted due to fault presence which leads to sudden change in ΔQ_n of the lines of the system. Therefore, the algorithm monitors the RPCQ for all the lines of the network in real-time. When non-zero RPCQ is detected, a red flag is initiated to declare fault detection. The threshold value used for fault detection was selected as 0.01 p.u. this value is based on previous analysis that during non-fault situations lines will have a near zero RPCQ. The faulty line would have the highest RPCQ as compared to the other lines. Once a faulty line is defined, the smart algorithm sends a trip signal to the circuit breakers at the terminals of line to open and isolate the fault. The number of required PMUs will be calculated based on the terminals of the required transmission lines under protection such that each terminal will have a PMU at it.

3. Modeling of the testing system

The benchmark testing system of the WSCC 9-bus was used for testing the proposed algorithm with the systems data used as provided in [7]. The series compensation level was set to 60% for 9-bus. The PMU was modeled with a reporting rate of 50 frames/second for 50 Hz system or simply 1 frame/cycle as defined in IEEE C37.118.1.

The transmission lines were modeled using frequency dependent line model available upon MATLAB. For the studied network, 6 PMUs are used at buses 7, 8, 9, 6, 4 and 5. PMUs are placed at the line terminals according to the criteria mentioned in previous section. The used PMUs might be considered as additional cost, however with the modernization of power systems and increasing number of PMUs deployed that cost be considered as a part of modern day plans for upgrading the system rather than the cost for algorithm itself [29 – 32]

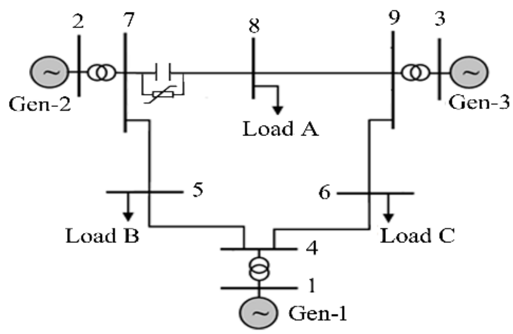

Figure 1. WSCC 9-bus system

4. Results and Discussion

The modeled WSCC 9-bus system was equipped with the proposed algorithm and tested its performance in detection different types of faults. the following subsectioins show its performnce for three phase faults, double line to ground, line to line and single line to ground faults. The impact of fault location was also tested.

4.1 Three Phase Faults

To provide adequate protection for series compensated transmission lines, a three phase fault was created on line 7-8 as shown in figure 1. The fault resistance was 0.1 ohms, the fault was created at 32 km from bus 7 that is equal to 10% of the line length. The series compensation level was set to 60 %. The fault occurred at 0.1 s from the simulation time with monitored RPCQ for all lines as shown in figure 2. The figure shows that at 0.12 s, the RPCQ of line 7-8 has risen to 0.35 indicating the line 7-8 is the faulty line while other lines remained at a near-zero value. The detection took 0.02 s or 1 cycle which considered relatively long period and for such reason the proposed algorithm will be considered as a back-up algorithm for local protection systems.

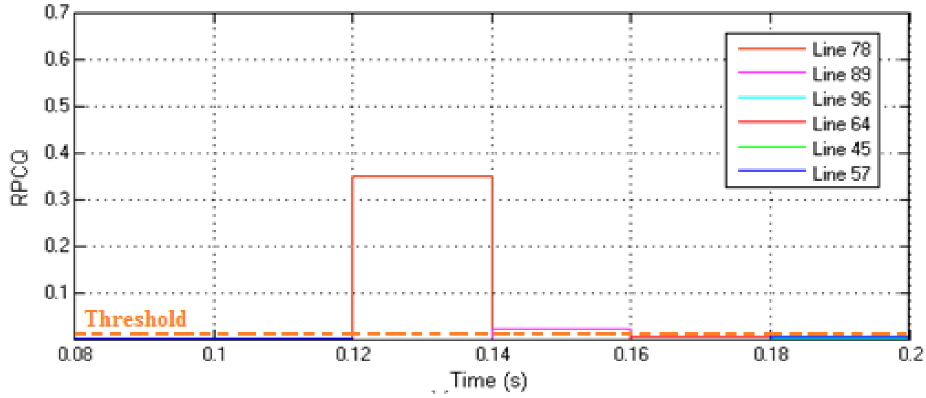

Figure 2. RPCQ for lines of WSCC 9 bus system during three phase faults

4.2 Double Line to ground fault

The effect of changing fault type to double line to ground fault was tested. The fault location and resistance were not changed. The results of the monitored RPCQ is shown in figure 3. the figure shows that at 0.12 s the RPCQ was increased to a considerable value indicating fault presence with the RPCQ of line 7-8 having the highest value showing it to be the faulty line.

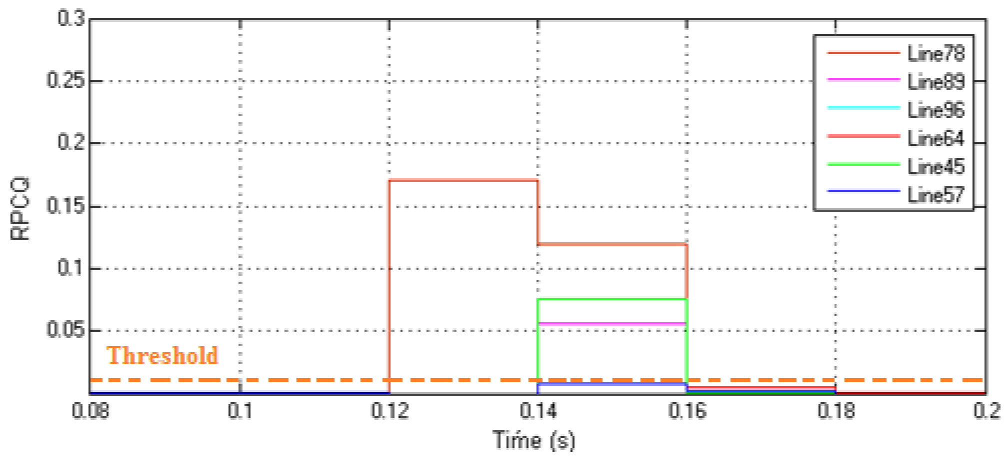

Figure 3. RPCQ for lines of WSCC 9 bus system during double line to ground faults

4.3 Line to line fault

The line to line unsymmetrical fault was also tested with other parameters unchanged as previous cases. The results of the monitored RPCQ for line to line fault on line 7-8 is shown in figure 4. The figure shows that at 0.16 s the RPCQ was notably rising to a detectable value for several lines with line 7-8 having the highest value showing it to be the faulty line.

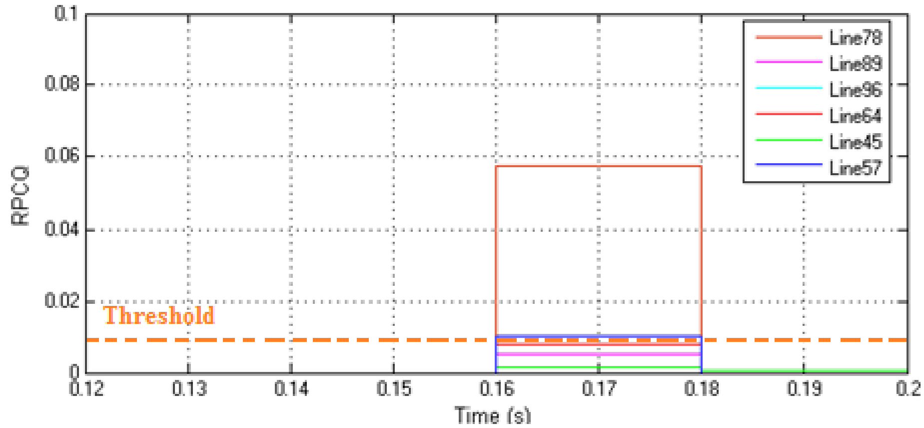

Figure 4. RPCQ for lines of WSCC 9 bus system during line-to-line fault

4.4 Single Line to ground fault

The single line to ground fault was tested as the final fault type to be tested with other parameters unchanged as previous cases. The results shown in the figure 5 indicate that the RPCQ for line 7-8 was the highest recorded value for the monitored RPCQ for all the lines indicating it as the faulty line. The algorithm sends a trip signal to the circuit breakers at the line 7-8 to isolate at the fault.

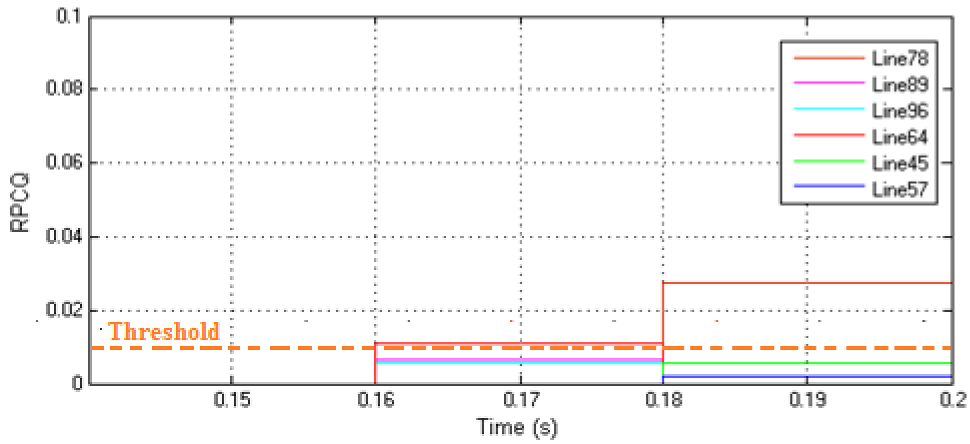

Figure 5. RPCQ for lines of WSCC 9 bus system during single line to ground fault

It is noted from results of sections 4.1 to 4.4 for different fault types that the time delay for fault detection is within one to three cycles regardless of the fault type. That is attributed to cyclic nature of PMU measurements.

4.5 Impact of changing fault location

The effect of changing the fault location for three phase faults from 10 % of the line length to 50% is shown in figure 6. The results show that line 7-8 was still correctly identified as the faulty line even for different fault locations. The location of three phase fault was varied from 10 %, 50% to 90% across line 7-8 and their results are presented in table 2. The fault was created at 0.1 s for all faults and delay time was recorded.

Table 2. RPQC for fault location varied from 10% to 90% of length of line 7-8 measured from bus 7

Fault Location	Name of the highest RPQC detected	Value of the highest RPQC detected	Time of fault detection	Delay time
Line 7-8 at 10 % from bus 7	RPQC of line 7-8	0.35 p.u.	0.12 s	1 cycle
Line 7-8 at 50 % from bus 7	RPQC of line 7-8	0.185 p.u.	0.14 s	2 cycles
Line 7-8 at 90 % from bus 7	RPQC of line 7-8	0.165 p.u.	0.12 s	1 cycle

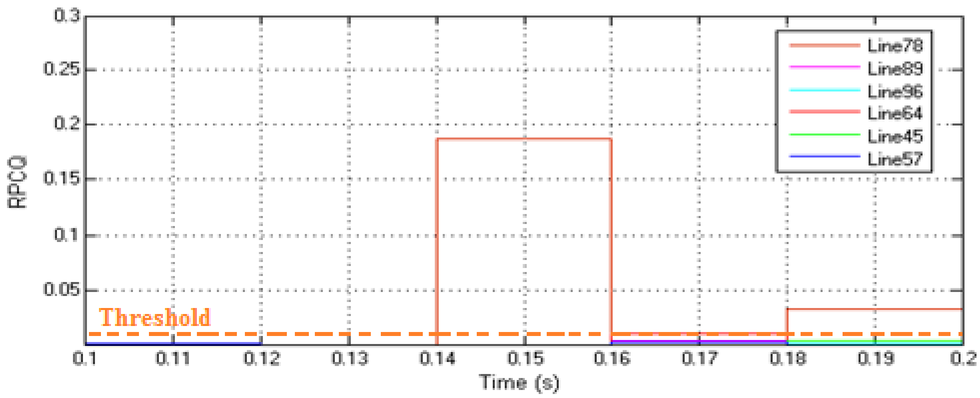

Figure 6. RPCQ for lines of WSCC 9 bus system during three phase fault at 50% of the length of line 7-8

4.6 Impact of high resistance faults

To examine the effect of high resistance faults, a three phase fault with high 100-ohm resistance was created on line 7-8 at 20 km from bus 7. The results presented in figure 7 showed the fault was detected at 0.12 s after 1 cycle from fault occurrence. Hence, it is evident that high resistance faults did not affect the successful detection of the fault.

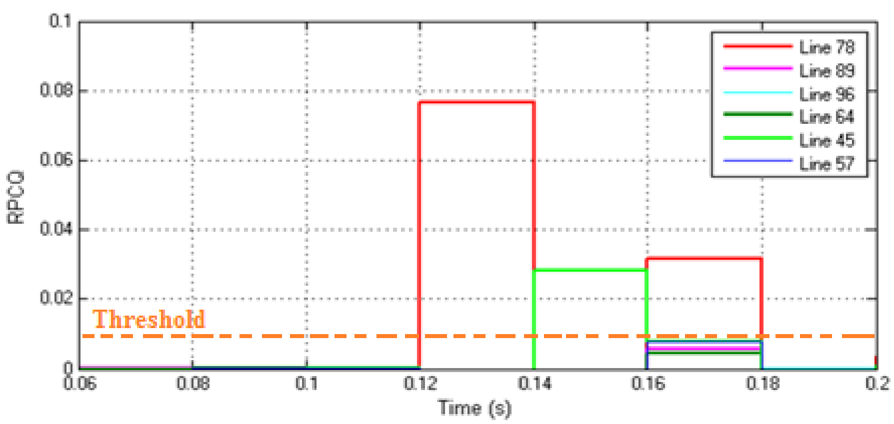

Figure 7. RPCQ for lines of WSCC 9 bus system during high resistance three phase fault on line 7-8

4.7 Impact of power swings

To examine the effect of power swings, a three-phase fault was created on line 7-5 at t = 0.03 s, the fault lasted for 0.05 s and cleared by opening CB at t = 0.08s creating a power swing. Following the clearance of the fault, a power swing occurs across lines 7-8, 8-9, 9-6 and 6-4 at 0.1 s. That is shown through misreading from the remaining lines.

However, this could be overcome by blocking the algorithm for 3 cycles following fault clearances and after that period the algorithm operates successfully as intended.

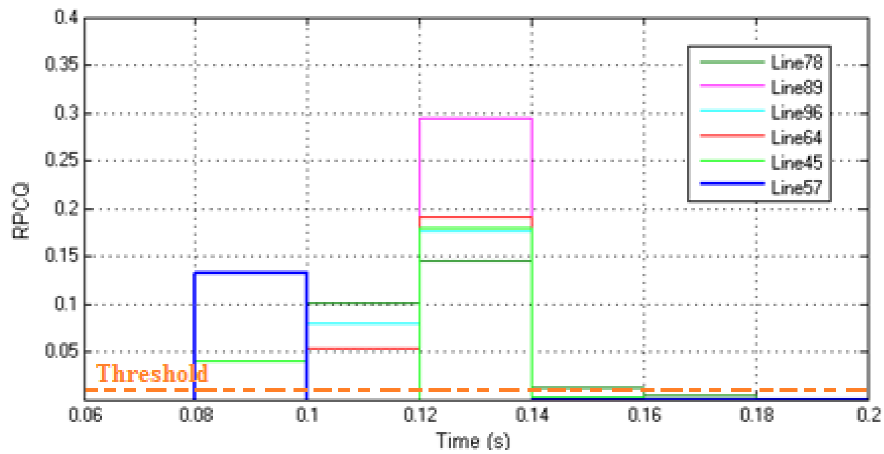

Figure 8. RPCQ for lines of WSCC 9 bus system during power swing

5. Conclusion

A new smart fault detection algorithm was proposed in this paper to detect faults in transmission networks. The system is based on using PMU placed at the terminals of the lines. The provided measurements from the PMUs are used to computed the rate of change of delta reactive power or RPCQ for each line. The RPCQ for non-faulty conditions is a zero-valued indicator. For faults, the RPCQ rise for all lines indicating the occurrence of the fault. The RPCQ of the faulty line is the highest valued RPCQ. To test the algorithm, a bench mark testing system WSCC 9-bus system was modeled using MATLAB/Simulink. The testing included different fault types as three phase, line to line, double line to ground and single line to ground faults. The results showed the robustness and reliability of the proposed algorithm in fault detection. The fault location was change to be in different positions of the line, and the proposed scheme still succeeded in detecting the faulty line correctly. Future challenges include overcoming the current limitations of cyclic measurements of PMUs and increasing the speed of communication links.

- **Conflict of Interest**

The author declares that there is no conflict of interest.

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