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Power Swing Detection Using rms Current Measurements

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Abstract – During a power swing, distance relays may mistakenly spread fault throughout the power grid, causing a great deal of damage. In some cases, such mistakes can cause global outages. For this reason, it is critical to make a distinction between power swings and faults in distance relays. In this paper, a new method is proposed based on RMS measurement to differentiate between faults and power swings. The proposed method was tested on two standard grids, demonstrating its capability in detecting a power swing and simultaneous fault with power swing. This method required no specific configurations, and was independent of grid type and zoning type of distance relays. This feature in practice allows the relay to be installed on any grid with any kind of coordination. In protective relays, the calculations applied to the microprocessor is of great importance. Distance relays are constantly calculating the current RMS values for protection purposes. This mitigates the computations in the microprocessor to detect power swings. The proposed method was able to differentiate between a fault and a power swing. Furthermore, it managed to detect faults occurring simultaneously with power swings.

Keywords: Power swing, Power system protection, Distance relay, RMS, Transient in power system.

1. Introduction

The values of transient faults in a power grid are constantly increasing. One such fault is a swing, which may arise due to a sudden turbulence or any other variation in demand, short circuit, excessive discharge, or reclosing in three phases of a single line. In this type of variation, distance relays may push the visible impedance into the protective zone, causing an unplanned distance relay operation. It should be noted; however, that malfunction in distance relays can cause instability in the grid. Therefore, it is crucial to study power swing in grids, where relays should function in a way to prevent unexplained outages. Several techniques have been examined to block distance relays during a power swing.

Blinder techniques and concentric characteristics have been proposed based on apparent impedance variations in [1, 2]. These methods require a great deal of offline stability to achieve the settings [3]. In addition, these methods do not respond to faults during the blocking period, and thus fail to differentiate between a rapid swing and a fault. In [4], a method is presented based on swing voltage center (svc). This method requires a long time to diagnosis, In addition, it is difficult to choose the right threshold. In [5], a wavelet transform method is proposed. This method requires a high sampling rate. In [6], energy extraction of high frequency components from front to back is investigated. The low DC method is presented in [7] The support vector machine (SVM) learning techniques are presented in [8] and too the derivation of the Adaptive Neural-Fuzzy Inference System (ANFIS) is expressed in [9]. In despite of the quick response, these methods required a lot of offline simulations to train different fault rates and power swings and additionally, they need to be trained again, when the network undergoes changes. In [10], a method is presented to detecting three-phase fault during power swing that it's based on transient monitoring. This method used of Window Averaging of Current Signal moving to detection power swing .It is fast and accurate in determining power swing, but it has complex calculations that make it difficult to implement it. [11] Describes a method based on the continuous impedance calculation that presented in [12]. To detection power swing a method presented based on prediction in [13] . Block the third zone (BTZ) method was presented in [14]. In [15], a new method was proposed to determine power swing based on superimposed components of the voltages magnitude to discriminate non-faulty conditions from fault events.

RMS (voltage or current) is a value commonly used in power systems as an easy method for accessing and describing phenomena pertaining to power systems [16]. RMS values can be calculated each time a new sample is obtained. Generally speaking, however, these values are updated at each cycle or half-cycle [17]. In addition, these distance relays are constantly computing RMSs, which is why they occupy less memory than a microprocessor.

In this paper, a new method is proposed to detect power swings through the RMS current measurement. The correct operation of this method on two standard system was explored through Digsilent and Matlab.

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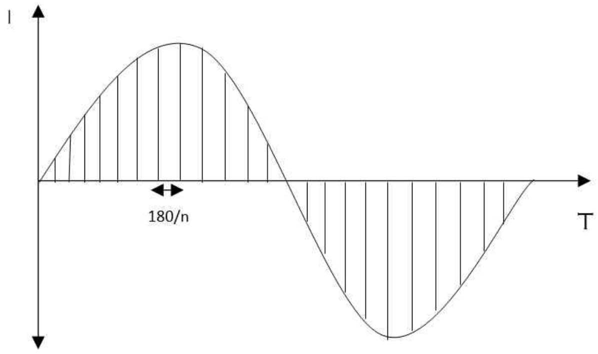

Fig. 1. Sampling method of alternating signals to calculate RMS current

2. Calculation of RMS

In the event of transient states, the calculated RMS will not provide the correct value of the new current state as long as the window in which RMS has been calculated completely includes new state samples. Although the variations are abrupt, it takes as long as a cycle for RMS to reach a new correct value [17]. The following is the easiest formula for calculating RMS [18]:

$$V_{rms} = \sqrt{\frac{\sum_{k=1}^{N} V_k^{\ 2}}{N}} \tag{1}$$

Which can be reformulated to calculate the current RMS:

$$I_{rms} = \sqrt{\frac{\sum_{k=1}^{N} I_k^{\ 2}}{N}} \tag{2}$$

In Formula (1), n is the total number of RMS window data. Fig. 1 shows how the alternating signal was sampled to calculate RMS.

For the calculation of RMS in this paper, every half-cycle was sampled.

3. Power Swing Detection Method

In the normal operating mode, a power grid's current RMS value is a constant number with very slight variations. Fig. 2 shows the RMS values of a power grid in the normal operating mode.

When a power swing occurs, the current RMSs change continuously in all three phases, but they change suddenly when a fault occurs. Fig. 3 shows the variations in RMS values during a power swing created after a fault.

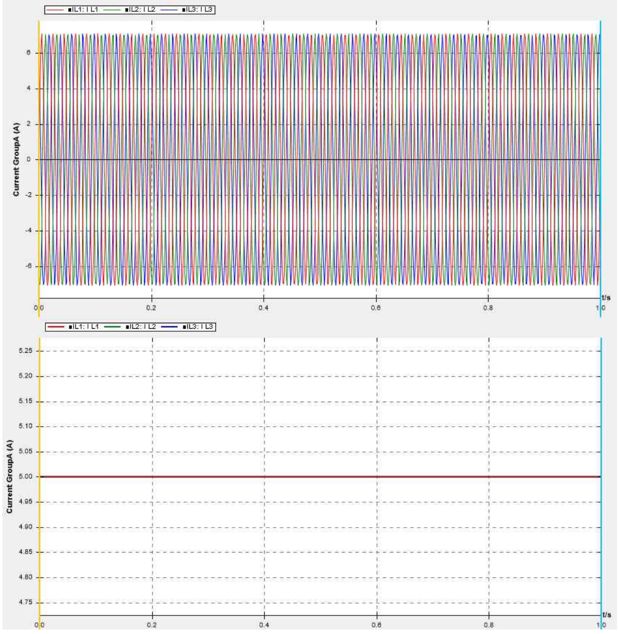

Fig. 2. RMS value of a power grid in normal operating mode

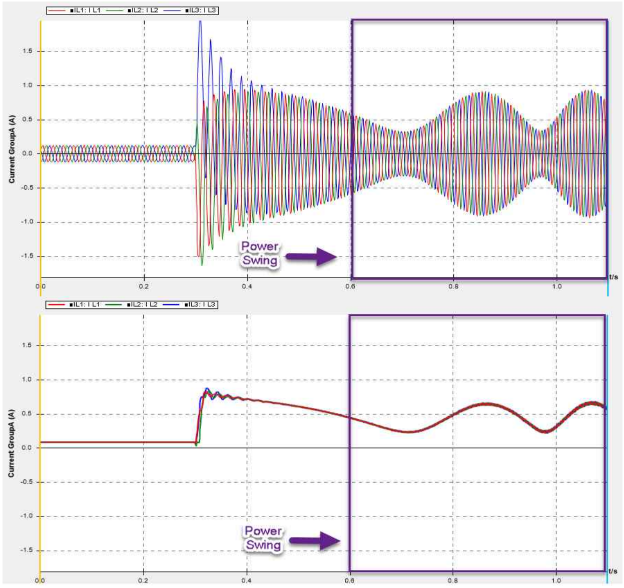

Fig. 3. Changes in RMS value of a power grid during power swing

As shown in Fig. 4, after creating a transient fault in the power system, the current RMS values change without a specific pattern. This change is different from one fault to another. Moreover, there are no three-phase swings with an identical variation. According to Fig. 3, however, the power swing created in the current three-phase involves an identical variation.

The RMS value is measured in each half cycle to determine power swing through RMS. Power swing will be detected if he RMS variations are identical in the three measured phases over one and a half cycle.

After Zone 3 relay starts, the power swing is detected

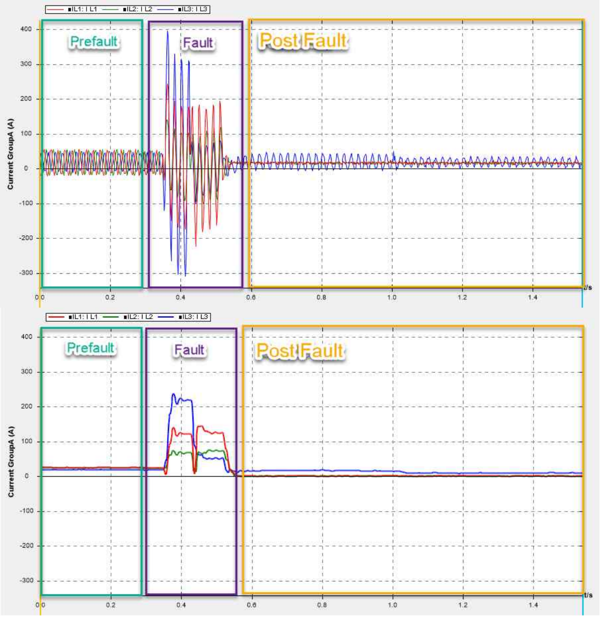

Fig. 4. Changes in RMS value of a power network during transient fault

first by calculating the RMS value in each current phase. Then, the difference between two successive current RMS values is calculated by the following formula, which is a modified version of the formula proposed in [17]:

$$di^{phase}(n) = \left|I_{rms}(n+1) - I_{rms}(n)\right| \text{ for } n = 1 \ldots L-1 \tag{3}$$

In the above formula, L represents the number of values in the current RMS. At the next stage, these values of RMS variations in each current phase should be identical. The variations are calculated through the following formula:

$$\begin{aligned} &if di^{phase(a)} = di^{phase(b)} = di^{phase(c)} \\ &PSB = True \end{aligned} \tag{4}$$

Fig. 5 illustrates the proposed algorithm for power swing detection. Whenever a fault detection unit in the distance relay finds an unusual state in the third zone, the new algorithm is activated to distinguish between a potential power swing and a fault. As previously stated, the relay detects whether a power swing has occurred or not after three half-cycles. For this reason, we first set the values of P and F to zero. P represents power swings and F represents faults. At the next stage, the RMS value is measured in a half-cycle. di is calculated for each phase and the condition of formula 4 is checked. If the condition is met, then the value of P is checked. If the value of P is greater than 3, power swing is detected. Otherwise, one is added to P, and the algorithm is restarted. If the condition of Formula 4 is not met, it will first be checked if F is greater than 10. If it was so, fault would be detected and the relay immediately issues a trip command. If power swing is detected in the relay, the algorithm will continue running as long as the fault is found in the third zone, so that the fault can be removed from the grid if it occurs simultaneously with power swing.

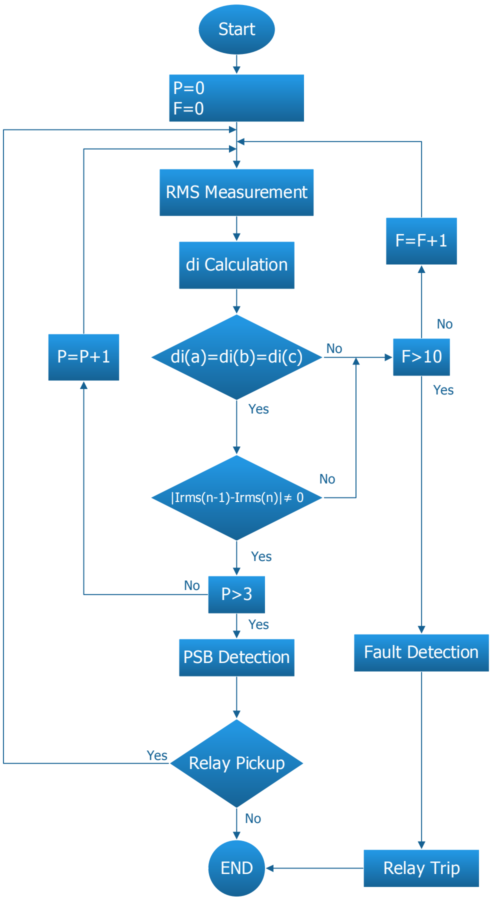

Fig. 5. Power swing detection algorithm that using RMS metering

In order to simultaneous detection of the fault and power swing, the algorithm utilizes RMS changes in the initial transient mode and steady state of the fault. In the single-phase and two-phase faults, even after passing through the initial transient conditions, the power swing condition is violated, (Fig. 6 (a, b)). For this reason, the fault frequency and the initial transient time will not be affected in this two types of fault. However, in a balanced three phase fault after the initial transient of the fault, the condition of the power swing expressed in Eq. (4) remains, and if the fault frequency is high enough that the initial transient section is less than 100 ms, the algorithm will be misunderstood and the fault will not be detected, (Fig. 6 (c)). To prevent such an event, a condition of power swing is added to the algorithm. As shown in Fig. 3, the RMS current value in the power swing is constantly changing, so the following condition is confirm in the power swing:

$$\left|I_{rms}(n+1) - I_{rms}(n)\right| \neq 0 \text{ for } n = 1 \ldots L-1 \tag{5}$$

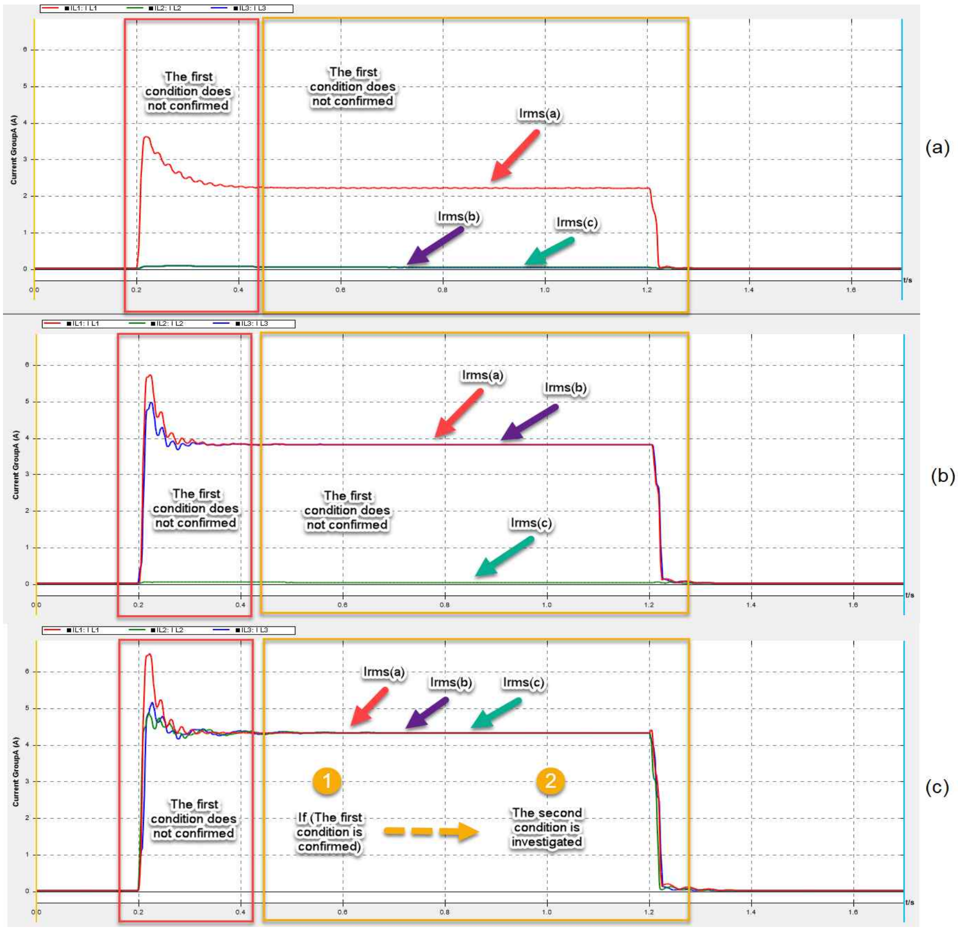

Fig. 6. (a) The RMS current value of single-phase fault. (b) The RMS current value of two-phase fault. (c) The RMS current value of three-phase fault

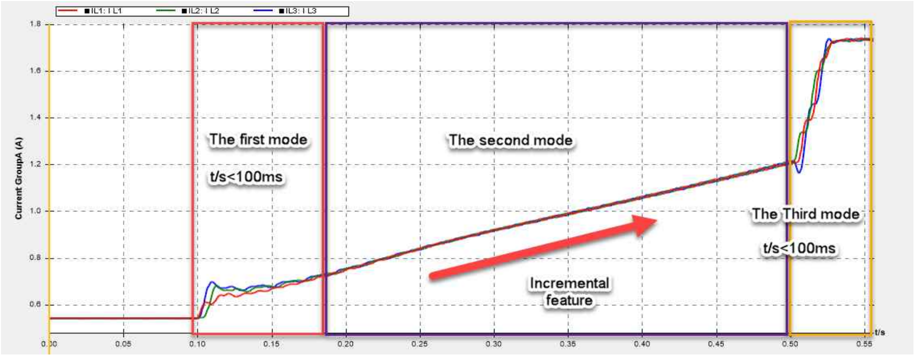

Fig. 7. Circuit breaker transient

In a balanced three-phase fault, after the initial transient of the condition, the condition presented in Eq. (5) does not exist and the value of the equation is equal to zero. In this algorithm, if the condition of Eq. (4) is not confirmed, a fault is detected and if it is confirmed the second condition is checked, and if the second condition is not satisfied, the fault will be detected.

As mentioned above, the algorithm detects the fault simultaneously with power swing after 100ms. Since the operation time of the backup relays in the second zone is 300 ms and in the third zone is 600 ms, [19], this is a proper time and it prevents the being miscoordination in power network.

4. The Effect of the Circuit Breaker's Transient State on the Expressed Algorithm Analysis

Opening the side-line circuit breaker causes occur a fault, create the transient state of the circuit breaker. This transient state may affect the power swing algorithm and cause the wrong detection of the fault. In Fig. 7, it can be seen that the RMS current of the circuit breaker is divided into three parts. The first and third sections that violate the condition of Eq. (4) are in principle less than 100 ms and will not have any effect on the algorithm. The second part, besides that, does not violate the initial condition of the power swing, as well as, because of the increase in the value of RMS, the second condition (Eq. (5)) will not be violated. According to the mentioned topics, the transient state caused by the circuit breaker trip will not cause incorrectly operation this algorithm.

5. High Impedance Fault Analysis

High impedance faults are generated from the collision of the conductors of the transmission lines to the trees or the earth and create a high resistance current path. The currents amplitude of the high impedance faults is lower than the nominal current of the system, which makes it hard to detect. Failure to detect these faults during the power swing can cause hazards such as fire and damage to the energy transmission equipment [20, 21].

Generally, the major feature of the high impedance faults is the low amplitude, the nature of the resistively, the nature of the randomness, and the occurrence of an arc during the fault. Fig. 8 shows the RMS current value of the single-phase, two-phase and three-phase high impedance fault. As you can see, the RMS current value of this kind of faults can split into 3 different sections. The first section is the moment of fault occurrence, which violates the initial condition according to the algorithm. The middle section does not violate the initial condition, but will violate the second condition. The third section, which is the second transient, will violate the initial condition. According to the mentioned above, the presented algorithm has the capability to detect high impedance fault simultaneously with the power swing.

6. A Suddenly Load Increase in During Power Swing

A suddenly increase in load can be considered with short circuit by a distance relay. When the load suddenly increases, the voltage and current will start to oscillation, which produces the state similar power swing. These oscillations

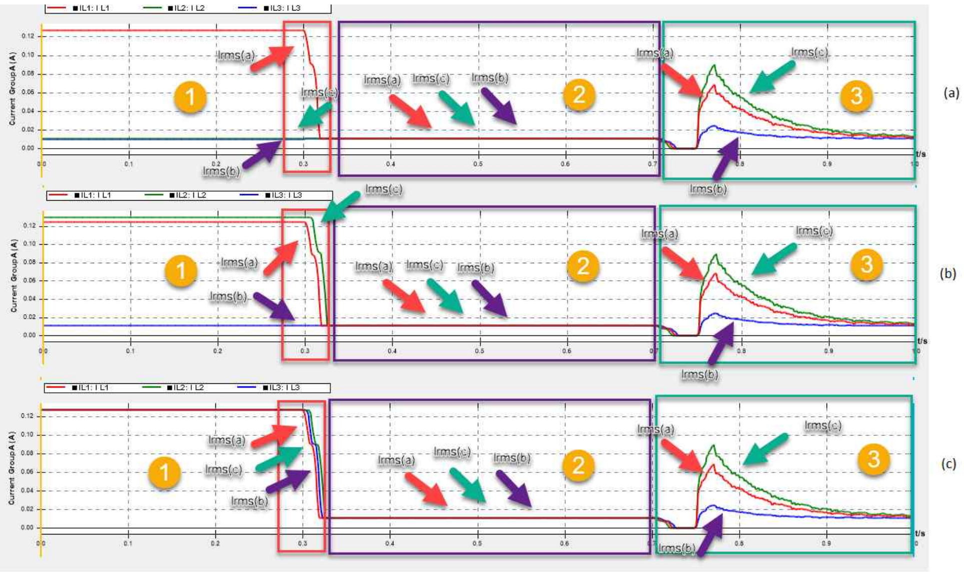

Fig. 8. (a) RMS current of the high impedance single-phase fault; (b) RMS current of the high impedance two-phase fault; (c) RMS current of the high impedance three-phase fault.

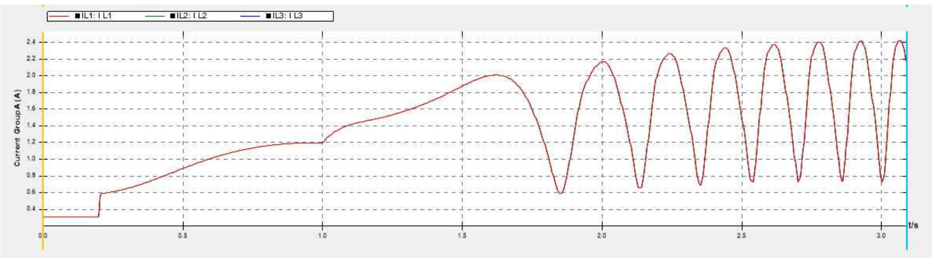

Fig. 9. Waveform after overload

themselves can enter the protective zones and if they are long time within the protective zones, can cause unwanted relay operation [22].

Fig. 9 shows the RMS sample of current resulting suddenly increase in load. As can be seen, this increase is not suddenly and has a slight delay, which makes possible the initial condition of the power swing. As can be seen that due to the sudden increase in load, a power swing is created. The sudden increase in load is described as one of the main causes of power swing occurrence in [11]. For this reason, in continue does not affected on the algorithm and does not cause wrong operation of relay.

7. Testing the newly proposed method

7.1 Testing white power swing

The proposed method was tested on a 9-bus WSCC, 60 Hz, 230 kV system. Fig. 10 shows the standard 9-bus system in Digsilent.

The distance relay is installed on Bus No. 8 of the grid. A fault is placed on Bus No. 4. To simulate a power swing. Once the fault is erased, a power swing is created and inserted into the third zone of the relay. The relay may inadvertently issue the Trip command unless it has previously been blocked. Fig. 11 shows the power swing viewed by the relay.

When the relay starts, the power swing algorithm is initiated. The new algorithm blocks the relay cycle after one and a half cycle. Fig. 12 shows the relay's performance after one and a half cycle. It should be noted that the

algorithm will continue running as long as the fault occurs in the third zone of the relay, so that the relay can be removed from the blocked state and cut off the deficient part in case a fault occurs simultaneous with power swing.

7.2 Testing white simultaneous fault and power swing

The two-area, Four-machine, 230 kV, 60 Hz system was employed to test the performance of the proposed method

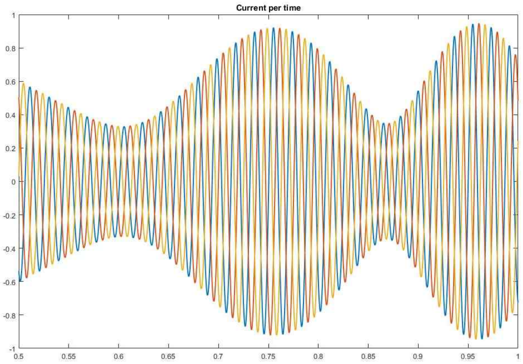

Fig. 11. Power swing of relay sighted

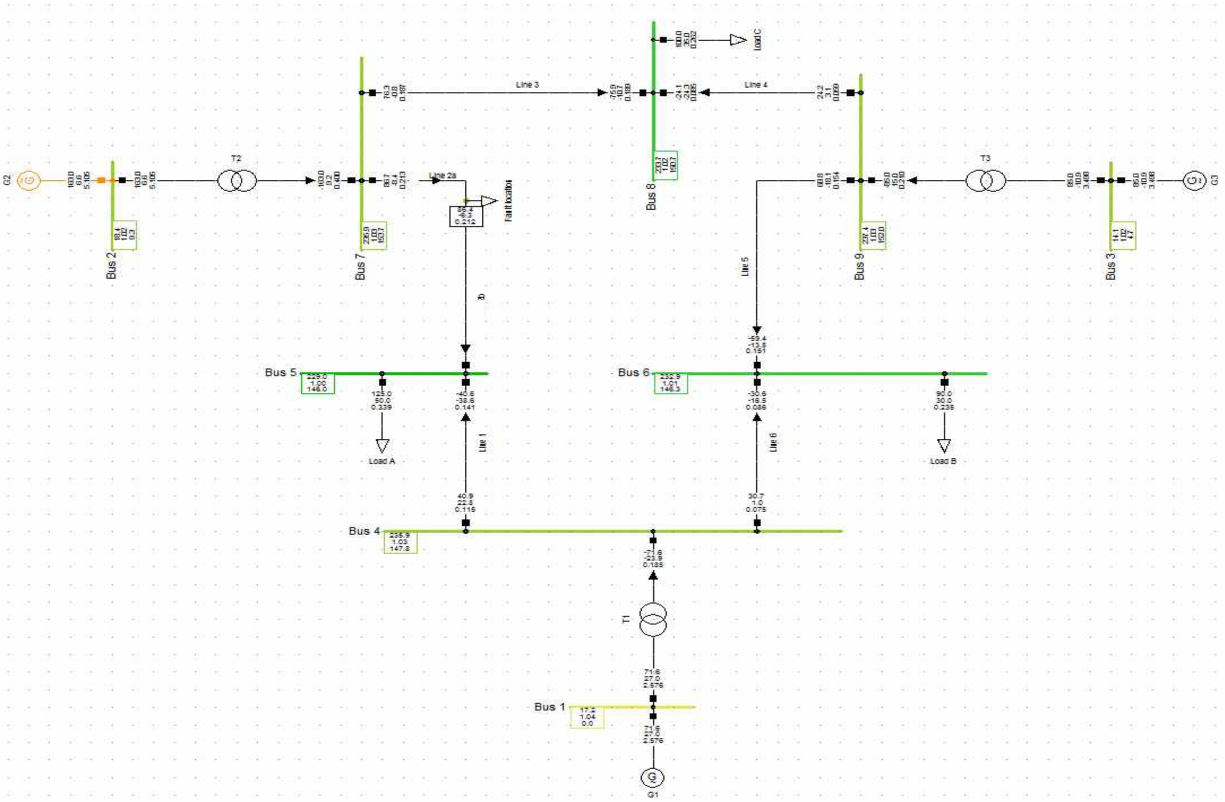

Fig. 10. The standard nine bus system in Digsilent

in simultaneous fault and power swing. Fig. 13 shows the grid in Digsilent.

This relay involved Bus No. 07, while line 07-08-01 was inserted for protection One 20% of line 07-08-02, a three-phase short-circuit was embedded. This fault was applied to the grid within 0.5 seconds. After 200 milliseconds, the fault was resolved by breakers on two sides of the line.

A short circuit was inserted within 3 seconds to create a fault simultaneous with power swing on relay Line 07-08-01. Fig. 14 displays power swing and fault simultaneous with power swing viewed by the relay.

As already mentioned, the power swing algorithm starts when the relay is initiated. The new algorithm blocks the relay after one and a half cycle. Afterwards, the relay keeps on functioning. It then removes the relay from the blocked state once the fault is applied to the grid, issuing the trip command immediately. Fig. 15 displays the relay performance.

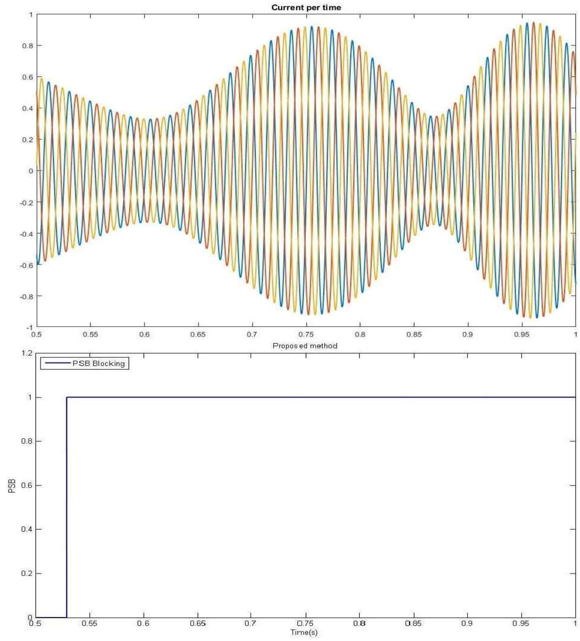

Fig. 12. Power swing detection by relay

8. Comparing with the Conventional Industrial Method

To illustrate the applicability of the proposed method, it is compared with the conventional industrial approach presented in [11, 23]. Tables 1 and 2 shows the results of testing the conventional industrial method and the mentioned method. As can be seen in Table 3 and 4, the conventional industrial algorithm detects the power swing

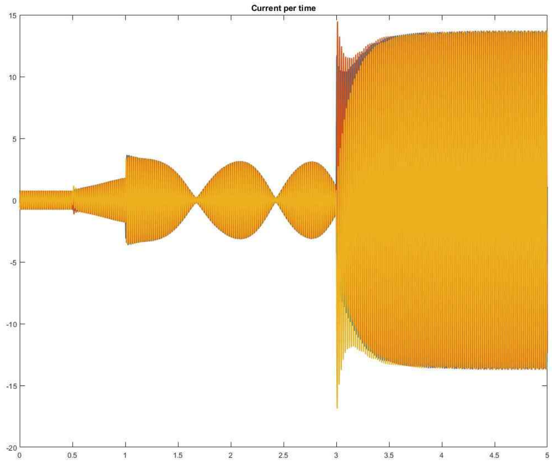

Fig. 14. Power swing of relay sighted

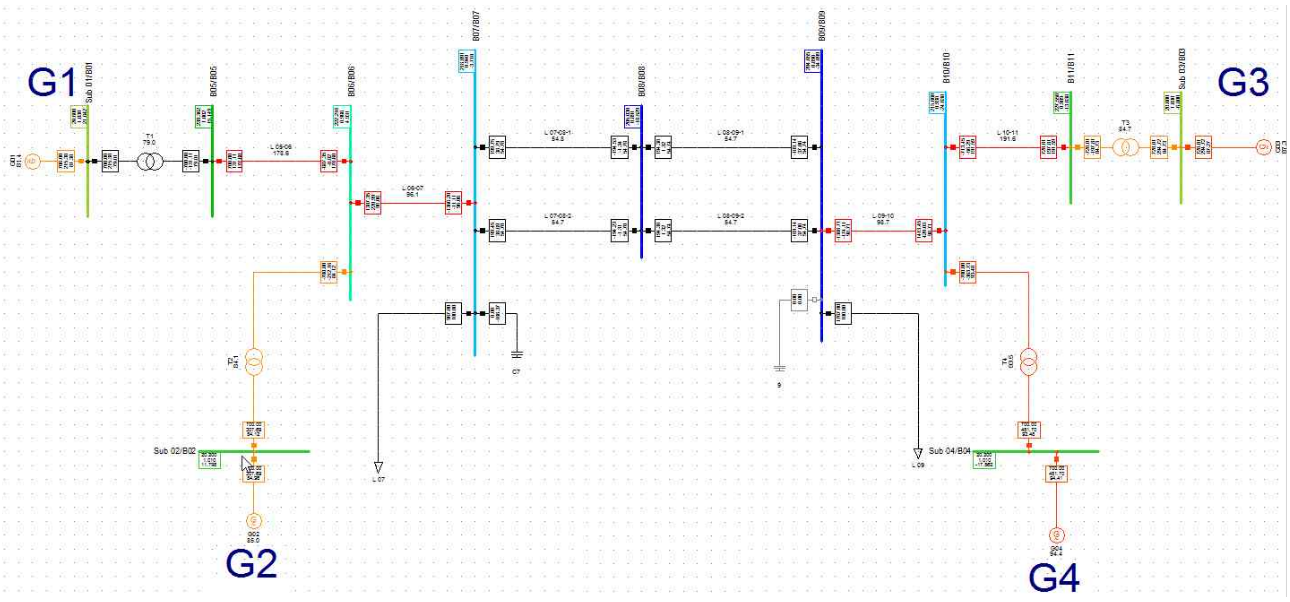

Fig. 13. Two-area, four-machine power system in Digsilent

Table 1. Results of testing the conventional industrial method

Test type	Current magnitude	Power swing detection	Fault detection test during power swing	Time of power swing detection	Time of fault detection
Power swing	-	Yes	-	103.8	-
Single phase fault during power swing(1)	Low	Yes	Yes	104.4	101.7
Single phase fault during power swing(2)	High	Yes	Yes	104.1	94
3 phase fault during power swing(1)	Low	Yes	Yes	107	126.6
3 phase fault during power swing(2)	High	Yes	Yes	104.1	120

Table 2. Results of testing the mentioned method.

Test Type	Current magnitude	Power swing detection	Fault detection test during power swing	Time of power swing detection	Time of fault detection
Power swing	-	Yes	-	30	-
Single phase fault during power swing(1)	Low	Yes	Yes	30	100
Single phase fault during power swing(2)	High	Yes	Yes	30	100
3 phase fault during power swing(1)	Low	Yes	Yes	30	100
3 phase fault during power swing(2)	High	Yes	Yes	30	100

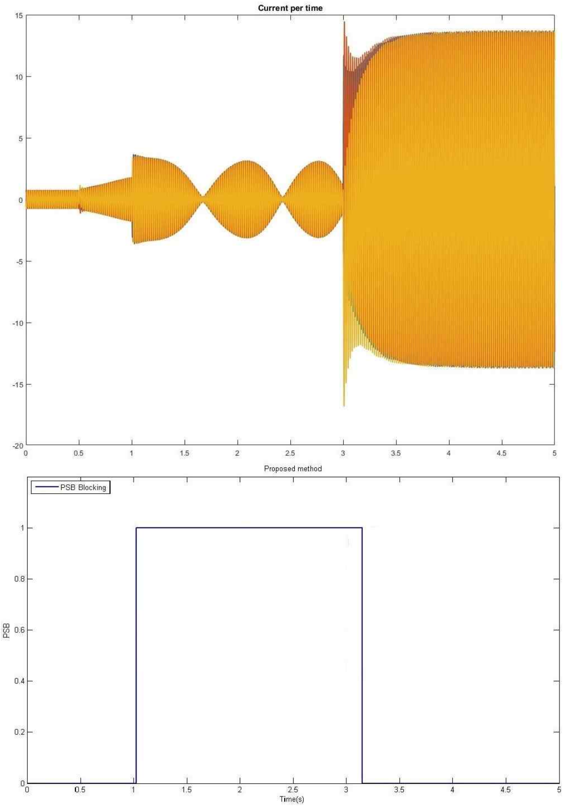

Fig. 15. Power swing detection by relay

in 100 ms, in the event that the proposed method detects the power swing in 30 ms. Also, the conventional industrial approach have the different operation against in different types of faults simultaneously with the power swing. The Figs. (16) and (17) shows the comparison of the proposed algorithm with the conventional industrial method.

The low means that the fault current amplitude is less than the power swing amplitude.

The high means that the fault current amplitude is more than the power swing amplitude.

Fig. 16. Power swing detection

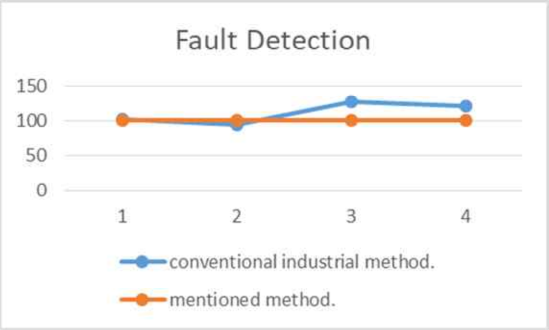

Fig. 17. Fault detection

9. Conclusion

Power swing is a transient phenomenon that is caused by various reasons. Power swing may enter in distance relay zones and cause the relay to operate incorrectly. This wrong operation can cause the network to become unstable and as a result, create blackouts.

In this paper, a new method for detecting the power swing is expressed based on the rate of current RMS variation. The proposed method is compared with the conventional industrial method and it is shown that its performance is better. Among the benefits of the method described, can mention the following:

1. Ability to fast detect the power swing.
2. Ability to detect various types of faults simultaneously with power swing, including three-phase faults and power swing.
3. Ability to detect of fast and slow power swings.
4. The presented method is independent of network type and as can be seen, it has been tested in three different networks.
5. The proposed method has high reliability.

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