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Development of busbar differential protection algorithm on PSCAD

Desarrollo del algoritmo de protección diferencial barras en PSCAD

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Abstract

This article analyzes the behavior of the fault currents by means of a numerical differential protection algorithm developed in a simulation program called PSCAD (Power System Computer Assisted Design). The protection algorithm does the current comparison in order to obtain a graph result which indicates the state of operation. The developed algorithm also has a variable fault control panel to activate several combinations of possible fault types. This differential protection algorithm is designed to protect only the internal faults for the busbar. Finally, the results are displayed by graphs from the response of applied faults. This can be used as simulation exercises for the undergraduate engineering students to better comprehend the operation of differential protection.

Busbar protection, Differential protection fault analysis, Internal and external faults

Resumen

Se analiza en este articulo el comportamiento de las corrientes de falla mediante el algoritmo de protección diferencial numérico desarrollado en el programa de simulación llamado PSCAD (Power System Computer Assisted Design). El algoritmo de protección realiza las comparaciones de las corrientes para poder obtener una grafica de resultado que indica el estado de la operación. El algoritmo desarrollado también tiene un panel de control variable para activar distintas posibles de combinaciones de tipos de fallas. Este algoritmo está diseñado para proteger solamente las fallas internas de la barra. Finalmente, los resultados son desplegadas en forma de graficas de acuerdo con las respuestas de las fallas aplicadas. Este puede ser utilizado como ejercicios de simulación para los estudiantes de licenciatura de ingeniería para comprender mejor la operación de la protección diferencial.

Análisis de fallas, Protección de barra, Protección diferencial, Fallas internas y externas

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Introduction

Protection relays contribute crucial aspects in the electrical power system health, reliability, continuity, security, energy quality, and substation personnel (Blackburn & Domin 2006). The length and outdoor characteristics of power system makes it vulnerable for multiple possible fault scenarios caused by lighting, human and/or animal accidents, substation insulator contamination and weather conditions. (Blackburn & Domin 2006). Hence, protection relays in power substations should operate to isolate the faulted zone and minimize the damage impact.

The Busbar Differential Protection within a substation detects faults by comparing the sum of all currents flowing into and out of the protected Busbar. This current sum must always be equal to zero (Kirchhoff's current law) in stable conditions (IEEE/PES Power System Relaying Committee 1979). Therefore, fault conditions are the appearance of a differential current (current not equal to zero). Due to its fast-tripping characteristic it is also used for important and costly elements such as: generators (Kasztenny B. & Finney D. 2005), transformers (Saleh S. & Ozkop E. 2021), and transmission lines (Blackburn & Domin 2006). Differential protection may also be used for active distribution lines (Chen G., et al 2020).

This can be achieved by positioning a current transformer in the protected zone. It is connected directly to the busbar which is needed to be protected. The current transformer plays an important role in the protection system by transforming the primary currents to small samples of secondary currents which is then processed to enable the comparison of the restraint and tripping current by the differential relay. Hence, the differential protection is a very reliable scheme based on Kirchhoff's current law. However, current transformer saturations need to be taken into consideration as their secondary samples may no longer be trustworthy and may mislead the differential protection (Kasztenny B. & Finney D. 2005). Shortly the logical result of the comparison is then used to activate the relay to open the busbar if there is any fault is in presence.

Some busbar protections used in the history can be mentioned:

- Percentage border or low impedance current differential protection.
- High impedance differential protection.
- Linear transducer differential protection.
- Differential protection based on stabilization.
- Differential protection relay

In this work, PSCAD (Power System Computer Assisted Design) platform has been used. Other power system analysis platform such as ATP can also be used for the differential protection modelling and analysis (Tavares K. & Silva K 2014).

Justification

A substation busbar is a thick strip of copper that conducts large amount of current. Its principal function is to supply several electrical circuits by connecting them together on the same node. Since there are many circuits that are connected on the same node, a fault located on the busbar (internal fault) can severely damage numerous circuits which can lead to possible failure of electrical components located nearby and furthermore cause significant economic loss. For that reason, the existence of "Busbar Differential Protection" is an essential component in the power system network to avoid the mentioned damages by tripping out the system when an internal fault has occurred. On the other hand, the protection should never trip out the system when there is an external fault no matter how close it is to the busbar (Elmore 2003).

The developed Busbar Differential Protection can be used as simulation exercises for the undergraduate engineering students to better comprehend the operation of differential protection when there is an internal or external fault.

Objective

To develop an academic numerical Busbar Differential Protection on PSCAD (Power System Computer Assisted Design) and analyze the operation and behavior of this protection for the different types of faults, whether internal or external.

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Hypothesis

The developed numerical Busbar Differential Protection on PSCAD should be sensitive enough to operate only for internal faults, in this case, faults on busbar. Whereas the algorithm should discriminate and not operate for any external faults whether they are single-phase, double-phase or even three-phase.

Differential protection problem formulation

The busbar differential protection works under certain conditions and characteristics of the circuit. Measurements read by the current transformer are taken from points of the protected zone which are used for conditioning. Hence, the protected zone of this configuration is the busbar that connects the generators to the transmission lines shown in Figure 1.

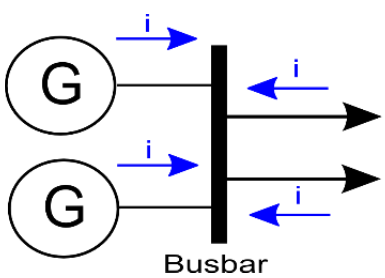

Figure 1 Busbar protection scheme
Source: Own elaboration

Current samples are then taken from the current transformer measurements for the algorithm comparison. Those sampled currents are presented in the following equations (Ziegler G. 2005):

$$I_{op_{me}} = |\overline{I_1} + \overline{I_2} + \overline{I_3} \ldots \overline{I_n}| \quad (1)$$

$$I_{rest} = |\overline{I_1}| + |\overline{I_2}| + |\overline{I_3}| \ldots |\overline{I_n}| \quad (2)$$

$$I_{diff} = 1\,A \quad (3)$$

$$I_{op_{cal}} = I_{diff} + k\,I_{rest} \quad (4)$$

Where $I_{op_{me}}$ represents the measured tripping current, I_{rest} represents the restraint current, I_{diff} represents differential current, $I_{op_{cal}}$ represents the calculated tripping current, k represents the percentage sensitivity factor of the differential protection and $\overline{I_1}, \overline{I_2}, \overline{I_3}, \overline{I_n}$ are the currents of each phase and neutral current.

The $I_{op_{me}}$ is the effective value (RMS) of the vector sum of all the current that goes in and out of the bus (Ziegler G. 2005). The I_{rest} is the geometric sum (magnitude) of each and every effective value that goes in and out of the bus. The I_{diff} is a programmed constant value which in the algorithm is set as 1 ampere. The $I_{op_{cal}}$ is the sum of differential current plus the product of the restraint current multiplied by the k factor. In which the k factor is a threshold that allows the manipulation of the algorithm sensibility in an interval of 20 to 90%. The threshold k represents a slope that decreases sensibility when the k value increases. So eventually the system's protection will be delayed or even become inactive when k value increases excessively. As a result, the threshold k is set to 80% due to the system characteristics in order to respond in an accurate way.

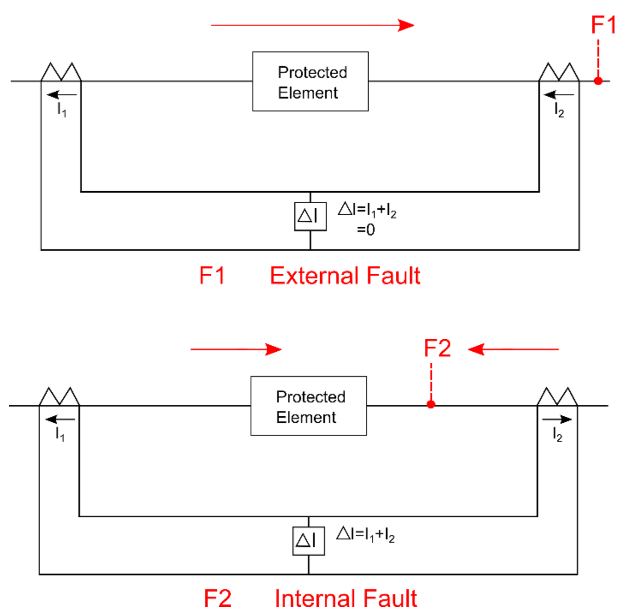

Figure 2 Differential protection internal and external faults
Source: Own elaboration

All in all, the tripping criterions of the protection algorithm are shown in Figure 2 and in the following equations:

$$I_{op_{me}} > I_{op_{cal}} \quad (5)$$

$$I_{op_{me}} < I_{op_{cal}} \quad (6)$$

Where equation 5 shows the numerical condition of internal fault (Tripping operation) and equation 6 shows the external fault condition or load (No tripping operation).

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The differential protection algorithm permits the formation of tripping condition and the manipulation of the reaction velocity. This is achieved by changing the k value. Figure 3 is a graph representation of the k slope along with measured tripping current, restraint current, as well as the tripping or operation zone.

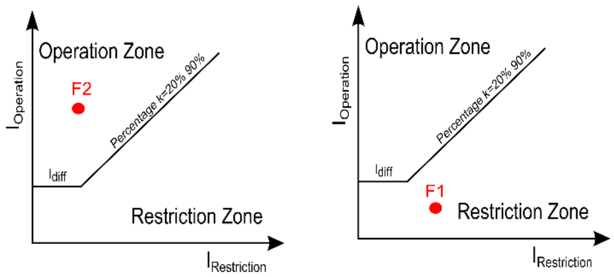

Figure 3 Differential protection characteristics: tripping zone and restraint zone
Source: Own elaboration

Description of the differential protection algorithm on PSCAD

Figure 4 presents the single line diagram of the principal circuit topology for the analysis of busbar differential protection on PSCAD.

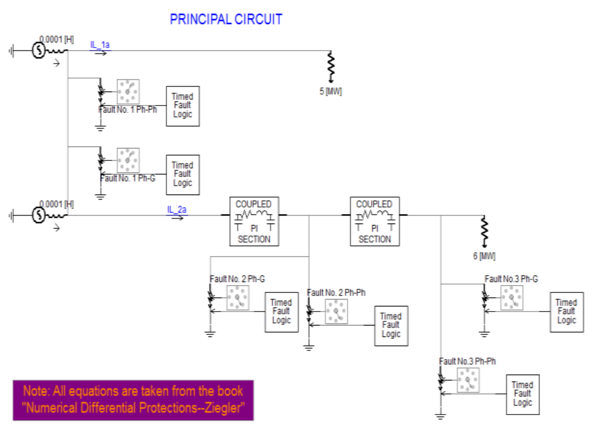

Figure 4 Principal circuit under study in PSCAD
Source: Own elaboration

The configuration of the power system presented in Figure 4, consists of 2 generators of 10 MVA each has an internal inductance of 0.1 mH. It also has 2 transmission lines, the first is a short transmission line (less than 80 km) which is named "Transmission line 1" and has 5 MW load installed. The second is a long transmission line (more than 240 km) which is named "Transmission line 2" and has 6 MW load installed. The "Transmission line 2" is divided in two different distances. One at 250 km and the other at 300 km where the external faults are located.

The algorithm faults are divided in two classes. The first class is phase to ground faults (A-g B-g C-g). The fault control panel is possible to manage the fault occurring time, duration of the fault, phase to ground resistance, and in which phase the fault occurred. The fault control panel is presented in Figure 5.

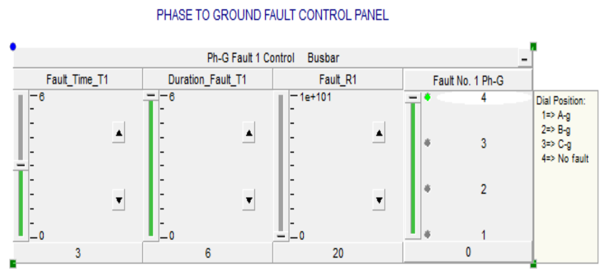

Figure 5 Phase to ground fault control in the protected zone (busbar)
Source: Own elaboration

The second class is phase to phase faults. (A-B A-C) and phases to ground (AB-g BC-g). This fault control panel is possible to manage the fault occurring time, duration of the fault, type of fault (which of the phases are involved) to run the simulation. The fault control panel is presented in Figure 6.

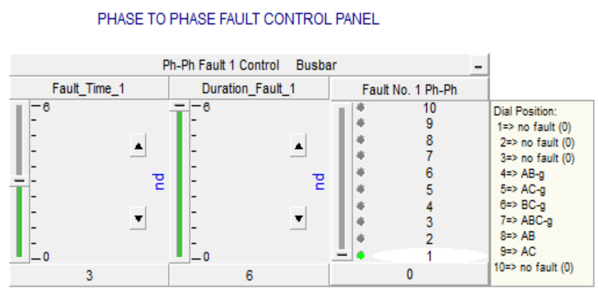

Figure 6 Phase to phase fault control in the protected zone (busbar)
Source: Own elaboration

All the phase to ground faults and the phase-to-phase faults are positioned on the busbar (protected zone). An external fault on Transmission line 2 at 250 km and another external fault on the same line at 300 km. Each class of fault corresponds to a fault control panel.

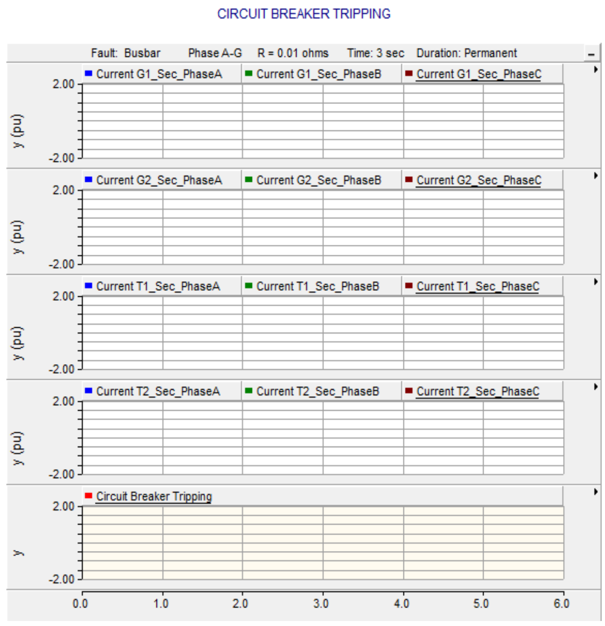

Figure 7 (a) Generator 1 currents. (b) Generator 2 currents. (c) 5 MW load currents. (d) 6 MW load currents. (e) Display of open or closed breakers: a "0" for closed breakers and a "1" for opened breakers
Source: Own elaboration

Figure 7 is a graph panel which shows all the secondary currents of the circuit. Signal "0" is used to represent "no internal fault", in the same way a unit pulse signal "1" is used to represent "the existence of internal fault".

Simulation and Results

Case 1.- Internal fault of phase A to ground in the principal busbar (R = 0.01 ohms).

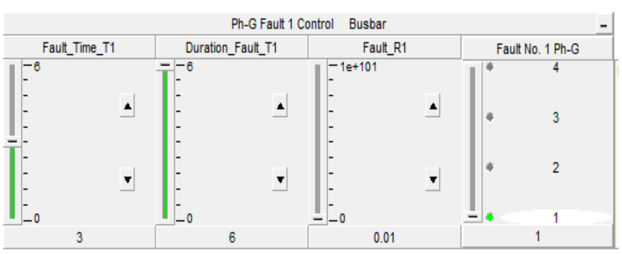

Figure 8 A-g fault adjustment (0.01 ohms), in the fault control panel
Source: Own elaboration

The fault occurred on the busbar within the protected zone, where phase A had contact to ground with a resistance of 0.01 ohms. The accident occurred at 3 sec during the simulation and had a permanent duration.

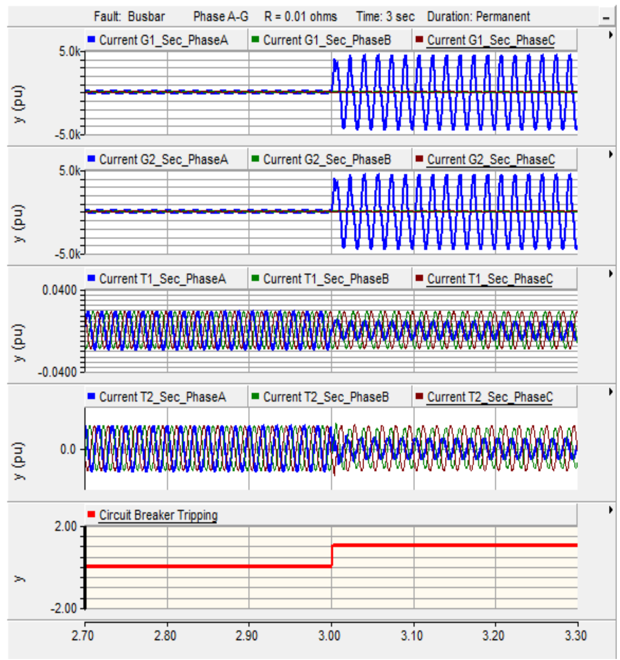

Figure 9 Fault graphs (Phase A-g R = 0.01 ohms). Internal fault
Source: Own elaboration

The phase A (6 MW) short circuit behavior was clearly observed in the graph. The short circuit current reaches KA levels and at the same moment the fault occurred it was observed that the graph of Figure 9 (e) had a raised unit pulse indicating the operation of the power circuit breakers. Therefore, protecting all the electrical components that are connected to the busbar in this way.

Case 2.- Internal fault of phase A to ground in the principal busbar (R = 20 ohms).

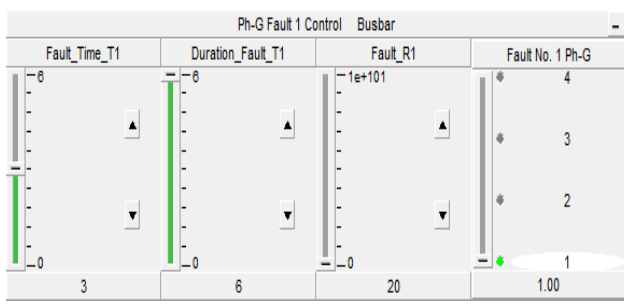

Figure 10 A-g fault adjustment (20 ohms), in the fault control panel
Source: Own elaboration

A similar situation as case 1, the phase A has a permanent fault or permanent short circuit, the only difference is that the resistance of case 1 was 0.01 ohms but now increased to 20 ohms for case 2.

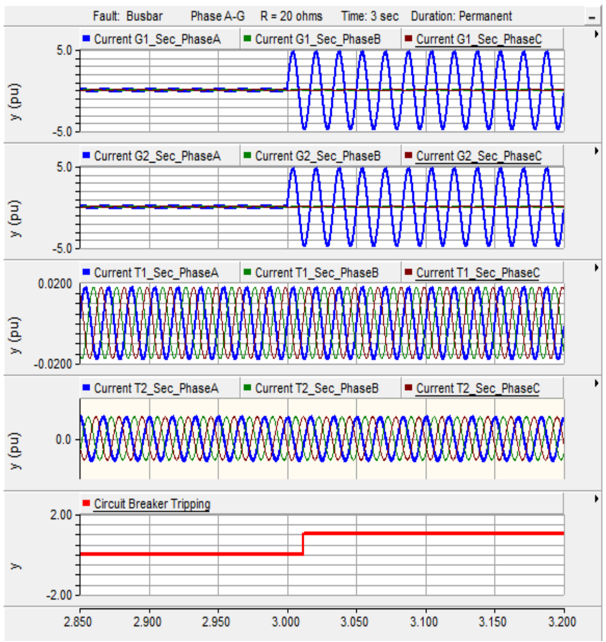

Figure 11 Fault graphs (Phase A-g R = 20 ohms). Internal fault
Source: Own elaboration

It was observed from the graph in Figure 11 that there was a fault in phase A, which was not a very elevated current in comparison to case 1. This was due to the increase of the resistance to 20 ohms. Even though the short circuit current is not very intense, there was an existence of internal fault in the protected zone, for that reason a unit pulse tripping of the power circuit breaker was shown clearly in Figure 11 (e).

Case 3.- External fault phase A to phase B, distance 250 km.

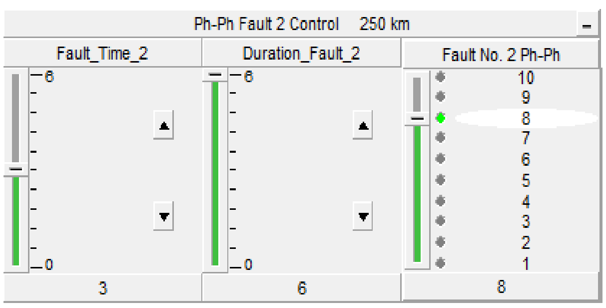

Figure 12 A-B fault adjustment
Own elaboration.

The permanent fault occurred at 3 sec during simulation and was located at 250 km from the protected zone. This is one of the most critical faults that a power system suffers, a phase-to-phase fault (A-B fault).

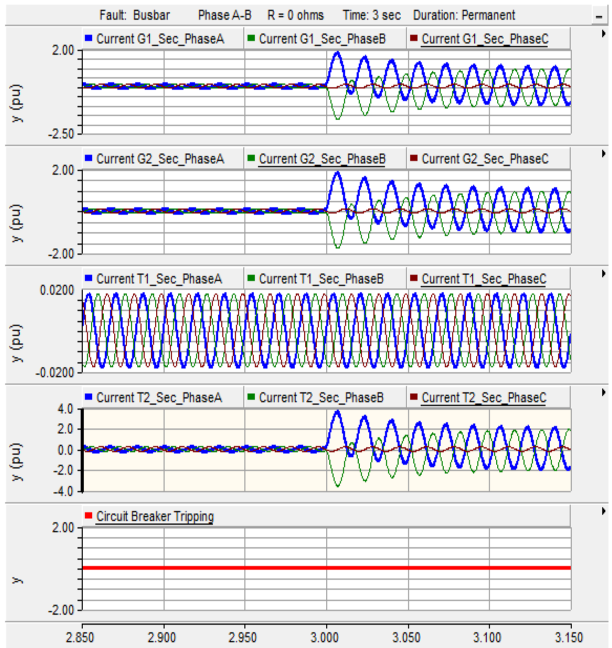

Figure 13 Ph-ph fault graphs (A-B). External fault
Source: Own elaboration

It is known that fault phase A to phase B should increase their magnitudes at the moment 3 sec of fault. Due to the distance of 250 km their magnitudes are not very elevated, but it is enough to activate the protection. The reason why the power circuit breakers did not trip was that this is an external fault. This is the correct response of the differential protection, it should only trip when there is an internal fault and under no condition should it trip for an external fault.

Differential Protection Overview Responses				
Cases	Internal Fault	External Fault	Protection Operation	Correct
F=A-g R=0.01	✓		Yes	Yes
F=A-g R=20	✓		Yes	Yes
F=A-B 250km		✓	No	Yes

Table 1 Summary of the simulation events and responses
Source: Own elaboration

From Table 1, it is observed that the developed busbar differential protection algorithm on PSCAD tripped for the internal faults even though fault resistance has been varied. On the other hand, the protection did not trip for the fault located at 250 km distance which corresponds to an external fault. Hence, the protection has performed correctly for the different fault events.

Acknowledgement

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Conclusions

The busbar differential protection is an absolute protection that does not perform coordination with other protective relays. In other words, the issue with this kind of protection is not the coordination or operation sequence problem, but in fact, the ability to discriminate internal and external faults. Thus, this protection principle protects only the element within its zone and does not offer backup protection operation for other elements.

As shown in the study results in this article, the developed busbar differential protection algorithm in PSCAD has successfully discriminated the internal and external faults. Since the algorithm has operated adequately for the different faults. In addition, fault resistance was varied and did not alter the correct behavior of the algorithm.

This platform is suitable to show behavior of differential protection for the undergraduate students. Aiming that they can easily understand the basic principle of differential protection and notice the difference of external and internal faults.

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