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Blocking the Distance Relay 3rd Zone Operation during Power Swings by DTLR Enhancement in MATLAB/Simulink

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Abstract

For many years distance protection relay has been one of the most commonly used devices amongst electrical protection equipment. Worldwide analysis of recent wide area cascading failures has shown that very often they were mainly caused by the mal-operation of the third zone of a distance protection relay. The load encroachment and power swing phenomena are the two dire problems to solve when dealing with the third zone of distance protection. The vast number of blackouts could have been avoided or the consequences lowered if the distance relay had not operated due to impedance encroachment while there was no such need. The way to improve operation of the distance protection relay by introducing a new blocking algorithm using Dynamic Thermal Line Rating (DTLR) to restrain relay from tripping when conditions in electrical power system allow for it.

Keywords: Principle of distance relay, 3rd zone distance protection, DTLR, power swing, load encroachment

Introduction

Recent wide area cascading failure have led to discussion of role played by the third zone of distance protection schemes which are universally used to protect transmission and distribution lines. It is recognized that a power system and its protection equipment is designed in such a way that the system can ride through a sequence of credible contingencies without causing wide-spread outages. However, it has been observed that unwanted third zone operations caused by unexpected loading conditions have often contributed to the cascading outages eventually leading to major blackouts affecting millions of people. Distance relays are double actuating quantity relay with one coil energized by current by voltage and other coil energized by current. The basic principle of impedance relay measures the impedance of the line at the relay location. When a fault occurs on the protected line section, measured impedance is the impedance of the line section between the relay location and the point of the fault. It is proportional to the length of the line and hence, to the distance along the line as in equation (1).The apparent impedance calculated in this way is compared with the reach point impedance (Z_R). If the measured impedance is less than the reach point impedance, it is concluded that a fault exists on the line between the relay and the reach point.

$$\mathbf{Z_R} = \frac{\mathbf{V_R}}{\mathbf{I_R}} --- (\mathbf{1})$$

A distance relay is designed to operate only for faults occurring between the relay location and the selected reach point, thus giving discrimination for faults that may occur in different line sections. The reach point of a relay is the point along the line impedance that is intersected by the boundary characteristic of the relay. Since this is dependent on the ratio of voltage and current and the phase angle between them, it may be plotted on an R/X diagram as in Figure 1 b. The loci of power system impedances as seen by the relay during faults, power swings and load variations may be plotted on the same diagram and in this manner the performance of the relay in the presence of system faults and other disturbances may be studied. This fact will be taken into account in this paper for zone 3 distance relay impedance characteristic encroachment to show the situations of power swing and load increase during particular system conditions and their influence on the distance relay operation.

Careful selection of the reach setting and tripping times for the various zones of protection enables correct co-ordination of the distance relay on a power system.

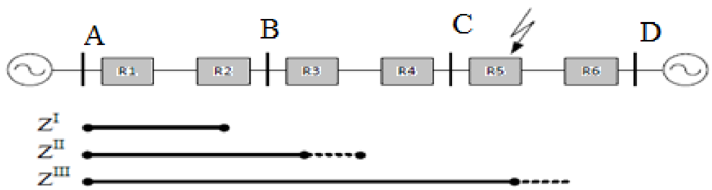

Fig. 1.a) Series transmission line with distance relays installed

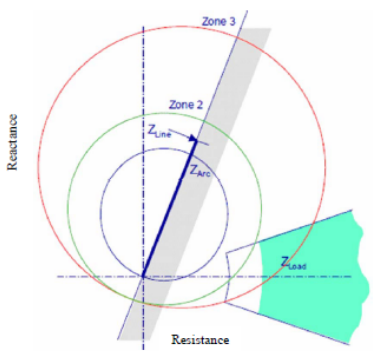

Fig. b) Distance relay characteristic of operation for zone 1, zone 2, zone 3 vs. load area

Main distance protection will comprise instantaneous directional Zone 1 and one or more time-delayed zones. Typical settings for three forward zones of basic distance protection are given as follows. Zone 1 settings of up to 85% of the protected line impedance. The resulting 15-20% safety margin ensures that there is no risk of the Zone 1 protection over reaching due to errors in the current and voltage transformers, inaccuracies in line impedance data provided for setting purposes and errors of relay setting and measurement. Otherwise, there would be a loss of discrimination with fast operating protection on the following line section. Zone 2 of the distance protection must cover the remaining 15-20% of the line [6]. To ensure full coverage of the line with allowance for the sources of error already listed above, the reach setting of the Zone 2 protection should be at least 120% of the protected line impedance. In many applications it is common practice to set the Zone 2 reach to be equal to the protected line section +50% of the shortest adjacent line.

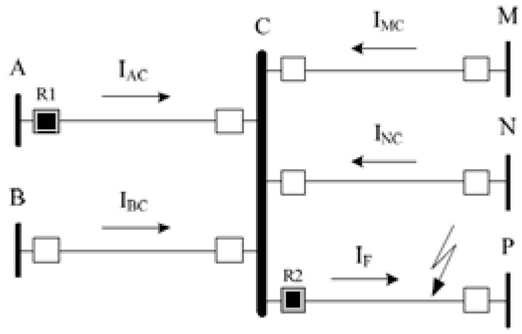

Fig. 2. Sample structure of an interconnected transmission network

On interconnected power systems (Fig.2), the effect of fault current infeed at the remote busbars will cause the impedance seen by the relay to be much greater than the actual impedance to the fault and this needs to be taken into account when setting Zone 3 like in equation (2). As the third zone of impedance relays with mho-characteristic covers significant part of the network and thus the impedance characteristic area is big, it is the most vulnerable zone to abnormal conditions in the electrical power system configuration and operation. Considering the problem of backing up the protection system of line CP (relay R2, Fig.2) by the distance relay R1 it must be taken into account that because of the currents contributions from the lines BC, CM and CN, the third zone
setting will be equal to:

$$\mathbf{Z_3} = \mathbf{Z_{AC}} + 1.2\,\mathbf{Z_{CP}}\left(1 + \frac{\mathbf{I_{BC}} + \mathbf{I_{MC}} + \mathbf{I_{NC}}}{\mathbf{I_{AC}}}\right) - -(2)$$

where: Z_3 is apparent impedance seen by the relay R1 in case of the other lines current contribution.

In case of an extreme situation of equal contribution to the fault current from all the remaining lines the third zone relay setting will be:

$$\mathbf{Z_3 = Z_{AC} + 4.8\, Z_{CP}} ------------- \mathbf{(3)}$$

Therefore the third zone is especially exposed to load encroachment and power swing-all these situations can lead to the measured impedance encroachment into the Zone 3 area. This results in relay mal-operation and can be a leading factor to a large scale blackout occurrence, Despite the fact of Zone 3 setting encroachment, the system operational conditions may not be dangerous and in case of load encroachment the load may be permissible due to the transmission lines temporary load ability. In case of stable power swing, after some time the system recovers to its normal operation conditions. The important issue is to distinguish whether the third zone area encroachment is a result of fault and the relay should operate, or it is one from above-mentioned situations and the relay decision about tripping should be restrained.

This paper is focused on the possibility of Dynamic Thermal Line Rating usage to prevent distance protection relay from tripping in situations of extreme load conditions and power swing by introducing an additional blocking signal into the standard distance relay. The blocking signal is based on the DTLR technique monitoring weather conditions and calculating the overhead conductor temperature and actual for ambient weather conditions conductor current limit and this analysed by using MATAB/Simulink.

Power swing:

Power system faults, line switching, generator disconnection, and the loss or application of large blocks of load result in sudden changes to electrical power, whereas the mechanical power input to generators remains relatively constant. These system disturbances cause oscillations in machine rotor angles and can result in severe power flow swings. Power swings are variations in power flow that occur when the internal voltages of generators at different locations of the power system slip relative to each other. Large power swings, stable or unstable, can cause unwanted relay operations at different network locations, which can aggravate the power-system disturbance and cause major power outages or power blackouts In fact, some transmission line relays may operate for stable power swings for which the system should recover and remain stable.

Enhanced distance protection scheme:

During the high load and power swing phenomena there is a high risk of the measured impedance encroachment into the Zone 3 area. Both these situations correspond to current values higher than the values during the normal operating conditions thus the measured impedance is sometimes even much lower than during the normal operating conditions (Eq.1). The standard way of designing protection devices usually does not take into consideration the Joule’s law, i.e. the fact that higher currents evoke higher conductor temperatures and each conductor has its thermal limit that due to the safety reasons cannot be exceeded.

The Dynamic Thermal Line Rating application introduces an additional algorithm into a standard distance relay, that is based on real-time conductor temperature calculation. The aim is to restrain the relay from tripping until the conductor temperature reaches its thermal limit. The block scheme of DTLR supported distance relay operation is presented in figure 3 below:

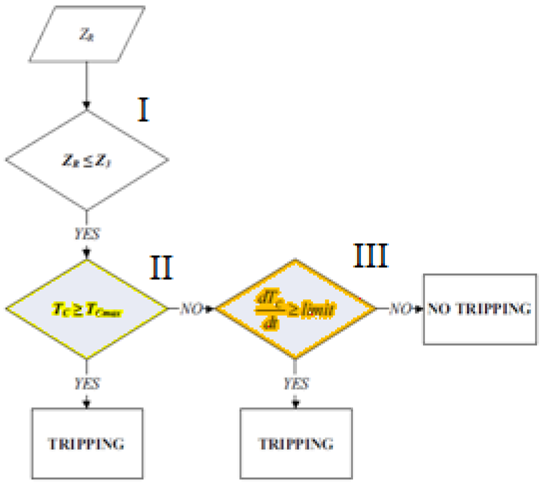

Fig3. Coordination of the distance protection and DTLR algorithm for distinguishing of the power swing cases.

Simulation Model

The DTLR application and relay performance in case of power swing is observed by three phase transmission line with distance protection relay by simulation model in Fig 4.

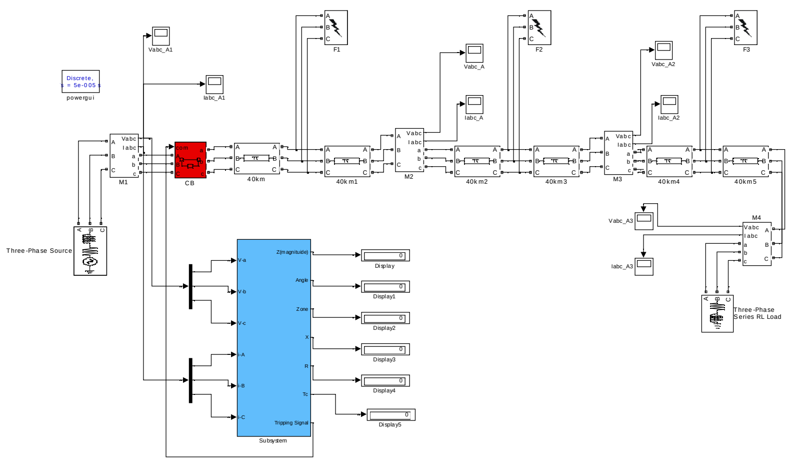

Fig. 4. Simulink model of three phase transmission line with distance protection relay.

Under normal steady state operating condition voltage magnitude of three phase transmission line, current and voltage magnitude during power swing as shown below:

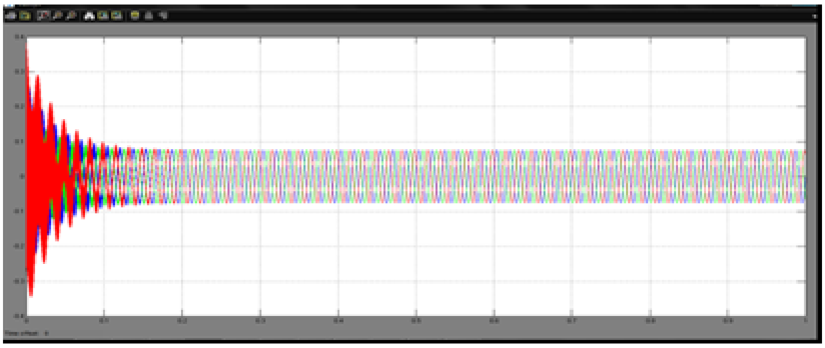

Fig.5 voltage magnitude under normal steady state operating condition

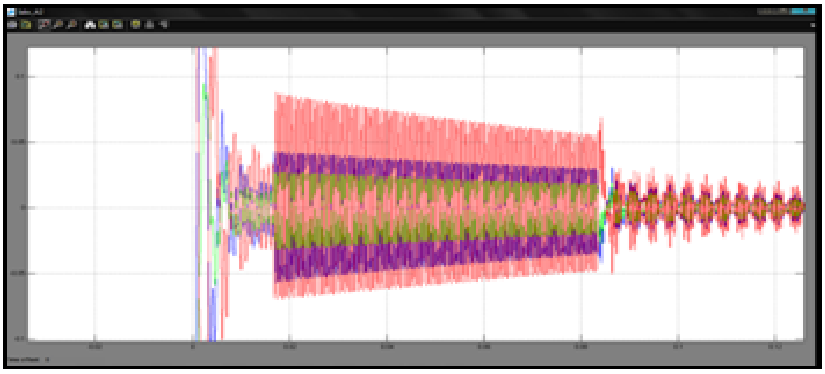

Fig.6 (a) Current magnitude during power swing

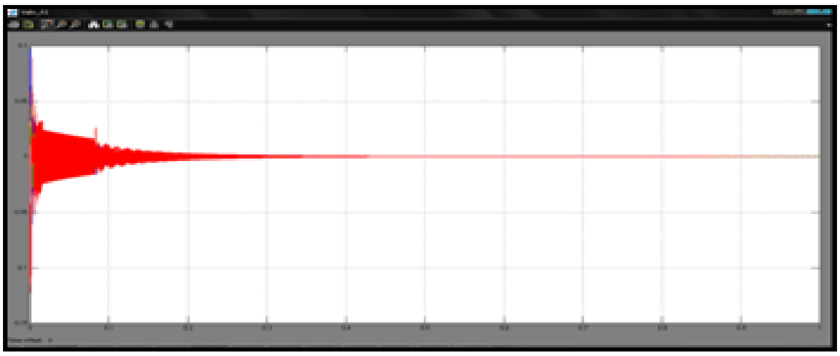

Fig.6 (b) Voltage magnitude during power swing

Expected outputs samples in Figures 7a and 7b below show For the current transient above there is a respective impedance trajectory that can be seen by the relay in case of some faults and power swing conditions. From the relay point of view there is no difference between these two phenomena. In each of presented situations the third zone setting area was encroached. The standard relay would operate in all five situations and that is why the additional algorithms, based on the Dynamic Thermal Line Rating, are pro-posed to be implemented into a distance relay. If introduced, a hope is justified that the relay would restrain itself from tripping in Power Swing situations, when it is not desired.

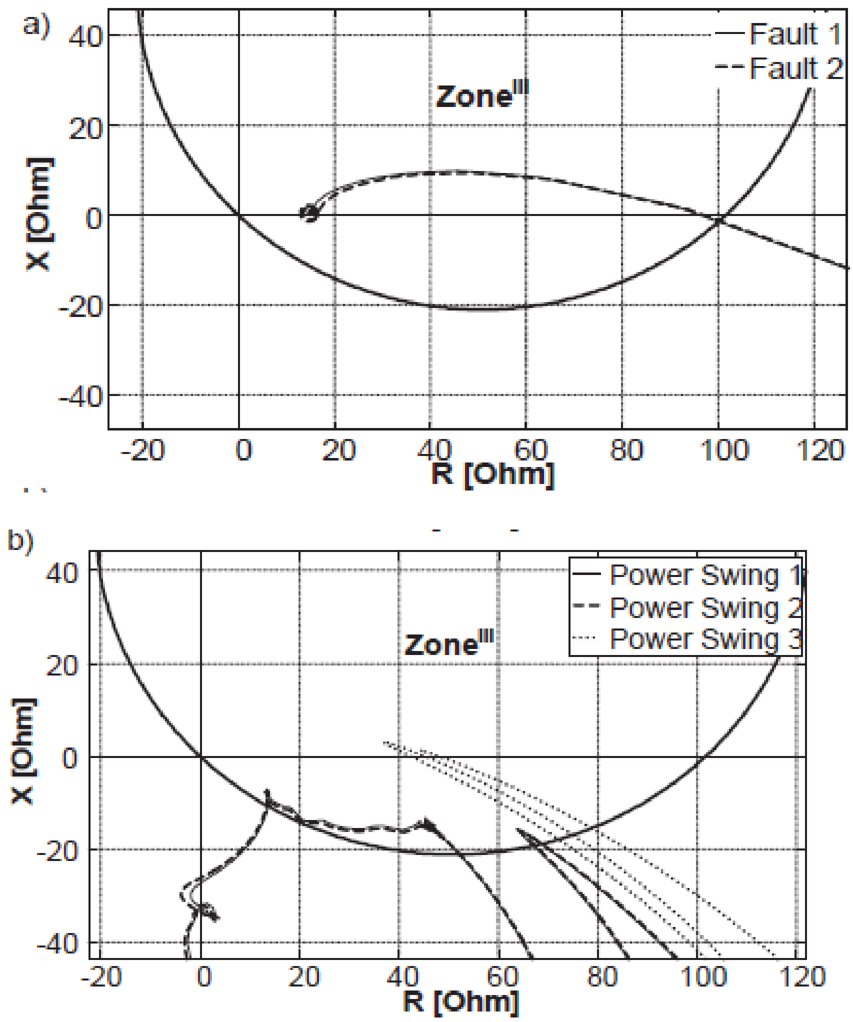

Fig. 5. Impedance trajectory encroaching third zone of a distance relay (circle char.) during: a) faults, b) power swing situations

On the contrary, the DTLR algorithm, based on the conductor temperature calculation and the rate of its change can help to avoid the relay operation, what enables operating power system stably and safely despite of the transient situation

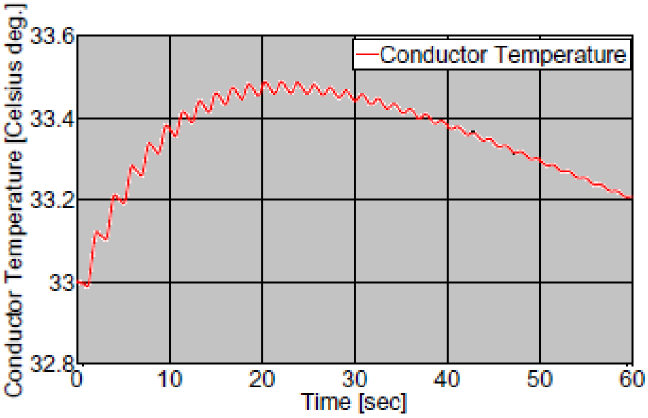

Fig.8 Conductor temperature during power swing from Figure 6a,6b.

Figure 8 presents the thermal behaviour of the transmission line conductor during power swing for favourable weather conditions. Because of the conductor thermal time constant, which is about 15 minutes, the conductor temperature does not change significantly, which results also in a low value of derivative. Thus, the DTLR algorithm blocks the distance relay, which makes continuous and safe operation of transmission line possible. This proves that also in the case of power swings the system reliability can be improved by introduction of additional DTLR algorithm into the standard distance protection relay.

Conclusion

Distance protection relays are more likely to mal-operate during power system swing because of the changing impedance. In order to prevent the distance protection from tripping during such conditions. So This paper presented the examination of a standard distance protection relay enhanced with two additional algorithms based on the Dynamic Thermal Line Rating, The DTLR can also introduce much better transmission line utilization and increase of the transmission system efficiency, bringing additional profits for operators. It can also improve the system reliability and safety avoiding unnecessary relay operations.

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