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Integral-based stabilization of generator differential protection

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ABSTRACT

This paper presents a new approach to stabilization of generator differential protection with use of the integral principle. An additional relay stabilization is needed especially for the cases of close external faults with CT saturation, energization of the near-by transformers or start-up of supplied motors. Most of contemporary produced generator protection devices do not employ any stabilization or may use the second harmonic restraint that is well known from transformer protection. The proposed here integral principle is simple and exhibits superior performance against other commonly applied algorithms. The theoretical investigations are followed by testing with simulation runs as well as recorded signals.

1. Introduction

The investigations related to differential protection of generators are presented in this paper, whereas special attention was put to relay performance for:

– external fault cases with CT saturation,
– magnetizing inrush due to block transformer energization,
– start-up of near-by motors.

It is obvious that in all abovementioned cases the differential protection of generator should be secure and restrain itself from tripping. Although it is so in most situations, unfortunately, there have been a lot of cases reported when generator protection maloperated under such external circumstances.

In Fig. 1 an exemplary recorded case of close external fault is presented. One can see that the level of fundamental frequency components in fault currents (phases L2, L3) is quite low, however, the content and time constant of the DC components is high, which led to saturation of current transformers. Thus, the generator relay measured substantial differential current, the stabilization from through current was not high enough and the tripping command was issued. The relay operation may be clearly noticed in Fig. 1 (also in Fig. 2) by the sudden decay of the currents due to tripping action.

In Fig. 2 a situation of near-by transformer energization is presented. Since the generator protection is not equipped with any harmonic restraint, as it is the case for power transformers, the differential relay was not blocked and false tripping command was generated. The examples presented here were a clear motivation for detailed analyses and simulation studies, with the aim of developing and validating a new solution able to eliminate problems mentioned.

The problem of differential protection behavior for close external faults with DC induced CT saturation is not new. The authors did some research related to this issue a few years ago, which led to development of an adaptive scheme described in [1–3]. The adaptive relay performs its task in several steps including calculation of the expected CT saturation period, determination of the necessary level of adaptation for given fault case (shifting up of the differential curve or slope changing of the stabilizing section), and execution of the on-line adaptation of the differential curve. Despite promising features of the developed algorithm further tests revealed that application of the adaptive scheme may be quite difficult for the wide variety of situations that may happen. An important challenge is related to inaccurate determination of the decaying DC component time constants, having influence on the proposed settings for differential curve adaptation. Some additional difficulties may arise from lack of detailed information about CT parameters that are required for proper operation of the algorithm. Thus, some other approaches should be investigated and new algorithms developed in order to assure better functioning of the generator differential protection for the cases under study.

Apart from the stabilized differential characteristic no additional stabilization is usually applied in the protection of generators, as it is a case for power transformer protection. Standard solution for transformer protection stabilization is the second harmonic ratio method,

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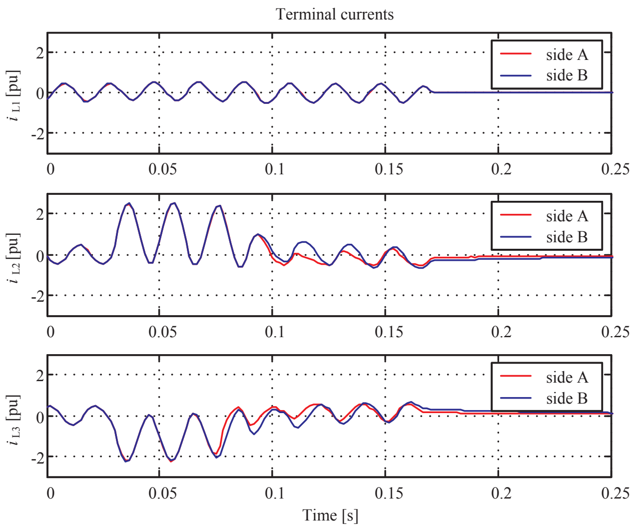

Fig. 1. Generator terminal currents during close external fault – recorded case.

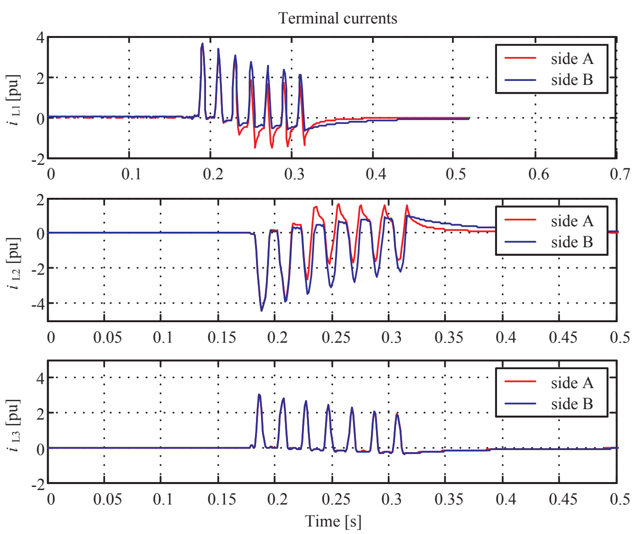

Fig. 2. Generator tripping due to transformer inrush – recorded case.

which is applied in products of most relay manufacturers, e.g. [4]. Other approaches (being mostly literature proposals) may include:

- usage of higher harmonics content in the differential currents to restrain and/or to block differential protection and differentiate between fault and inrush condition [5,12],
- application of a combined restraint/blocking method, whereas even harmonics of the differential current provide restraint, while both the fifth harmonic and DC component block protection operation [6],
- discrimination internal fault current from inrush current by comparing the similarity between the actual wave of differential current and two reference waves under two different frequency conditions per half cycle [7],
- schemes based on correlation algorithm where fault current is distinguished from the inrush current by usage of the waveform correlation coefficient between the first half-cycle and the latter-half-cycle of the differential current [8],
- stabilization based on the correlation coefficients between the differential current waveform in the non-saturation zone and two structured sinusoidal waveforms [9],
- usage of multi-criteria self-organized fuzzy approach [10],
- fuzzy-based power transformer differential protection algorithm employing flux-differential current derivate curve, harmonic restraint and percentage differential characteristic curve [11].

Some examples of improvements of generator differential protection given in the literature include:

- combination of three principles [13] – asynchronous increment of restraining and operating currents, higher harmonic content and current phase comparison,
- application of dual-slope dual-break-point operating characteristic when comparing the operating signal with the effective restraining signal and additional phase comparison supervision [14].

One can also find proposals of the protection operation improvement by appropriate compensation of CT saturation errors:

- based on least error squares (LES) filter aimed at estimating phasor parameters of the CT secondary current [15],
- with use of transient bias technique designed to overcome the effects of CT saturation [16].

Summarizing the above from the viewpoint of this paper goal one has to say that at the moment three most common practical approaches for generator differential protection stabilization, except for the basic percentage characteristic, are: harmonic restraint, asynchronous operation principle (operation sequence) and current phase comparison. These methods improve protection security, but they also have some major disadvantages:

– decreased sensitivity during faults combined with inrush, and generally slower operation for internal faults (harmonic restraint),
– inefficiency when fast CT saturation occurs (within less than 1/3 of the fundamental cycle) and when CT saturates due to long lasting DC component (operation sequence method),
– requirement for additional voltage measurement and possibility of incorrect decisions under low-current short-circuit cases (current phase comparison technique).

One has to admit that most of the abovementioned proposals are better suited and may ensure good behavior of transformer differential protection for most possible operation conditions. Distinguishing of generator-close transformer inrush conditions from fault currents could be possible with some of the approaches. However, their operation for close external faults as well as start-up of near-by motors may not be efficient enough due to the algorithms' features mentioned. Therefore, a new solution for the generator protection is still needed.

In this paper, the analyses of close external faults characterized by relatively low current level is presented in Section 2. First, the problem is approached from the theory side. The typical generator terminal signals during faults are analyzed and influence of CT saturation due to high content of decaying DC component is studied. The EMTP simulations follow, with analysis of CT type and loading effects on the differential current shape and relay operation. In Section 3 the new integral type stabilization algorithm is proposed and validated for both EMTP and registered cases of close generator faults. Its operation for other cases of external disturbances, including near-by transformer inrush and start-up of motors, is described in Section 4. The algorithm behavior for generator internal faults is studied in Section 5, which is followed by final conclusions and application recommendations.

2. Generator external faults – theoretical and simulative investigations

In order to understand the phenomena during close generator faults and differential protection operation let us analyze the cases of faults at