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HIGH SPEED PROTECTION FOR SERIES COMPENSATED PARALLEL LINE

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This paper describes a novel idea for fast protection of parallel series-compensated transmission lines operating in various configurations. It is based on the logic diagram of flag signals, which are determined using only one-end phase currents measurements. The developed method has been tested and evaluated using signals obtained from computer simulations. The detailed models of considered transmission line including the SC&MOV banks as well as the measurement channels have been developed. Using these models, the reliable data for fault on a double-circuit series-compensated transmission line, as well as for faults outside the line, have been generated under variety of fault scenarios. The sample test-case results of algorithm operation, as well as statistical evaluation are presented and discussed. References 10, table 1, figures 5.

Key words: distance line protection, series compensation, fast line protection, double-circuit line, fault detection.

I. Introduction. The parallel series-compensated lines (Fig. 1) are very important links between the power generation and energy consumption regions. All the advantages relevant for both the parallel arrangement and the series capacitor compensation are the primary reasons for increased use of such the transmission links. However, installation of series capacitors banks (SCs), equipped with nonlinear Metal-Oxide Varistors (MOVs) for overvoltage protection, on transmission lines causes certain problems for protective relaying and fault location.

Series capacitor shifts the fault-loop impedances which may result in tripping the healthy line. Additionally the misoperation trips are reported for faults outside the protected line. To avoid this misoperation the present practice relies on using traditional distance relays but with modified settings. Considerable shortening of the first zone of distance protection reach to 30-40% instead of 85% is applied. As a result of that, the quality of protection is not too high.

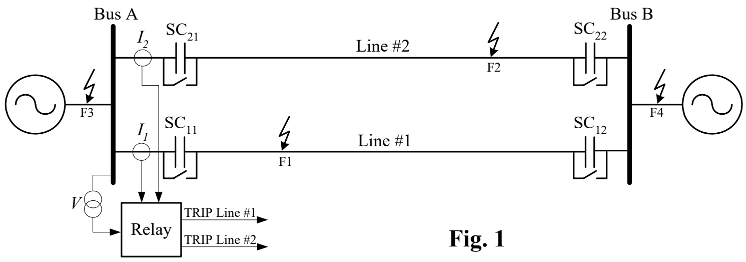

Fig. 1

Another problem is related to operation of directional element which is commonly used as a logic part in the line distance relays. Faults located close to remote end of the parallel line appear as in zone 2 of the relays on both, the faulted circuit and healthy circuit of the parallel line (e.g. F2 in Fig. 1 – Series compensated parallel line ATP-EMTP model used for testing protection algorithm in various operational configuration of the line during various internal faults (F1 or F2), as well as external faults (F3 or F4)). The directional element on the healthy circuit may be confused, and also moves into the trip area. That makes difficult or impossible the correct discrimination on the unfaulted line [1, 2].

Next important issue is connected to reliable determination if the fault is internal i.e. within the parallel line (between Bus A and Bus B) or external i.e. outside the line, and moreover the circuit of the line is supposed to be faulted. Simple assumption that during the fault in the line the currents in one of the circuits of the line should be significantly higher compared to the second circuit, in contrast to an external fault when the currents are quite similar in both circuits (in terms of amplitude and phase of phase currents) is quite good in case of parallel lines without series compensation. However, for series compensated lines, due to many reasons, currents observed in both circuits of the line may be pretty much the same instantly after internal fault occurs. Such transient period may last even 2–5 cycles after fault, and therefore the above assumption does not longer remain true. This makes the classical protection schemes may take wrong decision and consequently trip the healthy circuit of the line. This problem becomes even more serious in situation when the parallel circuits of the line have different parameters, e.g. due to different series compensation factors in each of the circuits.

Everything mentioned above create serious problems for distance protection as well as for coordination of the protection systems [3, 4]. A literature survey carried out shows, that so far have not yet been developed satisfactory and reliable algorithms for healthy/faulty circuit discrimination for series compensated parallel lines [5]. Although, many

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protection algorithms for double-circuit lines have been presented in recent years, but only few of them are concerned with series compensated lines [6–8]. Moreover, those algorithms are based usually on two-terminals data, and utilize both voltages and currents. One-terminal algorithms appear more attractive since they rely only on currents and/or voltages measured at common terminal and, therefore, no additional communication have to be provided between both terminals of the line. The new method which overcomes all mentioned problems is described in the paper. Method may be an important supplementation of the high-speed protection for double circuit series compensated line in existing protection systems.

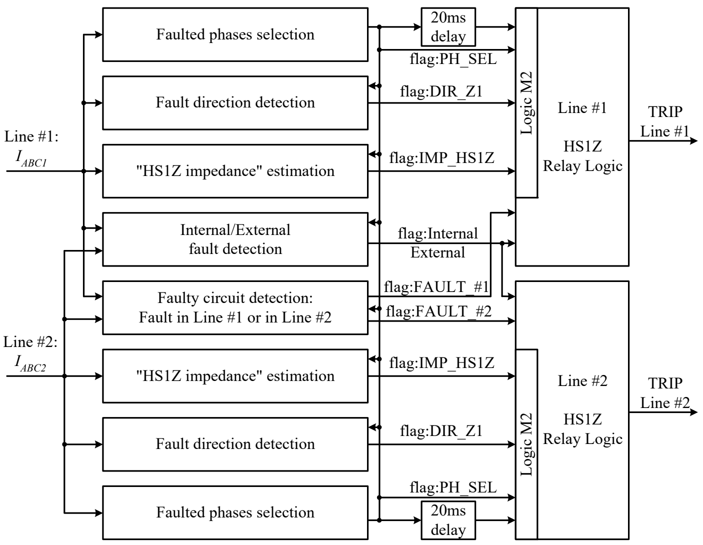

Fig. 2

II. Description of the method. In contrast to the classic distance protection, presented proposal of line relay is not based on fault loop impedance, but uses logic combination of some two-state flags. Flags provide information about fault occurrence detection, faulted phase selection, fault direction detection, information if the fault is internal or external [9], and which circuit of parallel line is faulted. Additionally, it is also calculated so-called "HS1Z simplified impedance", but it is not the fault loop impedance in the classical sense ("HS1Z" stands for "High Speed 1st Zone"). Algorithms for determining all of flags have been developed earlier by authors of this paper and described in details in references indicated. Due to the fact that all of these algorithms turned out to be very reliable and have a very short operation time (typically less than half of the cycle), the idea to combine them into one algorithm to try build new type of high-speed protection for parallel transmission lines was born. The block diagram of such proposal is given in Fig. 2. The samples of three-phase currents from both parallel lines (Line #1 and Line #2, as shown in Fig. 1) are the algorithm input signals. Current signals should be sampled with sampling frequency that provides at least 20 samples per cycle. Currents are taken only from one end of the line.

Based on input currents there are determined flags for both circuits of the parallel line: PH_SEL, DIR_Z1, IMP_HS1Z, Internal/ External, FAULT #1 and FAULT #2. Then flags' signals enter the logic units which eventually form a trip signal for each of the lines. Logical units essentially perform the function of a logical product, but with some additional time constrains. This process is carried out in parallel for each of the fault loops A-G, B-G, C-G, A-B, B-C and C-A. For high operational reliability, the algorithm is blocked 20 ms after the moment of fault detection (as evaluation tests have shown, more than 90% of faults presented algorithm trips within one cycle time window).

III. Test results. The series-compensated 400 kV, 300 km double-circuit transmission line was studied. Series capacitors (SCs) providing the compensation at 35% rate, were considered as installed at both ends of the line. Different scenarios with changing of a fault place and type, fault resistance, fault angle, pre-fault load of the line and equivalent system impedances were performed for evaluation of the presented algorithms. All faults took place in the Line #1 (F1), or in one of the systems A (F4) or B (F3). No fault was in the Line #2. The total number of tests considered in the study was 2,568 cases for each tested configuration type of the parallel line. Figs. 3 and 4 are concerned with test case of A-G fault in Line #1, at 0.50 p.u., R_f = 5Ω, t_{fault} = 0.06 s. in unbalanced double circuit series compensated line (SC_{22} is bypassed as given in Fig. 1). The waveforms of input phase currents and flags as action sequence processed by relay for both lines are shown. It can be seen that in the Line #1 output Trip flag is set in 4 ms after fault detected (5 ms after fault occurs), and no trip in Line #2 at all.

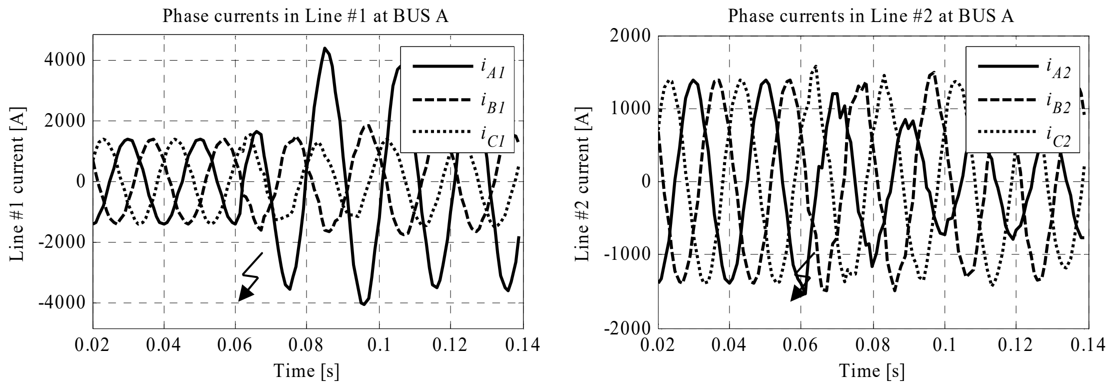

Fig. 3

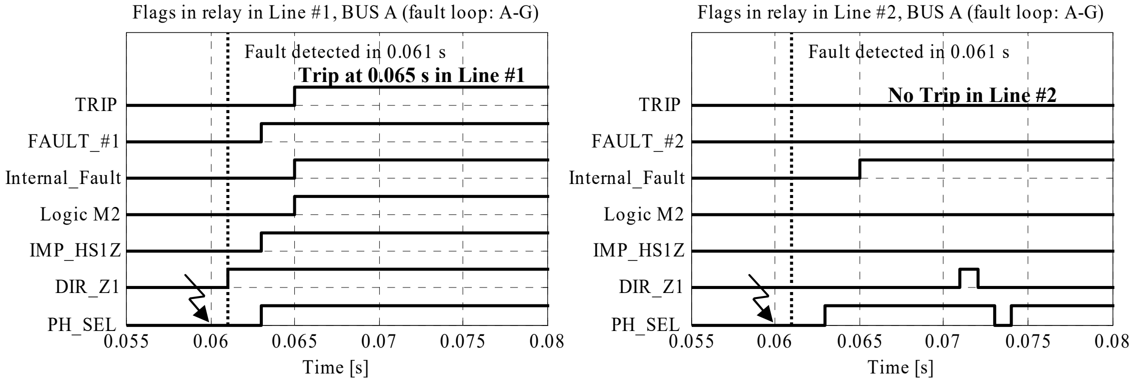

Fig. 4

Line #1 (F1), or in one of the systems A (F4) or B (F3). No fault was in the Line #2. The total number of tests considered in the study was 2,568 cases for each tested configuration type of the parallel line. Figs. 3 and 4 are concerned with test case of A-G fault in Line #1, at 0.50 p.u., $R_f = 5\Omega$, $t_{fault} = 0.06$ s. in unbalanced double circuit series compensated line (SC_{22} is bypassed as given in Fig. 1). The waveforms of input phase currents and flags as action sequence processed by relay for both lines are shown. It can be seen that in the Line #1 output Trip flag is set in 4 ms after fault detected (5 ms after fault occurs), and no trip in Line #2 at all.

Table presents the results of extensive evaluation of presented method for the compensated line as well as the two variants of the unbalanced line operation. It can be seen that in the first case, the method has efficiency close to 100% for faults in whole length of the line, whereas in the asymmetrical cases – around 85%, which is still very good result considering huge parameter asymmetry of the line circuits. Average operating time is 5–10 ms, the shortest time is 4 ms and the longest time is 20 ms.

	Fault location	Total number of test cases	Number of correct operations					
			Symmetrical parallel line with series compensation at both ends		Series compensated parallel line with SC_{22} bypassed at remote end of the Line #2		Series compensated parallel line with SC_{21}, SC_{22} bypassed at both ends of the Line #2	
			at BUS A	at BUS B	at BUS A	at BUS B	at BUS A	at BUS B
Relay operation performance in Line #1: TRIPS	Outside of the line (system A, Busbar A)	3696	3696 (100.0%)	3696 (100.0%)	3696 (100.0%)	3696 (100.0%)	3686 (100.0%)	3591 (97.2%)
	In the Line #1: (0.0 ÷ 1.0 pu of the line)	22176	21292 (96.0%)	21343 (96.2%)	19293 (87.0%)	16062 (72.4%)	16589 (74.8%)	16873 (76.1%)
	In the Line #1: (0.0 ÷ 0.8 pu of the line)	18480	18433 (99.7%)	18429 (99.7%)	17792 (96.3%)	15249 (82.5%)	15774 (85.4%)	15899 (86.0%)
	Outside of the line (Busbar B, system B)	3696	3696 (100.0%)	3696 (100.0%)	3673 (99.4%)	3696 (100.0%)	3696 (100.0%)	3696 (100.0%)
Relay performance in Line #2: BLOCKING	Outside of the line (system A, Busbar A)	3696	3696 (100.0%)	3696 (100.0%)	3696 (100.0%)	3696 (97.6%)	3696 (100.0%)	3662 (99.1%)
	In the Line #1: (0.0 ÷ 1.0 pu of the line)	24024	24015 (100.0%)	24015 (100.0%)	24022 (100.0%)	24024 (100.0%)	23999 (99.9%)	23999 (99.9%)
	Outside of the line (Busbar B, system B)	3696	3696 (100.0%)	3696 (100.0%)	3696 (100.0%)	3696 (100.0%)	3662 (99.1%)	3696 (100%)

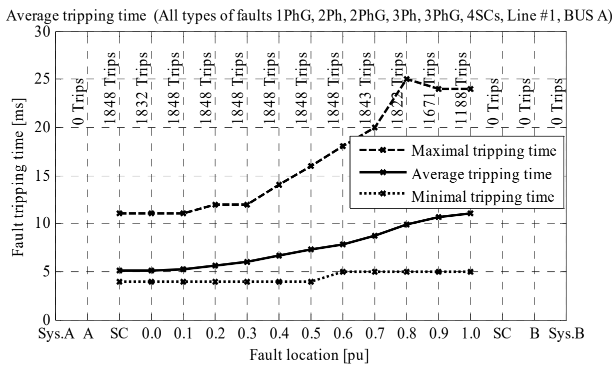

Fig. 5

Fig. 5 shows “HS1Z relay” operating time as a function of distance to the fault for fully compensated line, where average tripping time is from 5 up to 11 ms.

IV. Conclusion. This paper proposes a new method for protection of parallel series-compensated lines and uses one-end phase currents measurements only. The developed algorithms have been tested and evaluated using signals taken from ATP-EMTP [10] simulations of faults on a series-compensated transmission line in some different working configurations. The performed evaluation of the algorithm has shown that it is fully stable covering effectively almost 100% of the actual line length. The number of correct fault classification is near 100% in the cases of symmetrical parallel line, and remains above 82% in situations where line is unbalanced. Furthermore, as extensive evaluation have proven, algorithm is 100% resistant to faults outside line – there is no trip at all, as well as, it is almost 100% resistant to faults in the second circuit of the line – only very small number of unwanted trips occurred, however with long tripping time, above 30 ms i.e. when the relay has been already blocked. The presented method is very fast and operates in less than half of the fundamental frequency cycle.

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ВЫСОКОСКОРОСТНАЯ ЗАЩИТА ДЛЯ ПАРАЛЛЕЛЬНОЙ ЛИНИИ ЭЛЕКТРОПЕРЕДАЧИ С ЁМКОСТНОЙ КОМПЕНСАЦИЕЙ

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Представлена новая идея быстрой защиты параллельных линий электропередачи с продольной ёмкостной компенсацией, работающих в различных конфигурациях. Идея основана на обработке логических сигналов, которые определяются только с помощью измерения фазных токов. Представленный метод был тестирован и оценен по сигналам тока и напряжения, полученным в результате компьютерного моделирования (реализации программы ATP-EMTP). Разработаны подробные модели рассматриваемой линии электропередачи, включая банки SC & MOV, а также каналы измерения. С использованием таких моделей были проверены различные тестовые сценарии происходящих повреждений. Представлены и обсуждены примеры тестовых результатов работы алгоритма, дана их статистическая оценка. Библ. 10, табл. 1, рис. 5.

Ключевые слова*:* дистанционная защита линии, продольная компенсация, быстрая защита линии, параллельная линия электропередачи, обнаружение неисправностей.

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ВИСОКОШВИДКІСНИЙ ЗАХИСТ ДЛЯ ПАРАЛЕЛЬНОЇ ЛІНІЇ ЕЛЕКТРОПЕРЕДАЧІ З ЄМНІСНОЮ КОМПЕНСАЦІЄЮ

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Представлено нову ідею швидкого захисту паралельних ліній електропередачі з поздовжньою ємнісною компенсацією, що працюють у різних конфігураціях. Ідея заснована на обробленні логічних сигналів, які визначаються лише за допомогою вимірювання фазних струмів. Представлений метод було протестовано і оцінено за сигналами струму і напруги, отриманими у результаті комп'ютерного моделювання (реалізації програми ATP-EMTP). Розроблено детальні моделі лінії електропередачі,що розглядається, включаючи банки SC & MOV, а також канали вимірювання. З використанням таких моделей було перевірено різноманітні тестові сценарії виникаючих пошкоджень. Представлено та обговорено приклади тестових результатів роботи алгоритму, дано їхню статистичну оцінку. Бібл. 10, табл. 1, рис. 5.

Ключові слова*:* дистанційний захист лінії, поздовжня компенсація, швидкісний захист лінії, паралельна лінія електропередачі, виявлення несправностей.

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