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A Novel Scheme to Identify Faults Occurring During Power Swing for a Series-Compensated Line

Patel Sharadchandra J.[1], Patel Nilaykumar A.[2]

PG Student, M&V Patel Department of Electrical Engineering, CSPIT, CHARUSAT University, Changa, Gujarat, India[1]

Assistant Professor, M&V Patel Department of Electrical Engineering, CSPIT, CHARUSAT University, Changa, Gujarat, India[2]

ABSTRACT:In this paper, a novel fault detection technique for a series-compensated line during power swing is considered. There is a noticeable difference in fault detection technique of series compensated transmission line during usual operating condition and power swing condition due to certain reasons like frequency modulation, sub-harmonic oscillations, transients etc. Transients and sub-synchronous resonance phenomena in series-compensated line appear due to inclusion of capacitor in transmission line. So, fault detection during power swing condition in case of series-compensated line is extreme difficult. In this paper,anapparent power based technique for detecting presence of fault during power swing in series-compensated line is proposed. The proposed approach is a cumulative sum (CUSUM) of change in the magnitude of the apparent power based approach and is tested for an SMIB system. Various types of faults like Symmetrical, asymmetrical and high resistance fault occurring during the power swing are simulated through EMTDC/PSCAD to test algorithm. The performance of the proposed technique is found to be accurate.

KEYWORDS: Distance Protection, Power Swing, Series Compensation, Fault Detection, Apparent Power.

I.INTRODUCTION

Series compensation is maintained in a line to avail more power flow through a line, improve the voltage profile and to reduce the line loss [1]-[3]. However, inception of fault in a series compensated line leads to sub-synchronous resonance, voltage and current inversion situations [4]. Operation of MOV and air gap further adds transients in voltage and current waveforms [5]. Mismatch in mechanical and electrical powers occurs due to line loss, sudden loss of loads,and generator disconnection. This situations lead to presence of oscillation in voltage and current signals at the relay end[6]-[14]. Many relaying schemes are constrained duringpower swing present in a series compensated line [10]. Detection of asymmetrical and symmetrical faults during power swing in a series compensated line is challenging as the swing modulates the voltage and current waveforms.

Many techniques are available for fault detection during power swing present in normal transmission line [7]-[15]. In distance relay, power swing blocking (PSB) element blocks the relay operation during power swing and maintains the selectivity property [4]. Out of step trip (OST) element operates for fault during power swing and maintains the dependability property [4]. Settings of PSB and OST are difficult in distance relays specifically for high resistance fault, weak source and far end fault [7].In [15]-[17], negative sequence componentof current is used to detect fault during power swing in aseries compensated line. CUSUM of negative sequencecurrent is taken to detect the fault.

In this paper, a superimposed apparent power basedtechnique is proposed to detect the asymmetrical andsymmetrical faults present in a series compensated lineduring power swing. The difference between the pre andduring fault apparent power is considered for detectionprocess. The performance of the technique is tested forvoltage and current inversion cases. Other situations like highresistance fault, close-in fault, and far-end fault casesare also considered. The performance of the proposedtechnique is found to be accurate.

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II.APPARENTPOWER DURING POWER SWING IN A SERIES-COMPENSATED LINE

A 400 kV, 50 Hz system as shown in Fig. 1 is considered for evaluating the performance of the proposed technique. The detail system data are provided in Appendix A. In Fig. 1, line-1 and line-2 are 40% compensated. Relay R located at bus-M is considered for evaluating the performance of the technique.

$$S = V_a I_a + V_b I_b + V_c I_c \tag{1}$$

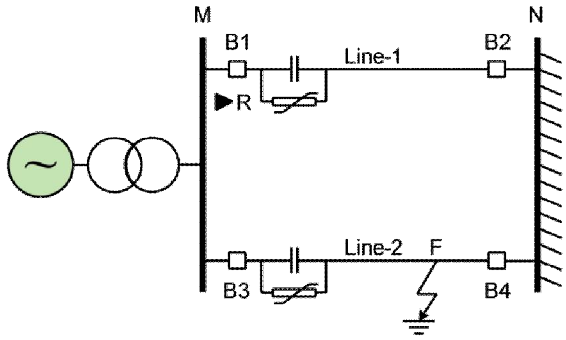

Fig. 1 Single-line diagram of the 400-kV power system

A three-phase fault is created at the middle of Line-2 at 0.6 s and cleared at 0.7 s by opening breakers B3 and B4. As a result power swing is observed in voltage and current signals of relay (Protecting Line-1) located at bus-M.

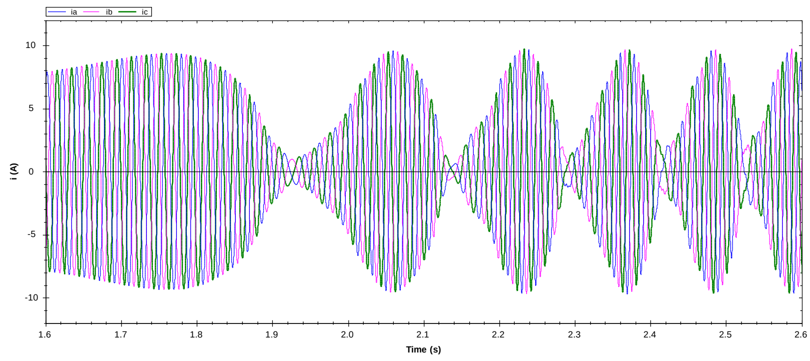

Fig. 2(a) Three-phase current waveforms at the relay bus during the power swing

During this condition, current and voltage waveforms are shown in Fig. 2(a) and (b), respectively. The apparent power at this situation is calculated using the expression provided in (1).

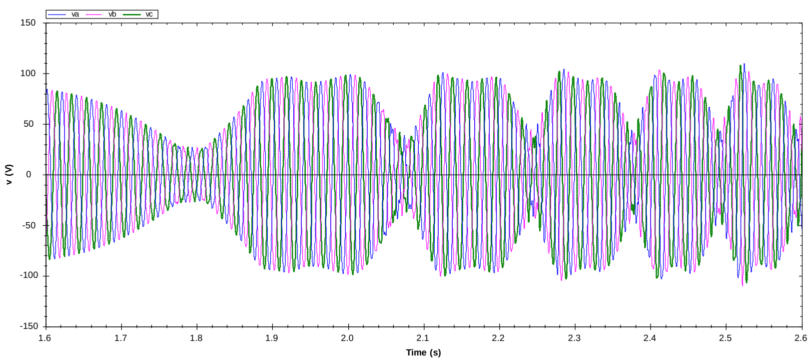

Fig. 2(b) Three-phase voltage waveforms at the relay bus during the power swing

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The real, reactive, and apparent powers are shown in Fig. 3. It is observed that the real and reactive powers are modulated with other frequency components and the sample values are oscillating within both positive and negative regions. At the same time, the apparent power is also oscillating but the magnitude varies within positive region only.By exploiting the pattern of apparent power, both asymmetrical and symmetrical faults can be detected during power swing present in series compensated line.

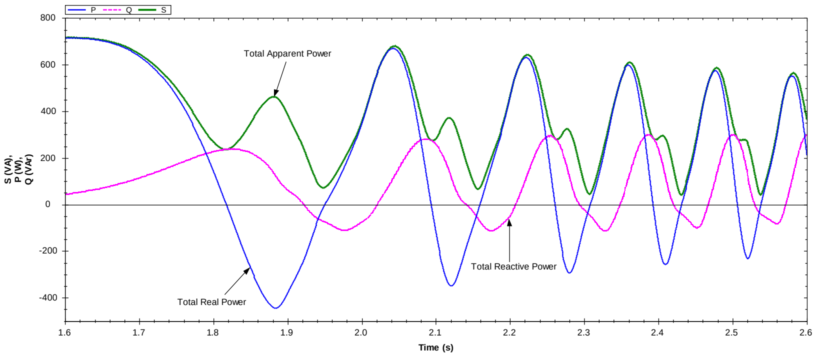

Fig. 3 The Apparent power (S), Real power (W), Reactive power (Q) at the relay R located at bus M during power swing

A line-to-ground fault of ag-type is created in line-1 during the swing and the apparent power is estimated using the expression provided in (1). The pre and during fault apparent powers are shown in Fig. 4. The apparent power during fault with only swing is increased and oscillates within positive region only.

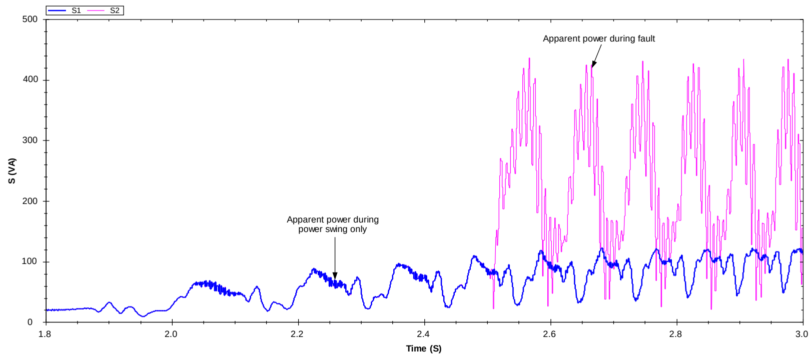

Fig. 4 The pre-fault and during fault apparent power (S) at the relay R

III. PROPOSED TECHNIQUE TO IDENTIFY FAULTS DURING POWER SWING

Voltage and current signals contain non-fundamental componens due to fault in a series compensated line during power swing. Presence of transients due to MOV and airgap operation, sub synchronous resonance, voltage and current inversions further make the fault detection process more complex. During power swing, both active and reactive powers oscillate within positive and negative regions, whereas the apparent power oscillates within positive region only.A change in the magnitude of the apparent power (ΔS) based technique is proposed to detect the asymmetrical and symmetrical fault present in a series compensated line during the power swing. With a suitable threshold, the cumulative sum of the ΔS based technique is selected in this paper for the fault detection during swing. In this paper, CUSUM is applied to obtain a good index for fault detection during the power swing where a change in apparent power is being used as the input signal.

The computation steps for the method are provided

A derived signal c_k is obtained as

$$c_k = \Delta|S_k| = |S_k| - |S_{k-1}| \qquad (2)$$

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For $c_k > \varepsilon$, the proposed CUSUM test is expressed as

$$J_k = \max\left(J_{k-1} + c_k - \varepsilon, 0\right) \quad (3)$$

Where the index J_k represents the test statistics and c_k is the drift parameter in it.

A fault is registered if

$$J_k > h \quad (4)$$

Where h is a constant and should be ideally zero. When $c_k > \varepsilon$, the value increases by a factor of the difference between c_k and ε . With further current samples available, the CUSUM process provides an easy way to decide on the fault situation by applying (4). After each fault detection index J , is reset to zero. For only the swing situation, J_k will be zero as $\Delta|S| < \varepsilon$.

In the proposed CUSUM-based fault detection technique, the value of ε is set to make $c_k = 0$ during swing (both stable and unstable) which finally helps to maintain the fault detector index $J = 0$. The value of ε is set at 20.In this paper, the value ofh is set at 0.02, considering all extreme fault situations during the power swing, for example, high resistance faults occurring at the far end of the line. The proposed method is based on the CUSUM approach and, therefore, a distinctly much higher index value J is obtained during the fault.

IV. RESULTS AND DISCUSSION

A. Single Line to Ground Fault

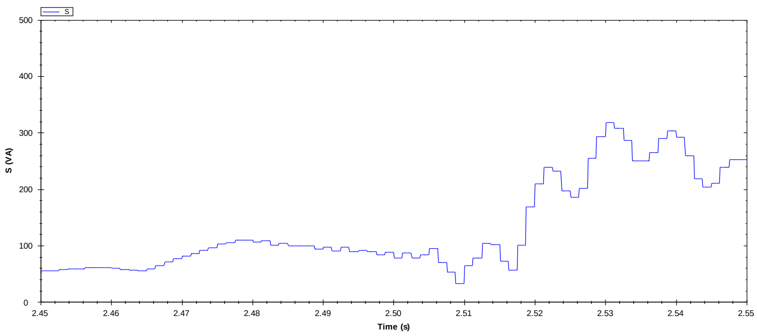

Fig. 5 Apparent powerduring the line-to-ground fault

The system as shown in Fig. 1 is considered for evaluating the performance of proposed technique. Swing is present in voltage and current measured at relay located at bus-M protecting line-1.

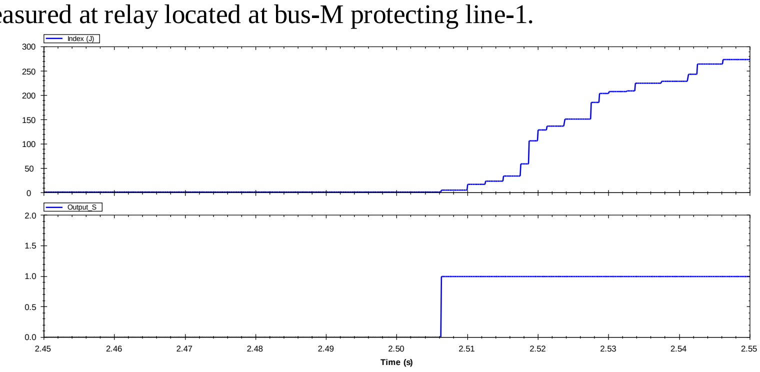

Fig. 6Performance during the line-to-ground fault

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At this situation, single-line to ground fault of ag-type is created at 2.5034 s at 256 km from the relay location with fault resistance of 0.1 Ω. The magnitude of apparent power and performance of proposed technique during line-to-ground fault is shown in Fig. 5 & Fig. 6 respectively. It is found that the magnitude of apparent power oscillates within positive region. At the inception of fault, there is a noticeable change in the magnitude of apparent power. That is why, an index (J) is used to identify the fault during power swing. The corresponding trip signal is generated within 2-3 ms.

B. High Resistance Fault (ag-fault)

In order to test the performance of the algorithm, ag-type fault with fault resistance of 100 Ω is created at 2.5034 s in line-1 at 256 km from the relay location. In case of high resistance fault, current magnitude is reduced and it becomes difficult to detect the fault using current magnitude only

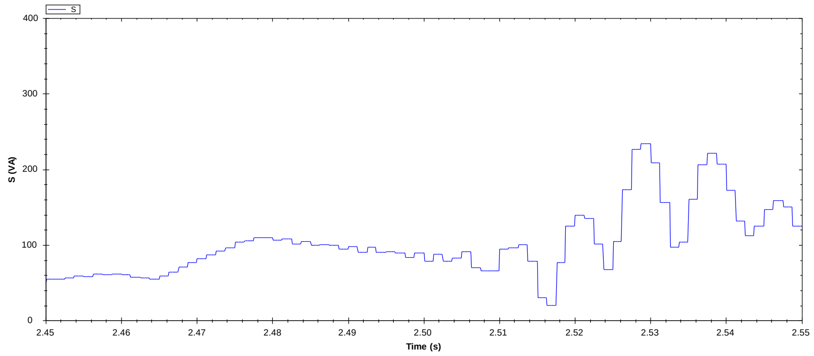

Fig. 7 Apparent power during the line-to-ground fault with fault resistance 100 Ω

. In most of the cases, MOV does not operate for high resistance fault. At this situation, change in magnitude of apparent power is calculated from (2). The index (J) and trip signal are shown in Fig. 8.

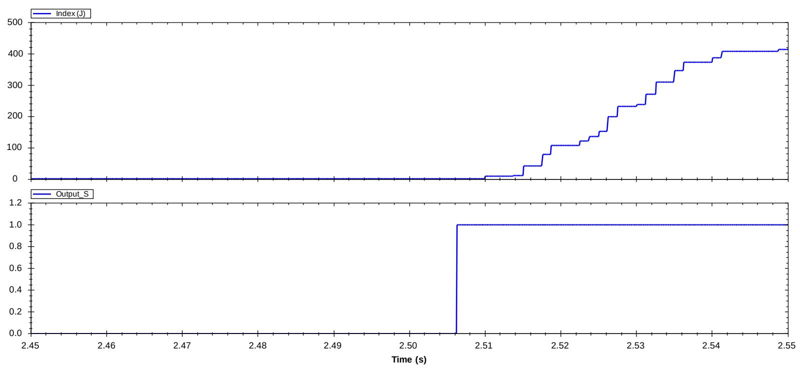

Fig. 8 Performance during the line-to-ground fault with fault resistance 100 Ω

C. Three-Phase Fault

Power swing and three phase fault both are symmetrical innature. It is always challenging to distinguish the three-phasefault during power swing. Many methods are proposed todetect the three-phase fault during power swing and everymethod has its own limitations. A three phase fault is created at 2.5034 s at a distance of 256 km from the relay location. With help of the proposed technique, the 'ΔS' is calculated.

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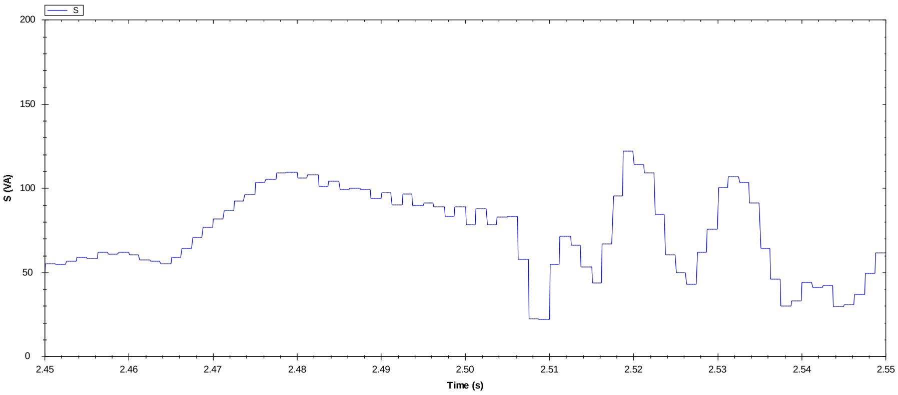

Fig. 9 Apparent powerduring the three-phase fault (100 Ω)

The value of index increases above the threshold as shown in Fig. 10. It is observed that the trip signal is '1' throughoutand the fault is detected properly.

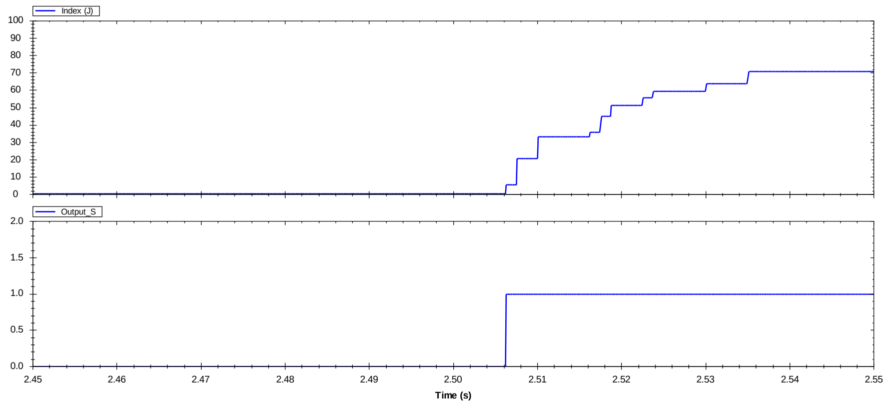

Fig. 10 Performance during the three-phase fault (100 Ω)

D. Close-in Fault

Three-phase close-in fault leads to collapse in voltagemeasured at the relay location. Such a situation alsointroduces subsidence transient in voltage signal.

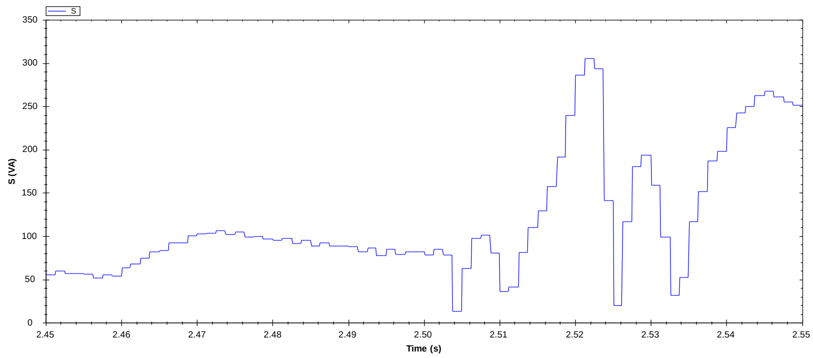

Fig. 11 Apparent powerduring the close-in fault

At the sametime, current magnitude increases significantly and MOVoperates as the energy level crosses the threshold value.

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To test the performance of the proposed technique, a three-phase fault is created in line-1, at a distance of 1 km with fault resistance of 100 Ω during power swingcondition. Duringclose-in fault condition, relay finds more fault current.

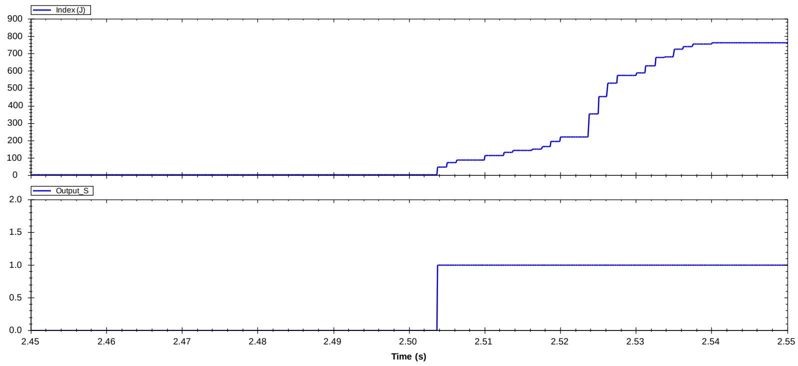

Fig. 12 Performance during the close-in fault

At this situation, change in magnitude of apparent power is calculated from (2). The index (J) and trip signal are shown in Fig. 12.

V. RESULTS ON FAULT DETECTION TIME FOR DIFFERENT FAULT LOCATION

Fault Inception Time (sec)	*Fault Distance (km)*	*Fault Detection Time (ms)*								
		ag fault		**3-phase fault**			**ab fault**		**abg fault**	
		0.1 Ω	**100 Ω**	**0.1 Ω**	**25 Ω**	**100 Ω**	**0.1 Ω**	**100 Ω**	**1 Ω**	**100 Ω**
2.5034	***1***	2.9	2.9	0.4	0.4	0.4	2.9	1.7	0.4	0.4
	64	5.4	5.4	7.9	7.9	9.2	2.9	2.9	1.7	1.7
	128	5.4	5.4	2.9	2.9	2.9	2.9	2.9	2.9	2.9
	256	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
	318	2.9	10.4	1.7	1.7	1.7	1.7	1.7	1.7	1.7

To see overall performance of the algorithm, different simulations were carried out for different type of fault at different fault location. Results clearly show that both symmetrical and asymmetrical faults including high resistance cases can be detected within a half cycle for the 50 Hz system. The proposed technique can detect high resistance fault also during power swing even when the phase angle of the relay voltage is close to 0^{o} to 180^{o}.

VI.CONCLUSION

In this paper, an alternate fault detection technique for aseries compensated line during power swing is proposed. The cumulative sum of change in magnitude of apparent power over a period is used to identify the faultduring power swing. The proposedtechnique clearly detects both symmetrical and asymmetricalfaults during power swing. The techniquehas been evaluated for different test cases like close-in fault,high resistance fault and far end fault.The performance of proposed method in the presence and absence of series-compensation in the transmission line during power swing is found to be accurate.

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APPENDIX A

System data for SMIB:

Generator:

600 MVA, 22 kV, 50 Hz, inertia constant = 4.4 MW/MVA,
X_d=1.81 p.u., $X_d^{'}$=0.3 p.u.,$X_d^{''}$=0.23 p.u., $T_{do}^{'}$=8 s, $T_{do}^{''}$=0.03 s,
X_q=1.76 p.u., $X_q^{''}$=0.25 p.u., $T_{qo}^{''}$=0.03 s, R_a=0.003 p.u.,
X_p(Potier reactance)=0.15 p.u.

Transformer:

600 MVA, 22/400 kV, 50 Hz, Δ / Y, X = 0.163 p.u.,
X_{core}=0.33 p.u., R_{core}=0.0 p.u., P_{copper} = 0.00177 p.u.

Transmission lines:

Length = 320 km.
Positive - sequence impedance = 0.12 + j 0.88 Ω/km.
Zero - sequence impedance = 0.309 + j 1.297 Ω/km.
Positive - sequence capacitive reactance = 487.723×10^3 Ω.km.
Zero - sequence capacitive reactance = 419.34×10^3 Ω.km.

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