Current Differential Protection affected by Capacitive current of EHV/UHV line

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***Abstract*—Based on distributed parameters line model, a current differential protection for extra high voltage and ultra high voltage (EHV/UHV) transmission lines is proposed in this paper. The distributed capacitance current in such lines has a severe negative impact on relaying of current differential protection. Thus the influence of distributive capacitive current on its protection during line to ground fault is carried out. In order to verify that current differential protection is influenced by capacitive current, capacitive reactance of transmission line is increased so that capacitive effect of line is reduced. An extensive simulation is carried out using PSCAD. The result shows that compensation of capacitive current in lines is necessary in proposed method to suppress its adverse effect on relaying of healthy phase.**

***Keywords*—Current differential protection; capacitance current; distributed parameters line model.**

I. INTRODUCTION

The transmission lines have the main responsibility of supplying the generated electric energy to distribution units, where the major electric consumers are located. Hence power flow through transmission lines should remain unaffected by using suitable transmission line protection systems. In 1904, British engineers Charles H. Merz and Bernard Price developed the first approach for differential protection. The advantages of the scheme proposed by Merz and Price were soon recognized and the technique has been extensively applied since then.

Differential protection compares the entering and leaving currents of protected zone. If the net sum of currents that enter and the currents that leave a protected zone is essentially zero, it is concluded that there is no fault in protection zone. However, if the net sum is not zero, the differential protection concludes that a fault exists in the zone and takes steps to isolate the zone from the rest of the system. The main constituent of a differential protection scheme is a differential relay. A differential relay is an over current relay having operating coil only which carries the phasor difference of currents at the two ends of a protected zone. It operates when phasor difference of secondary currents of the current transformers at the two end terminals of protected zone exceeds a preset value.

Current differential protection has been widely applied in various grid topologies and can still operate correctly even under complicated situations such as system oscillation and phase loss due to its simple principle, higher sensitivity and inherent ability of phase selection [4]. For high voltage short and medium transmission lines, it is one of the main protection schemes due to rapid tripping. However, for long transmission lines, where the terminals and current transformers are widely separated by considerable distances it is not possible to use differential relays. Still, current differential protection due to its simple principle, inherent phase-selection ability and excellent applicability under complex operating conditions has been widely adopted as the main protection in the EHV/UHV transmission lines.

In long transmission lines, distributed capacitance exists between line to line and line to ground [4]. As the distributed capacitances exist along transmission lines, a differential current can be composed by the distributed capacitive current when the line operates in normal condition. Thus, the sensitivity of the current differential protection of the line is limited [5].

As the voltage level and the length of the power line increases, the distributed capacitive current also increases which may severely distort the line current and voltage in transient and steady state period [4]. So the influence of capacitive current on current differential protection must be considered especially for the extra high voltage and ultra high voltage (EHV/UHV) transmission lines. To eliminate the influence of the capacitive current on the current differential protection, compensation methods are used for compensating the capacitive current of transmission line [5].

In this paper, a current differential protection for extra high voltage and ultra high voltage transmission lines based on distributed parameters line model is proposed. The impact of distributive capacitive current of transmission lines on current differential protection is simulated through PSCAD. This impact is further reduced by increasing the capacitive reactance of transmission line and the simulation results are obtained accordingly.

II. PRINCIPLE OF CURRENT DIFFERENTIAL PROTECTION

The principle of current differential protection is based on Kirchhoff's current law. Current differential protection is a comparison of current phasors at both sides of protected zone. Under normal conditions or during any external fault, the current phasors at both sides of protected zone are equal, but are not same in case of internal fault. This difference in current phasors actuates the relay which operates for internal faults and remains inoperative under normal conditions or during external faults.

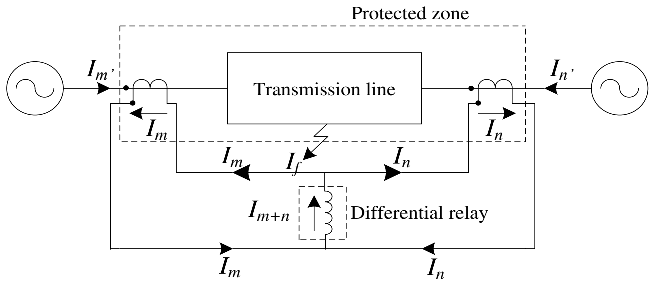

Fig. 1. Operation of differential protection scheme during internal fault in a two machine system.

Fig. 1 shows the behavior of current differential protection scheme during internal fault in a two machine system. In case of internal fault, both currents I_m and I_n add and flow through the differential relay to cause tripping. Thus, current phasors of each phase at both terminals are obtained and differential current I_{m+n} as well as restraining current I_{m-n} is calculated for each phase.

Equations (1) and (2), expresses the criterion which must be satisfied by current differential protection in order to cause tripping of differential relay.

$$I_{m+n} > K.I_{m-n} \quad (1)$$

$$I_{m+n} > I_{set} \quad (2)$$

Where I_{m+n} is differential current, I_{set} is threshold stalling current, K is stalling coefficient (0< K <1). The sensitivity of differential protection is relevant to the distributed capacitance current. The setting I_{set} is determined by distributed capacitance current. Increase in I_{set} affects the sensitivity of protection. In addition, stalling coefficient K is inversely proportional to the sensitivity of differential protection. For smaller value of K, higher will be the sensitivity.

III. SIMULATION AND RESULT ANALYSIS

In Fig. 2, a 440kV two machine system is used to charge the 400km long transmission line. The internal and external faults are created at different fault positions and the same are simulated using PSCAD.

Parameters of the transmission line are listed as follows:
Positive sequence resistance: r_1 = 0.01958 Ω/km.
Positive sequence inductance: l_1 = 0.8197 mH/km.

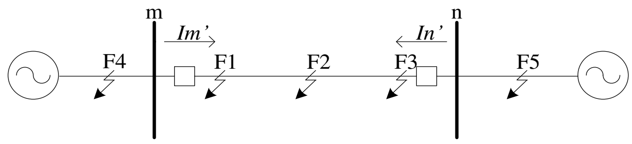

Fig. 2. Model of PSCAD simulation system.

Positive sequence capacitance: c_1 = 0.0135 µF/km.
Zero sequence resistance: r_0 = 0.2909 Ω/km.
Zero sequence inductance: l_0 = 2.7420 mH/km.
Zero sequence capacitance: c_0 = 0.0092 µF/km.

The equivalent system parameters are presented as follows: Z_{m1} = 0.1736 + j0.9848 Ω, Z_{m0} = 0.6424 + j3.6437 Ω, Z_{n1} = 0.1736 + j0.9848 Ω, Z_{n0} = 0.6424 + j3.6437 Ω, where Z_{m1}, Z_{m0}, Z_{n1}, Z_{n0} are the positive and zero sequence system impedance of terminal m and n, respectively. In Fig. 2, F1, F2 and F3 are internal fault positions created at 100km, 200km and 300km away from terminal m, while F4 and F5 are external fault positions. Line to ground (L-G) fault with varying fault resistances is simulated at these internal and external fault positions. The fault resistance R_{fault} is set as 0 Ω, 50 Ω, 100 Ω, 150 Ω, respectively. In Fig. 3, current differential protection for extra high voltage and ultra high voltage transmission lines is shown in simulation system and simulation results for different internal and external fault positions are shown in Tables I, II, III and IV.

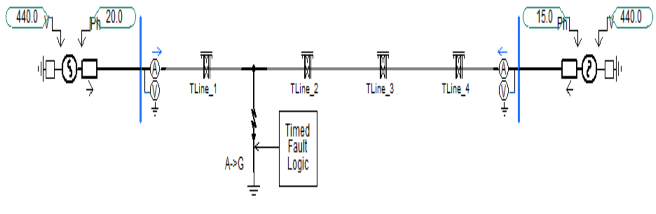

Fig. 3. PSCAD simulation system.

Under normal and external faults conditions, ignoring capacitance current, the currents at both terminals of transmission line are equal in magnitude and apart in direction. Therefore the differential current is zero. This

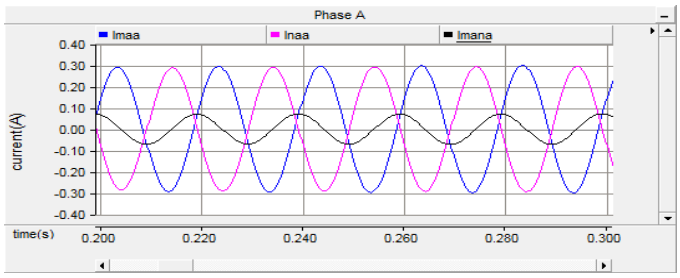

Fig. 4. Phase A two terminal currents which are out of phase and approximately zero differential current.

In case of an internal L-G (Line to ground) fault at F1, F2 and F3, phase A trips completely while phase B and C also trips due to large distributive capacitive current of the transmission line. The results showing this phenomenon is shown in Table I. In order to verify that tripping of phase B and C is caused due to distributive capacitive current, the capacitive effect of transmission line is considered to be reduced by increasing the capacitive reactance of transmission line. If capacitive reactance of line is set at particular higher value, it is seen that phase B and C remains unaffected by the capacitive current as shown in Table II. Therefore it is concluded that in case of internal faults phase B and C are mostly affected and trip due to presence of distributive capacitive current in transmission line.

TABLE I. CAPACITIVE CURRENT DURING INTERNAL FAULTS

Fault Position	R_{fault} (Ω)	Phase A		Phase B		Phase C	
		I_{m+n}	I_{m-n}	I_{m+n}	I_{m-n}	I_{m+n}	I_{m-n}
F1	0	6.6481	3.5075	0.4583	0.4268	0.4811	0.4110
	50	3.6195	2.1955	0.4662	0.4204	0.4375	0.4086
	100	2.2140	1.5043	0.4562	0.4175	0.4324	0.4107
	150	1.5925	1.1866	0.4507	0.4165	0.4322	0.4118
F2	0	4.9828	0.4141	0.4569	0.4141	0.4821	0.4141
	50	3.1662	0.4141	0.4686	0.4141	0.4429	0.4141
	100	2.0650	0.4141	0.4602	0.4141	0.4341	0.4141
	150	1.5193	0.4141	0.4543	0.4141	0.4326	0.4141
F3	0	6.6444	3.3777	0.4558	0.4015	0.4827	0.4107
	50	3.6034	1.5368	0.4655	0.4077	0.4388	0.4195
	100	2.1959	0.7547	0.4559	0.4106	0.4332	0.4175
	150	1.5742	0.4137	0.4506	0.4117	0.4328	0.4164

TABLE II. REDUCED CAPACITIVE CURRENT DURING INTERNAL FAULTS

Fault Position	R_{fault} (Ω)	Phase A		Phase B		Phase C	
		I_{m+n}	I_{m-n}	I_{m+n}	I_{m-n}	I_{m+n}	I_{m-n}
F1	0	1.5728	0.3948	0.0723	0.4178	0.0452	0.4234
	50	3.7071	2.1701	0.1002	0.4268	0.0646	0.4118
	100	2.2348	1.4905	0.0813	0.4233	0.0474	0.4151
	150	1.5748	1.1785	0.0724	0.4221	0.0443	0.4167
F2	0	5.2071	0.4201	0.1243	0.4201	0.1297	0.4201
	50	3.2824	0.4201	0.1071	0.4201	0.0756	0.4201
	100	2.1116	0.4201	0.0884	0.4201	0.0532	0.4201
	150	1.5231	0.4201	0.0782	0.4201	0.0466	0.4201
F3	0	6.8719	3.3277	0.1238	0.4028	0.1306	0.4282
	50	3.7055	1.5004	0.0998	0.4132	0.0663	0.4283
	100	2.2329	0.7297	0.0812	0.4167	0.0486	0.4250
	150	1.5728	0.3948	0.0723	0.4178	0.0452	0.4234

In case of external L-G (Line to ground) fault at F4 and F5, the phase A protection approaches for tripping, whereas phase B and C trips due to presence of distributive capacitive current in transmission lines. These results are as shown in Table III. To nullify the effect of distributive capacitive current, compensation is provided in the form of capacitive reactance and it is seen that the distributed capacitive current is approximately zero as shown in Table IV. Therefore reliability of the protection against the capacitive current increases and the line will sustain itself from tripping at external fault. Thus from the Table III and IV it is concluded that presence of distributive capacitive current in transmission lines causes mal-operation of protection in case of external faults.

TABLE III. CAPACITIVE CURRENT DURING EXTERNAL FAULTS

Fault Position	R_{fault} (Ω)	Phase A		Phase B		Phase C	
		I_{m+n}	I_{m-n}	I_{m+n}	I_{m-n}	I_{m+n}	I_{m-n}
F4	0	0.2601	2.5060	0.4715	0.5659	0.4690	0.5487
	50	0.4357	0.3200	0.4390	0.4217	0.4352	0.4077
	100	0.4363	0.3667	0.4379	0.4179	0.4360	0.4108
	150	0.4365	0.3825	0.4376	0.4166	0.4363	0.4119
F5	0	0.2602	2.5789	0.4673	0.3639	0.4731	0.3541
	50	0.4352	0.5076	0.4391	0.4063	0.4353	0.4201
	100	0.4361	0.4611	0.4379	0.4102	0.4360	0.4172
	150	0.4364	0.4455	0.4376	0.4115	0.4363	0.4162

TABLE IV. REDUCED CAPACITIVE CURRENT DURING EXTERNAL FAULTS

Fault Position	R_{fault} (Ω)	Phase A		Phase B		Phase C	
		I_{m+n}	I_{m-n}	I_{m+n}	I_{m-n}	I_{m+n}	I_{m-n}
F4	0	0.0577	2.5308	0.1292	0.5825	0.1272	0.5486
	50	0.0503	0.3252	0.0542	0.4276	0.0482	0.4134
	100	0.0505	0.3723	0.0525	0.4238	0.0495	0.4166
	150	0.0506	0.3882	0.0519	0.4225	0.0499	0.4178
F5	0	0.0578	2.6021	0.1264	0.3568	0.1299	0.3712
	50	0.0499	0.5143	0.0542	0.4124	0.0484	0.4264
	100	0.0504	0.4675	0.0525	0.4163	0.0496	0.4233
	150	0.0505	0.4517	0.0519	0.4175	0.0499	0.4222

When an internal L-G fault is created at F1 position with fault resistance R_{fault}=50 Ω, current differential protection principle trips phase A correctly but phase B and C also get tripped due to large distributive capacitive current as shown in Fig. 5. This is because, both criterions of current differential protection given by (1) and (2) are satisfied by results of each phase as obtained in Table I.

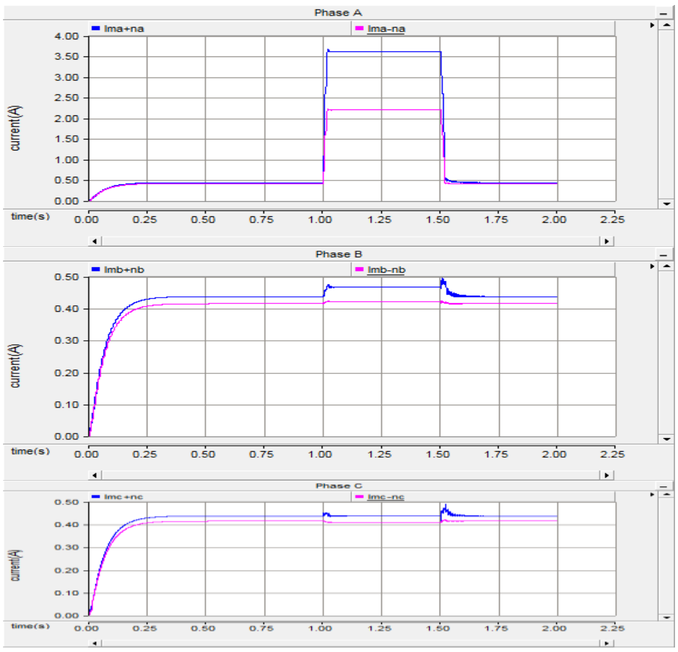

Fig. 5. Protection when internal L-G fault (R_{fault}=50 Ω) occurs at position F1.

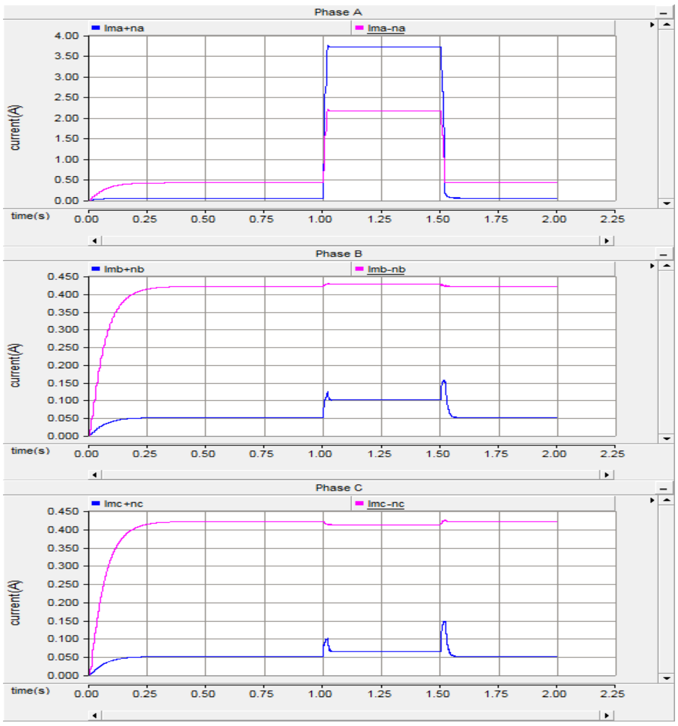

Fig. 6. Protection with reduced capacitive current when internal L-G fault (R_{fault}=50 Ω) occurs at position F1.

In Fig. 6, when capacitive effect of transmission line is minimized, only phase A trips while phase B and C remains stable which is desirable. The reason behind it is that only phase A results satisfies both tripping criterions of differential protection.

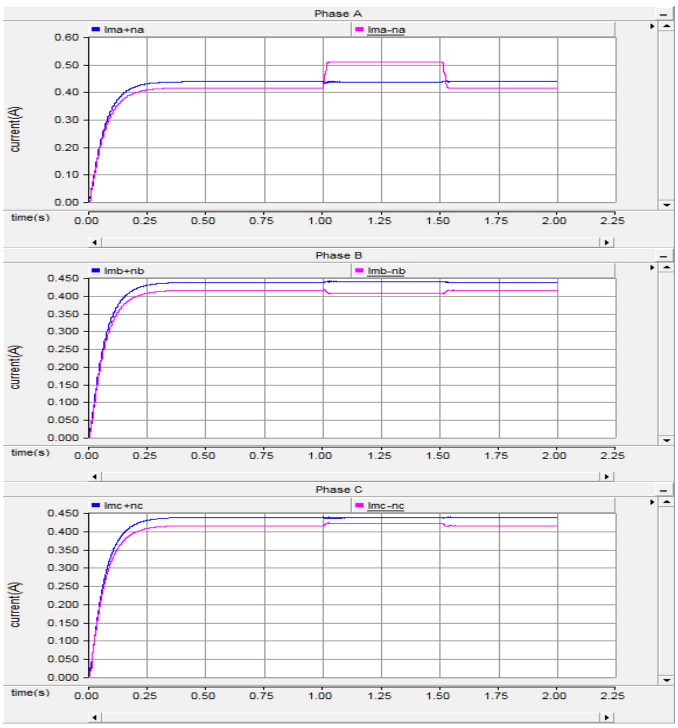

Fig. 7. Protection when external L-G fault (R_{fault}=50 Ω) occurs at position F5.

When an external L-G fault is considered at position F5, the protection for phase A approaches towards tripping. This is because phase A satisfies the first tripping criterion completely but approximately satisfies the second criterion. Whereas phase B and C get tripped because it satisfies both tripping criterions of differential protection due to presence of capacitive current in transmission lines. These results are shown in Fig. 7.

In Fig. 8, the current differential protection does not enable the tripping relays when capacitance of line is minimized because differential current is found to be approximately zero.

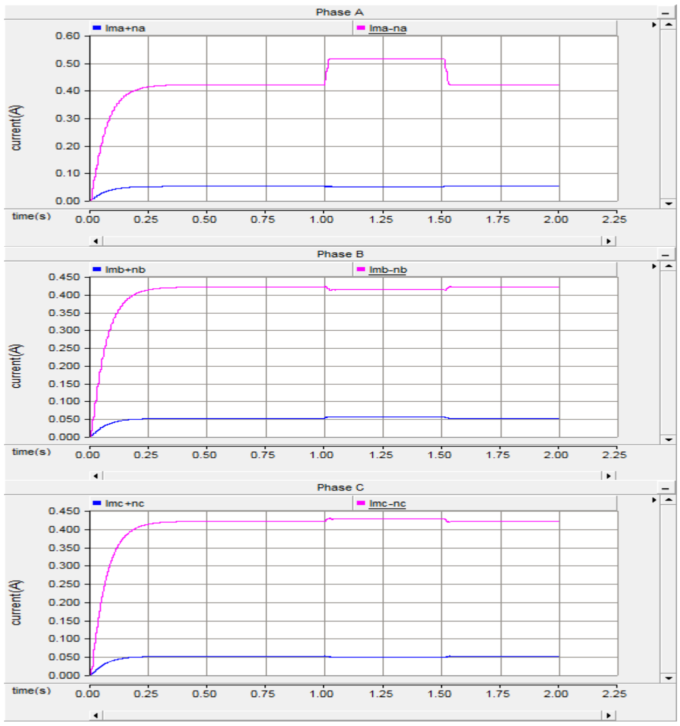

Fig. 8. Protection with reduced capacitive current when external L-G fault (R_{fault}=50 Ω) occurs at position F5.

IV. CONCLUSION

Due to presence of distributed capacitance, the capacitance current always exists on extra high voltage and ultra high voltage lines which affect the operation of current differential protection during internal and external faults. Thus the sensitivity and selectivity of current differential protection becomes low. Hence in order to eliminate the adverse influences of distributive capacitive current from line, its compensation is necessary.

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