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Current Differential Protection for Distributed Transmission Lines using Low Sampling Frequency

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Abstract**—** Current differential protection has been affected negatively by the distributed capacitive current of transmission lines. In order to solve the problem of distributed capacitance current of transmission line, the current differential protection in this paper is based on distributed parameters model of the transmission line. The current formula along with the transmission line is derived under this distributed parameter line model. The differential criterion is constructed with the current calculated from both ends to the set point. In order to improve the practicality of the criterion, the implementation of the differential protection is given under low sampling frequency. By adding a cubic spline data interpolation point at each sampling interval, the calculation of the set point distributed current under low sampling frequency is achieved. In order to improve the operating speed of current differential protection, the point is set at the midpoint of the line, and the magnitude of the current is calculated with a half data window absolute value integrals. The results show that the proposed novel current differential principle is not affected by the distributed capacitance current. It has obvious advantages compared with traditional current differential protection principle for the low sampling frequency requirement, fast action speed and the small amount of computation.

Keywords**—** current differential protection, distributed capacitance, distributed parameter, low sampling frequency

I. INTRODUCTION

Current differential protection has been widely used in power transmission lines, due to its higher sensitivity, simplicity and exceptional ability of phase selection in faults and abnormal circumstances. By taking it under consideration more precisely, it will be concluded that for current differential protection, digital communication channel has problems that has been solved by fiber optic technologies [1]. However, the distributive capacitance current affects the sensitivity and reliability of current differential protection while working on Extra/Ultra high voltage lines (EHV&UHV) as verified by [2]. As the voltage level rises and length of the transmission line increases, the circumstances acquire more solemn [3]. The study of current differential protection depicts that it remains unaffected by capacitance current while low sampling frequency is particularly important.

Nowadays, the undesirable influences of distributive capacitance are eliminated by using the phasor-based compensation algorithm [2], [4–5]. These techniques usually work on steady components rather of transient components if taking under consideration. During fault transient, response of the conventional current differential protection is not desirable. In a novel method to compensate the transient distributed capacitive current has the discrepancy of extra calculation based on the transmission parameters so more accurate results cannot be concluded while conversely, the conventional current phasor differential protection cannot operate rapidly, as during fault transient, phasor cannot easily be calculated in more accurate manners according to the report referenced as [6].

Bergeron method which deals theoretically with the impact of capacitance current explained as a faultless model. It requires high sampling frequency and cannot eliminate the shunt reactor current of transmission line, when considering practical terms and conditions; the Bergeron method has serious limitations [7]. Sampled values differential protection operates rapidly; however, the harmonic components impacts differential protection by means of sampled value that results in deteriorating the reliability of protection device practically [8-9].

In addition, the distributed capacitive current cannot affect the swift process of the traveling-wave current differential protection theoretically. While in practical manners the steadfastness of current differential protection relying on travelling wave is a major setback as travelling wave signal is much receptive to interruption [10]. However, long distance EHV and UHV transmission lines are needed to study novel principles with high sensitivity and reliability.

In this present work, we have reported the current differential protection for distributed transmission lines using low sampling frequency. When the external fault occurs, the differential current of the proposed current differential protection is much smaller than the braking current and the

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protection cannot act reliably. When the internal fault occurs, the differential current is much larger than the braking current therefore the protection can act sensitively. The effectiveness of the novel principle is verified based on PSCAD modeling and simulation. Theoretical performance analysis and PSCAD simulation results express that this novel principle has the following advantages. Firstly, its performance is not influenced to the distributed capacitive current. Secondly, transmission line is based on distributed parameter model with low sampling frequency, novel principle fully work on transient and steady states components. More-over this principle also acquires fast operation, reliable and high sensitivity and selectivity.

II. PRINCIPLE OF CURRENT DIFFERENTIAL PROTECTION

The main idea behind this paper is to immune the distributed capacitance current on EHV and UHV transmission lines. For this purpose, current differential protection for distributed transmission lines has been attained using low sampling frequency, as it has been worked on previously in distributed parameter model and not much preferred due to its erroneous outcome, so applied with time-domain algorithm on low sampling frequency for getting further accuracy, as low sampling frequency can be implemented swiftly on time-domain algorithm.

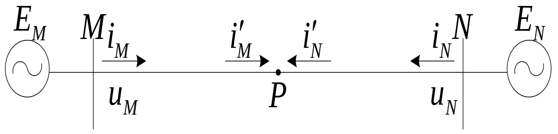

Fig. 1 Distributed transmission line model

In case of distributed transmission line model, kirchhoff's current law (KCL) doesn't executes, therefore in order to realize the sum of entering and leaving currents in distributed transmission i.e. KCL, a setting point is required to prove the presence of kirchhoff's current law. In the Fig. 1 a distributed transmission line model is depicted, where a point P is set for achieving the desired result of the implementation of KCL on the transmission line.

Actually, transmission lines have its conductance very small that can be neglected. For this reason, resistance, capacitance and inductance become essential for transmission line. Presume that R, L and C are resistance, inductance and capacitance of per unit length respectively. The calculation of current along the line through time-domain algorithm as given below: [11]

$$\begin{aligned} i'_M(x,t) = {} & \frac{1}{2Z}\left(\frac{Z + R.x/4}{Z}\right)[u_M(t + x/v) - i_M(t + x/v)\cdot(Z + R.x/4)] - \\ & \frac{1}{2Z}\left(\frac{Z - R.x/4}{Z}\right)[u_M(t - x/v) + i_M(t - x/v)\cdot(Z - R.x/4)] - \\ & \frac{1}{2Z}\cdot\frac{R.x}{2Z}[u_M(t) - i_M(t)\cdot(R.x/4)] \end{aligned} \tag{1}$$

$$\begin{aligned} i'_N(l-x,t) = {} & \frac{1}{2Z}\left(\frac{Z + R.(l-x)/4}{Z}\right)[u_N(t + (l-x)/v) - i_N(t + (l-x)/v)\cdot(Z + R.(l-x)/4)] - \\ & \frac{1}{2Z}\left(\frac{Z - R.(l-x)/4}{Z}\right)[u_N(t - (l-x)/v) + i_N(t - (l-x)/v)\cdot(Z - R.(l-x)/4)] - \\ & \frac{1}{2Z}\cdot\frac{R.(l-x)}{2Z}[u_N(t) - i_N(t)\cdot(R.(l-x)/4)] \end{aligned} \tag{2}$$

Where u_M, u_N, i_M and i_N are the voltages and currents of two terminals respectively as shown in Fig. 1, x is the distance from M terminal to P, $(l - x)$ is the distance from N terminal to P, t is the time, v is the propagation velocity which is equal to $v = 1/\sqrt{LC}$ and $Z = \sqrt{L/C}$. By applying time-domain algorithm and using these values, the extracted results will be standards of i'_M and i'_N.

To calculate these currents i'_M and i'_N by using (1) and (2), high frequency sampling must be used to get enough points, which is defect of time-domain algorithm. For solving this problem, cubic spline data interpolation has been used to achieve the same affect with low sampling frequency in this proposed paper. In this condition, current differential protection works very well, as i_M and i_N currents have not been used and in place of these currents, i'_M and i'_N currents data are used to operate the current differential protection.

In normal condition of the transmission system or due to an external fault, overlooking capacitance current, it is concluded that phases are reverse and magnitude is equivalent, whenever two ends currents are taken into description due to which the differential current is zero. Relay's sensitivity and reliability is directly affected by differential current that is same as capacitance current, whenever, capacitance current is taken under contemplation.

By using cubic spline data interpolation method, current has been evaluated. The current has a suitable number of sampling points in it. Afterwards, this data has been integrated. It is due to the reason that discrete points in time domain cannot be compared. The process of FFT can also be used for comparing the discrete points instead of the integration process, but FFT method requires huge computation procedure for extracting results, this makes the system response relatively slower. Therefore, integration method has been preferred. It has been done for taking the response of the system rapidly and in accurate manners.

For a Sine wave, if integration method is taken as (3) where half cycle window is used only, if the integration coefficient is pi/2, we have the integration result equal to amplitude of the sine wave.

$$\int_0^{\pi} \left|\sin\theta\right| d\theta = \frac{2}{\pi} \tag{3}$$

This means that integration coefficient is pi/2, half cycle data window is used. Thus the amplitudes of $i'_M + i'_N$ and $i'_M - i'_N$ can be obtained as (4) and (5), if we want the integration results have relationship with the true value.

$$I_{M+N} = \frac{\pi}{2}\int_{t_1}^{t_1+\frac{T_0}{2}} \left|i'_M + i'_N\right| dt \tag{4}$$

$$I_{M-N} = \frac{\pi}{2}\int_{t_1}^{t_1+\frac{T_0}{2}} \left|i'_M - i'_N\right| dt \tag{5}$$

In discrete domain, the (4) and (5) can be written as (6) and (7) respectively:

$$I_{M+N} = \frac{\pi T_s}{2} \sum \left| i'_M + i'_N \right| \tag{6}$$

$$I_{M-N} = \frac{\pi T_s}{2} \sum \left| i'_M - i'_N \right| \tag{7}$$

The equations given below express criterions of current differential protection as: [2]

$$I_{M+N} > I_{set} \tag{8}$$

$$I_{M+N} > K I_{M-N} \tag{9}$$

Where:

I_{set} is the threshold of stalling current and K is stalling coefficient $(0 < K < 1)$, having value equivalent to 0.5. In the criterion, half window has been used shown as $T_0/2$ for integration. When the line has no load, for preventing false method, secondary trip criterion is used, as given in (8), whenever an internal fault occurs in the line, this criterion consider it as an error, whereas major criterion is used in (9), when both criterions hold, differential relay could be tripped rapidly.

The distributed capacitance current is correlated to the sensitivity of differential protection. Capacitance current settles the setting I_{set} in the secondary criterion. The capacitance current may be very massive for the transmission lines having high concentration of voltage and long length. The protection sensitivity will get worse as I_{set} would be increased. Furthermore, the stalling coefficient K is correlated to the sensitivity of differential protection. For small valve of K, sensitivity would be higher. Low sampling frequency makes the protection very rapid.

Fig. 2 External fault on distributed transmission line model

Whenever, on distributed transmission lines, an external fault or normal fault occurs, in this circumstance, E_M and E_N are two sources, as shown in Fig. 2. The criterion would be $I_{M+N} = 0$ and $I_{M-N} = 2I_F$, under this circumstance, current differential relay would not trip.

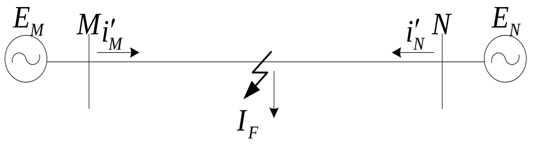

Fig. 3 Internal fault on distributed transmission line model

Internal fault, whenever occurs on distributed transmission line model as shown in Fig. 3, then $i'_N \neq 0$. So criterion I_{M-N} would be very small and $I_{M+N} = I_F$, current differential relay will be trip rapidly.

III. SIMULATION AND DISCUSSION

Fig. 4 shows a two-sources system with three phase 220kV voltage, 50Hz frequency, and the length of the distributed parameter transmission line is 400km. The transmission line has per unit length parameters, those are listed as follows:

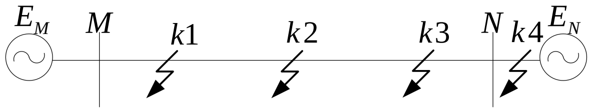

Fig. 4 Model of the transmission system

The positive sequence parameters are $R_1 = 0.01958\Omega / km$, $L_1 = 0.8197mH / km$ and $C_1 = 0.0135\mu F / km$ whereas zero sequence parameters are $R_0 = 0.2909\Omega / km$, $L_0 = 2.7420mH / km$ and $C_0 = 0.0092\mu F / km$. The system impedances of terminal M and N are $Z_{m1} = 0.1736 + j0.9848\Omega$, $Z_{m0} = 0.6424 + j3.6437\Omega$, $Z_{n1} = 0.1736 + j0.9848\Omega$ and $Z_{n0} = 0.6424 + j3.6437\Omega$.

As illustrated in Fig. 4, k1 and k2 are at near terminal M at the start of the line and at the center of the line respectively, while k3 has been positioned at end of the line whereas k4 is beyond the line at the negative direction of bus N. In order to authenticate the protection criterion, diverse range of faults with or without resistance is simulated at these four points. For getting the fault statistics in simulation, a 10ms-long data window, sampling frequency is 2 kHz has been used and Table I shows comparison of differential current and stalling current in novel principle and Table II shows the comparison of differential current and stalling current in traditional principle, when an AG fault occurs at k2, k3 and k4 respectively.

TABLE I. COMPARISON OF DIFFERENTIAL CURRENT AND STALLING CURRENT IN NOVEL PRINCIPLE

Fault Place	Fault R (Ω)	Novel Principle					
		A		B		C	
		I_{M+N}	I_{M-N}	I_{M+N}	I_{M-N}	I_{M+N}	I_{M-N}
k2	0	3.6689	0.8898	0.0483	0.8898	0.0288	0.8899
	100	1.4834	0.8898	0.0251	0.8898	0.0433	0.8899
	150	1.0684	0.8898	0.0280	0.8898	0.0427	0.8899
k3	0	169.04	83.517	0.0458	0.5038	0.0509	1.0725
	100	1.7552	0.2980	0.0390	0.8894	0.0387	0.8930
	150	1.1746	0.3973	0.0389	0.8895	0.0388	0.8918
k4	0	0.0095	1.1750	0.0460	0.5041	0.0505	1.0728
	100	0.0385	0.9017	0.0388	0.8898	0.0386	0.8933
	150	0.0385	0.8977	0.0388	0.8898	0.0386	0.8922

As it is exemplified in Table I that novel principle is immune the distributed capacitive current whereas in traditional principle in Table II due to comparatively larger value of distributive capacitive current; system can be affected or it can be tripped while in novel principle, distributive capacitive current cannot affect the phases B and C. Therefore novel principle is much more sensitive as compared to traditional principle at location k2 and k3.

TABLE II. COMPARISON OF DIFFERENTIAL CURRENT AND STALLING CURRENT IN TRADITIONAL PRINCIPLE

Fault Place	Fault R (Ω)	Traditional Principle					
		A		B		C	
		I_{M+N}	I_{M-N}	I_{M+N}	I_{M-N}	I_{M+N}	I_{M-N}
k2	0	3.4529	0.8705	0.3113	0.8705	0.3294	0.8717
	100	1.4185	0.8705	0.3141	0.8705	0.2975	0.8717
	150	1.0426	0.8705	0.3104	0.8705	0.2964	0.8717
k3	0	178.26	88.179	0.2943	0.4439	0.2888	1.0926
	100	1.7378	0.3015	0.2988	0.8703	0.2986	0.8749
	150	1.1579	0.3719	0.2989	0.8702	0.2985	0.8737
k4	0	0.1670	1.1841	0.2943	0.4442	0.2891	1.0929
	100	0.2987	0.8818	0.2990	0.8706	0.2987	0.8752
	150	0.2989	0.8781	0.2991	0.8706	0.2987	0.8741

Similarly considering location k4 which is an external fault, it is shown that distributive capacitive current will be almost negligible in novel principle as compared to the distributive capacitive current in traditional principle, when we see the Tables I and Table II, so the relatively higher distributive capacitive current can affect the relay to get trip, which again shows that novel principle is much more reliable and competent as compared to traditional principle.

TABLE III. COMPARISON OF DIFFERENTIAL CURRENT AND STALLING CURRENT IN NOVEL PRINCIPLE

Fault Place	Fault Type	Novel Principle					
		A		B		C	
		I_{M+N}	I_{M-N}	I_{M+N}	I_{M-N}	I_{M+N}	I_{M-N}
k1	AG	159.66	78.934	0.0512	1.2027	0.0454	0.7316
	BC	0.0385	0.8901	156.19	77.188	156.21	76.349
	BCG	0.0540	1.0978	154.52	76.059	182.22	89.709
	ABC	168.84	83.181	177.26	87.219	178.42	87.668
k2	AG	3.6689	0.8898	0.0483	0.8898	0.0288	0.8899
	BC	0.0386	0.8898	6.0701	0.8898	6.0704	0.8899
	BCG	0.0143	0.8898	6.5128	0.8898	5.8798	0.8899
	ABC	6.1934	0.8898	6.3329	0.8898	7.1197	0.8899
k3	AG	169.04	83.517	0.0458	0.5038	0.0509	1.0725
	BC	0.0388	0.8895	153.72	75.006	153.72	75.888
	BCG	0.0540	0.4753	137.86	67.750	196.85	97.066
	ABC	173.26	85.156	170.13	83.638	180.79	88.711
k4	AG	0.0095	1.1750	0.0460	0.5041	0.0505	1.0728
	BC	0.0386	0.8898	0.0334	1.9536	0.0377	1.0945
	BCG	0.0539	0.4756	0.0345	1.6975	0.0300	1.4504
	ABC	0.0202	1.5500	0.0321	1.5966	0.0334	1.7844

As compare in Table III and Table IV, distributed capacitance current in traditional principle is larger to novel principle, when AG, BC, BCG and ABC fault occurs at k1, k2, k3, and k4 respectively. So it can be concluded that novel principle much more sensitive and reliable compared to traditional principle.

TABLE IV. COMPARISON OF DIFFERENTIAL CURRENT AND STALLING CURRENT IN TRADITIONAL PRINCIPLE

Fault Place	Fault Type	Traditional Principle					
		A		B		C	
		I_{M+N}	I_{M-N}	I_{M+N}	I_{M-N}	I_{M+N}	I_{M-N}
k1	AG	168.01	83.127	0.2923	1.2202	0.2962	0.6870
	BC	0.2994	0.8709	161.48	79.871	161.35	79.057
	BCG	0.2892	1.1301	155.64	76.662	192.37	94.774
	ABC	175.20	86.443	182.16	89.778	185.31	91.186
k2	AG	3.4529	0.8705	0.3113	0.8705	0.3294	0.8717
	BC	0.2993	0.8705	5.9982	0.8705	6.0009	0.8717
	BCG	0.3271	0.8705	6.4384	0.8705	5.7730	0.8717
	ABC	6.2399	0.8705	6.2010	0.8705	7.1307	0.8717
k3	AG	178.26	88.179	0.2943	0.4439	0.2888	1.0926
	BC	0.2991	0.8702	158.01	77.229	158.02	78.095
	BCG	0.2843	0.4593	147.05	72.582	207.33	102.37
	ABC	180.09	88.664	175.81	86.625	186.87	91.831
k4	AG	0.1670	1.1841	0.2943	0.4442	0.2891	1.0929
	BC	0.2992	0.8705	0.2182	1.9159	0.2356	1.0759
	BCG	0.2844	0.4595	0.1982	1.6468	0.1915	1.4341
	ABC	0.1530	1.5616	0.1949	1.5351	0.1841	1.7768

As shown in Fig. 5 to Fig. 6, when external faults occur in a transmission line or the line is in ordinary situation, after compensation the differential current is approximately zero, though as compared to traditional principle the sensitivity is improved as the threshold value can be set slighter. Additionally in case of external faults, the differential current is far slighter as compared to stalling current, the novel principle does not trip but the traditional principle might trip.

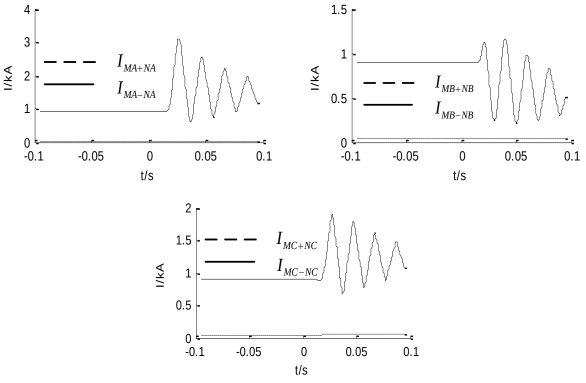

Fig. 5 Novel principle when external AG fault occurs at k4

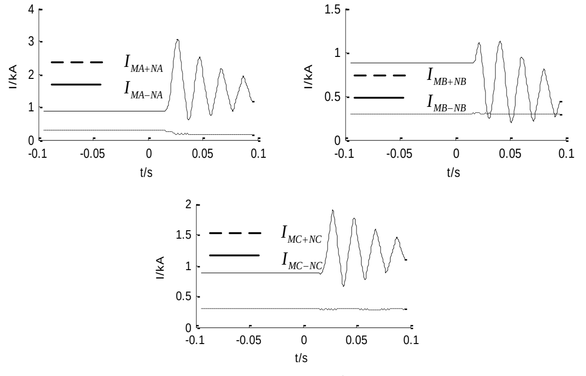

Fig. 6 Traditional principle when external AG fault occurs at k4

When external fault AG (RF=150Ω) occurs in the transmission line as shown in Fig. 7, then in novel principle, the distributive capacitive current is approximately zero after compensation. However, if traditional principle is taken under consideration, as shown in Fig. 8, the distributive capacitive current in that case is comparatively larger than in novel principle. The results depicts that the protection in traditional principle might trip due to distributive capacitive current but in novel principle will not be tripped due to zero distributive capacitive current in it. So, by taking such results under deliberation, it is concluded that novel principle is more sensitive and more reliable as compared to traditional principle.

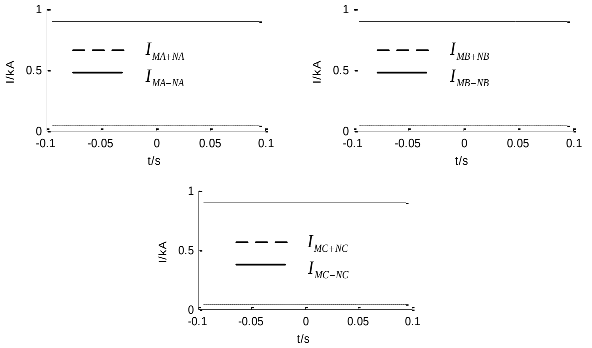

Fig. 7 Novel principle when external AG fault (RF=150 Ω) occurs at k4

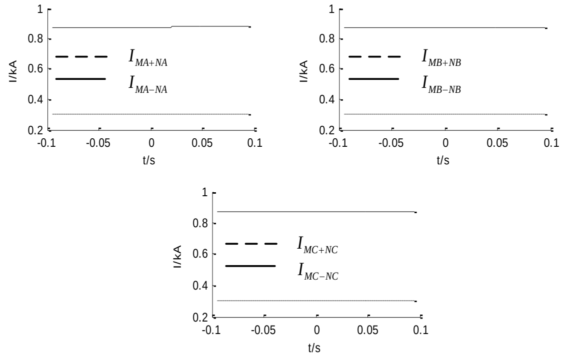

Fig. 8 Traditional principle when external AG fault (RF=150 Ω) occurs at k4

As shown in Fig. 9, when internal fault AG (phase-to-ground) occurs at location k2, current differential protection would rapidly work and trip the phase A, but in phase B and C, the differential current is approximately zero after compensation. Whereas in Fig. 10, phase B and C is might trip due to large distributive capacitive current. In the method described in this paper, more immunity to distributed capacitive current, which makes it more sensitive as compared to traditional principle.

Fig. 11 verifies, when an internal fault BC (RF=150Ω) occurs on the transmission line, the stalling current is much smaller than the differential current and the protection trip appropriately the phase B and C but phase A has approximately zero differential current after compensation. However, phase A might trip due to large capacitive current as shown in Fig. 12.

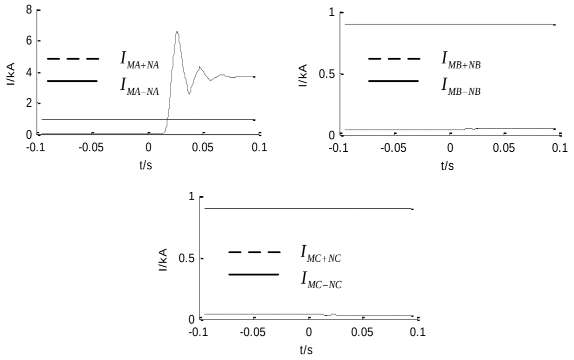

Fig. 9 Novel principle when internal AG fault occurs at k2

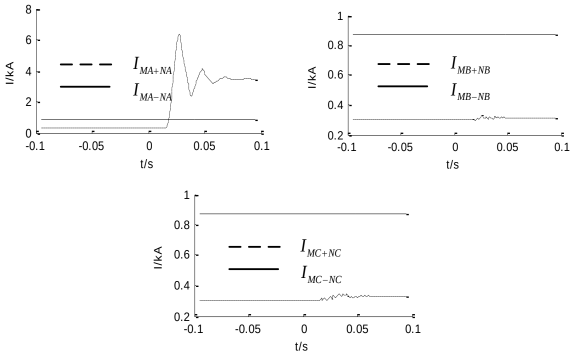

Fig. 10 Traditional principle when internal AG fault occurs at k2

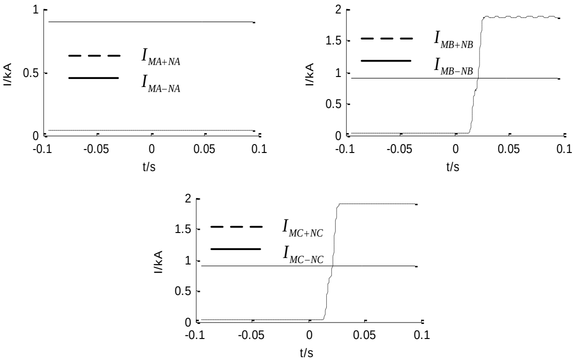

Fig. 11 Novel principle when internal BC fault (RF=150 Ω) occurs at k2

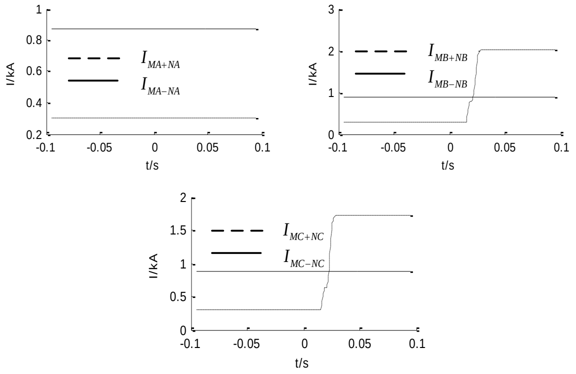

Fig. 12 Traditional principle when internal BC fault (RF=150 Ω) occurs at k2

IV. CONCLUSION

In this paper, current differential protection for distributed transmission lines using low sampling frequency is anticipated.

As demonstrated in the theoretical analysis and PSCAD simulation results, the following conclusions drawn are as below:

1) The capacitance current on extra high voltage and ultra high voltage transmission lines is very massive and the distributed capacitive current compensation is compulsory for the relay operate appropriately. For this purpose, current differential protection for distributed transmission lines has been accomplished with low sampling frequency, as low sampling frequency has been promptly executed on time-domain algorithm.

2) The novel principle has more reliable, fast operation speed and high sensitivity and selectivity for protections of EHV and UHV transmission lines as compared to traditional principle and also entirely works on transient and steady states, its performance is not being influenced by the distributed capacitive current.

Further research must be continued in classify to put the protection principle into practice and high performance, rapid response and appropriate stability is expected.

REFERENCES

[1] McMurdo, J. N., and G. C. Weller. "Applications of digital differential protection." Developments in Power System Protection, 1993., Fifth International Conference on. IET, 1993.

[2] Bi, T. S., Y. L. Yu, S. F. Huang, and Q. X. Yang. "An accurate compensation method of distributed capacitance current in differential protection of UHV transmission line." In Power Engineering Society General Meeting, 2005. IEEE, pp. 770-774. IEEE, 2005.

[3] Yan, L. I., De_shu, C. H. E. N., Zhang, Z., & Xiang_gen, Y. I. N. (2001). The emulation analysis for the influence of capacitance current of UHV transmission line on differential current protection and compensating countermeasure [J]. Relay, 29(6), 6-9.

[4] Yekai, Wu, and Zou Dongxia. "The Influence of Capacitance Current to differential Protection and Its Compensation Scheme [J]." Relay 25, no. 4 (1997): 4-8.

[5] Xinzhou, Dong, Shu Bin, Bo Zhiqian, and He Jiali. "Study of special problems on protective relaying of UHV transmission line." Automation of Electric Power Systems 28, no. 22 (2004): 19-22.

[6] Yining, Zhang, and Suonan Jiale. "Phaselet-based current differential protection scheme based on transient capacitive current compensation." Generation, Transmission & Distribution, IET 2.4 (2008): 469-477.

[7] Jiale, Suonan, Zhang Yining, Qi Jun, and Jiao Zaibin. "Current Differential Protection Based on Time-Domain Algorithm of Capacitive Current Compensating." JOURNAL-XIAN JIAOTONG UNIVERSITY 39, no. 12 (2005): 1370.

[8] Yang, J. C., X. G. Yin, D. S. Chen, Z. Zhang, and Z. H. Wang. "The study of sampled value differential protection." In Transmission and Distribution Conference and Exposition, 2003 IEEE PES, vol. 1, pp. 256-261. IEEE, 2003.

[9] Jingchao, Yang, Yin Xianggen, Chen Deshu, and Zhang Ze. "Study on the operating characteristic of sampled value differential protection." In Electrical and Computer Engineering, 2003. IEEE CCECE 2003. Canadian Conference on, vol. 1, pp. 335-338. IEEE, 2003.

[10] Dommel, H. W., and J. M. Michels. "High-speed relaying using traveling wave transient analysis." In IEEE TRANSACTIONS ON POWER APPARATUS AND SYSTEMS, vol. 97, no. 4, pp. 1011-1011. 345 E 47TH ST, NEW YORK, NY 10017-2394: IEEE-INST ELECTRICAL ELECTRONICS ENGINEERS INC, 1978.

[11] Song, Guobing, Jiale Suonan, Qingqiang Xu, Ping Chen, and Yaozhong Ge. "Parallel transmission lines fault location algorithm based on differential component net." Power Delivery, IEEE Transactions on 20, no. 4 (2005): 2396-2406.

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