International Journal of Engineering Works
Kambohwell Publisher Enterprises
ISSN: 2409-2770 Vol. 2, Issue 4, PP. 48-53, April, 2015
www.kwpublisher.com

A Novel Principle of Current Differential Protection for UHV and EHV Transmission Lines Based on Distributed Parameters Line Model

M. Arshad Shehzad Hassan, Guobing Song, Xiaoning Kang, Zaibin Jiao, Sohaib Tahir, Nouman Faiz

***Abstract*—** Distributed capacitive current of ultra high voltage and extra high voltage (UHV&EHV) transmission lines has a severe negative effect on current differential protection. The current differential protection in this proposed paper is based on distributed parameters line model of the transmission line and has been used to solve the problem of distributive capacitive current of transmission line. Time-domain algorithm has been used to calculate currents at the set point of the line by using both ends current. By adding linear interpolation with low computational rate at each sampling points has been achieved. The theoretical analysis of this method is broach to demonstrate how the novel principle is of high sensitivity in differentiating between the external and the internal faults of the line. After theoretical analysis and applying the pristine novel principle of current differential protection for UHV and EHV transmission lines based on distributed parameters line model, the simulation results illustrates that the analysis done in this paper is quite appropriate as desired, correspondingly this recently acquired principle is much reliable, compared to the traditional principle.

***Keywords*—** current differential protection, ultra high voltage and extra high voltage, capacitive current, linear interpolation, distributed parameters line model

I. INTRODUCTION

Reliable protection and high speed are the factors that improve the security, stability and efficiency of modern electric power system. Current differential protection has been used on a large scale for UHV and EHV transmission lines due to the reason that it has absolute selectivity, high sensitivity, and unfussiness. As the modern electric power industry is progressing, meanwhile the voltage level and the length of transmission line increases. Distributed capacitive current cannot be ignored in long-distance and UHV transmission lines especially in fault transient process, due to its strength; the effects of distributive capacitive current on current differential protection must be taken under consideration [1].

Consequently numerous principles have been introduced into current differential protection studies [2-3] and several most up-to-date devices have been established for performing the practical operations [4-5]. So far the selectivity and sensitivity of the current differential protection has been affected mostly by the distributive capacitive current. Shunt reactor has connected to line for limiting the self excitation on UHV and EHV long distance transmission lines and line frequency over voltage and it operates under compensation mode to compensate the distributive capacitive current. This shunt reactor is invalid to transient capacitive current but somewhat compensate the power frequency and steady state current. The current differential protection may not be operated properly by using even the shunt reactor, when the faults are afar the protected zone.

In order to eliminate the adverse influences of the distributive capacitive current from line frequency capacitive current compensation, phasor based compensation algorithm [6] is widely used method nowadays. Initially when fault incepts on a single ended line, during its switching on or without load condition, usually the transient capacitive current becomes higher than steady capacitive current, so transient capacitive current cannot be compensated by phasor compensation algorithm that is based on the current differential protection schemes, and so setback in order to avoid the manipulation of transient capacitive current, therefore it cannot access the swift obligation of relay protection in electric power system [7]. The procedure mentioned in [8] differential equation model for the compensation of the instantaneous value can reduce the amount of steady state current and the transient distributed capacitive current. Capacitive current cannot be eliminated properly but reduced to a suitable extent for time domain compensation because of the limit in the order of differential equations.

Bergeron method for dealing theoretically with impact of capacitance current is mentioned in [9]. As in this case the shunt reactor current of transmission line cannot be overcome properly and also very high sampling frequency is used, therefore, it has limitations in practical working. In addition, distributed capacitive current has been solved by using model identification based on integrated impedance according to report references [10-11]. However, it's greatly affected by

---

This work is supported by National Natural Science Foundation of China through grants No. 51037005, 51177127 and National Basic Research Program of China (973 Program) (2012CB215105).

M. Arshad Shehzad Hassan, Xi'an Jiaotong University, Xi'an, China, Email: arxhad@yahoo.com, Tel: +92-0344-7306780
Guobing Song, Xi'an Jiaotong University, Xi'an, China, Email: song.gb@mail.xjtu.edu.cn, Tel: +86-13572131892
Xiaoning Kang, Xi'an Jiaotong University, Xi'an, China, Email: kangxn@mail.xjtu.edu.cn, Tel: +86-13519195338
Zaibin Jiao, Xi'an Jiaotong University, Xi'an, China, Email: jiaozaibin@mail.xjtu.edu.cn, Tel: +86-13572881504
Sohaib Tahir, Xi'an Jiaotong University, Xi'an, China, Email: sohaibchauhdary@gmail.com, Tel: +92-0332-6699333
Nouman Faiz, COMSATS Institute Of Information Technology , Islamabad, Pakistan, Email: engr.noumanfaiz@gmail.com, Tel: +92-0334- 7076102

transient component because using the extraction of the fundamental frequency component and PI model, the sensitivity and reliability of the system reduced.

In this present paper, a novel principle of current differential protection for ultra high voltage and extra high voltage transmission lines based on distributed parameters line model is proposed. This proposed novel principle eliminates the impact of distributive capacitive current on long distance transmission lines using time-domain algorithm with low computational rate. Theoretical analysis and PSCAD based simulation results shows that novel principle fully works on external and internal faults, and also has high sensitivity and reliability with and without fault resistance.

II. NOVEL PRINCIPLE OF CURRENT DIFFERENTIAL PROTECTION

Taking into account the contradiction between the distribution characteristics of transmission line parameters and the applicable conditions of Kirchhoff's current law (KCL) in the traditional current differential protection, a kind of current differential protection principle un-affected by distributed capacitance current is put forward in this paper. Time-domain algorithm with linear data interpolation improves the sensitivity and reliability of differential current protection during steady state component and transient component.

Current differential protection is used for comparison between the entering and leaving currents of a zone. If these current are summed up and net result of the entering and leaving currents in a zone are equal to zero, then it shows that the system is accurate and errorless. On the other hand, if summing up of these entering and leaving currents is not resulted as zero, then it depicts that there is an error in the protection zone of the system.

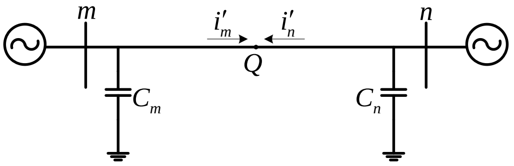

Fig. 1 Model of distributed transmission system

The model of distributed transmission system is shown in Fig. 1, where m and n are the two ends terminal interlinked with the voltage sources, Q is the set point for achieving the preferred result of the execution of KCL. In this case, the direction of two currents i'_m and i'_n has opposite directions as shown in the distributed transmission system in Fig. 1 on point Q. In this case C_m and C_n are capacitances on terminal m and n. In order to calculate the values of i'_m and i'_n, the calculation of time-domain algorithm is explicated below [12].

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

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

Where x is the distance from terminal m to Q, t is the time, and v is the propagation velocity having value equivalent to $v = 1/\sqrt{LC}$, While u_m and i_m are voltage and current of terminal m. $l - x$ is the distance from n to Q, u_n, i_n is the voltage and current of terminal n and $Z = \sqrt{L/C}$ (L is the length and C is the capacitance of the transmission line respectively). Whenever the transmission system shows normal state or when it faces external faults, negligence capacitance current, and the magnitude of the two ends currents remain equal but the phases remain opposite. That's why the differential current is zero. Having considered the capacitance current of the transmission line, that is the direct casting affect on relay's sensitivity and reliability. High computational rate is used to get more points by using equations (1) and (2) to calculate i'_m and i'_n, however time-domain algorithm is defect by high computational rate. Therefore, sensitivity and reliability of the current differential protection is decreased. In order to solve this problem linear interpolation has been used for getting enough points with low computational rate, which is not defect of time-domain algorithm. After getting enough points by using linear interpolation, integration method has been used for comparing data [13].

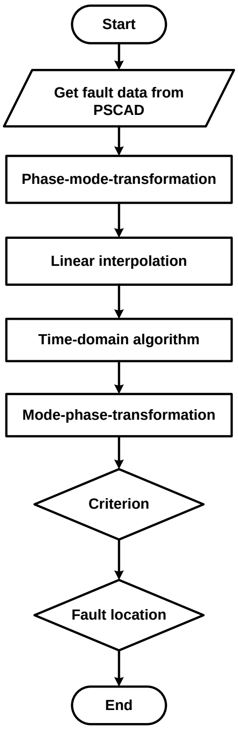

Fig. 2 Program flowchart of current differential protection for long-distance transmission line

A criterions equation (3) and (4) of current differential protection as given below: [6]

$$I_{m+n} > I_{set} \tag{3}$$

$$I_{m+n} > KI_{m-n} \tag{4}$$

Where I_{m+n} are differential current, I_{set} is threshold breaking current, K is stalling coefficient and its value is 0.5. The program flowchart of current differential protection for long-distance transmission lines is shown in Fig. 2.

III. SIMULATION AND RESULT DISCUSSION

To verify the usefulness of the expressed method, a three phase 440kV voltage of two machine system based on distributed parameters line model is built as shown in Fig. 3. 50Hz normal frequency and the length of the transmission system of 400km are utilized for simulation. PSCAD has been used to simulate different external or normal and internal faults. Sampling rate is employed at 2 KHz and MATLAB is implemented for protection design, accompanied by 10ms-long data window.

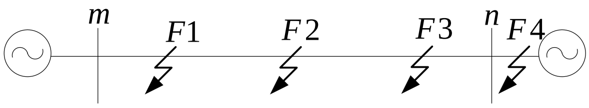

Fig. 3 Simulation model

The parameters of the transmission line are listed as follows:

Positive-sequence parameters:

- Resistance: $r_1 = 0.01958\Omega / km$
- Inductance: $l_1 = 0.8197 mH / km$
- Capacitance: $c_1 = 0.0135 \mu F / km$
- Impedance at terminal m : $z_{m1} = 0.1736 + j0.9848\Omega$
- Impedance at terminal n : $z_{n1} = 0.1736 + j0.9848\Omega$

Zero -sequence parameters:

- Resistance: $r_0 = 0.2909\Omega / km$
- Inductance: $l_0 = 2.7420 mH / km$
- Capacitance: $c_0 = 0.0092 \mu F / km$
- Impedance at terminal m : $z_{m0} = 0.6424 + j3.6437\Omega$
- Impedance at terminal n : $z_{n0} = 0.6424 + j3.6437\Omega$

Table I expressed that novel protection is unaffected by capacitive current after compensation, when an internal AG (phase-to-ground) fault occurs at F2 and F3, while phase B and C might be trip due to large capacitive current of the transmission lines in traditional protection as shown in Table II. Similarly, when an external fault or normal fault occurs at F4, Table I shows that capacitive current in novel protection is almost negligible after compensation but in traditional protection, distributive current is very massive as verified by Table II, so it is concluded that traditional protection has affected by capacitive current as compared to novel protection. In addition, novel protection is more reliable and sensitive as compared to traditional differential protection.

TABLE I. CAPACITIVE CURRENT IN NOVEL PROTECTION

Fault Position	R_{fault} (Ω)	Novel Protection					
		Phase A		Phase B		Phase C	
		I_{m+n}	I_{m-n}	I_{m+n}	I_{m-n}	I_{m+n}	I_{m-n}
F2	0	7.3235	1.7762	0.0964	1.7762	0.0575	1.7764
	50	4.6127	1.7762	0.0492	1.7762	0.0854	1.7764
	100	2.9611	1.7762	0.0501	1.7762	0.0865	1.7764
	150	2.1326	1.7762	0.0560	1.7762	0.0852	1.7764
F3	0	337.41	166.70	0.0913	1.0058	0.1015	2.1404
	50	6.9729	1.8585	0.0781	1.7752	0.0772	1.7892
	100	3.5037	0.5948	0.0778	1.7754	0.0773	1.7824
	150	2.3446	0.7931	0.0777	1.7755	0.0774	1.7802
F4	0	0.0188	2.3446	0.0917	1.0064	0.1007	2.1410
	50	0.0766	1.8233	0.0778	1.7759	0.0768	1.7899
	100	0.0769	1.7999	0.0775	1.7761	0.0770	1.7831
	150	0.0769	1.7920	0.0774	1.7762	0.0770	1.7809

TABLE II. CAPACITIVE CURRENT IN TRADITIONAL PROTECTION

Fault Position	R_{fault} (Ω)	Traditional Protection					
		Phase A		Phase B		Phase C	
		I_{m+n}	I_{m-n}	I_{m+n}	I_{m-n}	I_{m+n}	I_{m-n}
F2	0	6.9059	1.7410	0.6227	1.7410	0.6588	1.7434
	50	4.3601	1.7410	0.6384	1.7410	0.6069	1.7434
	100	2.8369	1.7410	0.6282	1.7410	0.5950	1.7434
	150	2.0853	1.7410	0.6208	1.7410	0.5928	1.7434
F3	0	356.53	176.35	0.5886	0.8878	0.5776	2.1851
	50	7.0341	1.9876	0.5973	1.7407	0.5974	1.7569
	100	3.4755	0.6029	0.5977	1.7406	0.5971	1.7498
	150	2.3157	0.7437	0.5978	1.7405	0.5971	1.7474
F4	0	0.3340	2.3682	0.5887	0.8884	0.5782	2.1858
	50	0.5964	1.7860	0.5977	1.7414	0.5977	1.7576
	100	0.5975	1.7637	0.5981	1.7413	0.5975	1.7505
	150	0.5978	1.7562	0.5982	1.7412	0.5974	1.7481

TABLE III. NOVEL PROTECTION WHEN EXTERNAL AG AND BC FAULT OCCURS AT POSITION F4

Fault Position	Fault Type	Novel Protection					
		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	AG	0.0188	2.3446	0.0917	1.0064	0.1007	2.1410
	BC	0.0771	1.7762	0.0624	3.8994	0.0721	2.1849

TABLE IV. TRADITIONAL PROTECTION WHEN EXTERNAL AG AND BC FAULT OCCURS AT POSITION F4

Fault Position	Fault Type	Traditional Protection					
		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	AG	0.3340	2.3682	0.5887	0.8884	0.5782	2.1858
	BC	0.5985	1.7410	0.4365	3.8318	0.4712	2.1518

An external fault AG and BC (phase-to-phase), whenever occurs in a transmission line, or when line is in ordinary circumstance, as depicted in Table III to IV. After compensation the differential current becomes approximately equals to zero in novel protection, on the other hand, in case of traditional protection wholesome value of distributive capacitive current is present as shown in Table IV. Hence the threshold tripping value is set to be a small constant and therefore, novel protection possesses relatively higher sensitivity, stability and accuracy. The novel protection has another benefit that protection doesn't trip in case of distributive capacitive current as protection trips when traditional protection is imposed on them.

The external fault BCG in the transmission lines takes on the distributive capacitive current to approximately zero after compensation in case of novel protection, as shown in Fig. 4. On the other hand, in Fig. 5, the traditional method has been adopted and as a result the distributive capacitive current is larger as compared to that in novel protection. By examining the results carefully, it can be concluded that distributive capacitive current can make the protection to get tripped in case of traditional protection while the protection cannot be tripped in novel protection as there is zero distributive capacitive current. So, it depicts that novel protection is comparatively much more reliable and sensitive than traditional protection.

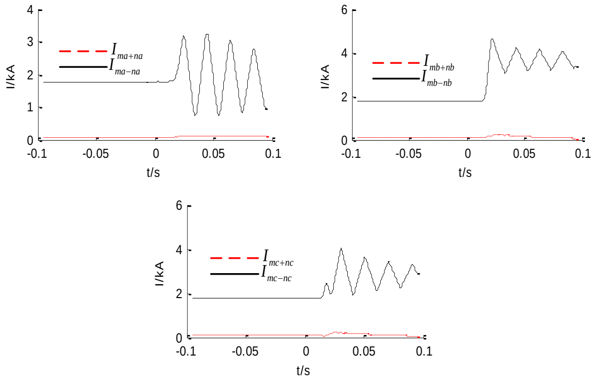

Fig. 4 Novel protection when external BCG fault occurs at position F4

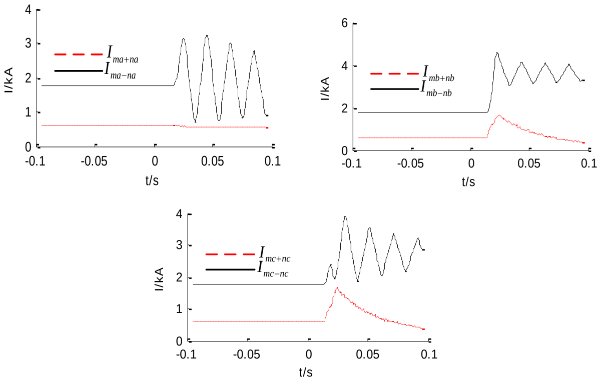

Fig. 5 Traditional protection when external BCG fault occurs at position F4

In case of external fault ABC, whenever it crops up in transmission line, as shown in Fig. 7, the protection will be tripped at location F4 due to the presence of distributive capacitive current in it; this is the case when traditional protection is taken under deliberation. Though if the novel protection is taken under consideration then in this case, the distributive capacitive current is approximately zero after compensation, therefore, stability of the protection against the capacitive current increases and the line will sustain itself from tripping, whenever a fault occurs. This phenomenon is shown in Fig. 6. By taking the whole discussion and results under deliberation, it is concluded that novel protection is comparatively lot more efficient and accurate in means of its stability against distributive capacitive current.

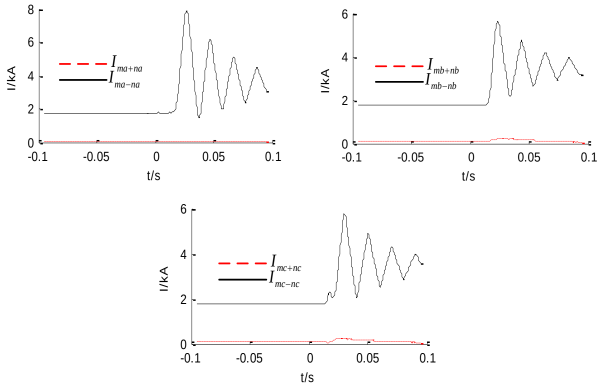

Fig. 6 Novel protection when external ABC fault occurs at position F4

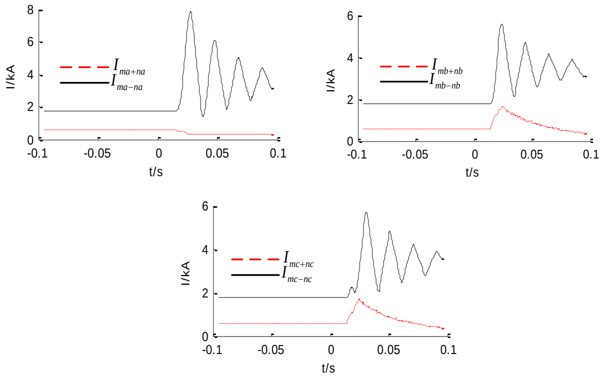

Fig. 7 Traditional protection when external ABC fault occurs at position F4

Whenever an internal fault occurs at the position F1, novel principle works very well and trip the phase A correctly but phase B and C has zero differential current after compensation as shown in Fig. 8. Whereas in Fig. 9 phase B and C might be trip due to large distributed capacitive current. Novel protection in this proposed paper is quite appropriate as compared to traditional protection. Dynamic simulation results show that the new protection principle can detect the internal fault reliably with different faults, and it has great performance.

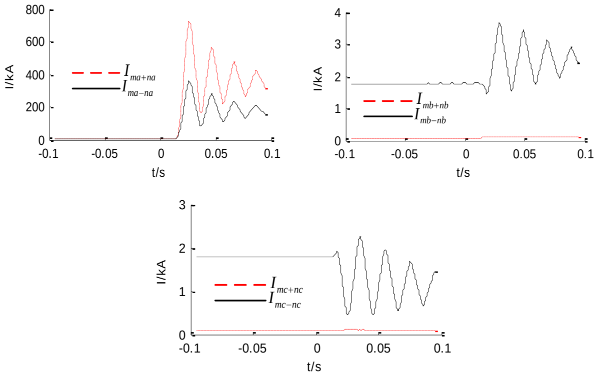

Fig. 8 Novel protection when internal AG fault occurs at position F1

ISSN: 2409-2770

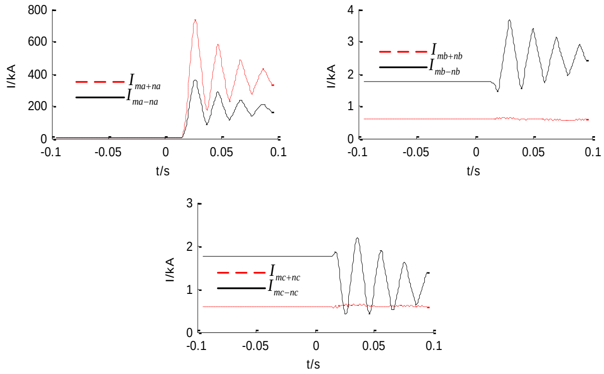

Fig. 9 Traditional protection when internal AG fault occurs at position F1

Simulation result clearly shown in Fig. 10 whenever internal fault occurs with 150Ω fault resistance at position F3, novel protection has zero capacitive current in phase B and C and trip the phase A swiftly. Whereas in Fig. 11, traditional protection might be trip due to large capacitive current in phase B and C. After whole discussion it is concluded that novel protection is more sensitive and efficient as compared to traditional protection when threshold set smaller.

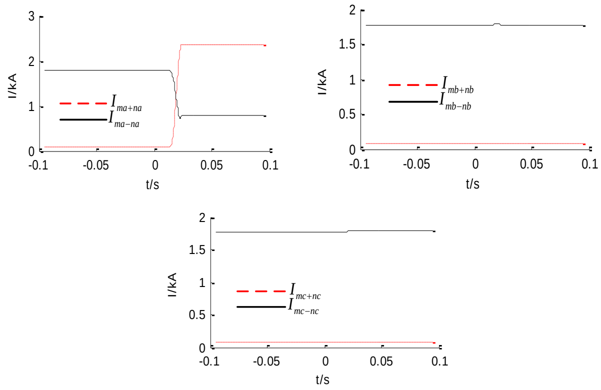

Fig. 10 Novel protection when internal AG fault (RF=150 Ω) occurs at position F3

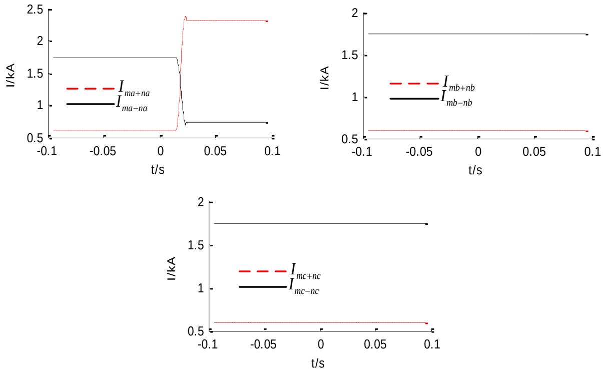

Fig. 11 Traditional protection when internal AG fault (RF=150 Ω) occurs at position F3

IV. CONCLUSION

PSCAD simulation results as well as the theoretical analysis exhibits the below mentioned conclusions:

(1) There is always a huge capacitance current on transmission lines with extra high voltage and ultra high voltage furthermore the reimbursement of the distributed capacitive current is essential for relay to operate properly. In order to fulfill this condition, low computational rate has been chosen for dealing with current differential protection for distributed transmission lines on time domain algorithm.

(2) In comparison with traditional protection, the novel protection has more rapid response, stability, sensitivity and selectivity for protections of EHV and UHV transmission lines.

(3) Novel protection works on steady state as well as in transient state. The performance in steady as well as in transient states is not influenced by the capacitive current of transmission lines.

REFERENCES

[1] 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.

[2] Yuan, R., Chen, D., Yin, X., Zhang, Z., Ma, T., & Chen, W. (2000, January). Principle and property investigation of the transient current differential protection based on correlation analysis. In Power Engineering Society Winter Meeting, 2000. IEEE (Vol. 3, pp. 1945-1949). IEEE.

[3] Shi L, Wang G, Zhao J. Adaptive current differential protection for transmission lines [J]. Presented at the 8th IEE Int. Conf. Developments in Power System Protection, April 2004, vol. 2, pp. 424–427.

[4] Li, K. K., Gang, W., Baoji, Y., & Jiali, H. (2001). Implementation of adaptive dispersed phase current differential protection for transmission lines. In IEE Conference Publication (No. 478, pp. 64-69).

[5] Ito, H., Shuto, I., Ayakawa, H., Beaumont, P., & Okuno, K. (2001). Development of an improved multifunction high speed operating current differential relay for transmission line protection. In Developments in Power System Protection, 2001, Seventh International Conference on (IEE) (pp. 511-514). IET.

[6] 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.

[7] 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.

[8] 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.

[9] 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.

[10] Suonan J, Liu K, Song G. A novel UHV/EHV transmission-line pilot protection based on fault component integrated impedance [J]. Power Delivery, IEEE Transactions on, 2011, 26(1): 127-134.

[11] Suonan J, Deng X, Liu K. Transmission line pilot protection principle based on integrated impedance [J]. Generation, Transmission & Distribution, IET, 2011, 5(10): 1003-1010.

[12] 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.

[13] M. Arshad Shehzad Hassan, Guobing Song, Xiaoning Kang, Zaibin Jiao, Chenqing Wang, Sohaib Tahir, "Current Differential Protection for Distributed Transmission Lines using Low Sampling Frequency" *International Journal of Engineering Works*, Vol. 2, Issue 3, PP. 42-47, March, 2015.

Muhammad Arshad Shehzad Hassan, born in Bahawalpur, Pakistan, on April. 11, 1990, received the M.Sc. degree in Electrical Engineering from Xi'an Jiaotong University, Xi'an, China, in 2014. His research interests include transmission line protection and fault location.

Guobing Song born in Henan, China, on Feb. 1, 1972, received the Ph.D degree at the Xi'an Jiaotong University, Xi'an, China, in 2005. Currently he works in the Xi'an Jiaotong University. His research interests include transmission line fault location and protections.

Xiaoning Kang born in Shaanxi, China, on March 2, 1968, received the Ph.D degree from the Xi'an Jiaotong University, Xi'an, China, in 2006. Currently he works in the Xi'an Jiaotong University. His research interests include fault location, substation automation and transformer protective relaying.

Zaibin Jiao received his B.Sc. and M. Sc. degree from Southwest Jiaotong University, Chengdu, China and the Ph.D. degree from the Xi'an Jiaotong University, Xi'an, China, in 2008. He joined Xi'an Jiaotong University in 2008, and currently works as a Lecturer. From 2011 to 2012, he visited the University of Hong Kong as a Post Doctoral Fellow. His areas of interest are power system protection and smart grid.

Sohaib Tahir born in Sahiwal, Pakistan, on Jan. 21, 1986, received the M.Sc. degree in Electrical Engineering from Xi'an Jiaotong University, Xi'an, China, in 2014. His research interests include three phase inverter, transmission line fault location and protections.

Nouman Faiz born in Bahawalpur, Pakistan, on Dec. 2, 1992, received the B.Sc. degree in Electrical Engineering from Islamia University Bahawalpur, Pakistan, in 2014, and is currently pursuing the M.Sc. degree at COMSATS Institute Of Information Technology, Islamabad, Pakistan. His research interests include transmission line protection and fault location.