RESEARCH ARTICLE OPEN ACCESS

Distance Protection Scheme for Series Compensated Transmission Lines

Vanitha.V*, Hemalatha.P**
*PG Scholar, M.P.N.M.J Engineering College, Erode, Tamilnadu, India.
**Assistant Professor, M.P.N.M.J Engineering College, Erode, Tamilnadu, India.
*vanithaeee@gmail.com,**hema12latha@gmail.com

Abstract
Conventional distance protection applies the positive sequence impedance to protect a line against short-circuit faults. Series-compensated lines may considerably change the positive sequence impedance of the fault path and cause the distance relays to maloperate. To overcome this problem, the mutual impedance between phases of a transmission line is used for the design of a new distance protection scheme. The voltages and currents of both ends of the line are applied to compute the mutual impedance between the relay and the fault point. The proposed scheme has a reliable performance in protection against single-phase and double-phase-to-ground faults and, therefore, it can be used as a backup protection. Simulation results approve the efficiency of the proposed method in protection of series-compensated transmission lines.
Index Terms**—**Distance protection, mutual impedance, series compensation, transmission line.

I. INTRODUCTION

SERIES compensation is a common practice to increase the loadability of transmission lines and improve the power system stability. Series capacitors are used to compensate a portion of inductive impedance of the line and provide a better voltage pro file along the transmission line [1]. Distance relays provide the main protection of transmission lines, as well as interconnected distribution networks. These relays measure the positive-sequence impedance to the fault and compare it with their predefined characteristic. The presence of series capacitor in the fault loop affects reach and directionality of distance relays. The reach of distance relays may experience two major problems: 1) the reduction of series inductance of line which shifts down the locus of fault impedance in the R-X plane, and decreases the reliability of relay and 2) sub synchronous resonance which may introduce remarkable delays in the response of digital phasor estimation methods.

Directionality of the distance relay in series-compensated lines may fail due to voltage or current inversions. A common solution for this problem is using memory voltage as the reference quantity to detect fault direction.

The literature shows that protection of series-compensated lines has been an interesting issue for protection engineers and has been the subject of many works for several decades.

Effects of series compensation on the performance of directional comparison relaying, as well as phase comparison protection, are analyzed in [4]. A modified procedure is presented in [5] for the protective zone setting of distance relays in series - compensated lines. In [6], the problems of distance protection in series-compensated lines are explained in detail. Series capacitors are commonly protected against transient over voltages by metal–oxide varistors (MOVs). The nonlinear function of MOV is considered in [7] and [8] to modify the distance protection by computing the voltage drop along the series compensator. This voltage drop is also used in [9], as well as some additional logics, to increase the accuracy and speed of the first zone of distance relays. In [10], some modification techniques are provided for pilot protection schemes to prevent malfunctions of the main line and its adjacent line relays. Problems associated with the directionality of protective relays in series- compensated lines are addressed in [11] where a new process of directional relaying using the phase difference between the pre fault and post fault currents is presented. In [12], the residual current is applied to compensate for the impedance measurement error in MHO relays.

Proposed protective schemes for series-compensated line are not limited to the distance protection. Differential protection, in the form of the phase comparison scheme, is expected to operate properly in series-compensated lines [13]. Some papers propose protection schemes using the transient features of currents and voltages during fault conditions. These schemes can be mainly divided into the traveling wave based [14]–[17] and superimposed-based methods [18], [19]. Despite high-speed performance, these schemes are dealing with two challenges: 1) If, for any reason such as measurement errors, the current and voltage samples of the transient time after fault inception are not properly achieved, the schemes cannot operate correctly. 2) In the case of slowly evolving faults, superimposed voltages and current may graduate so slowly that the required traveling waves are not generated.

This paper proposes a new distance protection, based on the mutual impedance between phases. Applying the voltages and currents of both ends of the line, the proposed scheme can protect the line against single-phase and double-phase-to-ground faults. Since the mutual impedance is not affected by series compensation, the proposed scheme can provide a reliable backup protection for series-compensated transmission lines. The rest of this paper is organized as follows: Section II analyzes the effects of series compensation on transmission lines. Section III explains the characteristic of the proposed relay .performance of proposed relay based on positive sequence impedance is discussed in Section IV. Simulation results are presented in Section V Finally, Section VI contains the conclusion of this paper.

II. EFFECTS OF SERIES COMPENSATION ON TRANSMISSION LINES

Series capacitive compensation in alternating current transmission systems can yield several benefits such as increases in power transfer capability and enhancement in transient stability. In Figure 3.1 series capacitors are connected in series with the line conductors to compensate the inductive reactance of the line. This reduces the transfer reactance between buses to which the line is connected, increases maximum power that can be transmitted, and reduces effective reactive power loss. Although series capacitors are not usually installed for voltage control, they do contribute to improving the voltage profile of the line.

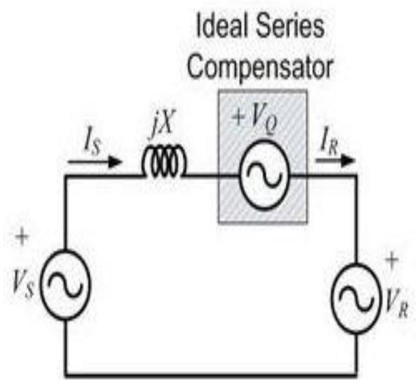

Fig.1.Ideal Series compensated system

To obtain maximum power transfer, series compensation is used. The power equation is given by P= (EV/X_L) sin δ. If line length increases inductive reactance also increases. If inductive reactance increases means power also decreases. To get maximum power X_L to be reduced. It is not possible to decrease the X_L value because it is fixed for conductors and tower configurations. Instead of reducing X_L value of the line a capacitor is placed in series with the transmission line.

III. CHARACTERISTICS OF THE PROPOSED RELAY

The shape of the operation zones has developed throughout the years. An overview of relay characteristics can be seen in the Fig.2.Modern distance relays offer quadrilateral characteristic, whose resistive and reactive reach can be set independently which is shown in Fig 2. It therefore provides better resistive coverage than any mho-type characteristic for short lines. This is especially true for earth fault impedance measurement, where the arc resistances and fault resistance to earth contribute to the highest values of fault resistance. Polygonal impedance characteristics are highly flexible in terms of fault impedance coverage for both phase and earth faults.

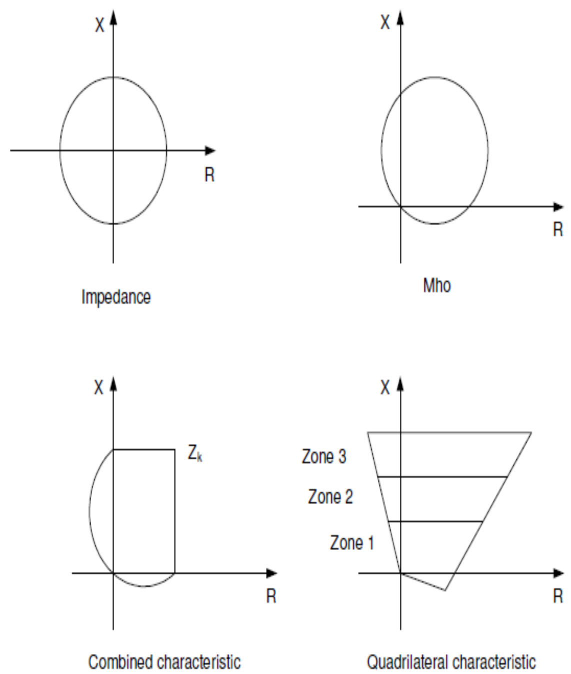

Fig.2 Different characteristic curves of distance protection relay

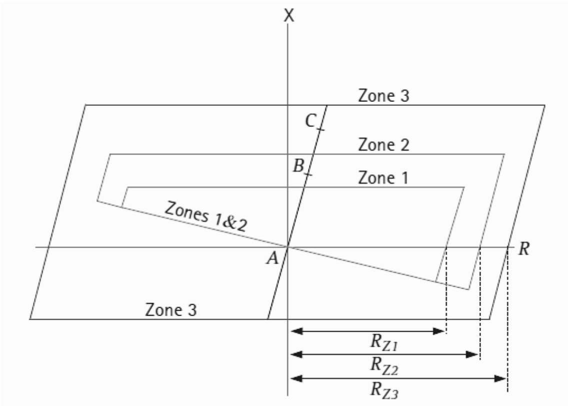

Fig.3.Quadrilateral characteristic curve of distance protection relay

For this reason, most digital relays offer this form of characteristic. Some numerical relays measure the absolute fault impedance and then determine whether operation is required according to impedance boundaries defined on the R/X diagram.

Traditional distance relays and numerical relays that emulate the impedance elements of traditional relays do not measure absolute impedance. They compare the measured fault voltage with a replica voltage derived from the fault current and the zone impedance setting to determine whether the fault is within zone or out-of-zone. Distance relay impedance comparators or algorithms which emulate traditional comparators are classified according to their polar characteristics, the number of signal inputs they have, and the method by which signal comparisons are made.

The common types compare either the relative amplitude or phase of two input quantities to obtain operating characteristics that are either straight lines or circles when plotted on an R/X diagram.

IV. PERFORMANCE OF PROPOSED RELAY BASED ON POSITIVE SEQUENCE IMPEDANCE

Assume resistance R=0.1Ω/km,Reactance X_L=0.4 Ω/km, line length=300km & X_C = 75% of X_L therefore X_C=75%x120 = 90Ω. Positive sequence impedance measurement is suitable only for uncompensated lines.In uncompensated line for load flow analysis relay should not operate and for short circuit it should operate.The total line impedance is calculated as below Z = $\sqrt{(R^2 + X^2)}$ = $\sqrt{(30^2 + 120^2)}$ **= 123.69Ω.**

In distance relay, for positive sequence measurement the setting of the impedance is 80% of the total line impedance.Z_{set} = 80% x Z= 80% x 123.09**= 98.954 Ω.**

Fig.4 shows the load flow analysis of an uncompensated line using ETAP.The impedance is measured by Z = Line voltage / √ 3 I= $(400\times10^3)/(\sqrt{3}\times 672.3)$. $\mathbf{Z_{measured}}$ = **343Ω.** Condition for the operation of the relay is $\mathbf{Z_{measured}} < \mathbf{Z_{set}}$, but here $\mathbf{Z_{measured}} > \mathbf{Z_{set}}$ = **343Ω > 98.954Ω**.Relay does not operate here.

The internal fault analysis of an uncompensated line is shown in fig 5.The impedance is measured by Z = Line voltage / √ 3 I= $(363.3\times10^3)/(\sqrt{3}\times 3.73\times10^3)$ $\mathbf{Z_{measured}}$ **= 56.23Ω.** Condition for the operation of the relay is $\mathbf{Z_{measured}} < \mathbf{Z_{set}}$ = **56.23Ω < 98.954 Ω** .Relay identifies the fault in the uncompensated line when there is real fault.

Fig.6.shows the external fault analysis of an uncompensated line using ETAP. The impedance is measured by Z = Line voltage/√3I=Z=Linevoltage/√3I= $(384.5\times10^3)/(\sqrt{3}\times1.57\times10^3)$. $\mathbf{Z_{measured}}$ = **141.59Ω.**Condition for the operation of the relay is: $\mathbf{Z_{measured}} < \mathbf{Z_{set}}$ but here $\mathbf{Z_{measured}} > \mathbf{Z_{set}}$ **=141.59Ω > 98.954 Ω** .Therefore Relay does not operate.

The system for series compensated line is shown in fig.7. For this total reactance X= X_L - X_C = 120Ω - 90Ω = 30Ω . After compensation net reactance value is 30Ω .The total line impedance is calculated as Z = $\sqrt{(R^2 + X^2)}$ = $\sqrt{(30^2 + 30^2)}$ **= 42.42 Ω** and Z_{set} = 80% x Z = 80% x 42.42=**33.94 Ω.**

Fig.8. shows the load flow analysis of a compensated line using ETAP.The impedance is measured by Z = Line voltage / √3 I=$(400\times10^3)/(\sqrt{3}\times 691.7)$,$Z_{measured}$ = 333.87Ω.

Condition for the operation of the relay is: $Z_{measured} < Z_{set.}$ But here $Z_{measured} > Z_{set}$ = 333.87 Ω > 98.954 Ω Therefore relay does not operate during normal operation.

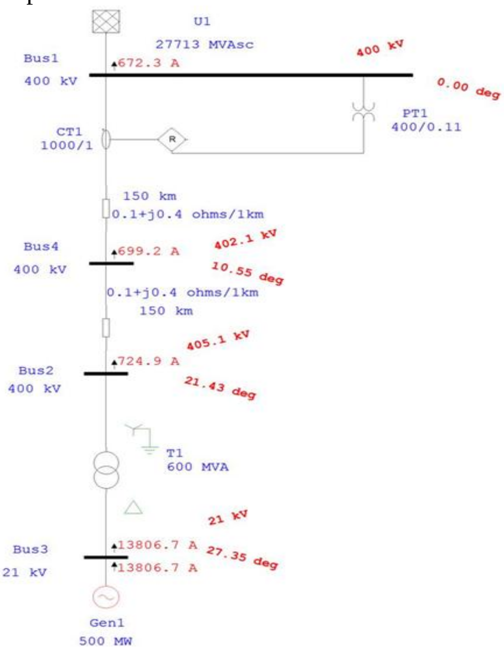

Fig.4.LoadFlow analysis of uncompensated line

Fig.9.shows the internal fault analysis of a series compensated line. The impedance is measured by Z =

Line voltage / $\sqrt{3}$ I=(363.3x10^3)/ ($\sqrt{3}$x 3.73x10^3),$Z_{measured}$ = 56.23Ω. In case of fault in a series compensated line the relay has to operate.

But actually it is failed to operate because the measured impedance value here is 56.27 Ω.It is greater than the set impedance value. If positive sequence impedance is measured for compensated line for distance protection means relay fails to operate when there is the real fault.

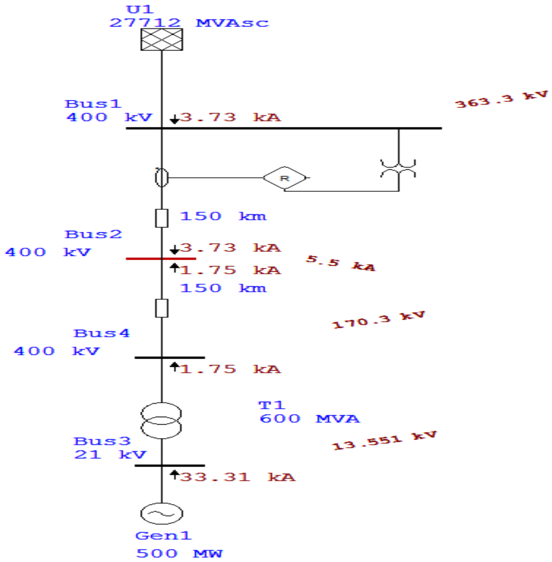

Fig.5.Internal fault analysis of uncompensated line

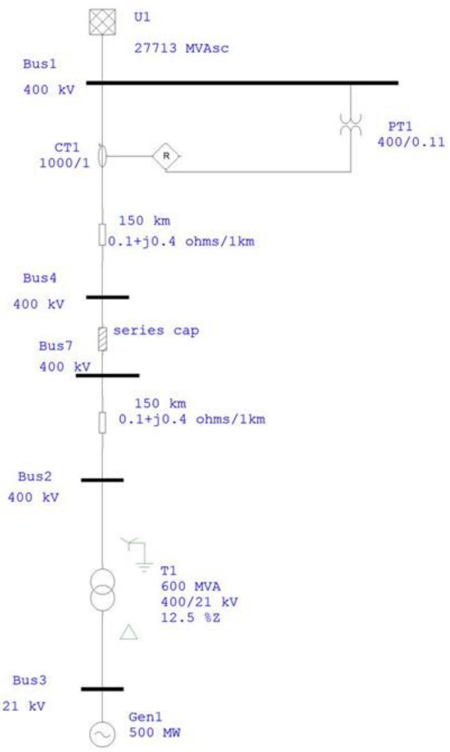

Fig.7.Series compensated system

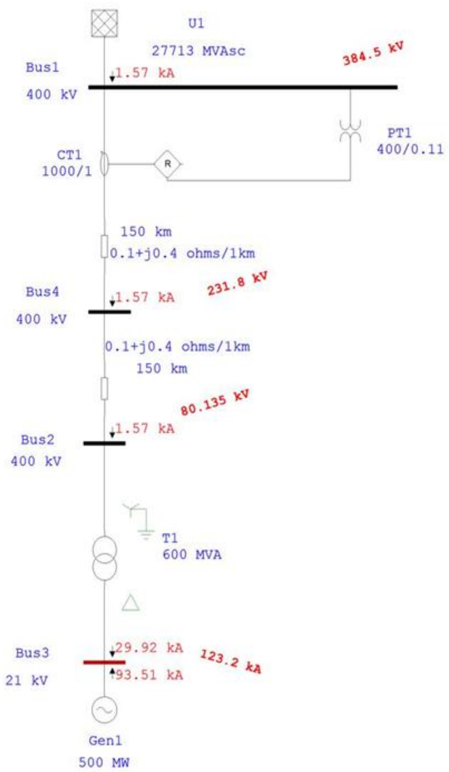

Fig.6.External fault analysis of uncompensated line

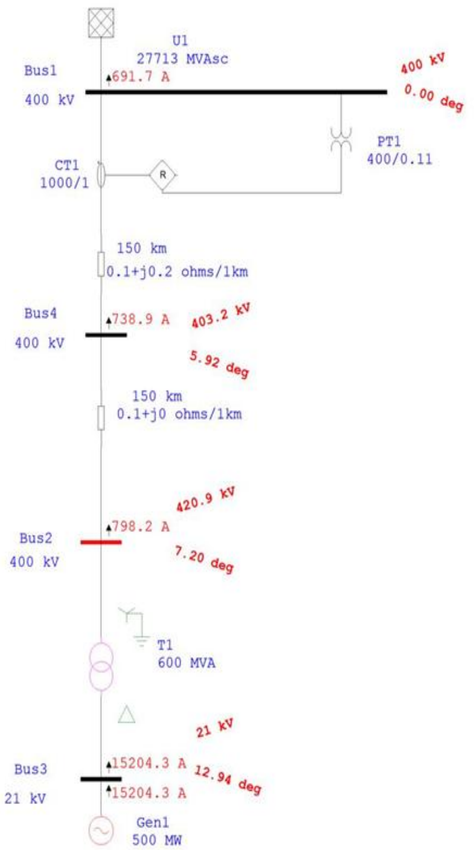

Fig.8.LoadFlow analysis of a series compensated line

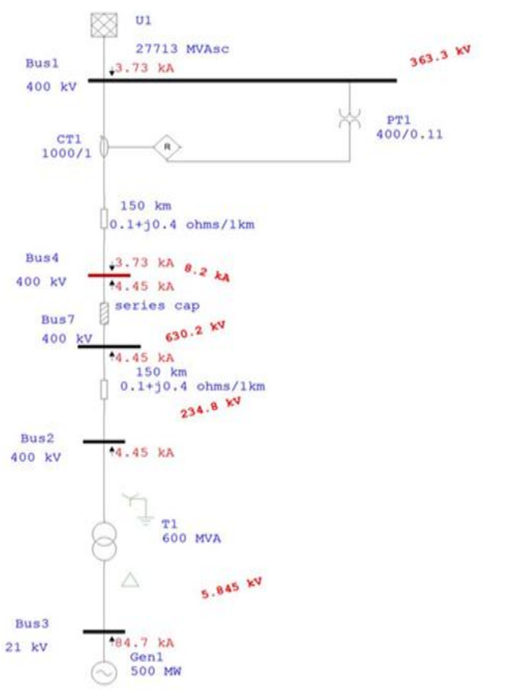

Fig.9.Internal fault analysis of a compensated line

V. VSIMULATION RESULTS

The transient stability analysis is done to detect the internal fault in a series compensated line and the simulation results are verified using ETAP.

Internal fault is created for a series compensated line and simulation results are verified using ETAP. Fig.10 shows the machine behavior during internal fault. From the machine characteristics it is observed that quad-characteristics of distance relay be pickup and isolate the fault.The transient stability analysis is done to detect the external fault in a series compensated line and the simulation results are verified using ETAP.

External fault is created for a series compensated line and simulation results are verified using ETAP. Fig.11shows the machine behavior during external fault from machine characteristics it is observed that quad-characteristics of distance relay will not pickup and isolate the fault.

Table I Simulation system data

Parameter	**Value**	**Unit**
System voltage	400	KV
System frequency	50	Hz
Lines	300	Km
length(AX,XY,YB)	0.1+j0.4	Ω/km
Linespositiveseq.series		
impedance	3.6	μΩx
Lines positive seq.		km
capacitive reactance	0.1+j0.4	
Lines zero seq. series		Ω/km
impedance	3.6	
Lines zero seq.		μΩx
capacitive reactance	0.01802+j0.36	km
Sources positive seq.	039	
impedance	0.01802+j0.36	%
Sources zero seq.	039	%
impedance		

The data for the simulated system is shown in Table I..The performance comparison of the conventional distance protection relay with the proposed protection scheme is analyzed for internal and external single phase to ground fault simulation done in ETAP software.

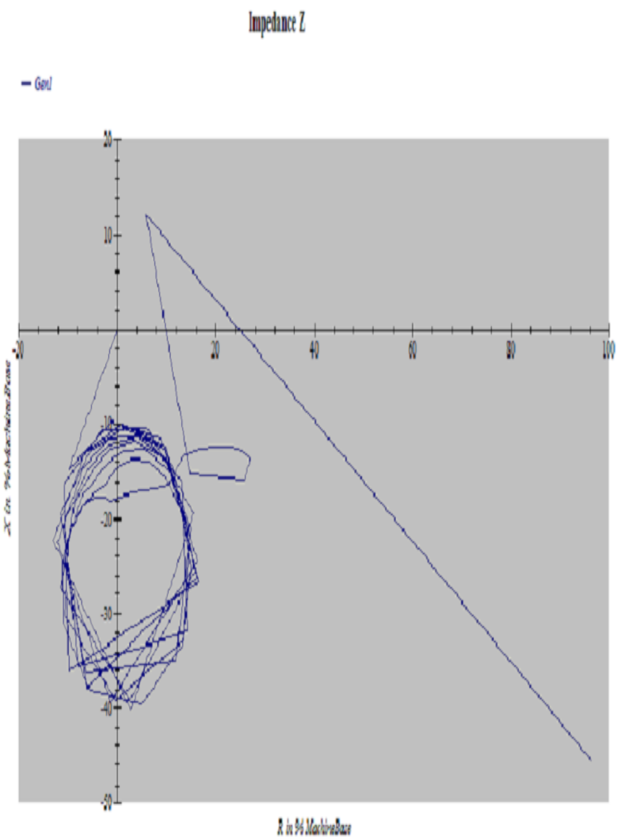

Fig.10.Machine behavior during internal fault in a compensated line

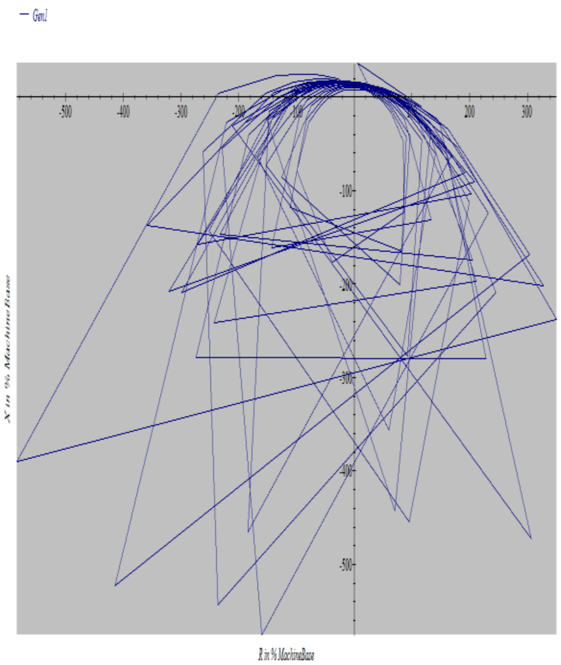

Fig.11.Machine behavior during external fault in a compensated line

VI. CONCLUSION

In this paper, the significance of distance protection relay and the need for series compensation for transmission lines are studied and detailed procedure of computation of mutual impedance both for initial setting the distance protection relay and for the mutual impedance to be seen by the relay during fault. Simulation of single line to ground fault in a series compensated line with and without the effect of fault resistance is studied for both internal and external fault.

Acknowledgement

We heartily convey our gratitude to **Prof.D.Sabapathi, ASP&HoD/EEE, M.P.N.M.J Engg. College**, for guiding and encouraging us to develop this project.

REFERENCES

[1] P. M. Anderson, *Power System Protection*. New York: IEEE, 1999.

[2] Ziegler, *Numerical Distance Protection; Principles and Applica-tions*. Erlangen, Germany: Publicis, 2006.

[3] C. Yu, "*A reiterative DFT to damp decaying DC and subsynchronous frequency components in fault current*," *IEEE Trans. Power Del.*, vol. 21, no. 4, pp. 1862–1870, Oct. 2006.

[4] J. Berdy, "*Protection of circuits with series capacitors*," *IEEE Trans. Power App. Syst.*, vol. PAS-81, no. 3, pp. 929–935, Feb. 1963.

[5] A. Newbould and I. A. Taylor, "*Series compensated line protection: System modelling & relay testing*," in *Proc. 4th Int. Conf. Develop. Power Protect.* 1989, pp. 182–186.

[6] B. Kasztenny, "*Distance protection of series-compensated lines: Prob-lems and solutions*," in *Proc. 28th Annu. Western Protective Relay Conf.*, Spokane, WA, 2001, pp. 1–34.

[7] E. Rosolowki, J. Izykowski, P. Pierz, M. M. Saha, P. Balcerek, and M. Fulczyk, "*Optimization of distance protection algorithm for series-compensated transmission line,"* in *Proc. IEEE Trondheim PowerTech*, 2011, pp. 1–7.

[8] D. Novosel, A. Phadke, M. M. Saha, and S. Lindahl, "*Problems and solutions for microprocessor protection of series compensated lines*," in *Proc. Develop. Power Syst. Protect.*, 1997, pp. 18–23.

[9] M. M. Saha, B. Kasztenny, E. Rosolowski, and J. Izykowski, "*First zone algorithm for protection of series compensated lines*," *IEEE Trans. Power Del.*, vol. 16, no. 2, pp. 200–207, Apr. 2001.

[10] T.S.Sidhu and M. Khederzadeh, "*Series compensated line protection enhancement by modified pilot relaying schemes*," *IEEE Trans. Power Del.*, vol. 21, no. 3, pp. 1191–1198, Jul. 2006.

[11] P. Jena and A. K. Pradhan, "*A positive-sequence directional relaying algorithm for series-compensated line*," *IEEE Trans. Power Del.*, vol. 24, no. 4, pp. 2288–2298, Oct. 2010.

[12] A. B. Shah, V. K. Sood, and O. Saad, "*Mho relay for protection of se-ries compensated transmission lines*," presented at the Int. Conf. Power Syst. Transients, Toronto, ON, Canada, Sep. 2009. Kasztenny, I. Voloh, and E. A. Udren, "*Rebirth of the phase com-parison line protection principle,"* in *Proc. 59th Annu. Conf. Protect. Relay Eng.*, 2006, pp. 193–252.

[13] D. W. P. Thomas and C. Christopoulos, "*Ultra-high speed protection of series compensated lines*," *IEEE Trans. Power Del.*, vol. 7, no. 1, pp. 139–145, Jan. 1992.

[14] J. A. S. B. Jayasinghe, R. K. Aggarwal, A. T. Johns, and Z. Q. Bo, "*A novel non-unit protection for series compensated EHV transmission lines based on fault generated high frequency voltage signals*," *IEEE Trans. Power Del.*, vol. 13, no. 2, pp. 405–413, Apr. 1998.

[15] A. Y. Abdelaziz, A. M. Ibrahim, M. M. Mansour, and H. E. Talaat, "*Modern approaches for protection of series compensated transmission lines*," *Elect. Power Syst. Res.*, vol. 75, pp. 85–98, 2005.

[16] C. Aguilera, E. Orduna, and G. Ratta, "*Fault detection, classification and faulted phase*

selection approach based on high-frequency voltage signals applied to a series-compensated line," *Proc. Inst. Elect. Eng., Gen. Transm. Distrib.*, vol. 153, no. 4, pp. 469–475, Jul. 2006.

[17] P. Jafarian and M. Sanaye-Pasand, "*High-speed superimposed-based protection of series-compensated transmission lines*," *Inst. Eng. Technol. Gen. Transm. Distrib.*, vol. 5, no. 12, pp. 1290–1300, 2011.

[18] S. M. Hashemi, M. T. Hagh, and H. Seyedi, "*Transmission-line pro-tection: A directional comparison scheme using the average of super-imposed components*," *IEEE Trans. Power Del.*, vol. 28, no. 2, pp. 955–964, Apr. 2013.

[19] S. M. Hashemi, M. Tarafdar hagh, Member IEEE and H. Seyedi," *A Novel backup distance protection scheme for series compensated Transmission lines"* IEEE Transactions on Power Delivery, vol.29, no.2, pp.699-707,Apr.2014.

BIOGRAPHY

Ms.V.Vanitha is studying M.E. (Power Systems Engineering) in M.P.Nachimuthu M.Jaganathan Engineering College, chennimalai-638112, Tamilnadu, India. She has presented a paper in International conference & 9 papers in national conference at various reputed institutions. She attended National Level seminars like Energy Management in recent trends, Investigation on Efficient Magnetic generators for future power needs. She attended the workshops like introduction to lab view for engineers organized by Innovative Invaders Technologies Coimbatore, Remote sensing &Digital Image Processing by ISRO and ETAP (Electrical Transient Analysis Program). She has presented many projects on project contest & guided many UG projects. She has undergone the prescribed course of training in Southern Railways Erode, Thermal Power Station; Mettur.She completed the courses like web designing, Hosting & multimedia training. She has participated twice in IEEE Student Professional Awareness Conference. She has undergone the skill Development programme on Artificial Intelligence methods in Engineering &Mind without fear. She has attended the faculty development programmes like enhancing academic performance, Embedded Control applications in Drives, Advances in process control & automation and emerging trends in electrical & embedded Technologies. She is the life member of Indian Society for Technical Education (ISTE).She is one of the members of IEEE. Her area of interest is in Power System Protection.

Mrs.P.Hemelatha completed her M.E Embedded System Technologies in Nandha Engineering College, Erode, Completed B.E Electrical and Electronics Engineering in Sasurie College of Engineering, Erode and has 6 years of teaching experience. Now working as an assistant professor in EEE department in M.P.Nachimuthu M.Jaganathan Engineering College, Erode. She attended many workshops like MATLAB based Training on Neural Networks in Engineering Applications, Embedded Systems and its Applications, Mat lab Simulation and Economic Utilization of Energy Sources. She is one of the members of ISTE.