EMTP Applied to Evaluate Three-Terminal Line Distance Protection Schemes

K. M. Silva, W. L. A. Neves and B. A. Souza

Abstract— **Digital protection schemes have been around for decades. Although there are many relay schemes reported in the literature, the protection engineer may gain more insight on how schemes work properly if well known cases are previously simulated with the EMTP to evaluate relay algorithms. Here, a very simple case study is presented in which the EMTP is used to evaluate the off-line performance of distance protection schemes applied to the three-terminal line of a 230 kV three-bus power network. The digital relays were modeled considering the logic of different distance schemes and relay-to-relay communication. The EMTP is a powerful tool to pinpoint limitations on the applicability of these distance protection schemes and may help engineers to develop new protection schemes.**

Keywords— **Power system protection, three-terminal transmission lines, distance schemes, EMTP.**

I. Introduction

THERE are technical and financial reasons to avoid the construction of a full switching electric power station for some high-voltage transmission line. There are cases in which the line must be tapped and divided into separate line segments, originating the well known multi-terminal transmission lines [1]. Among the several configurations, the simplest and most used is the three-terminal line with generation sources behind each terminal.

The protection of multi-terminal lines is a challenge to engineers, owing to the large number of line configurations with varying numbers of terminals, line lengths, source and load conditions [2], [3]. Both unit-protection and distance schemes may be adapted for use on multi-terminal lines protection, but distance schemes are more used [4].

The distance schemes may be divided into three groups: *intertripping*, *permissive* and *blocking* schemes [4]. They are used to accelerate in-zone fault clearance and/or prevent out-of-zone tripping, by means of the ON/OFF data exchange between the protection devices of each line terminal. However, their application is not straightforward, requiring careful consideration and schematic checking of all system operating conditions.

In order to evaluate the performance of protective systems, the use of Electromagnetic Transients Program (EMTP) has increased [5]. In fact, EMTP simulations provide a very good understanding of both relay performance and power system dynamics during transient conditions, revealing malfunctions of protective schemes. The EMTP has been used to model and test distance relays in closed-loop simulations [6]–[8], i.e., simulations in which the relay may interact with the system network models, tripping breakers in order to switch-off the faulted portion of the system. However, only the protection of two-terminal lines has been evaluated not including distance schemes.

Here, a very simple case study is presented in which the EMTP is used to evaluate the off-line performance of distance protection schemes applied to the three-terminal line of a 230 kV three-bus power network. The distance protection relay schemes are implemented using the MODELS environment of the Alternative Transient Program (ATP) version of the EMTP [9], taking into account the logic of different distance schemes and relay-to-relay communication. Some well known aspects about the performance of these schemes and limitations on their applicability are discussed. The EMTP may be a very useful tool to help engineers to develop new protection schemes.

II. Case Study Description

The performance of distance protection scheme applied to the 230 kV three-bus power network shown in Fig. 1 is evaluated. The three line segments originated from the buses A, B and C to the junction point P form a three-terminal line, named line ABC. The two-terminal line between bus B and C is named line BC. The power system generation is represented by the voltage sources $\hat{E}_A$, $\hat{E}_B$ and $\hat{E}_C$ behind their series impedances Z_A, Z_B and Z_C, respectively. The

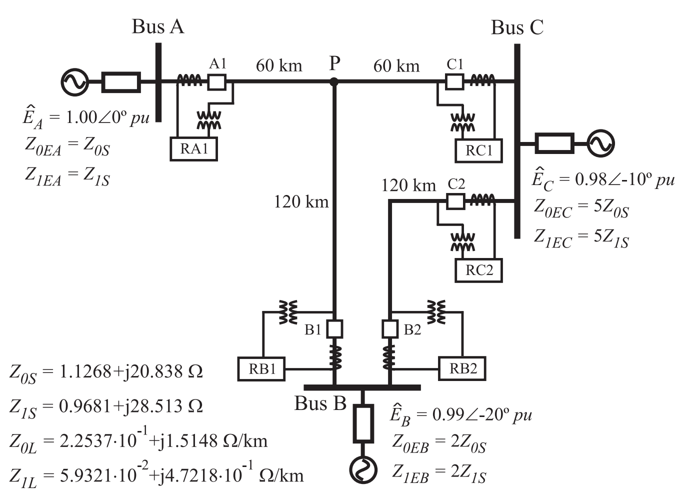

Fig. 1. Diagram of the test power system.

This work was supported by Brazilian National Research Council (CNPq).

The authors are with Department of Electrical Engineering at Federal University of Campina Grande, 882 Aprígio Veloso Av, Bodocongó, Campina Grande - PB, CEP:58.109-970, Brazil. E-mail: {kms, waneves, benemar}@ee.ufcg.edu.br.

Presented at the International Conference on Power Systems Transients (IPST'07) in Lyon, France on June 4-7, 2007.

series impedance of each power system component is also presented in Fig. 1. The first ”0” subscript corresponds to a zero sequence quantity whereas the first ”1” subscript corresponds to a positive sequence quantity. For instance, Z_{0EA} and Z_{1EA} are the zero and positive sequence impedance of source $\hat{E}_A$; and Z_{0L} and Z_{1L} are the zero and positive sequence impedance in Ω/km of all lines.

The following distance schemes are evaluated: direct underreaching transfer trip (DUTT), permissive underreaching transfer trip (PUTT), permissive overreaching transfer trip (POTT), directional comparison blocking (DCB) and directional comparison unblocking (DCUB) [4]. Some aspects about the performance of these schemes are discussed, taking into account the *infeed* and *outfeed* current effects, which are inherent to multi-terminal lines protection and well known to protection engineers [2].

The distance relay algorithms and distance scheme logics are implemented by means of MODELS environment of the Alternative Transient Program (ATP) version of EMTP [9]. In addition, the relay-to-relay communication is also emulated in MODELS environment. In this way, by the emulation of data exchange between the relays RA1, RB1 and RC1, the breakers A1, B1 and C1 are tripped properly, switching-off the line ABC whenever an internal fault is detected. The description of the EMTP simulation is presented next.

III. EMTP Simulations

The MODELS environment provides the monitoring and controllability of the EMTP power systems model. The voltage nodes, current branches and switches status of the power system model are the inputs to MODELS. These signals are processed and the output signals may interact with the EMTP power system model changing its state by controlling the switches operation. In this way, the states of the EMTP power system model may be dynamically changed in response to the outputs of MODELS environment [9].

The overall block diagram of the EMTP simulation is shown in Fig. 2. For each time step, four parameters are sent from the power system model to the inputs of MODELS:

1) The current in the secondary of the auxiliary current transformers (CTs).
2) The voltage in the secondary of the auxiliary voltage transformers (VTs).
3) The status of the switches which represent the breakers.
4) The ON/OFF data from the relays in remote ends, which depends on the chosen distance scheme.

The relay algorithm evaluates the MODELS inputs and computes two outputs:

1) The decision to trip local breakers.
2) The decision to send ON/OFF data to relays in remote ends.

The MODELS outputs depend on the detection of a fault by the relay algorithm. If this is the case, by the data exchange between the relays in each end of the line, the overall protection system trips the local breakers in order to switch-off the line.

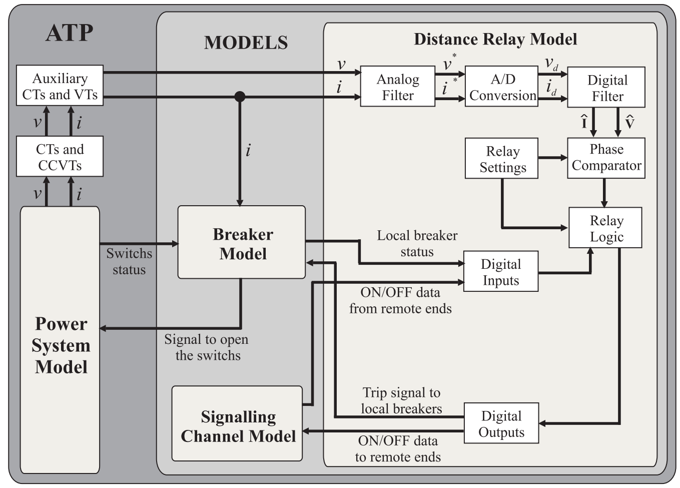

Fig. 2. Overall block diagram of the simulation using MODELS.

A. Instrument Transformers Models

Both CT and coupling capacitor voltage transformer (CCVT) models and their parameters were reported in the reference paper of IEEE Power System Relay Committee [10]. The CT model considers saturation effects of the core including the point by point flux-current curve. In the CCVT model, the ferroresonance suppression circuit is modeled using a capacitor connected to a non-saturable transformer, in which primary and secondary windings are connected in such a way that parallel resonance occurs only at the fundamental frequency.

Auxiliary ideal instrument transformers are used to scale down the CTs and CCVTs outputs to levels suitable to be used by analog-to-digital (A/D) converters. Their secondary burden is chosen in a appropriate way to obtain secondary voltages ranging from -10 to 10 V [8].

B. Breaker Model

For the sake of simplicity, the non-linear arc dynamics and losses are ignored in the breaker model. The breaker is essentially an ideal switch that opens whenever a trip signal is received. However, if reliable arc dynamic models are available these effects may be included in the breaker model [11].

The interrupting time of a circuit breaker used in 230 kV transmission lines lies around 2 cycles [1]. In this way, the breaker model was implemented in MODELS to emulate this interrupting time. This delays the trip signal sent from the relay model by 2 cycles and then coordinates the opening of each breaker pole in such way that a pole opens only when the current waveform crosses the zero line.

C. Signalling Channel Model

The signalling channel was modeled as a simple delay in the signals transmitted between the relays in each end of the protected line.

The worst stand-alone channel performances for distance schemes are [12]:

- 40 ms for intertripping schemes (DUTT).

- 20 ms for permissive schemes (PUTT and POTT).
- 15 ms for blocking schemes (DCB and DCUB).

The chosen values are presented in following sections.

D. Relay Model

The main features of the relay model are summarized in Tab. I. Voltages and currents are filtered by analog filters, in order to minimize the effect of aliasing as well as to attenuate high frequency components. These signals are converted into discrete forms by means of A/D converter models and the voltage and current phasors are estimated by the digital filter. These phasors are used in the phase comparator model in order to detect a fault within the relay protective zones. Finally, depending on the relay logic, a trip is sent to the local breaker. The relay logic takes int account the relay settings and phase comparator outputs. In addition, depending on the distance scheme, the relay may send a trip, a permissive or a blocking signal to relays in the remote ends of the line by the signalling channel model.

1) Analog Filter: According to sampling theory, an analog signal must be sampled using a sampling rate at least two times greater than the maximum frequency of the analog signal. Otherwise, it may occur the *aliasing effect*. In the relay model, an analog third-order Butterworth low-pass anti-aliasing filter is employed, whose transfer function is [13]:

$$H(s) = \frac{b_0}{s^3 + a_2 s^2 + a_1 s + a_0} \ , \tag{1}$$

where: $b_0 = 1.6452 \cdot 10^9$, $a_0 = 1.6452 \cdot 10^9$, $a_1 = 2.7873 \cdot 10^6$ and $a_2 = 2.3611 \cdot 10^3$.

2) A/D Conversion: The A/D converter takes instantaneous value of its input and converts it into an *n*-bit binary number, by using the sample-and-hold technique and the two's complement representation [8]. For instance, suppose an A/D converter with word size of $b+1$ bits and full-input ranging from $-V_{max}$ to V_{max}. The digitized value v_d of a voltage v may be computed as:

$$v_d = \begin{cases} RON\left[\dfrac{v\left(2^b - 1\right)}{V_{max}}\right] \text{ if } v \geqslant 0 \\ \\ RON\left[\dfrac{\left(2V_{max} - |v|\right) 2^b}{V_{max}}\right] \text{ if } v < 0 \end{cases} \tag{2}$$

where RON is the rounding operation. In this way, the floating-point output representation v_f may be computed as:

$$v_f = \begin{cases} Rv_d \text{ if } v \geqslant 0 \\ \\ R\left(v_d - 2^{b+1}\right) \text{ if } v < 0 \end{cases} \tag{3}$$

where R is the A/D resolution which may be computed as:

$$R = \frac{V_{max}}{2^b - 1} \tag{4}$$

The chosen sampling rate is 1920 Hz, that corresponds to 16 samples/cycle for the fundamental frequency of 60Hz.

3) Digital Filter: The chosen digital filter applied to phasor estimation was the cosine filter of one cycle, because it has been widely used in protective relays due to its inherent characteristics such as, rejection of exponentially-decaying dc offsets, rejection of all harmonics and good transient response [14].

4) Relay Settings: In order to simulate the relay, it is necessary to set its parameters: the maximum torque angle τ, the impedance reaches and operation time of both zone 2 and 3, for ground and phase-phase units of the relay; the value of the zero-sequence current compensation factor K_0; the transformer ratios of both CTs and VTs; and the distance scheme. The chosen values are presented in Section IV.

5) Phase Comparator: The phase angle comparator submodule implements the mho autopolarized characteristic, comparing the angle between $(Z\hat{I}_r - \hat{V}_r)$ and $\hat{V}_r$, where: $\hat{V}_r$ and $\hat{I}_r$ are, respectively, the measured voltage and current; and Z is the impedance reach of the protective zone [15].

6) Relay Logic: The relay logic takes into account the phase comparator output, the relay time coordination and the distance scheme logic. In this way, the relay acts to trip local breakers and to send ON/OFF data to relays in remote terminals of the line, thereby the remote breakers may be tripped.

7) Digital Inputs and Outputs: These modules are responsible to exchange ON/OFF data between the protective relays in each terminal of the line, depending on the chosen distance scheme. In addition, they are responsible to get the status of the local breaker and to send to it tripping signals.

TABLE I

MAIN FEATURES OF THE RELAY MODEL.

Requirements	Features
Components	• Butterworth analog filter • A/D converter • Mho autopolarized phase comparator • Relay logic depend on chosen distance scheme
Interface	• 4 channels of node voltages inputs and 4 channels of branch currents inputs • 3 channels of breaker status contact inputs • 6 channels of pilot signal inputs • 3 channels of trip signal outputs • 3 channels of pilot signal outputs
Protection Functions	• Phase distance • Ground distance
Distance Schemes	• Intertripping: DUTT • Permissive: PUTT and POTT • Blocking: DCB and DCUB
Others	• Generation of oscillography files, fault reports and event reports • Relay settings

IV. Settings Considerations

The relays RA1, RB1 and RC1 (Fig. 1) of the line ABC were set as follow:

- Zone 1 is required for the DUTT and PUTT schemes and may be used in POTT, DCB and DCUB schemes to improve performance. Its reach was set to cover 85 percent of the actual positive sequence line impedance to the nearest remote terminal, in order to avoid relay overreach under all operating conditions [2].
- In POTT and DCUB schemes the zone 2 was set to cover 125 percent of the larger positive sequence apparent impedance, in order to prevent all expected infeed current distribution [2]. In this paper, the zone 2 of DUTT, PUTT and DCB schemes was set the same way, and it was considered that the relay never operate on load impedance.
- The reverse-looking zone 3 in DCB scheme was set to be greater than the zone 2 reaches of the remote terminals. In fact, it was set to cover 25 percent of the difference between the larger apparent impedance and the actual positive sequence impedance of the line to the furthest terminal, but in the reverse direction.
- The K_0 factor was computed taking into account the larger positive and zero sequence apparent impedances, in order to prevent the effects of infeed currents [3].

The relays RB2 and RC2 (Fig. 1) of the line BC were set as follow:

- The zone 1 and zone 2 distance functions were set as 85 and 125 percent of the actual positive sequence line impedance, respectively.
- The K_0 factor was computed taking account the actual zero and positive sequence line impedances.

The zone 2 operation time of all relays were set to 150 ms, whereas the zone 3 operation time of the relays RA1, RB1 and RC1 were set to 400 ms. In addition, the maximum torque angle of all relays was chosen to be 60^o, in order to increase the fault resistance coverage.

In DCB scheme, the short time lag (STL) was chosen to be 20 ms, in order to accelerate in-zone 2 fault clearance in case of no blocking signal is received [4].

V. Simulation Results

On protection of three-terminal lines, the distance schemes performance is affected by the junction point location and current distribution for line faults under all operating conditions. The well known effects of infeed and outfeed currents in distance schemes performances are discussed next.

A. The Infeed Effect

Infeed describes a condition in which fault current flows into the faulted line from all line terminals. As a consequence, the distance relay may "see" an apparent impedances greater than the actual positive sequence line impedance from its location to the point of fault. In other words, the relay may underreach the fault due to infeed currents.

In order to analyze the effect of infeed currents, assume that the line BC of the Fig. 1 is out of service. Consider that a three-phase fault with incidence angle of 30^o and fault resistance of 1 Ω occurs 40 km from the junction point P toward bus B. According to the relays settings aforementioned, it is expected that all relays see this fault within their zone 1 tripping all breakers simultaneously. However, due to infeed currents, the relays RA1 and RC1 underreach the fault and see it within their zone 2 as shown in Fig. 3, where the dynamic locus of the apparent impedance seen from each relay unit is plotted.

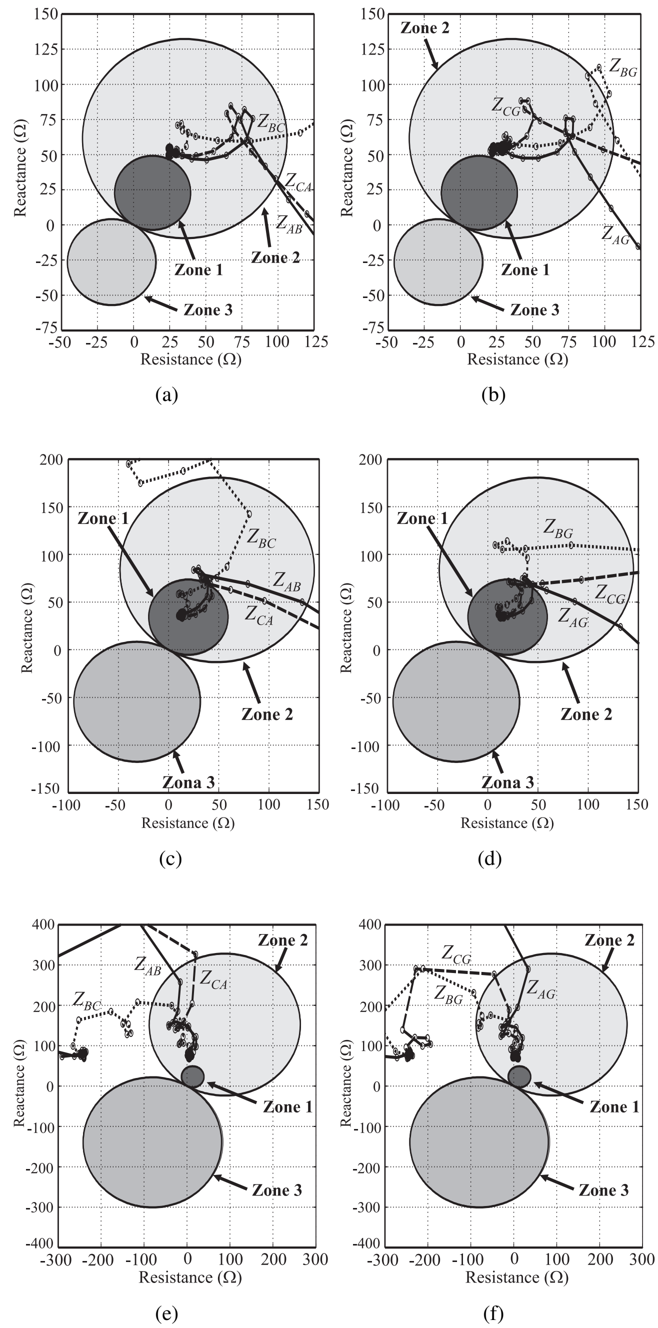

Fig. 3. Apparent impedance plotting considering infeed current distribution: (a) phase-phase units of the relay RA1; (b) phase-ground units of the relay RA1; (c) phase-phase units of the relay RB1; (d) phase-ground units of the relay RB1; (e) phase-phase units of the relay RC1; (f) phase-ground units of the relay RC1.

For the relay RC1, the actual positive sequence impedance from its location to the point of fault is $47.6\angle 82.8^{o}\ \Omega$. However, the impedance seen by its all units are nearly $76.5\angle 88.0^{o}\ \Omega$.

The total fault clearing time without considering any distance scheme is 198.5 ms. Distance schemes are needed to allow high speed line relaying.

Tab. II is a summary of the distance scheme performance, considering the worst stand-alone channel performances (Section III-C). DCUB scheme is the best and the DUTT scheme the worst. The permissive schemes PUTT and POTT have intermediate performances between intertripping and blocking schemes.

Tab III is the summary of distance schemes performances, considering the signalling delay of 10 ms for relay-to-relay signalling channel. Comparing to Tab. II, all schemes have better performances, except the DCB, which presents the same performance in both cases. It is also observed that DUTT and PUTT schemes have the same performance, with total fault clearing time of 64.07 ms. Whereas, the POTT and DCUB schemes totally clear the fault in 58.82 ms, but DCUB would be chosen since it is more reliable than POTT.

TABLE II
DISTANCE SCHEMES PERFORMANCES FOR INFEED CURRENTS, CONSIDERING DIFFERENT SIGNALLING DELAYS.

Distance Scheme	Fault Clearing Time (ms) Bus A	Bus B	Bus C
DUTT	94.54	56.72	94.54
PUTT	71.43	56.72	73.53
POTT	66.17	56.72	67.22
DCB	67.23	56.72	66.17
DCUB	64.07	56.72	64.07

TABLE III
DISTANCE SCHEMES PERFORMANCES FOR INFEED CURRENTS, CONSIDERING THE SAME SIGNALLING DELAYS.

Distance Scheme	Fault Clearing Time (ms) Bus A	Bus B	Bus C
DUTT	64.07	56.72	64.07
PUTT	64.07	56.72	64.07
POTT	58.82	56.72	58.82
DCB	67.23	56.72	66.17
DCUB	58.82	56.72	58.82

B. The Outfeed Effect

Multiterminal lines create the possibility of a current outfeed condition. Current outfeed occurs when, due to system sources, loads, and impedance conditions, current flows out from one or more line terminals during a fault. As a result, distance and directional relays may be affected, causing either a delay or a sequential operation.

Assume the system shown in Fig. 1 with the line BC in operation and with the source at bus C out of service. Assume also that a three-phase fault with incidence angle of 30^{o} and fault resistance of 1 Ω occurs 5 km from the bus B towards the junction point P. According to the relays settings, only the relay RB1 would de expected to see the fault within its zone 1, meanwhile the relays RA1 and RC1 would see it within their zone 2. However, the part of the fault current coming from bus A has two pathways: one from bus A to point P and to the fault location; the other one from bus A to point P, then to bus B and finally to the fault location. Thus, the relay RC1 sees the fault within its reverse-looking zone 3 until the breaker B1 opens. Then, the current direction seen by the relay RC1 is reversed and it now sees the fault within its zone 2 (Fig. 4). In other words, the fault will be cleared by the sequential trip signals from the relays RB1, RA1 and RC1. As a consequence, the total fault clearing time without considering any distance scheme is 245.8 ms.

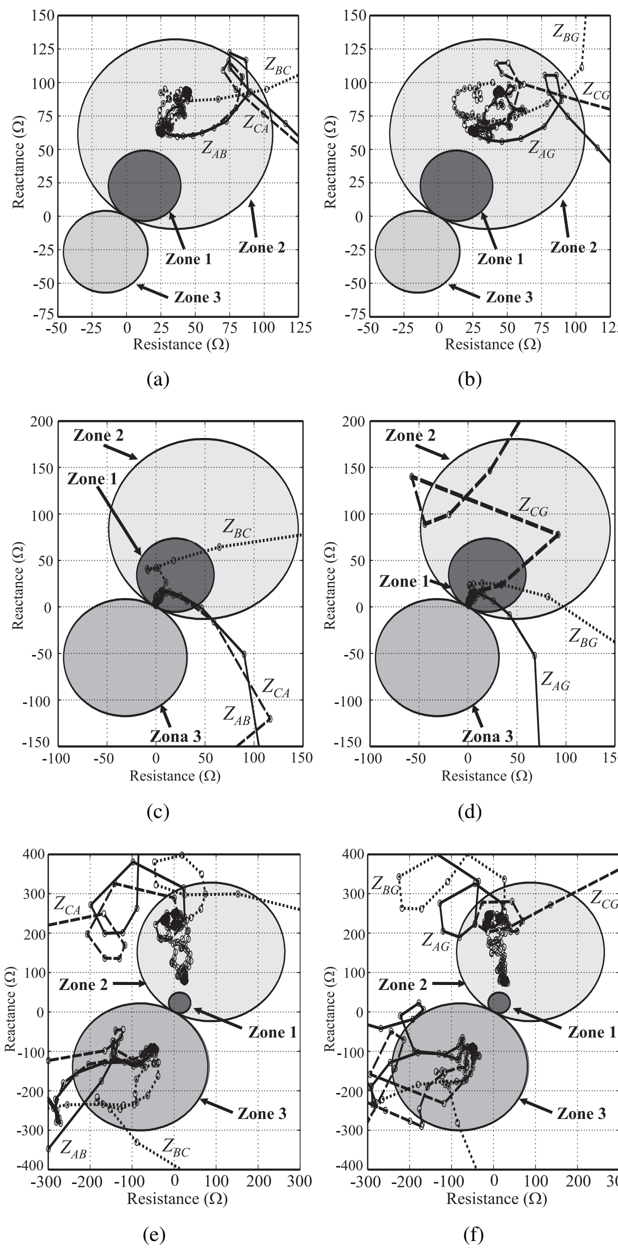

Fig. 4. Apparent impedance plotting considering outfeed current distribution: (a) phase-phase units of the relay RA1; (b) phase-ground units of the relay RA1; (c) phase-phase units of the relay RB1; (d) phase-ground units of the relay RB1; (e) phase-phase units of the relay RC1; (f) phase-ground units of the relay RC1.

The outfeed current also reduces the apparent impedance seen by the relay. For example, the impedance seen by the Z_{AB} unit of the relay RA1, with all terminal closed, is $66.6\angle 67.0^{o}$ Ω, but the actual positive sequence impedance from the relay location to the point of fault is $83.3\angle 82.8^{o}$ Ω.

In Tab. IV, it is summarized the distance scheme performance for outfeed current distributions, considering the worst stand-alone channel performances. Differently from the infeed current situation, the DUTT scheme presented the best performance, because the relay RB1 sees the fault within its zone 1 and quickly trip the local breaker B1 and send a transfer trip to the remote terminals. The other schemes are delayed due to sequential tripping, mainly the DCB scheme, where relays are blocked until breaker B1 opens.

The schemes performances considering the signalling delay of 10 ms between all relays are summarized in Tab. V. It was observed that all schemes improve their performance except DCB, which presents the same performance in both cases. The DUTT presents the best performance again, with total fault clearing time of 55.67 ms. Once more, the POTT and DCUB schemes showed the same performance.

TABLE IV

DISTANCE SCHEMES PERFORMANCES FOR OUTFEED CURRENTS, CONSIDERING DIFFERENT SIGNALLING DELAYS.

Distance	Fault Clearing Time (ms)		
Scheme	Bus A	Bus B	Bus C
DUTT	86.13	46.21	79.83
PUTT	67.22	46.21	96.64
POTT	114.49	46.21	94.54
DCB	97.69	46.21	122.90
DCUB	108.19	46.21	94.54

TABLE V

DISTANCE SCHEMES PERFORMANCES FOR OUTFEED CURRENTS, CONSIDERING THE SAME SIGNALLING DELAYS.

Distance	Fault Clearing Time (ms)		
Scheme	Bus A	Bus B	Bus C
DUTT	55.67	46.21	50.42
PUTT	54.42	46.21	95.59
POTT	102.94	46.21	96.64
DCB	97.69	46.21	122.90
DCUB	102.94	46.21	96.64

VI. CONCLUSIONS

This paper presented the use of a distance relay EMTP model to evaluate the performance of distance schemes in three-terminal line protection. Although the case study presented here is an engineering application of known aspects, the obtained results encourages engineers to use any EMTP version to evaluate protection schemes prior to putting relays in service, pinpointing limitations on the applicability of these schemes. This may help engineers to develop new protection schemes.

VII. ACKNOWLEDGMENTS

The authors would like to thank the reviewers for their invaluable contributions to improve the paper.

REFERENCES

[1] P. M. Anderson, *Power System Protection*. Piscataway, New Jersey, USA: IEEE Press Series on Power Engineering, 1999.

[2] *Protection Aspects of Multiterminal Lines*, IEEE PES/PSRC Special Publication 79TH0056-2-PWR, 1979.

[3] G. E. Alexander and J. G. Andrichak, “Application of phase and ground distance relays to three-terminal lines,” GE Protection and Control, Tech. Rep., Markham, Ontario, Canada, 1996.

[4] *Network Protection and Automation Guide*, 1st ed., Areva T&D, Paris, France, 2002.

[5] *Tutorial on Electromagnetic Transient Program Applications to Power System Protection*, IEEE PES/PSRC Special Publication, 2000.

[6] C.-H. Kim, M.-H. Lee, R. K. Aggarwal, and A. T. Johns, “Educational use of emtp models for the study of a distance relaying algorithm for protecting transmission lines,” *IEEE Transactions on Power Systems*, vol. 15, no. 1, pp. 9–15, Feb 2000.

[7] J. Y. Heo, C. H. Kim, K. H. So, and N. O. Park, “Realization of distance relay algorithm using emtp models,” in *International Conference on Power Systems Transients*, New Orleans, USA, Sept 2003.

[8] S. G. A. Perez, “Modeling relays for power system protection studies,” Ph.D. dissertation, University of Saskatchewan, Saskatoon, Saskatchewan, Canada, July 2006.

[9] L. Dube, *Models in ATP: Language Manual*, 1996.

[10] *EMTP Reference Models for Transmission Line Relay Testing*, IEEE PES/PSRC Special Publication, 2004.

[11] V. Paniraj and A. G. Phadke, “Modelling of circuit breakers in the emtp,” *IEEE Transactions on Power Systems*, vol. 3, no. 2, pp. 799–805, 1999.

[12] *Teleprotection Equipment of Power Systems*, IEC60834-1, 1999.

[13] A. V. Oppenheim and R. W. Schafer, *Discrete-Time Signal Processing*. New Jersey, USA: Prentice-Hall, 1989.

[14] E. O. Schweitzer and D. Hou, “Filtering for protective relays,” Schweitzer Engineering Laboratories, Inc., Pullman, Washington USA, Tech. Rep., 1993.

[15] E. O. Schweitzer and J. Roberts, “Distance relay element design,” Schweitzer Engineering Laboratories, Inc., Pullman, Washington USA, Tech. Rep., 1993.

Kleber Melo e Silva was born in João Pessoa, PB, Brazil, 1980. He received his B.Sc. and M.Sc. in Electrical Engineering from Federal University of Campina Grande, PB, Brazil, in 2004 and 2005, respectively. He is currently a PhD student at the same university. His research interest are electromagnetic transients, power quality, fault diagnosis and power system protection.

Washington Luiz Araújo Neves is an Associate Professor in the Department of Electrical Engineering at UFCG, Campina Grande, Brazil,. He received the B.Sc. and M.Sc. degrees in electrical engineering from UFPB, Brazil, in 1979 and 1982, respectively, and the Ph.D. degree from UBC, Vancouver, Canada, in 1995. From 1982 to 1985 he was with FEJ, Joinville, Brazil. He was a Visiting Researcher with the University of Alberta, Edmonton, Canada, from September 2004 to August 2005, and with UBC, Vancouver, Canada, from September to December 2005. His research interests are electromagnetic transients in power systems and power quality.

Benemar Alencar de Souza was born in Crato, CE, Brazil, 1954. He received his B.Sc., M.Sc. and Ph.D. in Electrical Engineering from Federal University of Paraíba, PB, Brazil, in 1977, 1981 and 1995, respectively. He works currently as a professor at the Department of Electrical Engineering of Federal University of Campina Grande, PB, Brazil. His research activities are mainly focused on optimization methods applied to power systems, electromagnetic transients, power quality and fault diagnostic.