Recursive Digital Filters Design to Compensate CVT Frequency Response: An Application for Transmission Line Controlled Switching

K. M. C. Dantas, E. P. Machado, W. L. A. Neves and L. C. A. Fonseca

***Abstract*— In this work Recursive Digital Filters (RDF) are used to correct the inaccuracies of the Capacitive Voltage Transformers (CVT) transient response to properly estimate the DC line voltage polarity and make controlled reclosing strategies applicable to uncompensated lines. The details of the filter design as well as the controlled reclosing strategies are addressed in the paper. The proposed approach is evaluated by means of EMTP simulations using data from the Brazilian Power System Grid and the results attest its efficiency.**

***Index Terms*— Controlled Switching, Recursive Digital Filters, Switching Overvoltage, Uncompensated Transmission Lines.**

I. Introduction

SWITCHING overvoltages have great influence on the insulation level of EHV (Extra High Voltage) and UHV (Ultra High Voltage) power systems. Therefore, researches related to surge reductions are very important for the power sector. Among the alternatives used to mitigate switching overvoltages, circuit-breaker controlled switching has being the focus of researches in the last years [1]–[9].

Controlled switching is the term used to describe the application of electronic control devices to control the mechanical closing or opening of circuit-breaker contacts at suitable instants [1]. It has been a desirable method for stress reduction and in particular for the reduction of switching overvoltages, becoming an issue of widespread interest to utilities and manufacturers [10], [11]. Regarding to line circuit-breakers, controlled closing and reclosing eliminates the need for pre-insertion resistors, which reduces the circuit-breakers associated maintenance and manufacturing costs and may limit the switching overvoltages to acceptable values, especially when used in conjunction with surge arresters [12].

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Methods for controlled switching of shunt compensated transmission lines have been reported in the literature [13]–[19]. Here, controlled reclosing of uncompensated lines is addressed. In this case, the line reclosing is normally performed with trapped DC charge on the line due to line capacitive effects. Any controlled reclosing strategy for uncompensated transmission line must know the DC line voltage polarity. This may be achieved by monitoring the voltage and current signals at the time of current interruption for the last circuit breaker to trip the line [20]. However, real time information on the current interruption at both transmission line ends may be necessary to assure the effectiveness of this procedure [4].

For EHV and UHV power systems, the voltage signals are provided by Capacitive Voltage Transformers (CVT). Generally, at fundamental frequency, the CVT presents 1.0 pu gain and nearly zero degree phase shift. However, CVT response is far from ideal when submitted to transients [21], [22]. These inaccuracies make it difficult to estimate the DC line voltage polarity and may cause malfunctioning of controlled switching methods, leading to high switching overvoltages.

In this work, Recursive Digital Filters (RDF) are used to correct the inaccuracies of the CVT transient response to properly estimate the DC line voltage polarity and make controlled reclosing strategies applicable to uncompensated lines, without the need for real time information on both line ends. The details of the filter design are addressed here. Data from the Brazilian Power System Grid is used to produce some case studies by means of digital simulations using EMTP (Electromagnetic Transients Program). The results attest the efficiency of the proposed procedure.

II. Basics on Line Controlled Switching

The closing command for the circuit-breaker is normally issued randomly at some instant $t_{command}$ with respect to the phase angle of the voltage across the circuit-breaker contacts, which is the reference signal for the controlled closing. Furthermore, the contacts making instant occurs after a period of time commonly called the operating time of the circuit-breaker ($T_{operating}$). The timing sequence for controlled closing is shown in Fig. 1, in which the optimal making instant is the zero crossing of the reference signal. The method consists on controlling the instant $t_{command}$ delaying it for a time interval T_{delay} in order that $t_{optimal}$, previously predicted, occurs at the instant $T_{delay} + T_{operating}$ after $t_{command}$.

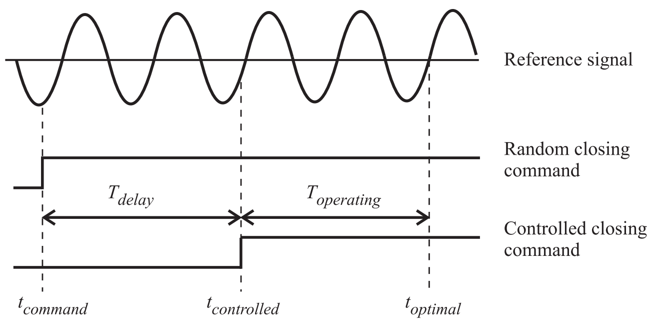

Fig. 1. Schematic controlled closing sequence.

A. *Transmission Line Closing*

During this operation, there is no trapped charge on the line and the optimal making instant for each transmission line phase is the zero crossing of the source side voltage. The reference signal and optimal making instants for this situation are illustrated in Fig. 2.

B. *Uncompensated Transmission Line Reclosing*

Transmission line reclosing operations are normally performed with trapped charge on the line. In the case of uncompensated transmission lines a DC line voltage may remain during the reclosing interval due to line capacitive effects. This trapped charge has an almost exponential decay with a relatively high time constant due to the low transmission line shunt conductance. Thus, the DC line voltage is still high at the contacts making instant and the reference signal for the controlled switching strategies is the voltage across the circuit breaker contacts, being necessary to monitor the source side voltage and the polarity of the DC line voltage.

The reference signal for a theoretical DC line voltage of -1.0 p.u is illustrated in Fig. 3. The possible optimal making instants for this line operating condition are also indicated in this figure.

III. Capacitive Voltage Transformers

For EHV and UHV power systems, the controlled switching reference signals (voltage signals) are provided by Capacitive Voltage Transformers (CVT). A typical electrical model for a 500 kV CVT is shown in Fig. 4 and consists of: capacitive divider, series inductance, intermediate potential transformer, ferroresonance suppression filter and burden [22]. Its frequency response (Fig. 5) presents a gain of 1.0 p.u and no phase shift only at power system fundamental frequency, amplification of frequencies slightly above and slightly below the fundamental frequency and attenuation of higher frequencies and DC signals. Therefore, the CVT response is far from ideal when submitted to transients. These inaccuracies make it difficult to estimate the DC line polarity and may cause malfunctioning of controlled switching methods, leading to high switching overvoltages.

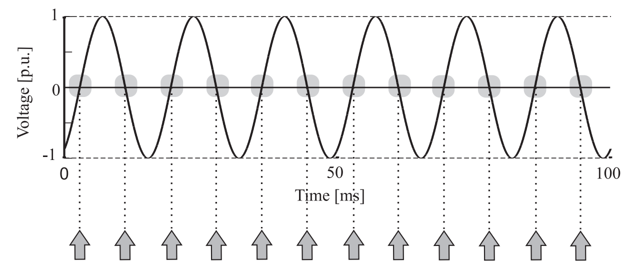

Fig. 2. Reference signal (source side voltage) and optimal making instants for transmission line closing.

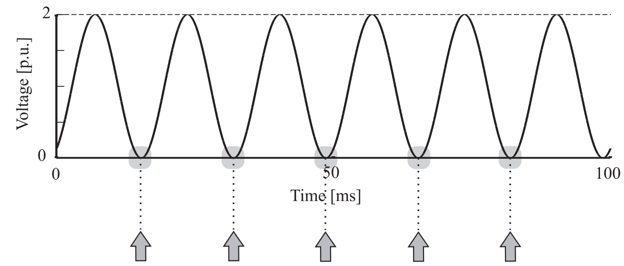

Fig. 3. Voltage across the circuit-breaker contacts for transmission lines without shunt compensation.

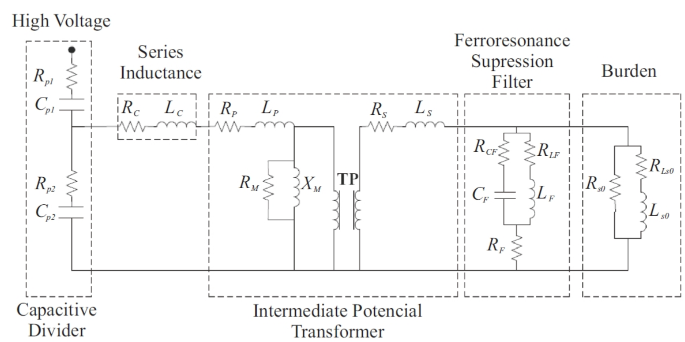

Fig. 4. 500 kV CVT model [22].

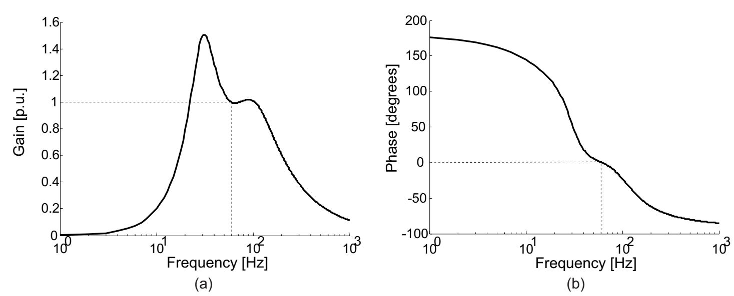

Fig. 5. 500 kV CVT frequency resposnse [22]: (a) Gain. (b) Phase.

IV. Recursive Digital Filter Design

The correction of the CVT transient response inaccuracies has been reported in the literature since the 1990s. Most of the proposed methods are applied for power system protection enhancement and are based on digital filters [23]–[26], artificial neural networks [27]–[29] or variations of the least square method for phasor estimation [30], [31].

Generally, those methods require the knowledge of the CVT's topology and its parameters. Besides, their application may not be generalized to every power system. Since there are several CVT topologies and the estimation of each parameter is not straightforward, the necessity to develop a new algorithm which is independent of these characteristics is evident.

Here, an algorithm for correction of the CVT transient response is proposed based on the distortionless system definition [32]. From a measurement point of view, a signal $x(t)$ is transmitted through a system with no distortion if the output signal $y(t)$ can be expressed by (1).

$$y(t) = Kx(t - t_0), \tag{1}$$

where K is a constant that changes the amplitude of the input signal and t_0 is a delay in the signal transmission. Applying the Fourier transform and using its time shifting property:

$$Y(j\omega) = KX(j\omega)e^{-j\omega t_0}. \tag{2}$$

Therefore, the frequency response of a distortionless system can be expressed according to (3). It has a constant gain and a linear phase for all frequency components. Here, the components of interest are DC and fundamental frequency.

$$H(j\omega) = \frac{Y(j\omega)}{X(j\omega)} = Ke^{-j\omega t_0} = K\angle - \omega t_0. \tag{3}$$

A Recursive Digital Filter (RDF) was designed to compensate the CVT frequency response (presented in Fig. 5) in the frequency range from 1 to 60 Hz. A lower threshold of 1 Hz was used due to difficulties on measuring the CVT low frequency response. The RDF is modeled by a rational function, according to (4).

$$H_a(\gamma_v, \mathbf{x}) = \frac{V_{out}(\gamma_v)}{V_{in}(\gamma_v)} = \frac{a_0 + a_1\gamma_v + \ldots + a_n\gamma_v^n}{1 + b_1\gamma_v + \ldots + b_m\gamma_v^m} \ , \tag{4}$$

where: a_i (for $i = 0, 1, \ldots, n$) and b_l (for $l = 1, 2, \ldots, m$) are the coefficients of the rational function; **x** is a vector of size $n + m$ containing the coefficients a_i and b_l; $\gamma_v = j\omega_v$ for s domain or $\gamma_v = z^{-1} = e^{-j\Omega_v}$ for z domain.

The identification process of the coefficients a_i and b_l can be formalized as an optimization problem whose objective is to minimize (5).

$$F(\mathbf{x}) = \sum_{v=1}^{npt} |(\alpha_v + j\beta_v) - H_a(\gamma_v, \mathbf{x})|^2 \ , \tag{5}$$

where npt is the number of points of the CVT frequency response data and $(\alpha_v + j\beta_v)$ is the reference frequency response, which is given by (6).

$$\begin{aligned} \alpha_v &= \text{Real}\left(\frac{1}{g_v(\cos(\phi_v) + j\sin(\phi_v))}\right) \\ \beta_v &= \text{Imag}\left(\frac{1}{g_v(\cos(\phi_v) + j\sin(\phi_v))}\right) \ , \end{aligned} \tag{6}$$

where g_v and ϕ_v are the gain and phase of the vth measured value of the CVT frequency response, respectively.

In this paper, the Levenberg-Marquardt method with the Levy initialization algorithm and a pre-conditioning technique have been used to solve this optimization problem in z domain [33]. The RDF transfer function can be written as a product of 2nd-order rational functions with real coefficients, according to (7).

$$\frac{V_{out}(z)}{V_{in}(z)} = k_0 \prod_{i=1}^{p} \frac{1 + c_{i1}z^{-1} + c_{i2}z^{-2}}{1 + d_{i1}z^{-1} + d_{i2}z^{-2}} \ , \tag{7}$$

where p is the number of 2nd-order rational functions (sections) and z^{-1} is the time delay operator. Thus, the RDF time domain representation can be straightforward obtained.

Other methods, specially those developed in the field of electromagnetic transient simulations, could be used to identify the coefficients of the recursive digital filter. However, some of those (vector fitting, for example) may not be appropriate when the reference frequency response presents an excessive phase delay due to the convolution between the CVT frequency response and the anti-aliasing filter used by data acquisition systems, such as digital recorders [33].

The CVT frequency response (presented in Fig. 5) in the range from 1 to 60 Hz and a sampling rate of 1920 Hz were considered to obtain the coefficients shown in Tab. I for the designed RDF.

TABLE I

RDF PARAMETERS IN z DOMAIN IDENTIFICATION FOR 500 KV CVT.

Section i	Coefficients - $k_0 = 5.2122450$			
	c_{i1}	c_{i2}	d_{i1}	d_{i2}
1	-1.5510932	0.6550390	-1.7543930	0.7825046
2	-1.9280347	0.9371981	-1.9999989	0.9999989
3	-1.4345871	0.4636554	0	0

By using present and past samples of the CVT secondary voltage waveform it is possible to properly recover the CVT primary voltage waveform in the frequency range used for the RDF design. The frequency response of the compensated CVT is illustrated in Fig. 6, which is close to an ideal CVT response in the considered frequency range. By using this procedure, the DC line voltage polarity can be properly estimated.

V. PROPOSED PROCEDURE

In this work, RDF are used to correct the inaccuracies of the CVT transient response to properly estimate the DC line voltage polarity and make controlled reclosing strategies applicable to uncompensated lines. This is an improvement of the uncompensated line controlled switching method presented in [16] and [34] and consists on estimating the reference signals (voltage across the circuit breaker contacts) ahead in time in order to predict the suitable making instants for line reclosing. A making instant is determined when the source side peak voltage has the same polarity of the DC line voltage.

The proposed procedure diagram is shown in Fig. 7. Generally, the source side and the line side voltage signals are provided by CVT, especially for EHV and UHV power systems.

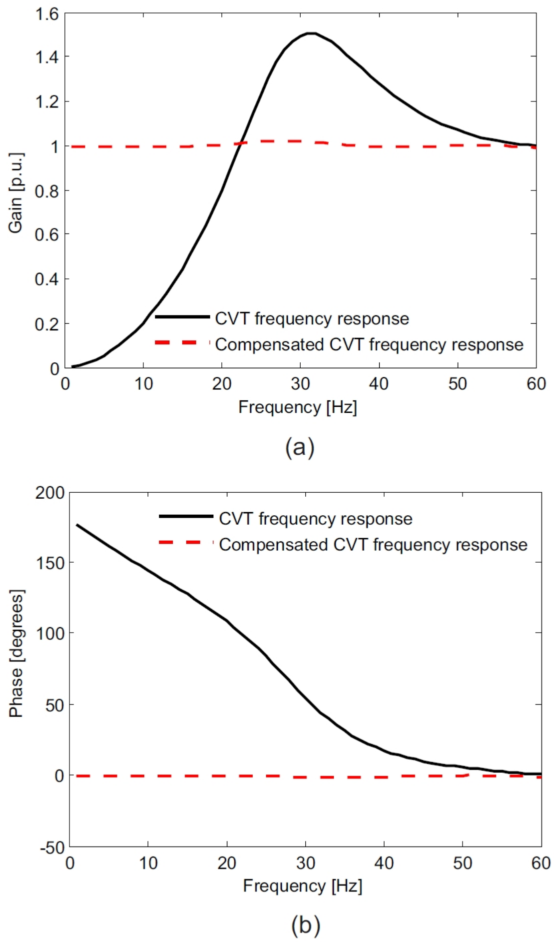

Fig. 6. CVT frequency response: (a) Gain. (b) Phase.

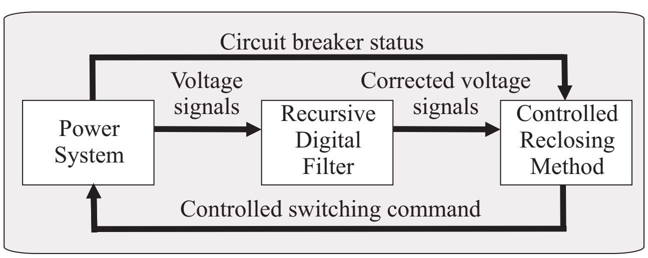

Fig. 7. Proposed procedure diagram.

Here, these voltage signals are first processed by the RDF and then provided to the controlled reclosing method that properly detects the DC line voltage polarity and the zero crossings of the source side voltage signals as soon as the line circuit breaker is opened. Then, the reference signals can be estimated ahead in time according to Fig. 8.

With the switching command issued at the instant $t_{command}$, t_{zero2} becomes the last zero crossing and the reference signal (s_{ref}) can be estimated after $T_{operating}$ by (8). The first instant estimated ahead in time is $t_{estimated}$.

$$s_{ref}(t) = A \cdot \sin(\omega_{sr} \cdot (t + \Delta T)) \ , \tag{8}$$

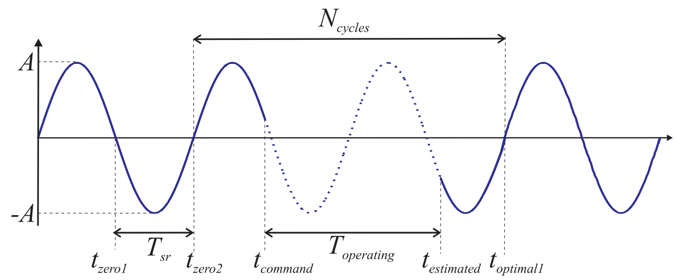

Fig. 8. Reference signal estimation ahead in time.

where,

$$\omega_{sr} = \frac{\pi}{T_{sr}} \ , \tag{9}$$

$$\Delta T = T_{operating} + (t_{command} - t_{zero2}) \ , \tag{10}$$

T_{sr} is the half period and A is the amplitude of the signal.

The optimal making instants to reclose an uncompensated line are the instants of source side peak voltage (negative or positive), depending on the polarity of the DC line voltage. If the polarity is positive, the optimal making instant is given by (11). If the polarity is negative, the optimal making instant is given by (12). The next optimal making instants for each case will be held every $2T_{sr}$ seconds.

$$t_{optimal} = t_{zero2} + \left(N_{cycles} + \frac{1}{4}\right) \cdot (2T_{sr}) \ . \tag{11}$$

$$t_{optimal} = t_{zero2} + \left(N_{cycles} + \frac{3}{4}\right) \cdot (2T_{sr}) \ . \tag{12}$$

N_{cycles} is the number of cycles between t_{zero2} and $t_{optimal1}$, in Fig. 8, and is given by (13).

$$N_{cycles} = \text{int}_{\text{sup}}\left(\frac{\Delta T}{2 \cdot T_{sr}}\right) \ , \tag{13}$$

where $\text{int}_{\text{sup}}(x) = x$ when x is an integer, otherwise x is rounded to the next higher integer.

Once the optimal making instants are determined the controlled switching command is issued accordingly.

VI. Proposed Procedure Evaluation

The proposed procedure was evaluated through digital simulations using the ATP (Alternative Transients Program) [35] and was implemented using the MODELS language [36]. Data from the 500 kV Brazilian Power System Grid reported by [16] were used to produce some case studies. Its single-line diagram is shown in Fig. 9 and the focus is on the 400 km transmission line between Milagres and S. J. do Piaui, considering no shunt compensation and no surge arrester at line ends. The line is modeled using distributed constant-parameters whose data are shown in Table II. The CVT model discussed in Section III is used to provide the voltage signals necessary to the controlled switching method.

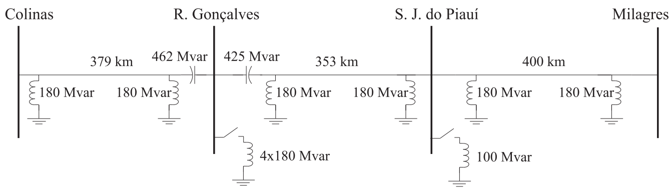

Fig. 9. Single line diagram from part of the Brazilian Power System Grid.

TABLE II
SEQUENCE PARAMETERS FOR THE LINE MILAGRES - S. J. DO PIAUI.

Sequence	R (Ω/km)	X (Ω/km)	ωC ($\mu\mho$/km)
Zero	0.4930	1.339	2.890
Positive	0.0186	0.267	6.124

A. DC Line Voltage Polarity Estimation

The line side voltage for an uncompensated line opening is presented in Fig. 10. After line opening (around 0.4 s), a DC line voltage can be observed. The CVT secondary voltage and its inaccuracies on measuring DC signals are highlighted in this figure. The application of the proposed RDF to correct the inaccuracies of the CVT transient response is also shown in Fig. 10. By using this procedure, the DC line voltage polarity can be easily and accurately estimated and then provided to controlled switching strategies for uncompensated lines.

B. Switching Overvoltage Analysis

The line side voltages for an uncompensated line controlled reclosing are presented in Fig. 11 and 12 considering the properly estimation of the DC line voltage polarity and mistaking this polarity, respectively. It can be observed that overvoltages are low for the first case, with maximum values below 1.80 p.u. along the line. However, the overvoltages may reach high values (above 4.0 p.u.) when reclosing the line considering the wrong DC line voltage polarity.

VII. CONCLUSION

In this paper, Recursive Digital Filters (RDF) were specially designed to correct the inaccuracies of the Capacitive Voltage Transformers (CVT) transient response and properly estimate the DC line voltage after line opening. By using this procedure, controlled reclosing strategies were successfully applied to uncompensated lines without the need for real time information on the current interruption at both line ends and low switching overvoltages were achieved. It was shown that severe overvoltages may be originated when the DC line polarity is mistaken.

The proposed approach for RDF design is also effective for dynamic correction of the CVT transient response and can be extended to other applications such as the improvement of numerical distance relay speed and reliability.

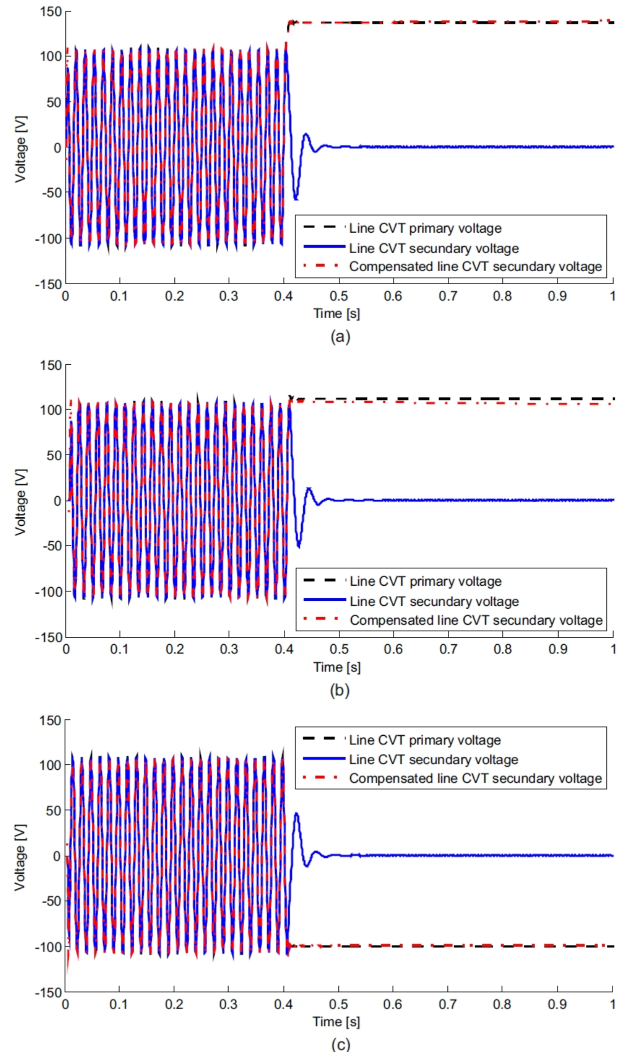

Fig. 10. Line side voltage for an uncompensated line opening. (a)Voltage in Phase A. Voltage in Phase B. Voltage in Phase C.

REFERENCES

[1] CIGRE Task Force 13.00.1, "Controlled Switching: A State of the Art Survey - Part I," *ELECTRA*, no. 162, pp. 65–97, Oct. 1995.

[2] CIGRE Working Group 13.07, "Controlled Switching of HVAC Circuit Breakers: Guide for Application Lines, Reactors, Capacitors, Transformers - 1st Part," *ELECTRA*, no. 183, pp. 42–73, Apr. 1999.

[3] ——, "Controlled Switching of HVAC Circuit Breakers: Planing, Specification and Testing of Controlled Switching Systems," *ELECTRA*, no. 197, pp. 21–33, Aug. 2001.

[4] CIGRE Working Group A3.07, "Controlled Switching of HVAC Circuit Breakers. Benefits & Economic Aspects," Jan. 2004.

[5] H. Ito, "Controlled Switching Technologies, State-of-the-Art," *Transmission and Distribution Conference and Exhibition 2002: Asia Pacific, IEEE/PES*, Oct. 2002.

[6] M. Sanaye-Pasand, M. Dadashzadeh, and M. Khodayar, "Limitation of Transmission Line Switching Overvoltages Using Switchsync Relays," *International Conference on Power Systems Transients (IPST)*, Montreal, Canada, Jun. 2005.

[7] D. Goldsworthy, T. Roseburg, D. Tziouvaras, and J. Pope, "Controlled Switching of HVAC Circuit Breakers - Application Examples and Benefits," *61st Annual Conference for Protective Relay Engineers*, College Station, Texas USA, Apr. 2008.

[8] K. M. C. Dantas, W. L. A. Neves, D. Fernandes Jr., and L. C. A. Fonseca, "A Suitable Method for Line Controlled Switching," *International Conference on Power Systems Transients (IPST)*, Vancouver, Canada, Jul. 2013.

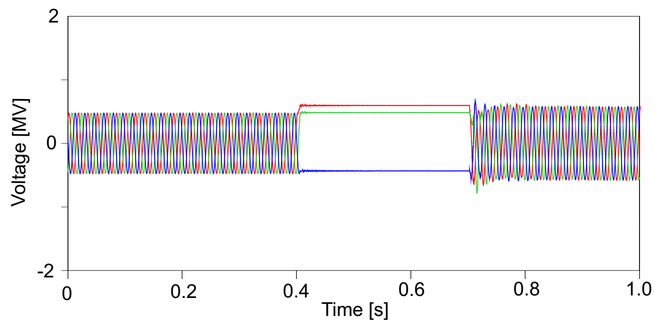

Fig. 11. Line side voltage due to line reclosing and properly estimating the DC line voltage polarity.

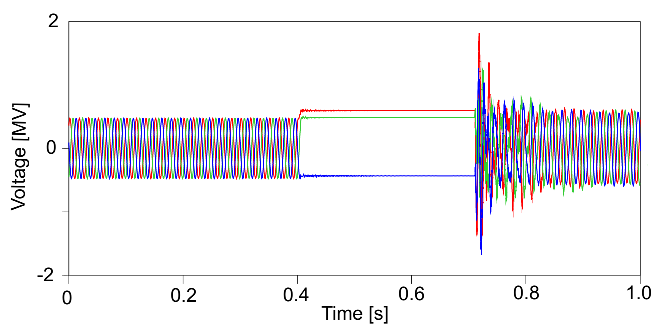

Fig. 12. Line side voltage due to line reclosing and mistaking the DC line voltage polarity.

[9] M. Atefi and M. Sanaye-Pasand, "Improving controlled closing to reduce transients in hv transmission lines and circuit breakers," *IEEE Transactions on Power Delivery*, vol. 28, pp. 733—741, 2013.

[10] Mitsubishi Electric Corporation, *Mitsubishi Electric Advance - Controlled Switching System, vol. 117*, Japan, March 2007.

[11] ABB, *Controlled Switching, Buyer's & Application Guide*, 3rd ed., ABB, Ludvika, Sweden, April 2009.

[12] K. M. C. Dantas, W. L. A. Neves, D. Fernandes Jr., G. A. Cardoso, and L. C. A. Fonseca, "On Applying Controlled Switching to Transmission Lines: Case Studies," *International Conference on Power Systems Transients (IPST)*, Kyoto, Japan, Jun. 2009.

[13] K. Froehlich, C. Hoelzl, M. Stanek, A. C. Carvalho, W. Hofbauer, P. Hoegg, B. L. Avent, D. F. Peelo, and J. H. Sawada, "Controlled Closing on Shunt Reactor Compensated Transmission Lines. Part I: Closing Control Device Development," *IEEE Trans. Power Delivery*, vol. 12, no. 2, pp. 734–740, Apr. 1997.

[14] U. Samitz, H. Siguerdidjane, F. Boudaoud, P. Bastard, J. Dupraz, M. Collet, J. Martin, and T. Jung, "On Controlled Switching of High Voltage Unloaded Transmission Lines," *e&i Elektrotechnik und Informationstechnik*, vol. 119, pp. 415–421, Dec. 2002.

[15] G. Pilz, P. Schegner, C. Wallner, H. Muhr, and S. Pack, "An Algorithm for the Three-Pole Controlled Auto-Reclosing of Shunt Compensated Transmission Lines with an Optimization for the Second and Third Pole," *e&i Elektrotechnik und Informationstechnik*, vol. 121, pp. 446–451, Dec. 2004.

[16] K. M. C. Dantas, D. Fernandes Jr., W. L. A. Neves, B. A. Souza, and L. C. A. Fonseca, "Mitigation of Switching Overvoltages in Transmission Lines via Controlled Switching," *IEEE Power & Energy Society General Meeting*, Pittsburgh, USA, Jul. 2008.

[17] P. Mestas, M. Tavares, and A. Gole, "Implementation and Performance Evaluation of a Reclosing Method for Shunt Reactor-Compensated Transmission Lines," *IEEE Trans. Power Delivery*, vol. 26, no. 2, pp. 954–962, Apr. 2011.

[18] K. M. C. Dantas, W. L. A. Neves, D. Fernandes Jr., G. A. Cardoso, and L. C. A. Fonseca, "Real Time Implementation of Transmission Line Controlled Switching," *International Conference on Power Systems Transients (IPST)*, Delft, The Netherlands, Jun. 2011.

[19] K. Dantas, W. Neves, and D. Fernandes, "An approach for controlled reclosing of shunt-compensated transmission lines," *Power Delivery, IEEE Transactions on*, vol. 29, no. 3, pp. 1203–1211, June 2014.

[20] H. Seyedi and S. Tanhaeidilmaghani, "New controlled switching approach for limitation of transmission line switching overvoltages," *Generation, Transmission Distribution, IET*, vol. 7, no. 3, pp. 218–225, March 2013.

[21] D. Fernandes Jr., W. Neves, and J. Vasconcelos, "Coupling Capacitor Voltage Transformer: A Model for Electromagnetic Transient Studies," *Electric Power Systems Research*, vol. 77, no. 2, pp. 125 – 134, 2007.

[22] E. Pajuelo, G. Ramakrishna, and M. Sachdev, "Phasor Estimation Technique to Reduce the Impact of Coupling Capacitor Voltage Transformer Transients," *IET Generation, Transmission & Distribution*, vol. 2, no. 4, pp. 588–599, Jul. 2008.

[23] H. B. Siguerdidjane, J. Gaonach, and N. L. Rohellec, "Applications of Digital Power Simulators: Advantages," *IEEE Transactions on Power Delivery*, vol. 12, no. 3, pp. 1137–1142, Jul. 1997.

[24] J. Izykowski, B. Kasztenny, E. Rosolowski, M. M. Saha, and B. Hillstrom, "Dynamic Compensation of Capacitive Voltage Transformers," *IEEE Transactions on Power Delivery*, vol. 13, no. 1, pp. 116–122, Jan. 1998.

[25] E. P. Machado, D. Fernandes Jr., and W. L. A. Neves, "A Recursive Filter to Correct Disturbance in the Secondary Voltage of Coupling Capacitor Voltage Transformers," *Proceedings of the 16th International Symposium on High Voltage Engineering, Cape Town, South Africa*, Aug. 2009.

[26] C. A. Silva, D. Fernandes Jr., W. L. A. Neves, and E. P. Machado, "Coupling capacitor voltage transformer: A device to correct its secondary voltage in real time," *Journal of Control, Automation and Electrical Systems*, vol. 24, no. 3, pp. 339–348, Apr. 2013.

[27] M. M. Saha, J. Izykowski, M. Lukowicz, and E. Rosolowski, "Application of ann Methods for Instrument Transformer Correction in Transmission Line Protection," in *Developments in Power System Protection*. IEE, 2001, pp. 303–306.

[28] H. K. Zadeh and Z. Li, "Development and Hardware Implementation of a Reliable Protective Relay Data Acquisition System," *International Journal of Electrical Power & Energy Systems*, vol. 44, no. 1, pp. 495 – 505, 2013.

[29] S. M. Saleh, E. M. Abould-Zahab, E. T. Eldin, D. K. Ibrahim, and M. I. Gilany, "Neural Network-Based Technique Used for Recovery the CCVT Primary Signal," *Power & Energy Society General Meeting*, 2009.

[30] E. Pajuelo, G. Ramakrishna, and M. Sachdev, "Phasor Estimation Technique to Reduce the Impact of Coupling Capacitor Voltage Transformer Transients," *IET Generation, Transmission & Distribution*, vol. 2, no. 4, p. 588599, 2008.

[31] F. B. Ajaei, M. Sanaye-Pasand, M. Davarpanah, A. Rezaei-Zare, and R. Iravani, "Mitigating the Impacts of CCVT Subsidence Transients on the Distance Relay," *IEEE Transactions on Power Delivery*, vol. 27, no. 2, pp. 497 –505, Apr. 2012.

[32] S. HAYKIN and B. VAN VEEN, *Signals and Systems*, 2nd ed. John Wiley & Sons, 2003.

[33] E. P. Machado, D. Fernandes Jr., and W. L. A. Neves, "Síntese de um Filtro Inverso - Vector Fitting versus Levenberg-Marquardt," *XX Congresso Brasileiro de Automática, Belo Horizonte, Brasil*, 2014. (In portuguese).

[34] A. S. e Silva, "Linhas de Transmissão não Compensadas: Manobra Controlada Considerando a Correcão da Resposta do TPC," Master's thesis, (In Portuguese), Federal University of Campina Grande, Campina Grande, Brazil, Aug. 2014.

[35] *ATP - Alternative Transient Program*, Leuven EMTP Center, Herverlee, Belgium, 1987.

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