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Research/Technical Note

Optimal Recloser Setting, Considering Reliability and Power Quality in Distribution Networks

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Abstract: Reclosers and fuses are the commonplace protective devices in distribution networks. A recloser can prevent long-time outages by clearing temporary faults before operation of the fuses in the system. Thus, it decreases the rate of long-term outages and improves system reliability and power quality. Despite positive features of reclosers, each operation of a recloser causes a momentary voltage interruption that exacerbates power quality. Nowadays, power quality issues have become more important because of the increasing use of sensitive equipment to voltage interruptions. According to the mentioned concerns, it seems necessary to set reclosers to strike a balance between power quality and the effectiveness of fuse saving scheme. Thus, we proposed a method to set reclosers. Due to the random nature of faults, the proposed method is stochastic based on the Monte Carlo method. The proposed method determines the optimal number of operations, reclosing intervals, and protection zones. The proposed method efficiency is evaluated according to the simulation results, and the proposed method is capable of establishing an optimal trade-off between power quality and protection efficiency.

Keywords: Power Quality, Recloser, Reclosure, Reliability

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1. Introduction

Nowadays, there is an increasing demand for high-quality and reliable electrical energy and protection systems play a significant role in the improvement of the system reliability [1], [2]. With integrating different energy resources and loads such as wind turbines and electric vehicles in smart grids [3] the system protection is of utmost importance. Since the consequences of low-standard electrical energy impose a considerable economic loss on customers as shown in [4] and [5] that special post-fault tasks are required for minimization of the economic losses. As an example, the cost of power interruptions to U. S. customers is $79 billion annually (divided into sustained outages: 33%, momentary outage: 67%) [6]. Faults are the major source the interruptions in distribution networks [7]. Overcurrent protection is the most common protection system in distribution networks. The statics provided in [8] shows that 70-90% of faults on overhead lines are temporary. Therefore, reclosers can improve the reliability of distribution networks. Previously, interruptions shorter than a few minutes were not considered as a source of worry to the most of the customers [9]. As permanent outages were the main concern of utility operators, protection systems were designed to decrease the system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI), and consequently the energy not supplied (ENS) [8]. In order to achieve these goals, the fuse-saving scheme (also referred to as feeder selective relaying) was employed. In this scheme, reclosers operate faster than the other overcurrent protection (OCP) devices to clear temporary faults [7], [8]. The fuse-saving scheme decreases permanent outages, however, increases the number of momentary voltage interruptions. Nowadays, electronic devices such as microcomputer-based devices and adjustable speed drivers are sensitive to momentary voltage interruptions [8]. Therefore, short-time voltage interruptions result in extensive sensitive load shutdowns. It has been reported that momentary outages account for two-third (52.3 billion dollars per year) of the overall power interruption cost in the USA [11], [12]. This indicates the main drawback of the fuse-saving scheme that decreases SAIFI at the expense of an increase in momentary average interruption frequency index (MAIFI). Thus, some utilities employ the fuse-blowing scheme (also known as instantaneous relay blocking) The fuse-blowing scheme decreases MAIFI, however, at the expense of an increase in SAIFI and SAIDI. The effect of reclosers on system outages has been studied in several publications. In [13], a technique proposed to identify the number, type, and location of the protective devices to reduce only SAIFI. Reference [13] is extended in [14] by using a goal programming approach to improve MAIFI. As discussed in [15], a non-linear binary programming solution is utilized to minimize the outage costs in distribution networks. In [16], non-linear binary programming model is used to reduce both SAIFI and SAIDI. In [17], the effects of protective devices on different indices such as MAIFI, SAIFI, SAIDI, and cost of ENS are studied, and it is shown that the cost of ENS is a more precise index than the other indices. Previous authors addressed many aspects of protection system to improve the system reliability. However, the effects of recloser settings, on system reliability and power quality, have not been studied in the literature. Hence, in this paper, we studied the effects of reclosers and proposed an approach based on the Monte Carlo method to set reclosers in distribution networks. The method is also applicable to be implemented in smart micro-grids since the energy resiliency is highly considered in smart grids [18-21]. The objective of the proposed method is minimization of total outage costs by establishing a trade-off between transient and permanent outages. In this regard, this paper aims at finding: 1) the optimum reach (zone) of a recloser, 2) the number of fast shots, and 3) and the reclosing time intervals. The concerned problem involves many parameters with random nature such as fault location, fault type, fault resistance, and fault nature (i.e., temporary or permanent.) Thus, a stochastic computational method is employed. As the Monte Carlo method has proven to be a beneficial statistical computational technique in attaining approximate answers to the stochastic problems with complex and non-linear parameters [22]. The outcomes of simulations indicate a decrease in outage costs resulted by the proposed method in which the recloser settings are optimally selected without new investment costs. This paper is organized as follows: In Section 2, the recloser and system outage features are described. In Section 3, the proposed method is described. In Section 4, the case study and simulation results are presented and discussed, and in Section 5, conclusion is stated.

2. Reclosers and Systems Outages

Reclosers exert considerable influence on both transient and permanent outages. Although there are some typical operating sequences for reclosers, it is more appropriate that operating sequence (shuts) of a recloser are selected based on the network specifications. Reclosers affect the system reliability and power quality in three ways as follows,

1) The effect of the shot number: each fast-shot gives temporary faults a chance to be cleared without causing a permanent outage. Therefore, if the number of fast-shots is increased, permanent outages, and consequently, SAIFI will decrease. On the other hand, as the number of fast-shots increases, a less number of loads can withstand the repetitive momentary voltage interruptions [23]. It leads to an increase in momentary outages and MAIFI.
2) Reclosing interval: reclosing interval is defined as the open-circuit time between an automatic opening and the succeeding automatic reclosure [1]. According to (1) and Figure 1, as reclosing interval increases, Risk of Arc Re-ignition (RAR) will decrease [24], [25].

$$R_{FO}(\Delta t_{DT}) = \int_{V_{min}}^{V_{max}} G(V)\, F(V, \Delta t_{DT})\, dv \qquad (1\ )$$

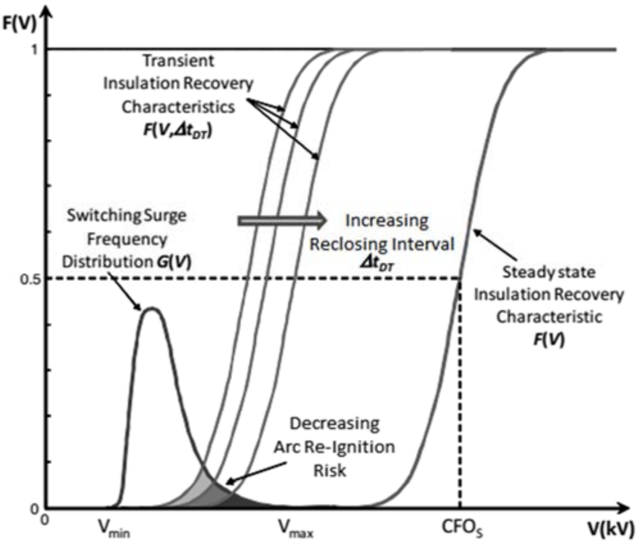

Figure 1. *The probability distribution function related to reclosing dead times.*

Where $G(V)$ is the switching surge frequency distribution, $F(V, \Delta t_{DT})$ is the transient flashover probability at different auto-reclosing dead times, $V_{\min}$ and V_{max} are the minimum and maximum switching over voltages. It is concluded from (1) and Figure 1 that longer reclosing intervals lead to less permanent outages caused by temporary faults. However, each device withstands an specific duration of voltage interruptions. Therefore, by increasing reclosing intervals, more equipment will be dropped out. 3) Reach (Zone) of reclosers: according to [26], and referring to Figure 2(a), the reach (or zone) of a recloser is defined as a section of a power network that the recloser operates for faults inside it before the other protective devices, while devices outside operate before the recloser. In other words, the fuse-saving scheme is used inside the reach while the fuse-blowing scheme is employed for the faults outside the reach. The reach (zone) of a recloser, contrary to differential or distance protection, is dependently settable. That is, the wideness of a recloser reach is related not only to its own curve but also to the time.

Current characteristics (TCC) curves of downstream protective devices. Referring to Figure 2(a) and (b), we can change the reach of the recloser by moving its fast-shot curve in selectivity diagram. For example, referring to Figure 2, if we decide that the recloser saves all the fuses in Reach 1, its fast-shot curve must be placed below the minimum melting time (MMT) curve of F1. In order to extend the recloser zone to reach 2, then the fast-shot must be placed below the MMTs of F1, F2, and F3. However, it is not always possible to place a recloser fast-shot curve below all the fuse MMTs, considering errors, delays, and grading time (also called as discrimination time or time interval) [27], [13].

The faults outside a reach cause a permanent outage for the loads downstream since a recloser clears temporary faults inside its zone. However, an extension to the reach of a recloser results in a decrease in permanent outages. On the other hand, fast operations of a recloser cause momentary voltage interruptions for downstream loads and it is highly probable that these interruptions cause momentary outages, especially for sensitive loads. Therefore, as the reach of a recloser extends the number of the momentary outages in the system increases.

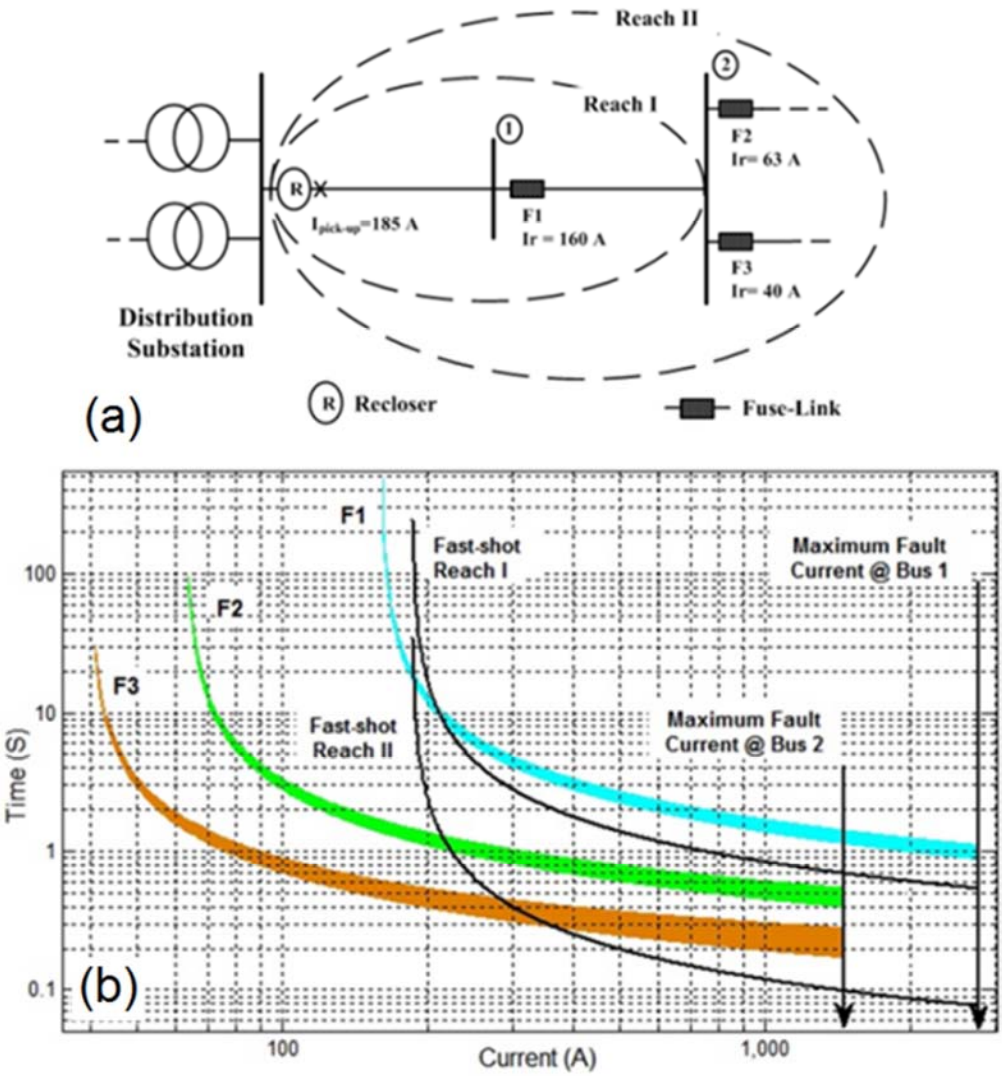

Figure 2. *(a) The reaches (zones) of a recloser. (b) The recloser time-inverse curves.*

3. The Proposed Method

The main goal of the proposed approach is to minimize the total outage cost resulted from a recloser and also to strike a balance between transient and permanent outages. Optimal setting of a recloser involves parameters with random natures such as fault location, fault type, fault resistance, and fault nature (temporary or permanent). These inputs are obtained based on historical data. Therefore, deterministic analyses of such data are inefficient as the input uncertainties may be ignored, while a stochastic method handles those uncertainties. In order to incorporate uncertainties the Monte Carlo method, a computational algorithm relying on repeated random sampling to obtain numerical results is used in the proposed method. The optimum settings for a recloser are achieved through the following steps and the flowchart is shown in Figure 3.

1. At first, one of the possible combinations of reclosing

interval, the number of shots and recloser reach is chosen as settings of the recloser.

2. Faults with random characteristics are generated, considering the following points:
   a) Fault location: The probability of fault occurrence in each line is selected using the available statistical data.
   b) Fault resistance: different fault resistances from zero (solid fault) to 100 ohms are considered.
   c) Fault type: the probability of different fault types (e.g., SLG, LL, LLG, and 3L) are selected based on available statistical data.
   d) Fault nature: between 70% to 90% of faults in aerial lines are permanent. However, this value should be in line with the available statistical data available for the system under study.
3. The costs of transient and permanent faults are calculated. The cost of transient faults are calculated as

$$C_m = \sum_{i=1}^{n} P_i \, T_i C_i \qquad (2)$$

Where P_i, T_i and C_i are, respectively, power consumption, restoration time and energy cost for load i and n is the number of loads that suffer momentary outages. Cost of the permanent outage (ENS cost) is also calculated using (3) as follows

$$C_s = P_d T_r C \qquad (3)$$

Where P_d is total power consumption of the downstream loads, T_r and C are restoration time of the network and energy cost, respectively.

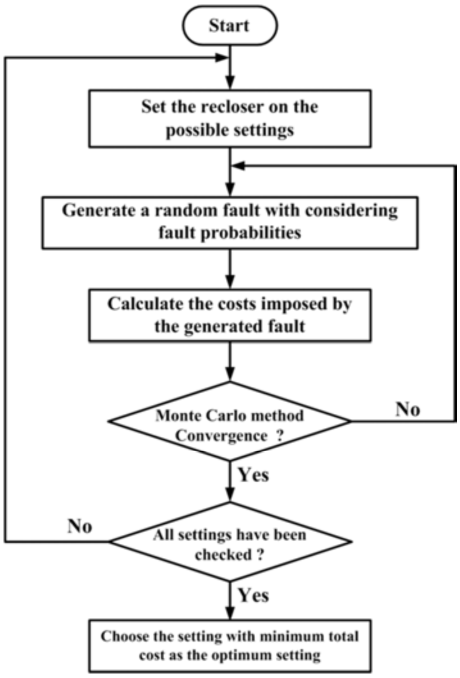

Figure 3. *The flowchart of proposed method.*

1. By repeating the steps 2 and 3, faults are generated and the costs are calculated. This procedure is repeated until the Mont Carlo method converges for each possible recloser setting.
2. Finally, the recloser settings that result in the lowest total cost among all possible settings is selected as the optimum settings.

4. Case Study

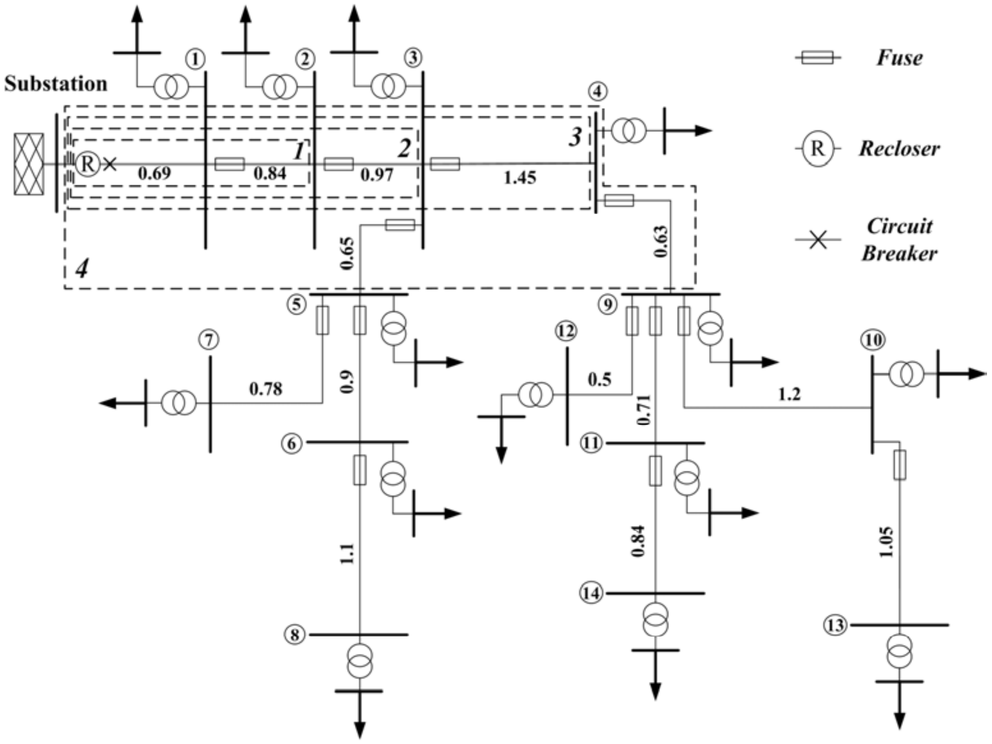

Figure 4. *The schematic of the test system. The possible recloser zones are shown with numbers 1 to 4. The lengths of lines are in kilometer.*

The single-line diagram of the system under study is depicted in Figure 4. In this network, fuses have been used to protect lateral lines and a recloser has been installed in the substation. Table 1 and Table 2 show the line parameters and load data, respectively. The type of transformers is DYn and its ratio is 20/0.4 kV. Four possible settings for the recloser are considered as follows: Case 1: two fast shots with a 1.5-second reclosing interval. Case 2: one fast shot with a 1.5-second reclosing interval. Case 3: two fast shots with a 0.5-second reclosing interval. Case 4: one fast shot with a 0.5-second reclosing interval. The total number of faults in this network is considered as 15 faults per year and the probabilities of different fault types are as follows: LG = 75%, 2LG = 17%, 3LG = 3%, 2L = 3%, and 3L = 2%. In addition, 80% of faults in this network are temporary. Table 3 presents the percentage of temporary faults that are cleared in each recloser shot according to the reclosing interval. The probability of fault occurrence in each line is proportionate to the line length.

The fault resistance has a normal distribution with a mean value of 5 Ω and a standard deviation of 1 Ω [7]. The loads based on their sensitivity to power quality problems (i. e., voltage sag and momentary voltage interruption) are classified into three categories as follows: (A) Highly sensitive, (B) medium sensitive, and (C) low sensitive as shown in Table 4. The energy cost and the average duration of supply restoration for this network are 150 \$/(MW·Hour) and 2.5 Hour, respectively. The average cost of shots is considered as \$10 per shot [17]. By setting a number of shots and reclosing interval based on the abovementioned cases and repeating the proposed Monte Carlo method temporary and permanent outage costs, and case 3 is selected as the optimum setting for the recloser in the test system.

Table 1. *Line impedance per length.*

Parameters per Length	1, 2 Sequence Impedance (Ohm/ km)	Zero Sequence Impedance (Ohm/ km)
Resistance (R)	0.45	0.6
Reactance (X)	0.36	1.59

Table 2. *Active and reactive power of connected loads.*

Bus Num	P (MW)	Q (MVAr)	Bus Num	P (MW)	Q (MVAr)
1	0.6	0.25	8	0.6	0.25
2	0.65	0.5	9	0.35	0.09
3	0.55	0.38	10	0.45	0.15
4	0.65	0.5	11	0.35	0.09
5	0.32	0.15	12	0.56	0.24
6	0.35	0.09	13	0.56	0.24
7	0.56	0.24	14	0.35	0.09

Table 3. *Clearance probability of temporary faults in each recloser shot.*

Reclosing Interval (S)	One Fast Shut	Tow Fast Shuts	
	Clearance Probability (%)	Clearance Probability in First Shut (%)	Clearance Probability in Second Shut (%)
0.8	80	50	10
1.5	80	80	15

Table 4. *ITIC curves for the three categories of loads.*

Magnitude of Voltage sag (P. U)	Withstanding duration (S)		
	A	B	C
0	0.02	0.3	1
0.5	0.2	0.5	1.5
0.7	0.5	1	2
0.8	10	12	15

5. Conclusion

Reclosers are the essential part of the power system and can prevent long-term outages by detecting and interrupting temporary faults. Due to the quick operation of reclosers, some power quality issues may happen in the system. In this paper, a Monte Carlo based method has been proposed for setting reclosers. In this method the optimal number of operations, the reclosing intervals, and the protection zones is determined. The simulation results validate the efficiency of the proposed method.

References

[1] Gers, J. M., and Holmes, E. J., “Protection of electricity distribution networks,” IET Press, 1998.

[2] M. A. Chitsazan, A. M Trzynadlowski, “Harmonic Mitigation in Interphase Power Controllers Using Passive Filter-Based Phase Shifting Transformer”, Energy Conversion Congress and Exposition (ECCE), 2016 IEEE, pp. 1-5, Sep. 2016.

[3] I. Niazazari, H.A. Abyaneh, M. J. Farah, F. Safaei, andH. Nafisi,“Voltage profile and power factor improvement in PHEV charging station using a probabilistic model and flywheel,” In Electrical Power Distribution Networks (EPDC), 2014 19th Conference on pp. 100-105. May. 2014.

[4] R. Jalilzadeh Hamidi and H. Livani, “A travelling wave-based fault location method for hybrid three-terminal circuits,” IEEE PES-GM, pp. 1-5, Jul. 2015.

[5] R. Jalilzadeh Hamidi, H. Livani, “Traveling wave-based fault location algorithm for hybrid multi-terminal circuits,” IEEE Trans. Power Delivery, Vol. 32, No. 1, pp. 135-144, Feb. 2017.

[6] Koner, P., and Ledwich, G.: ‘SRAT-distribution voltage sags and reliability assessment tool’, IEEE Trans. Power Delivery, 2004, vol. 19, pp. 738–744.

[7] Patne, N. R., and Thakre, K. L., “Effect of transformer type on the estimation of financial loss due to voltage sag–PSCAD/EMTDC simulation study”, IET Generation, Transmission & Distribution, 2010, vol. 4, pp. 104–114.

[8] IEEE Std C 37.60-2012, ‘High-voltage switchgear and control gear - Part 111: Automatic circuit reclosers and fault interrupters for alternating current systems up to 38 kV’, 2012.

[9] Math H. Bollen, “Understanding power quality problems: voltage sags and interruptions,” Wiley-IEEE Press, ISBN: 9780470546840, 2000.

[10] M. A. Chitsazan, A. M Trzynadlowski, “State Estimation of Power Systems with Interphase Power Controllers Using the WLS Algorithm”, Energy Conversion Congress and Exposition (ECCE), 2016 IEEE, pp. 1-5, Sep. 2016.

[11] Koner, P., and Ledwich, G. ‘SRAT-distribution voltage sags and reliability assessment tool’, IEEE Trans. Power Delivery, 2004, vol. 19, pp. 738–744.

[12] Williams, C., McCarthy, C., and Cook, C. J.: ‘Predicting reliability improvements’, IEEE Power and Energy Magazine, 2008, vol. 6, pp. 53-60.

[13] Soudi, F., and Tomsovic, K., ‘Optimized distribution protection using binary programming’, IEEE Trans. Power Delivery, 1998, vol. 13, pp. 218–224.

[14] Soudi, F., and Tomsovic, K. ‘Optimal trade-offs in distribution protection design’, IEEE Trans. Power Delivery, 2001, vol. 16, pp. 292-296.

[15] Bupasiri, R., Wattanapongsakorn, N., Hokierti, j., and Coit, D. W. ‘Optimal electric power distribution system reliability indices using binary programming’, Annual Reliability and Maintainability Symposium, 2003, pp. 556-561.

[16] Zambon, E., Bossois, D. Z., Garcia, B. B., and Azeredo, E. F.: ‘A novel nonlinear programming model for distribution protection optimization’, IEEE Trans. Power Delivery, 2009, vol. 24, pp. 1951–1958.

[17] Haakana, J., Lassila, J., Kaipia, T., Partanen, J., “Comparison of Reliability Indices from the Perspective of Network Automation Devices,” IEEE Trans. Power Delivery, Vol. 25, No. 3, pp. 1547–1555, 2010.

[18] V. Sarfi, I. Niazazari, and H. Livani, "Multiobjective fireworks optimization framework for economic emission dispatch in microgrids." North American Power Symposium (NAPS), 2016, pp. 1-6, Nov. 2016.

[19] M. A. Chitsazan, G. B. Gharehpetian, M. Arbabzadeh,” Application of Voltage Source Convertor in Interphase Power Controller”, Proceedings of the World Congress on Engineering and Computer Science 2012 Vol II, WCECS 2012, October 24-26, 2012, San Francisco, USA.

[20] R. Jalilzadeh Hamidi, H. Livani, S. H. Hosseinian, and G. B. Gharehpetian, “Distributed cooperative control system for smart microgrids,” Electric Power System Research, Vol. 130, pp. 241-250, 2016.

[21] J. Chen and Q. Zhu, "A Game-Theoretic Framework for Resilient and Distributed Generation Control of Renewable Energies in Microgrids," IEEE Trans. Smart Grid, Vol. 8, No. 1, 2017.

[22] S. Mark and S. Mordechai, “Applications of Monte Carlo method in science and engineering,” INTECH, 2011.

[23] Martinez, J. A., and Martin-Arnedo, J. ‘Voltage sag studies in distribution network–part II: voltage sag assessment’, IEEE Trans. Power Delivery, 2006, vol. 21, pp. 1679–1688.

[24] G. Celli, Emilio GHIANI, Fabrizio Pilo, Sergio Tedde, “Extending switching reclosing time to reduce interruptions in distribution networks,” CIRED, 21 St. International Conference on Electricity Distribution Frankfurt, 6-9 June 2011.

[25] G. Celli, E. Ghiani, F. Pilo, S. Tedde, “A probabilistic fault arc reignition model for mv distribution networks,” 17-th Power Systems Computation Conference, Stockholm Sweden - August 22-26, 2011.

[26] COOPER, Analysis of distribution systems reliability and outage rate, R280-90-7, 2004.

[27] Jamali, S., and Shateri, H. ‘Optimal siting of recloser and sectionalizers to reduce non-distributed energy’, IEEE PES Transmission and Distribution Conference and Exhibition: Asia and Pacific, Dalian, China, 2005, pp. 1–7.