Reliability Study of a Smart Distribution System with Optimal Sizing and Placement of Capacitors

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2021 IEEE PES Innovative Smart Grid Technologies - Asia (ISGT Asia) | 978-1-6654-3339-6/21/$31.00 ©2021 IEEE | DOI: 10.1109/ISGTASIA49270.2021.9715699

***Abstract*— This work introduces a new modified IEEE 33-node test system to be smart by implementing distributed renewable generation, smart metering load characteristics, and optimal installation of capacitors. The Particle Swarm Optimisation (PSO) technique is adopted to compute the optimal sizing and placement of capacitor in the original network. Then, to assess the reliability of the original and modified test systems, a sequential Monte Carlo simulation takes place. The relevant contribution of this paper is that it offers a comprehensive approach of a reliability assessment in a distribution system, where several smart features have been implemented. In addition, the modified system opens a pathway for future research in which smart distribution system analysis is required related mainly to reliability assessment.**

***Keywords*— capacitor, Particle Swarm Optimisation, power losses, reliability assessment, sequential Monte Carlo simulation, smart distribution system, smart grids**

I. INTRODUCTION

Capacitors are extensively used in transmission and distribution networks to reduce power losses, release feeder capacity, improve voltage profiles, reactive power compensation, and power factor correction [1]. All these aspects result in relevant effects on the cost of investment in the network. Therefore, placement of capacitors is a complex optimisation problem due to the benefits of reducing power losses and decrease installation costs to be minimum. Moreover, the impact on the system reliability should be analysed after the implementation of such devices and other smart characteristics to have a global assessment of the system.

Approximately 13% of global generation is wasted in the distribution side since most of distribution components have a significant consumption of reactive power [1]. In addition, a rising demand for reliable electrical services, enhanced quality, and an increasing introduction of distorting devices may result to a higher demand of quality by both users and stakeholders [2].

Inaccurate capacitor placement would reduce the system benefits, or even increase power losses and cause system disturbances [3].

Given the relevance of the topic, many different optimisation approaches have been proposed for such problematic. In 1997, Chis et al. developed heuristic search strategies (HSS) for optimal placement of capacitors in distribution netwroks [4]. In 2007, the authors in [5] proposed a particle swarm optimisation (PSO) based capacitor placement on radial distribution networks. They additionally designed the loss sensitivity factor (LSF) for improving the research space of the optimisation algorithm in order to enhance accuracy and reduce processing time. Same year, Prasad et al. produced a fuzzy-genetic algorithm (FGA) for optimal placement of capacitors and sizing in radial distribution networks [6]. In 2011, the authors in [7] proposed a new evolutionary technique (NET) to optimize capacitors in parallel in distribution systems. In 2014, Elsheikh et al. performed a two-stage method; in one hand, (i) they used LSF to recognise the suitable buses for capacitor allocation, and (ii) a discrete particle swarm optimisation to get the capacitor power to be implemented [8]. In 2015, the authors in [9], in addition to the LSF, introduced the voltage stability index (VSI) to get the optimal location of capacitor. They also introduced the bacterial foraging optimisation algorithm (BFO) to compute the optimal sizing of capacitors. In the same year, in [10], the authors determined the critical buses to allocate capacitor using LSF to optimally find the allocation of capacitors by using an ant colony optimisation (ACO) algorithm. In 2016, Abdelaziz et al. proposed flower pollination algorithm (FPA) to optimize the size and location of capacitors in radial networks, and power loss index (PLI) [11]. Finally, same year, Ahmed et al. proposed a new hybrid particle swarm optimisation (HPSO) method for placement and sizing of capacitors in radial networks [2]. One gap of these studies is that they did focus their attention only in the power losses reduction, leaving aside reliability evaluation. Furthermore, the integration of smart features such as DERs is not considered in the distribution system.

On the other hand, the attempt of probability defining distribution functions related to the distribution reliability indexes by developing simulation and analytical techniques had been studied in the past [12-23]. In this context, a proposed suitable technique to analyse chronological issues of a complex power system is the Sequential Monte Carlo Simulation (MCS).

Motivated by the aforementioned facts, this paper introduces a modified IEEE 33-node test feeder to be smart by implementing new features such as smart metering load characteristics, distributed renewable generation, and optimal installation of capacitors to turn the system more efficient. The Particle Swarm Optimisation (PSO) technique is used to compute the optimal capacitor sizing and placement. Likewise, a Sequential Monte Carlo Simulation (MSC) is developed for evaluating the system reliability. The modified IEEE 33-node open a pathway for future research, in which smart distribution system is required. This paper is structured in 7 sections. Section II presents the optimisation methodology, objective function and constraints; section III introduces the optimisation techniques PSO; section IV develops the reliability study procedure and the technique SMCS; section V describes the case studies to validate the proposed techniques; section VI shows the results from the simulations; and finally, section VII brings the conclusions.

II. OPTIMISATION METHODOLOGY

A. Power Losses

To determine the power losses, according to the Joule effect, we considered a line between buses "i" and "j", impedance is represented by $Z_{ij} = R_{ij} + jX_{ij}$, current by I_{ij} and the power flow by $P_{ij} + jQ_{ij}$, as follows:

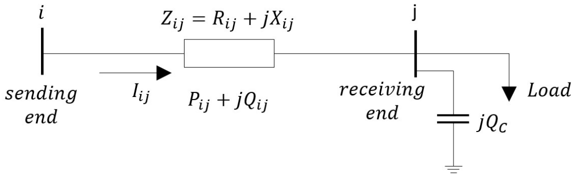

Fig. 1. Single-line diagram of a distribution line

Therefore, the power losses can be rewritten as:

$$P_{ij}^{loss} = \frac{P_{ij}^2 + Q_{ij}^2}{V_i^2} R_{ij} \tag{1}$$

$$Q_{ij}^{loss} = \frac{P_{ij}^2 + Q_{ij}^2}{V_i^2} X_{ij} \tag{2}$$

From (1) and (2), it can be observed that one effective method to improve power losses is to reduce the reactive power transmission through distribution lines Q_{ij} without affecting the real power transmission and voltage profiles. Consequently, the installation of a suitable capacitor with size Q_c at the load side, may fit the reactive power load consumption and reduce the active power losses.

B. Objective Function

The aim of introduction of reactive capacity in a distribution system is to improve voltage levels and reduce overall system losses. These would also reduce the total energy cost and maximize the savings. Nevertheless, installation of capacitors incurs investment costs. Thus, the optimisation problem is to maximise the savings per year subjected to given operational constraints.

$$\max f = maximise(saving_{function}) \tag{3}$$

$$saving_{function} = K_L P_T^{loss} - \sum_{0}^{j} K_j^{Cap} Q_j^{Cap} \tag{4}$$

where, K_L stands for the total yearly per unit costs of power losses expressed in $(\$/kW_{year})$, P_T^{loss} is the overall reduction of losses after placement of capacitors, j represents the candidates for capacitor placement, K_j^{Cap} stands for the annual capacitor expenses in $(\$/kVAr_{year})$, and Q_j^{Cap} represents the size of a capacitor at jth location.

C. Constraints

The optimisation problem is subjected to the next constraints:

- Equality constraints for power balance including the overall generation P_{Total}^G and Q_{Total}^G, overall load P_{Total}^L and Q_{Total}^L, overall losses P_{Total}^{loss} and Q_{Total}^{loss}, and total reactive power of capacitors to be placed Q_{Total}^C.

$$P_{Total}^G = P_{Total}^L + P_{Total}^{loss} \tag{5}$$

$$Q_{Total}^G + Q_{Total}^C = Q_{Total}^L + Q_{Total}^{loss} \tag{6}$$

- Voltage limits at each V_i which includes V_{max} and V_{min} for maximum and minimum acceptable values. $i = 1,2,3,\dots n$ where (n stands for busbars)

$$V_{min} \le V_i \le V_{max} \tag{7}$$

- The apparent power $S_{(i)}^{line}$ transported by any branch is restricted by the thermal capacity of the line $S_{l(i)}^{thC}$.

$$S_{(i)}^{line} \le S_{l(i)}^{thC} \tag{8}$$

- Generation at each bus is limited by the maximum and minimum value of each generator installed.

$$P_{min}^G \le P_i^G \le P_{max}^G \tag{9}$$

$$Q_{min}^G \le Q_i^G \le Q_{max}^G \tag{10}$$

- The maximum size of capacitors Q_{max}^C is limited by the overall reactive power of the load Q_{Total}^L.

$$0 \le Q_{max}^C \le Q_{Total}^L \tag{11}$$

III. OPTIMISATION TECHNIQUES

The scope of this study is to carry out a reliability assessment of a smart distribution system rather than to introduce a new optimisation technique for sizing and placement of capacitors. For this reason, the optimisation problem is approached by using the well-known Particle Swarm Optimisation (PSO). This optimisation technique consists of an iterative algorithm, which evolves a cluster of particles by competition and cooperation among the particles themselves through iterations [2]. Each particle signifies a possible solution. Particles change their place in a search space and update their velocity subjected to their own and neighbour's movement behaviour, trying to get a better position at every iteration, subjected to the objective function and constraints.

At this work, the particles position is defined as the capacitors to be installed $Q_1^c, Q_2^c, \dots, Q_j^c$. The available ranges of capacitors and their costs per year K_j^{Cap} are considered in reference [24] and contrasted with references [1] and [25]. The power flow is executed at each iteration to get the voltage V_i at all buses, the losses P_{Loss}, the power flow $S_{l(i)}$, and generation at each bus P_i^G and Q_i^G. Finally, the overall yearly saving cost function exposed in (*3*) and (*4*) is calculated subjected to the constraints. The developed procedure is exposed in Fig. 2.

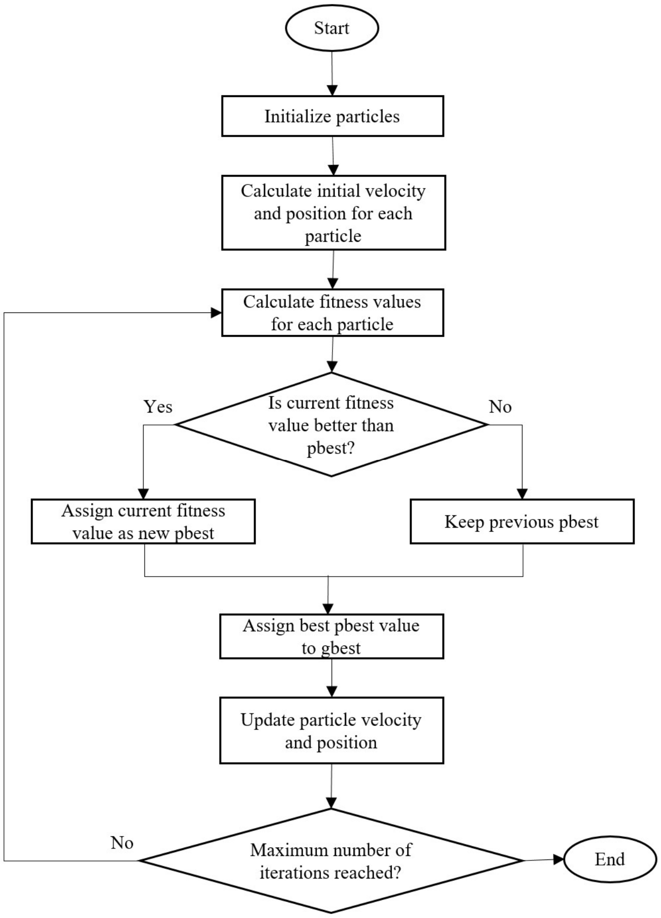

Fig. 2. Algorithm for the implemented PSO

IV. RELIABILITY ASSESSMENT PROCEDURE

A. Reliability Indices

Following the IEEE Guide for Electric Power Distribution Reliability Indices, three main indexes for evaluating the reliability in a distribution network are to be analysed: SAIFI, SAIDI, CAIDI [26]. Additionally, the Average Energy Not Supplied (AENS) will be get from the case study to get a better understating of the reliability problem.

B. Sequential MCS

Each of the modelled components in the network is to be formulated by a binary-state (up-down) model [27]. The up-state is defined as the time during when the component remains working and is called time-to-failure (TTF). The down-state is for the time during when the component is out of service due to reparation or replacement and is termed time-to-repair (TTR). These two indices depend on several aspects comprehending size, type, functioning, climate and physical location [28]. The state-space model of a system with n components is presented in Fig. 3.

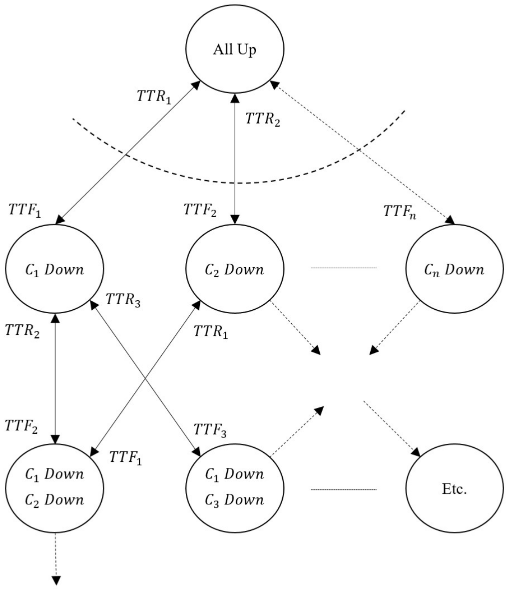

Fig. 3. State-space model of a system. Each component of the system is represented by C_i, TTF_i and TTR_i. The failure of any component would lead the respective load point to fail.

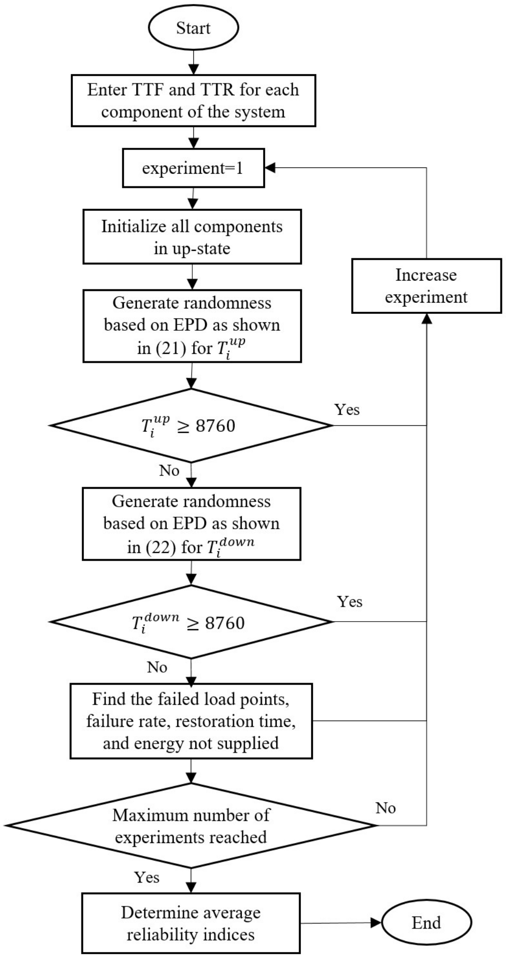

Fig. 4. Algorithm of the implemented sequential MCS. The procedure considers a time of one year (8760 hours).

The sequential MCS models the system states in chronological order [29]. In cooperation with the TTF and TTR indices, uniformly distributed independent random numbers are applied to generate an artificial operating history T_i^{up} and repair history T_i^{down} of each component. The TTF and TTR are assumed to be constant and an exponential probability distribution (EPD) is developed to model the uncertainty of TTF and TTR [13, 27, 30].

$$T_i^{up} = -\frac{1}{TTF_i} \ln (U_1) \tag{12}$$

$$T_i^{down} = -\frac{1}{TTR_i} \ln (U_2) \tag{13}$$

Where T_i^{up} and T_i^{down} define the reparation and restoration records of a network component. U_1 and U_2 are independent random numbers distributed uniformly between $[0, 1]$.

The search process for defining failed loads is adopted from [31]. The developed procedure is presented in Fig. 4.

V. CASE STUDIES

The proposed methodology and techniques PSO and sequential MCS have been applied to the following scenarios.

A. Test Case 1: IEEE 33-node test feeder

The system data to execute the power flow has been adopted from [32].

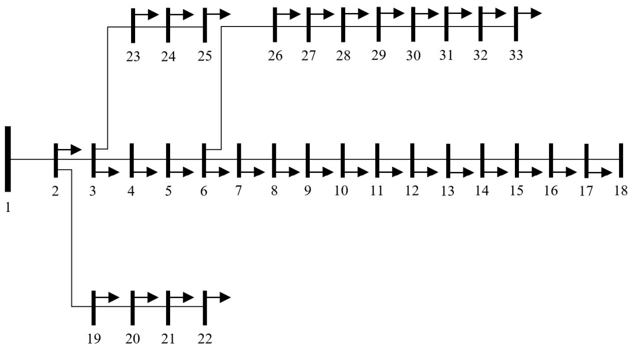

Fig. 5. Test Case 1: IEEE 33-node test feeder

B. Test Case 2: Modified IEEE 33-node Test Feeder

A modified IEEE 33-node test is introduced by including:

1. Smart metering load characteristics (SMLC): resulting from [33] are implemented (winter profiles for households) as shown in Fig. 6.

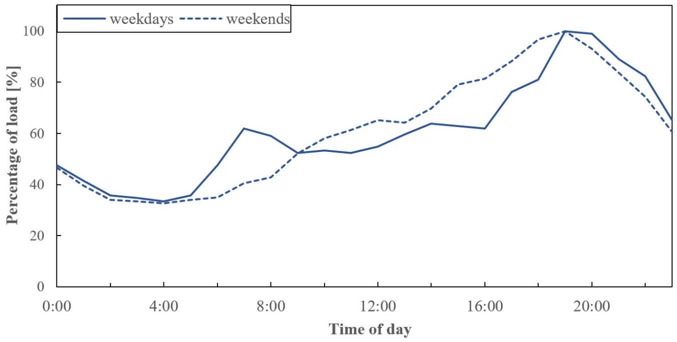

Fig. 6. Smart metering hourly load profiles for weekdays and weekends, in percentage of peak load.

2. Distributed renewable generation (DRG): which is another optimisation problem beyond this work. It has been already analysed in [34] using a Bat-inspired algorithm as well as a PSO analysis, and it is validated in the IEEE 33-node test feeder. Likewise, hourly generation output profiles for wind and solar units are used over the year of analysis as shown in Fig. 7 [35].

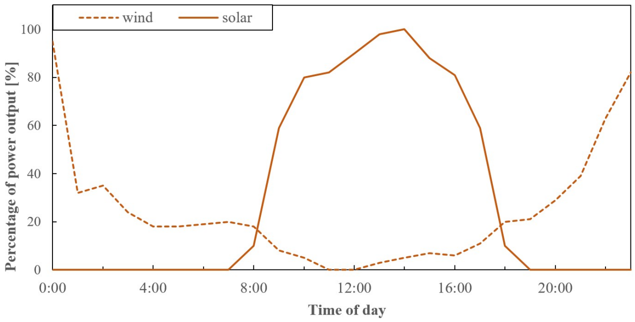

Fig. 7. Power output hourly profiles for wind and solar units, in percentage of installed capacity.

3. Results from the PSO optimisation process (capacitors size and place).

VI. TEST RESULTS

The proposed algorithms are modelled and simulated in MATLAB.

A. Sizing and Placement of Capacitors

The PSO algorithm is tested at full load (worst scenario) and DRG is working at 20% of their capacity. Voltage limits are considered between $V_{min} = 0.9$ and $V_{max} = 1.1$ per unit [1, 34, 36]. Power limits for renewable generation are set at rated power and $Q_{min}^G = Q_{max}^G = 0$ per unit. The available ranges of capacitors Q_j^{Cap} and their costs per year K_j^{Cap} are presented in Table I [1, 24, 25]. The overall reactive load of the test feeder limits the maximum size of capacitors $Q_{max}^C = 2400\ kVAr$. The equivalent per unit yearly costs of losses K_L is considered to be 168 \$/kW from [1, 2, 36]. We set the iterations to 150, and the population size to 200.

TABLE I

STANDARD CAPACITORS RANGES AND THEIR YEARLY COST

Size (kVAr)	Cost (\$/kVAr/year)	Size (kVAr)	Cost (\$/kVAr/year)
150	0.500	1350	0.207
300	0.350	1500	0.201
450	0.253	1650	0.193
600	0.220	1800	0.187
750	0.276	1950	0.211
900	0.183	2100	0.176
1050	0.228	2250	0.197
1200	0.170	2400	0.170

Table II shows the results for the proposed scenarios, from Test Case 1 and until Test Case 2 is fully implemented. The total power losses are reduced from 201 kW at Test Case 1 to 51 kW at Test Case 2 (all smart features implemented). The contribution of capacitors in total loss reduction is 67 kW, the SMLC contributes to 58 kW loss reduction, and DRG to 23 kW. The least voltage is improved from 0.913 to 0.943 per unit. The overall yearly costs decrease from 33,802 to 9,688 \$/year. The power factor increases from 0.849 to 0.995. The reactive power losses decrease from 134.8 to 34.8 kVAr. The effects on voltage profiles are presented in Fig. 9.

TABLE II

RESULTS OF DIFFERENT SCENARIOS AND PSO ALGORITHM

Item	Uncompensated		Compensated			
	Test Case 1	Test case 1 + DRG	Test case 1 + DRG + capacitors		Test case 2 (SMLC)	
Total active losses (kW)	201.205	177.292	110.013		51.601	
Active loss reduction (%)	-	11.88	37.95		53.10	
Total reactive losses (kW)	134.819	118.457	73.642		34.792	
Reactive loss reduction (%)	-	12.14	37.83		52.76	
Vmin (pu), node 18	0.913	0.921	0.943		0.943	
Vmax (pu), node 2	0.997	0.997	0.998		0.998	
Power factor	0.849	0.849	0.995		0.995	
Optimal place node and size of capacitors (kVAr)	-	-	2	150	2	150
			3	750	3	750
			7	300	7	300
			10	300	10	300
			32	900	32	900
Total compensation (kVAr)	-	-	2400		2400	
Annual active loss-cost ($/year)	33802.44	29785.06	18482.18		8668.97	
Total compensation cost ($/year)	-	-	1019.7		1019.7	
Total annual cost ($/year)	33802.44	29785.06	19501.88		9688.67	
Net saving ($/year)	-	4017.38	10283.17		9813.22	
Savings (%)	-	11.88	34.52		50.32	

Finally, the Test Case 2 including all new smart features is presented graphically in Fig. 8.

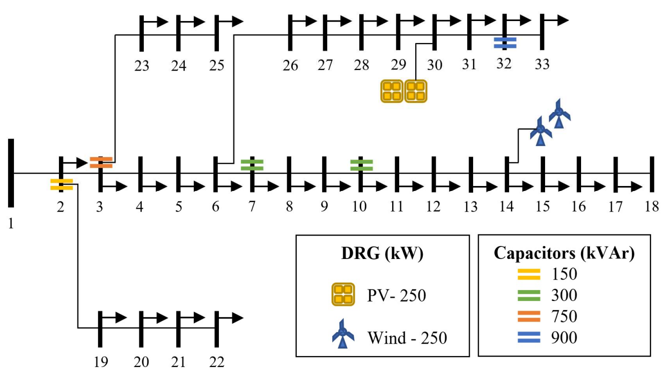

Fig. 8. Test Case 2: Modified IEEE 33-node test feeder

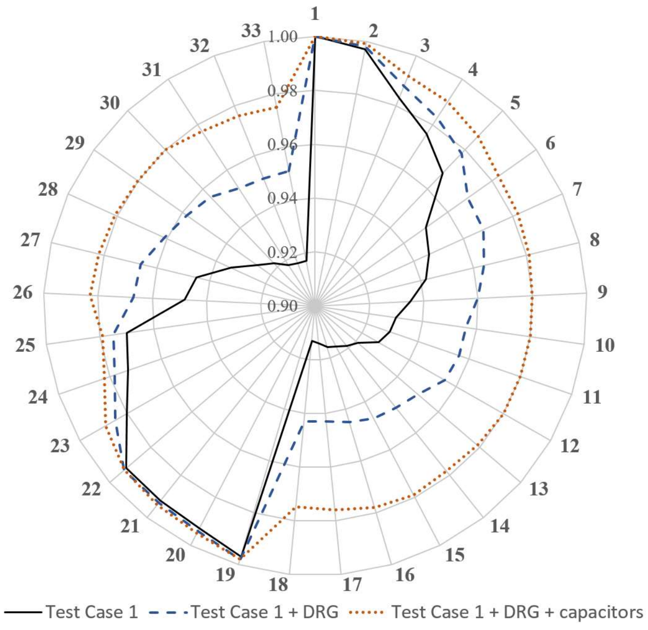

Fig. 9. Voltage profiles resulting from the proposed scenarios

B. *Reliability Assessment*

The SMCS algorithm is applied to both Test Case 1 and 2. For the sake of simplicity, this model just considers the system lines, generators, and capacitors as failing components. Breakers, fuses, switches, busbars, and weather conditions would be considered in a future analysis, and thus, they are assumed fully reliable. The failure TTF and repair TTR data for each component is adopted from [37], considering a TTF between 0.24 and 0.55 occurrences/year, and a TTR between 3.40 and 3.50 hours. The TTF for PV and wind units are 0.1 and 0.25 occurrences/year, respectively; and the TTR is 20 hours for both generation units [38]. Customers are considered to have an average peak load of 2.5 kW and 4.0 kVAr [37]. Finally, the number of experiments is set to 1000. The resulting reliability indexes are shown in Table III.

TABLE III

RELIABILITY INDEXES

Index	SAIFI	SAIDI	CAIDI	AENS
Test Case 1	0.30177	4.48427	14.85101	66.08721
Test Case 2	0.24597	3.65515	14.86001	53.86795

Units: SAIFI - interruption/customer. Year, SAIDI - hours/customer.year, CAIDI - hours/customer interruption, AENS - kWh/customer.year

The incorporation of smart features on the original IEEE 33-node test feeder, reduces the system average interruption frequency and duration by 18%.

VII. CONCLUSIONS

This work presents a comprehensive analysis of a reliability assessment in a new smart distribution system. A modified IEEE 33-node test feeder is introduced by including DRG, SMLC, and optimal installation capacitors. Once the smart distribution system is fully designed, a sequential MCS method is implemented to assess the reliability.

The PSO results show that, as expected, the implementation of capacitors decreases the overall system losses, enhances the voltage levels and power factor, and drops the total annual cost of the system. Nevertheless, their sizing and placement should obey to an optimisation problem to maximize the benefits and avoid unnecessary losses. Likewise, the sequential MCS method computed four reliability indices (SAIFI, SAIDI, CADI, AENS). The results show that the incorporation of smart characteristic in the original test system improves the system reliability by 18%.

REFERENCES

[1] H. Lotfi, M. Samadi, and A. Dadpour, "Optimal capacitor placement and sizing in radial distribution system using an improved Particle Swarm Optimization algorithm," in *Electrical Power Distribution Networks Conference (EPDC), 2016 21st Conference on*, 2016, pp. 147-152.

[2] F. Salinas-Herrera, D. Salinas-Herrera, and G. Pardo-Salazar, “Coordinated Strategy for SVC Operation: Ecuadorian Case,” in 2021 IEEE PES Innovative Smart Grid Technologies Conference-Latin America (ISGT Latin America), 2021, pp. 1–6.

[3] H. Khodr, F. Olsina, P. De Oliveira-De Jesus, and J. Yusta, "Maximum savings approach for location and sizing of capacitors in distribution systems," *Electric Power Systems Research,* vol. 78, pp. 1192-1203, 2008.

[4] M. Chis, M. Salama, and S. Jayaram, "Capacitor placement in distribution systems using heuristic search strategies," *IEE Proceedings-Generation, Transmission and Distribution,* vol. 144, pp. 225-230, 1997.

[5] K. Prakash and M. Sydulu, "Particle swarm optimization based capacitor placement on radial distribution systems," in *Power Engineering Society General Meeting, 2007. IEEE*, 2007, pp. 1-5.

[6] P. Prasad, S. Sivanagaraju, and N. Sreenivasulu, "A fuzzy-genetic algorithm for optimal capacitor placement in radial distribution systems," *ARPN Journal of Engineering and Applied Sciences,* vol. 2, pp. 28-32, 2007.

[7] A. Elmaouhab, M. Boudour, and R. Gueddouche, "New evolutionary technique for optimization shunt capacitors in distribution networks," *Journal of Electrical Engineering,* vol. 62, pp. 163-167, 2011.

[8] A. Elsheikh, Y. Helmy, Y. Abouelseoud, and A. Elsherif, "Optimal capacitor placement and sizing in radial electric power systems," *Alexandria Engineering Journal,* vol. 53, pp. 809-816, 2014.

[9] K. Devabalaji, K. Ravi, and D. Kothari, "Optimal location and sizing of capacitor placement in radial distribution system using bacterial foraging optimization algorithm," *International Journal of Electrical Power & Energy Systems,* vol. 71, pp. 383-390, 2015.

[10] A. A. El-Ela, A. Kinawy, M. Mouwafi, and R. El-Sehiemy, "Optimal sitting and sizing of capacitors for voltage enhancement of distribution systems," in *Power Engineering Conference (UPEC), 2015 50th International Universities*, 2015, pp. 1-6.

[11] A. Abdelaziz, E. Ali, and S. A. Elazim, "Optimal sizing and locations of capacitors in radial distribution systems via flower pollination optimization algorithm and power loss index," *Engineering Science and Technology, an International Journal,* vol. 19, pp. 610-618, 2016.

[12] R. Billinton and R. N. Allan, *Reliability evaluation of engineering systems: concepts and techniques*: Springer Science & Business Media, 2013.

[13] W. Li, *Reliability assessment of electric power systems using Monte Carlo methods*: Springer Science & Business Media, 2013.

[14] A. Patton, "Probability distribution of transmission and distribution reliability performance indices," in *Reliability Conference for Electric Power Industry*, 1979, pp. 120-122.

[15] R. Billinton and R. Goel, "An Analytical Approach Td Evaluate Probability Distributions Associated with the Reliability Indices of Electric Distribution Systems," *IEEE transactions on power delivery,* vol. 1, pp. 245-251, 1986.

[16] M. d. G. Da Silva, "Reliability assessment of meshed distribution systems," University of Wales, Institute of Science and Technology, 1993.

[17] R. Allan and M. Da Silva, "Evaluation of reliability indices and outage costs in distribution systems," *IEEE Transactions on Power Systems,* vol. 10, pp. 413-419, 1995.

[18] R. E. Brown, S. Gupta, R. D. Christie, S. S. Venkata, and R. Fletcher, "Distribution system reliability assessment using hierarchical Markov modeling," *IEEE Transactions on Power Delivery,* vol. 11, pp. 1929-1934, 1996.

[19] S. Asgarpoor and M. J. Mathine, "Reliability evaluation of distribution systems with nonexponential down times," *IEEE transactions on power systems,* vol. 12, pp. 579-584, 1997.

[20] R. Billinton and P. Wang, "Distribution system reliability cost/worth analysis using analytical and sequential simulation techniques," *IEEE Transactions on Power Systems,* vol. 13, pp. 1245-1250, 1998.

[21] P. Wang and R. Billinton, "Reliability cost/worth assessment of distribution systems incorporating time-varying weather conditions and restoration resources," *IEEE Transactions on Power Delivery,* vol. 17, pp. 260-265, 2002.

[22] A. L. Da Silva, A. Cassula, and C. Sacramento, "Reliability evaluation of distribution systems under load transfer restrictions," in *Proc. 7th Int. Conf. PMAPS—Probab. Methods Appl. Power Syst*, 2002, pp. 9-14.

[23] A. L. Da Silva, A. Cassula, R. Billinton, and L. Manso, "Integrated reliability evaluation of generation, transmission and distribution systems," *IEE Proceedings-Generation, Transmission and Distribution,* vol. 149, pp. 1-6, 2002.

[24] M. Mosbah, R. Mohammedi, S. Arif, and A. Hellal, "Optimal of shunt capacitor placement and size in Algerian distribution network using particle swarm optimization," in *Modelling, Identification and Control (ICMIC), 2016 8th International Conference on*, 2016, pp. 192-197.

[25] H. D. Dehnavi, Y. Azizi, and M. Shafiei, "A new method based on fuzzy system and gravitational optimal detector for capacitor placement, considering nonlinear loads," in *Power System Conference (PSC), 2015 30th International*, 2015, pp. 256-263.

[26] Transmission and D. Committee, "IEEE Guide for Electric Power Distribution Reliability Indices," *IEEE Std 1366™-2003,* 2003.

[27] A. Huda and R. Živanović, "Distribution system reliability assessment using sequential multilevel Monte Carlo method," in *Innovative Smart Grid Technologies-Asia (ISGT-Asia), 2016 IEEE*, 2016, pp. 867-872.

[28] B. Retterath, S. Venkata, and A. Chowdhury, "Impact of time-varying failure rates on distribution reliability," in *Probabilistic Methods Applied to Power Systems, 2004 International Conference on*, 2004, pp. 953-958.

[29] R. Billinton and L. Gan, "Use of Monte Carlo simulation in teaching generating capacity adequacy assessment," *IEEE transactions on power systems,* vol. 6, pp. 1571-1577, 1991.

[30] A. Chowdhury and D. Koval, *Power distribution system reliability: practical methods and applications* vol. 48: John Wiley & Sons, 2011.

[31] R. Billinton and P. Wang, "Teaching distribution system reliability evaluation using Monte Carlo simulation," *IEEE Transactions on Power Systems,* vol. 14, pp. 397-403, 1999.

[32] M. E. Baran and F. F. Wu, "Network reconfiguration in distribution systems for loss reduction and load balancing," *IEEE Transactions on Power delivery,* vol. 4, pp. 1401-1407, 1989.

[33] D. Scholz and F. Müsgens, "How to improve standard load profiles: Updating, regionalization and smart meter data," in *European Energy Market (EEM), 2017 14th International Conference on the*, 2017, pp. 1-6.

[34] J. Candelo and H. Hernández, "Location and Size of Distributed Generation to Reduce Power Losses using a Bat-inspired Algorithm," in *VII Simposio Internacional sobre Calidad de la Energía Eléctrica*, 2013.

[35] W. Su, J. Wang, K. Zhang, and A. Q. Huang, "Model predictive control-based power dispatch for distribution system considering plug-in electric vehicle uncertainty," *Electric Power Systems Research,* vol. 106, pp. 29-35, 2014.

[36] A. Askarzadeh, "Capacitor placement in distribution systems for power loss reduction and voltage improvement: a new methodology," *IET Generation, Transmission & Distribution,* vol. 10, pp. 3631-3638, 2016.

[37] R. N. Allan, R. Billinton, I. Sjarief, L. Goel, and K. So, "A reliability test system for educational purposes-basic distribution system data and results," *IEEE Transactions on Power systems,* vol. 6, pp. 813-820, 1991.

[38] A. A. Alkuhayli, S. Raghavan, and B. H. Chowdhury, "Reliability evaluation of distribution systems containing renewable distributed generations," in *North American Power Symposium (naps), 2012*, 2012, pp. 1-6.