Energy Optimization using a Self-Healing Method based on Multi-SOP Coordination in Active Distribution Networks

Yahya Mirzaiee Demneh[1], Mehran Emadi[2*]
1- Department of Electrical Engineering, Mobarakeh Branch, Islamic Azad University, Mobarakeh, Isfahan, Iran.
Email: ymmirzaie@gmail.com
2- Department of Electrical Engineering, Mobarakeh Branch, Islamic Azad University, Mobarakeh, Isfahan, Iran.
Email: emadi.mehran49@gmail.com (Corresponding author)

Received: February 2022 Revised: April 2022 Accepted: May 2022

ABSTRACT:
The main task of a network-connected SOP is to improve power quality in an active distribution network. In the references, two control modes are created for SOP operation using back-to-back voltage source converters. Using these two modes depends on the distribution network conditions in which the SOP is located. The independent control of real and reactive power provides power control at first mode. The second mode is source restoration which with a voltage controller makes it possible to feed isolated loads due to network faults. In this research, an optimal method is presented based on the several SOPs' performance for active distribution networks and with the help of it, it is presented using self-healing capability based on energy optimization that is presented. Compared to conventional switches, the coordination of multiple SOPs is capable of providing voltage support and effectively raising the source restoration range so as to enhance the load restoration level. Surveys and simulations in the standard IEEE 33-bus network in various scenarios show that if network reconfiguration are used with SOPs, loads in the power outage area are completely restored, which effectively improves the flexibility of distribution networks.

KEYWORDS: Energy Optimization, Self-Healing, Multi-Sop Coordination, Active Distribution .

1. INTRODUCTION

The main purpose of energy management is to minimize system operating costs such as maintenance, fuel, and the cost of power purchased from the main grid. It should be noted that the micro grid exchanges energy with the main network. Taking energy from high voltage levels and distributing it in lower voltage networks conventionally design power systems, and regarding that, there are large production units connected to transmission networks. This leads to high energy losses as well as significant cost increases. Thus, a large number of small generators must be connected to distribution networks. The main task of the SOP connected to the network is to improve the quality of power in the active distribution network. Regarding this purpose, some standards have been developed and the most famous standard is IEEE1547-2018 which is related to the operation of power electronics in the power grid. In the references, two control modes are created for SOP operation using back-to-back voltage source converters. Using these two modes depends on the distribution network conditions in which the SOP is located. The independent control of real and reactive power provides power control at first mode. The second mode is source restoration, which, with a voltage controller, makes it possible to feed isolated loads due to network faults. In the following, more details will be provided about each of these two control modes. In case of any faults occurring, faulty network elements must be located and the network must be reconfigured to disconnect them from the network and return as many customers as possible to the network. In this study, automatic restoration is considered, in which reconfiguration is performed by remote control switches. In the case of any faults, the SOP can adjust the power distribution between the feeders with acceptable accuracy as well as high speed and provide the necessary support to supply voltage. Therefore, maximum restoration can be achieved in the area where the load has been interrupted due to a fault as well as network reliability can be improved significantly. SOP with its control logic can improve power flow regulation in distribution network feeders. Thus, it can solve one of the problems of these networks regarding power regulation. Conventional networks use mechanical equipment and

Paper type: Research paper
DOI: https:// 10.30486/mjtd.2022.695919
How to cite this paper: Y. Mirzaiee Demneh, M. Emadi, "**Energy Optimization using a Self-Healing Method based on Multi-SOP Coordination in Active Distribution Networks**", Majlesi Journal of Telecommunication Devices, Vol. 11, No. 2, pp. 89-93, 2022.

load break switches, but SOPs with electronic switches are able to respond to network needs at a very high speed. The capability of this equipment in unbalanced compensation as well as its capacity to supply voltage sources has caused SOP to significantly improve the quality of power in the distribution network. Due to its high speed, it can limit the fault occurrence in a few milliseconds as well as limit the fault occurrence in other parts of the network [1].

2. Self-Healing in Distribution Network

Power grids now have to operate in more random environments and under different operating conditions, while still ensuring system reliability and security. The automation of a smart distribution system provides optimal control under normal operating conditions and the ability to quickly self-heal to restore services in case of a power outage. Optimal energy management and self-healing are crucial features of a smart distribution system. Due to the fact that self-healing task is usually used in post-fault emergencies, operational and time constraints can add to the complexity of the problem. Regarding the level increase of penetration of distributed generation resources, the randomness of their production and irreversible loads, new challenges are created for the operation and self-healing process of distribution systems. The ability to operate independently and individually is one of the important features of active distribution systems. In conventional distribution systems, loads are often supplied from the transmission network. Thus, following the disruption or fault, all or a part of the connected loads of the distribution systems are disconnected from the main network [2]. However, due to the presence of distributed energy sources in active distribution systems, these networks are more flexible than conventional networks. In these systems, if the network is equipped with appropriate control and management systems, distributed energy sources can provide and support areas that have been disconnected from the network due to the fault [3]. On the other hand, smart grids offer new capabilities to increase the performance of distribution systems. One of them is self-healing which can increase network reliability [4]. To provide such a capability, it is necessary to design software tools and devices for active distribution systems to enable the self-healing process to be automated if necessary. Accordingly, the implementation of appropriate methods can increase the continuity of power supply operation when a part of the network is disconnected from the rest. An appropriate restoration scheme optimizes certain parameters under existing constraints. The primary goal is to resupply as many customers as possible and to prioritize critical customers such as hospitals. Secondary goals are to minimize the number of switching operations (or their overall cost for equipment), to keep the final network configuration close to the nominal condition, and to balance the load to prevent congestion during peak demand. Self-healing methods in both centralized and distributed (or decentralized) algorithms are presented in the reference [5]. In centralized methods, all elements of the self-healing system are connected to a "centralized management unit" through communication links. Therefore, these methods require an appropriate communication infrastructure, which may include long communication links.

3. Performance Basics

The SOP is a powerful electronic device installed in power distribution networks instead of ordinary open points. This device is able to control the real power flow, reactive power compensation and voltage regulation in normal network operation conditions, as well as fast fault isolation and source healing in abnormal conditions. SOPs are power converters that consist of two AC and DC converters connected via a DC link capacitor. The SOP structure consists of two back-to-back H-Bridge inverters and a DC link capacitor that can be used as a voltage-controlled-current-source. By controlling the two back-to-back converters, the current amplitude can be equalized between the two feeders by transferring the active power, and also reactive and harmonic power compensation can be done for the two feeders. Thus, the isolated section is fed. The main function of the SOP is to transfer the active and reactive power of the isolated section. In the central part of this power transfer is the DC link capacitor, which is located between the two converters. Since the output power of the capacitor is equal to the product of the voltage and current of the capacitor, if the voltage of the capacitor and consequently the capacitor current is disturbed and fluctuates, the transmission performance is completely affected. SOP is capable of improving local voltage profiles, controlling real power and reactive power flow, or even limiting fault current to maximize the capacity of using distributed generation resources in the distribution network. Circular distribution networks are less preferred regarding the need for complex and expensive protection systems. In contrary; in radial networks, simplicity makes them more preferable. Placing the SOP at the end of the radial feeders is a suitable fit, as it enables them to provide maximum loads during fault isolation. Additionally, while taking advantage of radial networks with a simple protection system, it also provides high reliability of ring networks. The main purpose of SOP is to balance the load on the connected feeders by keeping the voltage level within the allowable range and restoring the source after fault in the intact parts of the feeders.

Source restoration is the process by which the power supply, after isolating the faulty part of the feeders, provides the power required for the intact part which was immediately taken out of service when a system fault occurred. After removing the faulty part, the SOP speeds up the restoration process; because they can restore the power supply in a few milliseconds. But in conventional systems, it takes hundreds of milliseconds. SOP can function similarly to other power electronics. For example, “Static Synchronous Compensator (STATCOM)", active filters or “Unified Power Flow Controller (UPFC) " can be mentioned [6]. It should be considered that there are differences in performance basics of these equipment, which are discussed in details in [7]. The Comparison of SOP with static transformer and D-UPFC is shown in table1.

Table 1. Comparison of SOP with static transformer and D-UPFC.

Performance	D-UPFC	SOP	ST
Reactive power compensation	✓	✓	✓
Real power control	✓	✓	✓
Load balancing	✓	✓	✓
Number of converters	۲	2 or more	1 to 3
Ability to isolate faults	×	✓	×
Number of connectable feeders	۱ or more	2 or more	1 or more
Position in the distribution network	At the convention al transformer	Typically at the end of the feeders	Alternative to conventional transformers
Two-way power transmission	×	✓	✓

4. Control Mode

The SOP performance is such that one of the converters always acts as a rectifier depending on the load conditions and delivers power to the capacitor. In other words, it charges the capacitor and the other converter acts as an inverter and receives power from the capacitor. If, for any reason, the inverter cannot receive power from the capacitor, it will increase the capacitor voltage and in critical conditions will lead to system instability. On the other hand, if the power exchange is done simultaneously, due to the presence of harmonics (especially second-order harmonics), the capacitor voltage will ripple and fluctuate. Thus, it will lead to poor power transmission. Also, a voltage drop will reduce the transmission power and on the other hand, capacitor overvoltage will increase the power or in other words increase the converter current. Therefore, failure to stabilize the DC link capacitor voltage will cause the SOP system instability. Two control modes for SOP operation are created using "back-to-back voltage source converters". Using these two modes depends on the distribution network conditions in which the SOP is located. One of the two converters always plays the same role, but the latter changes state in control logic depending on the situation, which can be normal or faulty. In the first mode(Power Flow Control Mode), power control by controlling the flow allows independent control of real and reactive power. In the second mode(Supply Restoration Mode), source restoration with a voltage controller makes it possible to feed the isolated loads due to network faults [8].

5. Proposed Logic and Objective Function

SOP control is different from other network-connected converters; because it is connected with at least two feeders. The real power control depends closely on the DC link capacitor voltage and is therefore very crucial for normal and abnormal SOP operating conditions. Fluctuations in this voltage will cause fluctuations in the power delivered to the SOP, which is not acceptable. System load distribution constraints and topology constraints need to be considered in the final formulation. Additionally, SOP implementation is largely controlled by power-based electronic devices. Since these devices are high-priced, power switches in distribution networks cannot be fully substituted with SOP in a short period of time. Source restoration in active distribution networks should be considered a combination of SOPs and network reconfiguration. Using SOPs can not only help network restoration, but also create reactive power to decrease power losses and prevent recurring switching actions. Therefore, the objective functions are considered to be a weighted linear combination of the maximum active power of the restored loads, the minimum cost of power losses and the switching operation, which are formulated as (1), (2), (3).

$$\max f = w_1 f_R - w_2 f_L \quad (1)$$

$$f_R = \sum_{iesn} \mu_i \Pi_i P_i^L \quad (2)$$

$$f_L = C_L (\sum_{ijesb} R_{ij} I_{ij}{}^2 + \sum_{iesn} P^{SOP-L}) \quad (3)$$

Where;

f: The objective function used, which is the amount of load disconnected from the network in the area where the fault occurred.
f_L:It is part of the objective function used economically and it models the cost of power outages.
f_R:The part of the objective function used that indicates the amount of load restored by the SOP.
C_L: Load cost on the under-review network
ω_1And ω_2: Weight coefficients used
π_i: Weight coefficient of load importance on the bus i
μ_i::The coefficient related to the level of load restoration in node i, which is a number in the range from zero to one.
S_b: A collection of all system branches.
S_n: A collection of all system buses.
I_{ij}: Branch current between bus i and bus j

6. Combination with Network Reconfiguration

SOP implementation is largely controlled by power-based electronic devices. Since these devices are high-priced, power switches in distribution networks cannot be fully substituted with SOP in a short period of time. Source restoration in active distribution networks should be considered a combination of SOPs and network reconfiguration. Related restrictions are added as relations(4), (5),(6),(7) [9].

$$U_i^2 - U_j^2 + (R_{ij}^2 + X_{ij}^2) I_{ij}^2 - 2(R_{ij} P_{ij} + X_{ij} Q_{ij}) + M(1 - a_{ij}) \geq 0 \quad (4)$$

$$U_i^2 - U_j^2 + (R_{ij}^2 + X_{ij}^2) I_{ij}^2 - 2(R_{ij} P_{ij} + X_{ij} Q_{ij}) - M(1 - a_{ij}) \leq 0 \quad (5)$$

$$-Ma_{ij} \leq P_{ij} \leq Ma_{ij} \quad (6)$$

$$-Ma_{ij} \leq Q_{ij} \leq Ma_{ij} \quad (7)$$

Where;
α_{ij}: A binary variable indicating the state of the line between two buses i and j. When the line is connected, the value of this parameter will be one.
P_{ij}: The real power transmitted from bus i to bus j in kilowatts
Q_{ij}: Reactive power transmitted from bus i to bus j in reactive kV
R_{ij}: The real part (resistance) of the line between bus i and bus j
X_{ij}: The imaginary part (reactance) of the line between bus i and bus j
$U_i\, U_j$: Bus voltage i and j
M: A very large coefficient

7. Used Test Network

SOP implementation is largely controlled by power-based electronic devices. Since these devices are high-priced, power switches in distribution networks cannot be fully substituted with SOP in a short period of time. Source restoration in active distribution networks should be considered a combination of SOPs and network reconfiguration. Related restrictions are added as relations(4), (5),(6),(7) [9].

Table 2. Restoration results for different scenarios.

Quantity	**Scenario**				**Unit**
Restored load	Fourth	Third	Second	First	
Ratio of restored load to total	KW	1216.98	2326.61	1712.23	KW
Ratio of restored critical load to total	percent	66.42	71.48	52.60	percent
Critical load	percent	98.50	98.73	97.89	percent
Nodes without full restoration	-	33,32,31,30,29, 25,24,4	23, 4, 24, 25, 30	5, 4, 23, 24, 25, 29, 30, 31, 32, 33	-

The results of voltage profile studies after maneuvering in four scenarios are shown in Figure 1. The assumption in this figure is that a fault occurs between nodes 2 and 3 in the network.

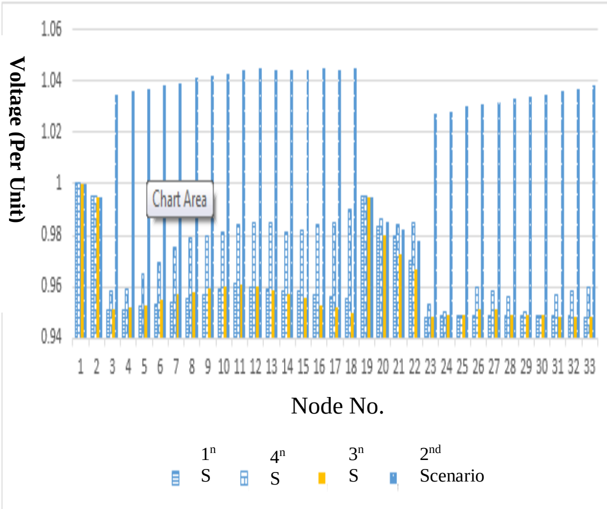

Fig. 1. Results of voltage profile studies after maneuvering in four scenarios.

8. Conclusions and Suggestions

SOP control is different from other network-connected converters; because it is connected with at least two feeders. Real power control depends closely on the DC link capacitor voltage and is therefore very important for normal and abnormal SOP operating conditions. Fluctuations in this voltage will cause fluctuations in the power delivered to the SOP, which is not acceptable. Compared to conventional switches, the coordination of multiple SOPs is capable of providing voltage support and effectively raising the source restoration range so as to enhance the load restoration level. Four schemes have been chosen to examine the effectiveness of the proposed load restoration method with SOP. Surveys and simulations show that with a combination of network reconfiguration and SOPs, loads are fully restored in the area, which effectively improves the flexibility of distribution networks. Due to the very high cost required to build power electronics, locating and determining the optimal size of SOPs can be considered to further improve the reliability of active distribution networks.

REFERENCES

[1] W. Cao, J. Wu, N. Jenkins, C. Wang, and T. Green, "Operating principle of soft open points for electrical distribution network operation," *Applied Energy*, vol. 164, pp. 245-257, 2016.

[2] "A distributed self-healing method for active distributed systems," in *8th International Conference on Renewable Energy Research and Applications*, Brasov, ROMANIA, 2019.

[3] H. Farzin and M. Monadi, "Reliability Enhancement of Active Distribution Grids via Emergency V2G Programs: An Analytical Cost/Worth Evaluation Framework," *Scientia Iranica, 2019*, vol. 26, no. 6, pp. 3635-3645, 2019.

[4] Z. Wang and J. Wang, "Self-Healing Resilient Distribution Systems Based on Sectionalization Into Microgrids," *IEEE Transactions on Power Systems*, vol. 30, no. 6, pp. 3139-3149, 1-11.

[5] H. Farzin, M. Moeini-Aghtaie, and M. Fotuhi-Firuzabad, "A hierarchical scheme for outage management in multi-microgrids," *International Transactions on Electrical Energy Systems*, vol. 26, pp. 2023-2037, 2016.

[6] khaled syfullah fuad, hossein hafezi, kimmo kauhaniemi, and hannu laaksonen, "Soft Open Point in Distribution Networks," *IEEE Access*, vol. 8, pp. 210550-210565, 2020.

[7] J. M. Bloemink and T. C. Green, "Increasing distributed generation penetration using soft normally-open points," *IEEE Transactions on Power Delivery*, vol. 28, no. 2, pp. 911-919, 2013.

[8] Wanyu Cao, Jianzhong Wua, Nick Jenkins, Chengshan Wang, Timothy Green, "Operating principle of Soft Open Points for electrical distribution network operation," *Applied Energy*, vol. 164, p. 245–257, 2016.

[9] Esmaeili M, Sedighizadeh M, Esmaili M. , "Multi-objective optimal reconfiguration and DG (Distributed Generation) power allocation in distribution networks using Big Bang-Big Crunch algorithm considering load uncertainty," *Energy*, vol. 103, pp. 86-99, 2016.

[10] M. Monadi, H. Hooshyar, L. Vanfretti, F. Mahmood, J. I. Candela, and P. Rodriguez, "Measurement-based Network Clustering for Active Distribution Systems," *IEEE Transactions on Smart Grid*, vol. 10, no. 6, p. 6714–6723.