

Simulation of Self-Healing in Samawa City Distribution System

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K E Y W O R D S	ABSTRACT	
Self-healing, distribution system, CYMDIST, MATLAB, smart protection	Self-healing is the ability of a distributi power after permanent faults. This p outages in the distribution network elen fault. The work aims to restore maximut the affected areas, after the isolatic procedure of switching operations. In t used for the simulation and analyses of City. MATLAB 2017b/Simulink was through the simulation of smart pro remotely by a central control unit. proposed self-healing system on Sama maximum power restoration with a operations that have been achieved afte constraints.	ion system to automatically restore paper investigates the impact of ments following the occurrence of a m available power to consumers in on of faulted parts, by optimal this work, CYMDIST software was f a distribution network in Samawa used to implement self-healing, tection system that is controlled The results of implementing the wa a New 11 kV network show a minimum number of switching ier fault isolation without violating
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1. INTRODUCTION

Self-healing schemes in a distribution system act after locating a fault to minimize the number of the out of service areas and to restore the maximum possible electrical power to the outage areas by changing the system configuration, while meeting the system and operational constraints [1, 2]. A fully automated self-healing scheme can only apply within a smart grid [3] where remote controlled switching equipment are used for switching actions to; isolate fault, shed or restore loads, and change the system configuration [4]. In this paper, the proposed self-healing scheme for protection of a distribution system aims to automatically restore power after permanent faults.

To ensure a reliable operation of a distribution system whenever a fault occurs on some section of the system, the following actions are required [5]:

- 1) Fault Isolation: the faulted section is to be isolated from the rest of the system as quickly as possible by opening the appropriate circuit breakers/isolators.
- Power Restoration: Power should be restored to healthy sections that may be disconnected during the isolation of the faulted section by opening and closing certain switches in the network.
- 3) Fault Repair: The faulty section should be repaired, and the time of repair depends on various factors like; type of fault, location of fault, and availability of repair crew.

In [6], self-healing has been employed for IEEE 9-bus and IEEE 14-bus electrical power networks. The electrical power networks were modelled using the Electrical Transient Analyzer Program (ETAP) simulation environment. Three different protections; overcurrent protection, transformer protection and directional overcurrent protection, have been applied for various types of faults. In [7], self-healing distributed algorithms were used, and these algorithms are based on rules developed for two sets of switches; substation and located in the network. The implementation in each switch is made without any kind of centralized control, allowing the switching decision to be taken by restricting communication only between adjacent switches. Even so, the operating conditions of the entire network required for the solution of the problem are observed, with taking into consideration of their pre-fault conditions. The author in [8], proposed implementing a Binary Particle Swarm Optimization (BPSO) technique for reconfiguration of the network. The technique ensures maximum customer connectivity and minimum power losses. The proposed algorithm was tested on IEEE 33-bus distribution network using MATLAB simulation. Restoring the power supply through network reconfiguration during a fault event. Switching commands for the switches were sent via SCADA. The author in [9], applied a One-Line Remaining (OLR) algorithm to the 38- bus 400 kV network of south Indian grid (the Indian smart power grid). The algorithm identified areas of the power system that are connected to the rest of the system by only a single line as a result of an initial outage of a line. It has been found that the algorithm can correctly identify the last tie line that, when removed, would create an island.

2. MATHEMATICAL MODEL OF SELF-HEALING OPTIMIZATION TECHNIQUE

To obtain an optimal post fault configuration, different switching combinations will be tested to select a configuration which ensures a maximum customer connectivity and minimal power losses by satisfying a number of objectives with constraints [8, 10].

I. Objective functions

A. Minimization of out-of-service areas:

$$\min F_1(\bar{X}) = \sum_{i_1}^{b_1} L_i - \sum_{i \in B} L_i$$
(1)

where,

 $\bar{\mathbf{x}}$ = switch state vector of network under consideration For service restoration.

$$\overline{\mathbf{x}} = [\mathbf{Sw}_1, \mathbf{Sw}_2 \dots \mathbf{Sw}_{Ns}]$$

 $Sw_j = Status \text{ of } j^{th}$ switch. A closed switch is represented by 1 and an open switch is represented by 0.

 N_S = Total number of switches in the network.

b1 = Number of energized buses in the network before fault.

 $L_i = \text{load on } i^{th} \text{bus.}$

B = Set of energized buses in the restored network.

B. Minimization of losses:

Power losses are the second objective calculated using load flow. If two or more configurations have the same consumer connectivity, then the configuration with the least power losses is selected.

min F4(\overline{X}) = Power loss in the restored network

C. Minimizing number of switching operations:

$$\min F_3(\bar{x}) = \sum_{j=1}^{N_S} |Sw_j - SwR_j|$$
(2)

Where, $\bar{\mathbf{x}} =$ is the switch status vector of the network,

$$\bar{\mathbf{x}} = [\mathbf{S}\mathbf{w}_1, \mathbf{S}\mathbf{w}_2 \dots \mathbf{S}\mathbf{w}_{Ns}] \tag{3}$$

Ns: is the number of switches in the network,

 Sw_j : is the status of j^{th} switch in network just after fault. SwR_j : is the status of j^{th} switch in the network after restoration.

II. The constraints

A. Radial topology

Distribution line protection is designed for radial feeders so an important constraint is to avoid forming loops in the network. Accordingly, at least one switch in each identified loop should be opened.

B. Bus voltage deviation

Bus voltages should not violate their limits, where V_{min} and V_{max} are the minimum and maximum limits for rms voltages at a given bus, respectively. The limits adopted are; $V_{min} = 0.95$ per unit and $V_{max} = 1.05$ per unit [10].

$$V_{min} \le V_j \le V_{\max} \tag{4}$$

where,

 V_{min} = Minimum acceptable bus voltage & V_{max} = Maximum acceptable bus voltage. V_i = Voltage at J^{th} bus.

C. Thermal limitation

Another constraint, which is defined by the current passing through the network conductors [11].

$$I_j \le I_{j_{\max}} \tag{5}$$

where,

 I_j : is the load current in line j.

 $I_{j_{max}}$: is the maximum allowed load current in line j.

D. Power source constraints:

The total loads of any partial network should not exceed the maximum capacity of the main power source [12].

$$P_t \le P_s^{\text{max.}} \tag{6}$$

$$Q_t \le Q_s^{\text{max.}} \tag{7}$$

3. SIMULINK MODEL OF SMART PROTECTION DEVICES

The reclosers and sectionalizers devices are simulated in MATLAB to be controlled by the central control unit. The control unit monitors the values of the currents that flow in the feeder, and compares them with the currents of the reclosers and sectionalizers. For any abnormal condition, instructions are sent by the central control unit to the circuit breakers according to the control algorithm actions. Figure 1 shows the Simulink model of the central control unit with smart protection devices.



Figure 1: Block diagram showing smart protection devices with central control unit connected to a distribution network as simulated in MATLAB/SIMULINK

4. THE CENTRAL CONTROL UNIT

The central control unit was simulated in MATLAB to operate automatically all smart protection devices by sending the control signals through the communication channels to restore the network to healthy situation. The control unit consists of two main units:

- 1. Monitoring unit (module F), for the detection of unusual increase in the currents as shown in Figure 2. This unit monitors the values of the voltages and currents (V and I) in each part of the feeder. In case of any abnormal increase in the currents from the setting values in this unit, a signal will be sent to the comparison unit by the switches (SA).
- 2. Comparison Unit, for the comparison between the information received from module F with the setting values of the relays, as shown in Figure 3. In case of unusual increase in the currents, an interruption signal is sent to the reclosers that connected to the relays through switches (S).



Figure 2: The monitoring and detection units inside the central control unit (module F), simulated in MATLAB/SIMULINK



Figure 3: The comparison unit inside the central control unit, simulated in MATLAB/SIMULINK

5. THE PROPOSED SELF-HEALING SCHEME FOR PROTECTION OF A DISTRIBUTION SYSTEM

The proposed self-healing scheme for protection of a distribution system aims to automatically restore power after permanent faults, as given by the flowchart in Figure 4. The scheme starts by running load flow program for calculating the actual values of voltages and currents (V and I) in each part of the feeder. These actual voltages and currents (V and I) in each part of the feeder will be entered to the central control unit as reference values. The current and voltage transformers (C.T and V.T) measurements are entered online to the central control unit. In the central control unit, the monitoring unit (module F) monitors the values of the voltages and currents (V and I) in each part of the feeder for the detection of abnormal increase in the current. In case of any abnormal increase in the currents from the reference values in this unit, a signal will be sent to the comparison unit through the switches (SA). The comparison unit compares between the information received from blocks (F) with the setting values of the relays. In case of fault detected an interruption signal is sent to the reclosers that connected to the relays through switches (S). To detect if the fault is permanent the recloser is controlled by the central control unit to disconnect the power from the feeder. But after a short period, a signal will be sent to close the recloser returning the power to the feeder. If the fault remains the recloser will be disconnected again indicating a permanent fault. This process with the help of central control unit will return the power to the feeder in a short period of time less than a few seconds as in the traditional method based on the devices setting. After locating a permanent fault the reclosers and sectionalizers are controlled by the central control unit to minimize the number of the out of service areas. To restore the maximum possible electrical power to the outage areas the system should be reconfigured while meeting system and operational constraints. The central control unit operates automatically all smart protection devices by sending the control signals through the communication channels to restore the network to healthy situation.



Figure 4: Flowchart representing the proposed self-healing scheme for protection of a distribution system.

6. CASE STUDY

Samawa New distribution system in Samawa City, the province of Muthanna, Iraq has been considered as the case study in this work. The original GIS diagram of Samawa New network is shown in Figure 5, using the coordinations given by Ministry of Electricity (MOE), depending on the Global Positioning System GPS and Geographic Information System GIS. A single line diagram of Samawa New network was drawn using CYMDIST software as shown in Figure 6.



Figure 5: The original GIS diagram of Samawa New distribution system



Figure 6: Single line diagram of Samawa New network

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Samawa distribution network consists of 9 feeders outgoing from the new Samawa sub-station. The sub-station consists of 2 x 31.5 MVA, 33/11 kV power transformers. Samawa New feeder 2-2 was selected to implement the proposed self-healing protection system on it. Power outage is simulated assuming a fault in the outgoing main line (underground cable) from the new Samawa sub-station, feeder Samawa New 2-2. The network data for feeder 2-2 are given in Table I.

section No.	From Bus	To Bus	*Conducto r type	Section length (m)	Real Powe r Load (kW)	Reactive Power Load (kVAr)	Load type
112	S_N_2-2	112	Type 2	30.48			
113	112	113	Type 2	81.99	411.25	254.86	Residential
114	113	114	Type 2	3.04	411.25	254.86	Residential
115	113	115	Type 2	19.20	411.25	254.86	Residential
116	115	116	Type 2	28.65	411.25	254.86	Commercial
117	116	117	Type 2	8.83	259.09	160.56	Residential
118	116	118	Type 2	12.19	259.09	160.56	Residential
119	118	119	Type 2	6.7	259.09	160.56	Residential
120	119	120	Type 2	49.98	259.09	160.56	Residential
121	120	121	Type 2	24.68	259.09	160.56	Commercial
122	121	122	Type 2	3.35	259.09	160.56	Residential
123	122	123	Type 2	4.26	164.5	101.94	Residential
124	123	124	Type 2	26.82	164.5	101.94	Residential
125	122	125	Type 2	13.1	259.09	160.56	Residential
126	125	126	Type 2	12.8	164.5	101.94	Residential

 TABLE I: Line and load data for Samawa New distribution network feeder 2-2 [MOE].

*Type 2: Shielded underground cable11 kV

7. FEEDER SAMAWA NEW 2-2 OUTAGE

In case a fault on section_112, the monitoring unit detects an abnormal increase in current exceeding its rated limit. This will send a signal to the comparison unit, which in turn compares the currents in each part of the feeder with the currents on which the relays are set, to locate the fault. Comparison unit will send a signal to Sw_112, which will open Sw_112, within 0.02 seconds (depending on the device specification), resulting in power outage in Feeder Samawa New 2-2. This leads to interruption of power supply for sections (112 to 126), as shown in Figure 7. The total load for the unserved consumers is 3800 kW, as given in Table II.

TABLE II: Summary of self-healing protection system operation following the outage of feeder 2_2.

Feeder	Fault location	Switch	Section	Consumer		
outage		opened to clear fault	From section	To section	s Unserved (kW)	
Samawa New 2_2	Section_112	Sw_112	112	126	3800	



Figure 7: Single line diagram of Samawa New network after outage of feeder Samawa New 2-2.

8. RESTORE SERVICE THROUGH A SELF-HEALING PROTECTION SYSTEM.

Self-healing protection technique reconfigures the network by opening and closing switches to restore power to consumers, as quickly as possible, after an outage [8], according to heuristic algorithm [13]. To restore power to consumers; this requires upgrading manual switches to remote-controlled switches [14]. The main objective of power restoration when a fault occurs is to restore the maximum possible power by neighboring feeders that can withstand the extra load. Power restoration solutions are based on three criterias; minimizing the amount of forced outage load, minimizing the number of switching operations, and load balancing to minimize the risk of overload. The operating constraints have to be checked for the network; voltage drop limits, line/transformer capacity limits, and feeder load limits. In addition, feeders should be kept radial since the feeders in practice are usually operated radially.

9. SELF-HEALING SERVICE RESTORATION FOR FEEDER SAMAWA NEW 2-2.

The smart protection devices and monitoring control unit have been implemented as a protection system with self-healing on Samawa New distribution system. Three-phase fault is considered on Samawa New distribution system. The overall smart distribution system performance has been analyzed and evaluated using MATLAB/Simulink 2017b, as simulated in Figure 8.The central control unit works is to isolate the fault on section_112. The control unit operates automatically to control all smart protection devices through sending the control signals for power restoration to the smart protection devices for optimal reconfiguration of the network. Sending closing signal to N/O tie-switches (Tie_Sw_57) and (Tie_Sw_156), allowing transfer of 2300 kW and 1500 kW from feeder Samawa new 2-2 to Samawa new 2-3 and feeder Samawa new 1-2 respectively after fault isolation as illustrated in Table III. Opening N/C switch (Sw_117) split load to avoid overloading on feeder Samawa new 2-3 and also on feeder Samawa new 1-2. The reconfiguration is shown in Figure 9. This process will return the power to the feeder 2-2 during 0.06 sec. (based on the device specification).



Figure 8: Simulink Model of the proposed self-healing protection system of Feeder Samawa New 2-2.



Figure 9: Restoring service by self-healing Samawa New feeder 2-2.

TABLE III: O	ptimal switching p	olan of self-healing t	for feeder Samawa I	New Y-Y.
		9		

Section no.	Switch no.	Status	Action	power restored kW	Consumers Unserved kW
Samawa New _ 117	Sw_117	0pen	Clear fault	0	3800
Samawa New _∘∨	Tie_Sw_°V	Close	T û	2000	<u>^</u>
Samawa New _\\Y	Sw_11Y	0pen	- Transfer	3800	0
Samawa New _1°7	Tie_Sw_1°	Close	louu		

10. DISCUSSION OF RESULTS

As shown in Table IV during normal operating conditions, feeder of Samawa New 2-2 operates with load 235 A/phase (68.8% loading). Considering service restoration on feeder Samawa New 2-2 after fault isolation, feeders Samawa New 2-3 and Samawa New 1-2 restore electrical power to feeder Samawa New 2-2 due to availability of spare capacity in these Feeders. This increases their loads from 150 A/phase and 230 A/phase to 293 A/phase and 324 A/phase (85.1% loading) and (94.1% loading), respectively. The results show that all voltages are within operating limits and all cable loading are within the current loading capacity. The load flow results given in Table V shows a comparison between voltage and current magnitudes for all the buses of the system before and after applying network self-healing method. Figures (10) and (11) show the bus voltage profile and feeder current loading obtained before and after fault isolation of feeder Samawa New $^{-\gamma}$.

Feeder Name		Before resto	oration		After restoration			
	Current/ Phase (A)	Feeder Loading (%)	kW	kVar	Current/ Phase (A)	Feeder Loading (%)	kW	kVar
Samawa New 2-2	2*5	64.4	3800	2355	2*5	64.4	3800	2357
Samawa New 2-3	150	43.8	2500	1389	893	8°.1	4821	2826
Samawa New ۲_ ۱	440	٦6.7	۳۷	2295	324	94.1	5201	3221

TABLE IV: Power restoration by self-healing for feeder Samawa New 2-2.

 TABLE V: Current loading of Samawa New network after reconfiguration following the fault in section Samawa New 112.

Feeder	Load summary of Samawa New network, during normal operating conditions					Load summary of Samawa New network, during after self-healing following the fault on feeder 2-2.				
*name	Total	Load	Minimu m voltage	Current / phase	Feeder current Loadin	Total Load		Minimu m voltage	Current / phase	Feeder current Loading
	kW	kv Ar	on feeder (p.u.)	(A)	g (%)	kW	kv Ar	on feeder (p.u.)	(A	(%)
S-N 1-2	37	229 3	0.984	229.9	٦٦ <u>.</u> ٧	07. 1	۳۲۲ 1	0.988	۳۲4	٩4.١
S-N 1- É	۳	۱۸٥ ٩	0.991	187.3	54.1	۳۰۰	۱۸٥ ٩	0.982	187	54.7
S-N 1-5	۲۱.	۱۳۰ ۰	0.987	13•.2	۳۷٫۸	۲۱۰ ۰	۱۳۰ ۰	0.98£	۱۳۱	۳۸.2
S-N 1-7	9	557	0.992	55.9	16.3	9	557	0.987	56	16.3
S-N 1-10	32	198 4	0.989	198.9	54.4	32	198 4	0.981	200	58.4
S-N ^r -2	38	۲35 6	0.99٤	230	68.8	38	۲35 5	0.988	735.8	68.8
S-N 7-3	25	138 9	0.988	150.9	4۳.۸	٤٨٢ ٢	۲۸۲ ۲	0.996	893	٨٥.1
S-N ^r -6	26	161 0	0.989	161.4	4٦.٦	26	161 0	0.981	162	47.4
S-N 6-2	300	185	0.993	18.6	5.4	300	185	0.989	18	5.4

*S-N: Samawa New







Figure 11: Current loading for feeders of Samawa New network, before and after self-healing of feeder Samawa New 2-2.

11. CONCLUSION

The simulation results of the smart protection self-healing system by using MATLAB/SIMULINK and CYMDIST shows the validity and effectiveness of the technique to overcome the drawbacks of the traditional protection system. The implementation of the simulated smart protection self-healing system on Samawa New distribution network show the capability of the optimal switching plan to restore maximum power to consumers during self-healing, while maintaining the current flows and voltage levels in the network within their acceptable limits. The simulation results show that a self-healing system can improve the performance of the distribution system after fault occurred in the distribution system. Replacing manual switches by remotely controlled switches with central control unit speeds up fault isolation and reduces the time of interruption.

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