Outage Management in Smart Distribution Networks by Restricting the Faulty Section

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***Abstract*— New decentralized method for outage management in smart distribution networks using Multi-Agent Systems (MAS) is presented in this paper. In this study, definition of MAS, the tasks of each individual agent and their functionality are explained in details according to the simulated sample of power distribution. Subsequently, some scenarios which may occur in smart distribution networks have been simulated and analyzed. The objective of this study is to restrict the faulty area as much as possible and consequently maximize the customers' welfare by means of suitable prioritized load-shedding in small portions. The results indicate that by considering the prioritized load-shedding, both utility and customers will nearly approach their goals.**

***Keywords*— Outage Management, Smart Distribution Networks, Multi-Agent Systems, Load-Shedding**

I. Introduction

The increasing growth of electricity consumption, geographical scope, environmental considerations and increased cost of customers outages in distribution networks, have created a new approach to the usage of DER and the capabilities of smart networks. The aim is to manage more efficiently the outages, reduce the customer loss and also to improve the operational efficiency by speeding up data exchange and automation for load management by comprehensive decisions with decreased operating costs [1-5]. As a result, distribution networks which serve as the interface between the transmission network and the consumer, with utilization of characteristics of Smart Grids, Distributed Generations and Demand Side Resources become much more active than before. Subsequently planning, operational studies of distribution networks such as Load Flow, Reliability, Security, Stability, Short Circuit and etc. will be affected by this approach [4]. Smart networks should include new features such as: 1-Self-Healing, 2-Cyber Security, 3-Real Time Pricing, 4-Energy Management System (EMS), 5-Outage Management System (OMS) and also 6-Increased Network Reliability. These networks will interact with new technologies such as devices with two-way interconnectivity like Advanced Measurement Infrastructure (AMI), Distribution Automation (DA), Modern Communication and Telecommunication Networks, Home Area Networks (HAN), Demand Response (DR) and Distributed Electrical Resources (DER) [1, 2]. Smart grid have a wide range, with utilization of AMI it would have the capability to collect important metering parameters such as Voltage, Current, ... and furthermore, monitoring, receiving so many information such as status, real time events, etc. and following that having control on the entire network [6]. The real time, bi-directional communication between the consumer and the utility integrated with Home Energy Management System (HEMS), enables end users to interfere their energy consumption based on individual preferences (price, environmental concerns, etc.) [3, 7]. Decentralized control and management of the power grid is one of the most important features of the smart grid which could be achieved with implementation of MAS [6]. Outage management in smart distribution networks will be introduced as awareness of fault occurrence, finding the fault location, fault isolation, network re-configuration and energize the interrupted loads as much as possible. All these operations will be done in order to: 1-Reduce human errors, 2-Decrease time of troubleshooting, 3-Simplify & speed up decision making, 4-Reduce duration of outage, 5-Activate the system recovery, 6-Reduction of interrupted loads, 7-Increase the network reliability and finally 8-Extend the customers welfare [8]. To achieve this object, acceptance of smart distribution networks will be inevitable in future. Therefore, each element which is used in distribution networks should not only become smart but also should have the capability to communicate which other elements in the network in order to accelerate the decision making in critical situations.

This paper presents the concept of outage management in distribution networks from the perspective of the services which MAS can perform. This paper is discussed in five sections. In section II, the problems of outage management and benefits of usage of proposed method will be expressed. The characteristics of MAS and also the simulated feeder with related agents are briefly introduced respectively in section III. Next in section IV, two case studies are analyzed, followed by conclusion which is described in section V.

II. Problems and the Solutions

In conventional method without utilization of prioritized load-shedding, the results will be followed by loss of a large amount of loads without considering their values. The amount of load consumption will depend on the capacity of the Auxiliary Feeders and applicable DGs. In this method the Simple Sectionalizer of pre-fault will be opened, and the next Simple Sectionalizer will be the one which the capacity of power sources and accumulated load consumption are somehow equivalent with each other. Decision of selecting post-fault Simple Sectionalizer will be gain if one of the following two conditions is met:

1. The required consumption exceeds the available power source capacities, which then it will find the first Simple Sectionalizer of which it could feed the rest of the feeder.

2. Reach to the Simple Sectionalizer agent which has been stored in a memory as a post-fault Simple Sectionalizer, then open command will be issued to related Simple Sectionalizer agent.

By utilization of decentralized smart methods such as MAS, it will be possible to gather the information from several agents in different locations, implement variable and complex algorithms, make the decisions, speed up the operation, accelerate self-healing with minimized switching, maximize the customer welfare and also increase the network reliability all together without any human intervention.

The proposed method in this paper indicates that, not only finding the faulty location and also energizing the feeder up to pre-fault Simple Sectionalizer will be done as quickly as possible, but also it would be possible to restrict and minimize the effect of faulty area to the rest of the loads which are located at the end of the feeder. For this reason two steps will be done accordingly. One of them is selecting the pre and post-fault Simple Sectionalizer to be disconnected in order to restrict the faulty area, and on the other hand, make the balance between the power source capacities with the load consumption by implementation of load-shedding in small steps with the lowest priority of the loads and appliances.

III. Proposed System

Proposed outage management method is composed of several agents with variable characteristics which will be briefly presented in accordance with simulated distribution feeder in this part. And finally this section will be summarized with short explanation of fault locating algorithm.

A. Agents

The agent is defined as an automated hardware or software which gathers the information from its located environment, analyze them in order to perform different kinds of automated tasks and eventually reach to the overall goals of the system. Collection of two or more agents is called a Multi-Agent System (MAS). The main characteristics of MAS are: 1.Proactivity, 2.Reactivity, 3.Social, 4.Autonomy [8, 9].

Software agents run in a platform as a software environment and JADE, an open source platform fully implemented in JAVA software, is one of the most desirable platforms for this purpose[10]. Simulated agents are as following.

1) System Manager agent: The agent which used to simulate the sample of distribution network. It collects the whole information related to the simulated feeder such as Main Sections, Auxiliary Feerders, Main CB, Simple Sectionalizers, Fault Indicators, DGs and etc. in order to have an overall view of the power grid. In some cases it will send some required parameters to the specified agents, for instance the prioritization of loads will be done through this agent. It will send random numbers to the Load agents which the highest number indicates the lowest priority and vice versa.

2) Current relay agent: It will be used to protect the feeder in OC/EF/SEF. This agent have the coordination with Main Circuit Breaker (CB) in order to prevent the extension of fault to the power grid.

3) Under Voltage relay agent: It will be used to alert the feeder from under voltage situations and subsequently the prioritized load-shedding procedure will be initiated with droping off the lowest priorities of loads and related appliances till the clearance of alarm.

4) Main CB Agent: It is located at the beginning of the distribution feeder. If fault occurs, it will isolate related feeder from the network. Eventually it will be closed as long as the protection relays issue required permissions. The status of Main CB is considered to be “closed” in normal operation mode.

5) DG Agent: DG refers to a variety of technologies which generate electricity located at or near essential loads. In fault occurance this agent will be disconnected, and while the fault is cleared or isolated, if the DG is not within the fault location then it may be connected, otherwise, it will be blocked. The Simple Sectionalizer of DG is considered to be "closed" in normal condition mode. In this study, the capacities of DGs are supposed not to be sufficient enough to supply existing load consumptions and the amount of it will be asked to perform suitable maneuvers.

6) Auxiliary Feeder agent: As its name indicate, if the capacity of this agent is required then it will be connected in critical situations or etc., however in normal conditions it operates independently.

7) Fault Indicator (FI) agent: This instrument is installed along different sections of the feeder in order to save the fault location, sense the direction of the fault in both directions and indicates it by physical changes [8]. Different status of FI are shown in TABLE I, FI is the passive agent, which means that it holds the status and only reports it while it is asked.

TABLE I. Status of FI or Simple Sectionalizer agents [8]

Direction of fault	**Status**
Direction toward the end of feeder	1
No sense of fault	0
Direction toward the beginning of feeder	-1

8) *Simple Sectionalizer agent:* The sectionalizer is a self-contained, circuit-opening device used in conjunction with protective devices in order to automatically isolate faulty sections of electrical distribution systems. Same as FI it could sense, detect and also save the fault direction. In addition, this agent has the capability to be controlled (connected or disconnected) whether locally or remotely. Proposed Simple Sectionalizer is the collection of sectionalizer with FI and it is assumed to be uninterruptible under load with remote control capabilities [8]. In proposed method, when any fault occures, Simple Sectionalizers of pre and post-fault is considered to be disconnected. In normal operation, the status of all Simple Sectionalizer agents is considered to be "closed". Same as FI, the status of each Simple Sectionalizer will be assigned as defined in TABLE I.

9) *Main Section agent:* Each feeder will be divided into different zones which will be fed by related Auxiliary Feeders if it is required. This agent will be responsible for the respective feeder zones. After fault occurrence, this agent will check the status of the Simple Sectionalizers and FIs and it will start from the end of its related zone, thereby, it could be able to locate and isolate the faulty section [8]. As it is shown in Fig.1, the simulated feeder is divided into 3 zones, so three different Main Sections will be used in this study.

10) *Load agent:* Each section will be defined by a load. The amount of load consumption will be asked while any fault occures in order to make the balance with the available source capacities and it would be decided whether to start the procedure of prioritized load-shedding or not. In this study, the simulated feeder has 20 loads so random priorities from 1 to 20 will be assigned to these loads. Each consumer also has 5 appliances, so 5 different priorities will be used too.

11) *AMI (Advanced Metering Infrastructure)*: AMI is an integrated system of smart meters, communications networks with data management systems which enables two-way communication between utilities and customers. It collects and saves the real time consumption of difference appliances in customer side and in case of fault occurrence, it would also have the possibility to disconnect or whether connect the appliances as required [11].

B. Components of simulated system

As it is illustrated in Fig.1, simulated feeder is included with: one Substation, one Main CB, one OC/EF/SEF and one UV protection relays, 3 Main Sections, 3 Auxiliary Feeders and also 2 DG units with their related Simple Sectionalizers, 10 Simple Sectionalizers, 11 Fault Indicators, 20 Load points which each one contains two consumers, including two AMIs and each consumer contain 5 electrical appliances.

C. Find the Fault Location

After fault occurrence, each Main Section agent will be triggered to check the status of Simple Sectionalizers and Fault Indicators of its own covered zone one by one from the end of the section in order to find and isolate the faulty area with minimum affects to the other loads. The responses will be compared with previous stored status according to TABLE II and if the comparison is positive which means that the fault is detected so pre and post Simple Sectionalizers of this section will be opened for isolating and also restricting faulty section immediately [8].

TABLE II. FINDING THE FAULT LOCATION [8]

Comparison	Result
First PreviousFIStatus (At system startup)	+1
CurrentFIStatus – PreviousFIStatus > 0	Fault detected
CurrentFIStatus – PreviousFIStatus ≤ 0	Fault not detected, next

IV. CASE STUDIES

In this section two different scenarios with both conventional and proposed methods will be simulated and analyzed.

1) Detected EF at section 17

In this scenario, DG-2 is located in faulty area, so it will be blocked and its power capacity will not be considered as the available power source.

a) *Conventional method:* As shown in TABLE IV, it seems that remained capacity of Auxiliary Feeder-3 (35 A) is not sufficient for consumption of L_{18}, L_{19} and L_{20}(52 A), then there is no chance to feed these loads. So two Simple Sectionalizers of 15 and 20 will be disconnected both together not just only for isolating the faulty section but also because of insufficiency of Auxiliary Feeder-3 to feed remained loads.

b) Proposed method: Main CB and DGs will be disconnected immediately after fault occurrence. The procedure of finding the faulty location will be initiated. As it is shown in TABLE III, the agent of Main Section-3 will find the fault location in its zone (in section 17) and subsequently issues the open command to pre and post Simple Sectionalizers of faulty section. So the Simple Sectionalizers of 15 and 17 are selected to be disconnected in order to isolate the faulty area and following that Main CB agent will be closed to energize the feeder up to Simple Sectionalizer 15.

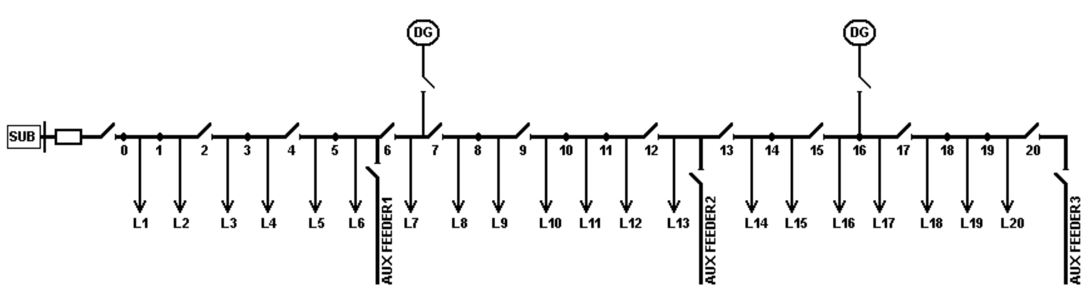

Fig. 1. Simulated Distribution Feeder

TABLEIII. FINAL STATUS OF FI AND SIMPLE SECTIONALIZERS (EF AT 17)

Name	FI0	FI1	Sim2	FI3	Sim4	
Status	1	1	1	1	1	
Name	**FI5**	**Sim6**	**Sim7**	**FI8**	**Sim9**	
Status	1	1	1	1	1	
Name	**FI10**	**FI11**	**Sim12**	**Sim13**	**FI14**	
Status	1	1	1	1	1	
Name	**Sim15**	**FI16**	**Sim17**	**FI18**	**FI19**	**Sim20**
Status	1	1	-1	-1	-1	-1

The capacity of the Auxiliary Feeder-3 (35 A) and the consumption of loads L_{18}, L_{19} and L_{20} (52 A) will be asked. So at this moment the procedure of load-shedding will be initiated and it will start to shed through lowest priorities of both loads and related appliances. L_{19}, with priority of 20 is the lowest and L_{20} with priority of 4 is the highest priorities among these available loads. So the appliances with the fifth priority of L_{19}, L_{18} and L_{20} will be shed while checking below comparison:

$$\text{Aux-Feeder3} \geq (1.05 \times \sum_{i=18}^{20} L_i) \quad (1)$$

The load-shedding of fifth priority is finished but as it is shown in TABLE IV, only (12 A) is decreased and above comparison is not met, so it will continue to shed the fourth priority till the comparison is established. Finally when the load consumption and available power sources are balanced, then Auxiliary Feeder-3 will be connected.

TABLE IV. PRIORITIZED LOAD-SHEDDING (EF AT SECTION 17)

Aux-Feeder 3			35 A			
Total load before Load-Shed			(Section3) 52 A			
Total load after Load-Shed			(Section3) 52 A - (Section3) 20 A = 32 A			
Total Load - Load-Shed			52 A - 20 A = 32 A			
Load No.	**Priority** $_L$	**Consumption**		**Shed-Level (A)**		**Total Load-Shed**
		before Load-Shed	***after Load-Shed***	***Level 5***	***Level 4***	
Load 18	19	18 A	10 A	4	4	8 A
Load 19	20	18 A	10 A	4	4	8 A
Load 20	4	16 A	12 A	4	Stop	4 A
	Total	52 A	32 A	12	4	20 A
			Total	20		

c) Outcome: While in conventional method the total load (52 A) will be disconnected, but in proposed method by shedding just (20 A) it would be possible to feed rest of the loads which is around (32 A).

2) Detected OC at section 10

In this scenario, both DGs are not located in faulty area, so they both will be disconnected immediately after fault detection and as soon as fault isolation, the requirement of DGs will be calculated and analyzed.

a) Conventional method: The available capacities are related to Auxiliary Feeder-2 (54 A), Auxiliary Feeder-3 (27 A) and DG-2 (if applicable) which will be (86 A) in total. By starting calculation of load consumption from the end of both second and third Main Sections, it seems that Auxiliary Feeder-3 could not feed the accumulated consumptions of L_{18}, $L_{19}$and L_{20} which is (46 A).On the other hand, Auxiliary Feeder-2 could only feed accumulated consumptions of L_{13}, L_{14} and L_{15} which is (48 A). In addition to Simple Sectionalizer 9, three other Simple Sectionalizers of 12, 15 and 20 will be disconnected. Simple Sectionalizer 12 as post-fault , Simple Sectionalizer 15 due to lack of power capacity and Simple Sectionalizer 20 to isolate the last loads of the third Main Section. Note that there is no need for DG-2 in this case, so L_{16}, L_{17}, L_{18}, L_{19} and L_{20} will be disconnected. Finally, the total loads with consumption of (48 A) will be fed out of (128 A).

b) Proposed method: Main CB and DGs will be disconnected immediately after fault occurrence. The procedure of finding the faulty location will be initiated. As it is shown in TABLE V, the agent of Main Section-2 will find the fault location in its zone (in section 10) and subsequently issues the open command to pre and post Simple Sectionalizers of faulty section. So the Simple Sectionalizers of 9 and 12 are selected to be disconnected in order to isolate the faulty area and following that Main CB agent will be closed to energize the feeder up to Simple Sectionalizer 9.

TABLE V. FINAL STATUS OF FI AND SIMPLE SECTIONALIZERS (OC AT 10)

Name	FI0	FI1	Sim2	FI3	Sim4	
Status	1	1	1	1	1	
Name	**FI5**	**Sim6**	**Sim7**	**FI8**	**Sim9**	
Status	1	1	1	1	1	
Name	**FI10**	**FI11**	**Sim12**	**Sim13**	**FI14**	
Status	-1	-1	-1	-1	-1	
Name	**Sim15**	**FI16**	**Sim17**	**FI18**	**FI19**	**Sim20**
Status	-1	0	0	0	0	0

Then the capacity of the Auxiliary Feeder-2 (54 A), Auxiliary Feeder-3 (27 A), DG-2 (5 A) and also the amount of consumption of loads from L_{13} to L_{20}(128 A) will be checked. As shown in TABLE VI, it seems that for balancing the consumption with power source, load-shedding will be required. L_{19} with priority of 20 is the lowest and L_{18} with priority of 2 is the most valuable load. Then the appliances with the fifth priority of L_{19}, ... and L_{18} will be shed respectively while checking below comparison:

$$\text{Aux-Feeder2+Aux-Feeder3+DG-2} \geq (1.05\times \sum_{i=13}^{20} L_i) \quad (2)$$

While this comparison is not met, it goes some steps further and begins load-shedding of the appliances with the fourth priorities. When above comparison is established, then it is the time to find optimized cut-off separator between Main Section-2 and 3. As it is shown in TABLE VI, Auxiliary Feeder-3 (27 A) could only feed last three loads (28 A) but it needs one more load-shedding to do so. Finally by load-shedding of third priority of L_{19} it would be possible. So the optimized cut-off separator between two Main Sections will be Simple Sectionalizer 17, therefore the load consumption before Simple Sectionalizer 17 should be calculated. As it is shown in TABLE VI , capacity of Auxiliary Feeder-2 and DG-2, both together would be around (59 A) and the load consumption L_{13} to L_{17} after first load-shedding is (50 A), so it seems that we have much more capacity in our power sources to feed much more loads. In this stage the procedure of load store (6 A) will be initiated and at the end it could be seen that (56 A) will be fed via these two power sources.

TABLE VI. PRIORITIZED LOAD-SHEDDING (OC AT SECTION 10)

Aux-Feeder 2				54 A						
Aux-Feeder 3				27 A						
DG 2				5 A						
Total load before Load-Shed (A)				(Section2) 18 A + (Section3) 110 A = 128						
Total load after first Load-Shed (A)				(Section2) 18 A - (Section2) 8 A + (Section3) 110 A - (Section3) 42 A = 78						
Total load after Load-Shed & Store (A)				(Section2) 18 A - (Section2) 8 A + (Section3) 110 A - (Section3) 38 A = 82						
Aux2 + Aux3 + DG-2				54 A + 27 A + 5 A = 86 A						
Total Load - Load-Shed (Remained Load)				128 A - 46 A = 82 A						
Disconnector				Sim_Sec_17						
Load Number	**Priority L**	**Consumption before Load-Store**	**Consumption after First Load-Shed**	**Consumption after Second Load-Shed**	**Consumption after Load-Store**	**Shed-Level**			**Total Load-Shed**
						Level 5(A)	***Level 4 (A)***	***Level 3(A)***	
Load 13	11	18 A	10 A	10 A	10 A	4	4	Stop	8 A
Load 14	13	18 A	12 A	12 A	12 A	4	2	Stop	6 A
Load 15	15	12 A	6 A	6 A	6 A	2	4	Stop	6 A
Load 16	8	14 A	10 A	10 A	12 A	2	~~2~~	Stop	2 A
Load 17	4	20 A	12 A	12 A	16 A	4	~~4~~	Stop	4 A
Load 18	2	20 A	14 A	14 A	14 A	2	4	Stop	6 A
Load 19	20	16 A	8 A	6 A	6 A	6	2	2	10 A
Load 20	17	10 A	6 A	6 A	6 A	2	2	Stop	4 A
	Total	128 A	78 A	76 A	82 A	26	18	2	46 A
					Total	46 A			

c) Outcome: While in conventional method, from total of (128 A) just (48 A) will be fed and the rest will be disconnected, but in proposed method by shedding just (46 A) it would be possible to feed rest of the loads which is around (82 A).

V. ACKNOWLEDGMENT

In this study the outage management in smart distribution networks with perspective of MAS is simulated and analyzed in JADE platform. Balancing the customer's consumption by integrating prioritized load-shedding with available power sources not only speeds up finding the faulty section, feed the most loads and subsequently increase customer welfare but also it restricts the fault location as small area as possible.

Two case studies were analyzed and the results indicate that, in first case study of proposed method, 61.53% of loads will be fed in comparison with conventional method which there is no chance to do so. However, this result would be variable and it depends on mostly two parameters, the capacity of Auxiliary Feeder-3 and also the amount of accumulated consumptions related to last loads of the feeder. In second case study, with conventional method 37.5% and by using proposed method 64.06% of loads could be supplied and 26.56% less loads will be disconnected, which means that in this case we could feed the affected loads 1.7 times much more than conventional method. Ultimately, it also indicates that the maximum reliability of network and customer welfare both together will be achieved by utilization of prioritized load-shedding.

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