SMART FAULT MANAGEMENT SCHEME FOR ELECTRICAL DISTRIBUTION NETWORKS

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ABSTRACT

Self-healing is very important feature of automation network. The paper suggests a simple control technique for Self-healing with intelligent switching for distribution networks. The technique is considering the most common normal and abnormal conditions. The technique detects the faults, isolates faulty section, restores service to healthy sections and simplifies the system reconfiguration. Also, the technique with the distributed intelligent electronic devices, intelligent switching and advanced communication system protects reconfiguration system from loading exceeding the capabilities of network. The paper presents application of proposal technique of self-healing on IEEE test feeder.

INTRODUCTION

Conventional distribution system may be unsatisfied for power quality requirements and deregulated markets which look forward to improve power supply reliability, system operating efficiency and power quality. To satisfy these requirements, distribution automation should be provided which is a common trend in the last decade [1], [2]. The demand for reduced outage rates has led most electric companies to reconfigure their networks from radial to normally open loop. Once a faulted section is isolated, power can be restored to the rest of the network from an alternative source. The distribution networks become more complex after restoration action. This task is economically achieved by introducing pole mounted distribution automation (DA) switches, which are remotely controlled from a central control room [1-5]. The protection devices that were coordinated may no longer coordinate with network reconfiguration [3].

Self-healing is one of the most important features of automation network. "Uninterrupted power supply problem" is a real challenge for self-healing control, which requires real-time monitoring of network operation, predicting the state power grid, timely detection, rapid diagnosis and elimination of hidden faults without human intervention. Automatic restoration system automatically reconfigures the distribution system after a fault and quickly restores service to sections of the feeder which are not affected by the fault [6] [7]. The reliability of self-healing depends on the reliability of the common used elements with distribution automation systems, such as remotely controlled switches, intelligent electronics devices (IEDs) and its communication techniques [9]. Widely use of intelligent switching which contains the intelligent electronic devices presents advanced features in protection, metering, control and monitoring which allows the improve grid reliability [5]. There are types of these switches specifically designed for automating overhead distribution networks. The intelligent switching system would not reduce the number of outages, but it would reduce the outage duration. Every remotely controlled switch is associated with a microprocessor-based controller. It would continuously remotely communicate with control center [16].

Nordman in [10] presents an agent concept aim to limit the communication networks saturation. In [10], the process and decision making closing into lower level as possible by delegation from control center. In this technique, sub control system located at the secondary substations 11/0.4kV (Fig.3). The technique is not adequate for pole mounted distribution automation because large number of equipments must be installed on the medium voltage tower at every controlled node. There are two motorized control switches and load break switch and the distribution transformer every secondary substation. Overhead distribution automation has been a common trend for most electric companies worldwide [17-19]. To overcome the communication problem may use robust communications technique like GSM. Some studies implements self-healing schemes using protection-oriented communications technology to clear faults and restore load in less than one second [11]. Any way all techniques [10-12] are limited for two feeders or simple loop. The drawback of using a loop scheme is that control decisions rely only on local measurement [3]. Local devices do not have awareness of the state of all alternate sources.

This paper presents solutions for implementing self-healing grids designed to improve reliability by laying the availability of health sections for a grid that will meet future requirements as well. The paper proposed a simple control technique for management of distribution grids considering the most common normal and abnormal conditions. The technique detects the faults, isolates faulted section, restores service to non-faulted sections and simplifies the system reconfiguration. The technique with the distributed intelligent electronic devices and advanced communication system protects reconfiguration system from loading exceeding the capabilities of system. The main idea of the proposed technique depends on dividing any system into main feeder and accompanied branches in order to divide the network into selected number of sections. These sections are controlled by intelligent switching and built-in intelligent sensors with communication features. In case of fault occurrence, the fault current is sensed using built-in IEDs and the technique collects all data and information through the communication system. Then, the technique makes the decision and takes action to restore non-faulted sections using intelligent switching.

II. THE PROBLEM EVALUATE

The main feature of conventional distribution network is redial in operation and energized from one source. In automation network, there are alternative sources but also the feeders are energized from one source [3]. The multiple alternative sources to increase reliability is benefits and difficult in operation. However, the constraints of transfer the load from the source to the other are exceeded. There are several processes to achieve the transferring action. For example, restoring service to a feeder section may result in overload conditions, excessive voltage drop, or power factor degradation. The control system will select the alternative feeder that has the most capacity. The switching operation is required to economical intelligent switching.

Commonly, the load transfer operation is producing the network reconfiguration. The setting of protection scheme of conventional distribution network is selected for certain configuration. In self-healing, the protection setting of automation network must change the setting for the new configuration network. The new setting is considered the update load current and the minimum short circuit. The protection relay must be commissioning with the automation system and allows the remotely new setting. Therefore, enhances the performance of the used protective elements with distribution automation units [14].

III. PROPOSAL TECHNIQUE

The IEEE 123 node test radial feeder operates at a nominal voltage of 4.16 kV [15]. While this is not a popular voltage level it does provide voltage drop problems that must be solved with the application of voltage regulators and shunt capacitors [15]. There are enough switches in the feeder to provide alternate sources for restoration process as shown in Fig.1. Firstly, the selected feeder is divided into main feeder and accompanied branches in order to divide the network into selected number of sections as shown in the figure. In the figure, the main switches are S1, S2 and S3. The accompanied branches switches are SB11, SB21 and SB31 respectively. There are switches normally closed for the initial conditions and others normally open to provide alternate paths of power flow as shown in Fig.2. The positions and initial conditions of the switches are demonstrated in table [1]. To achieve the technique, the switching is considered intelligent switching. Every switch is controlled number of nodes. These nodes are called sections. There are six sections for six closed switches. The number of potential faulty sections equals to the number of closed switches. The switches NO23, NOB1B3 and NOB3 are normally open to provide alternate paths of power flow. The switches NO1, NO2 and NO3 are normally open to provide alternative sources.

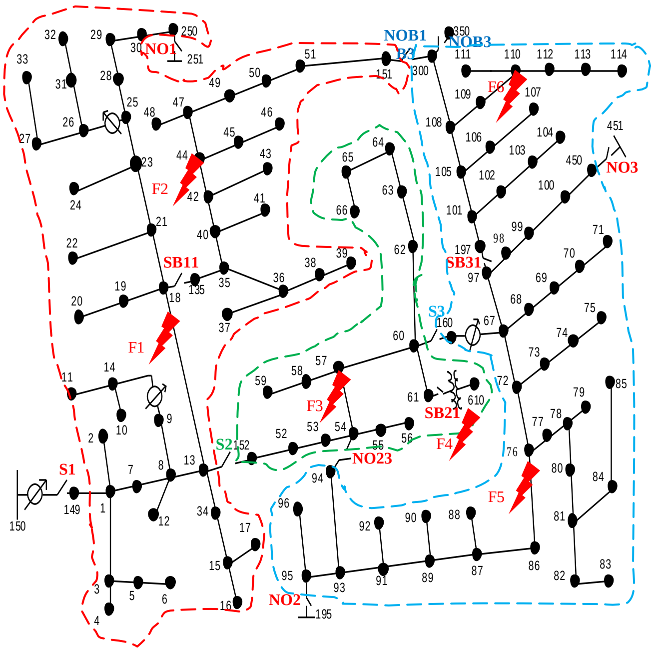

Fig.1. IEEE 123 node test feeder

Table 1. The initial conditions of the switches

Three Phase Switches			
Switch	Node A	Node B	Normal
S1	150	149	Closed
S2	13	152	Closed
S3	60	160	Closed
SB11	18	135	Closed
SB21	61	160	Closed
SB31	97	197	Closed
NO1	250	251	Open
NO2	95	195	Open
NO3	450	451	Open
NO23	54	94	Open
NOB3	300	350	Open
NOB1B3	151	300	Open

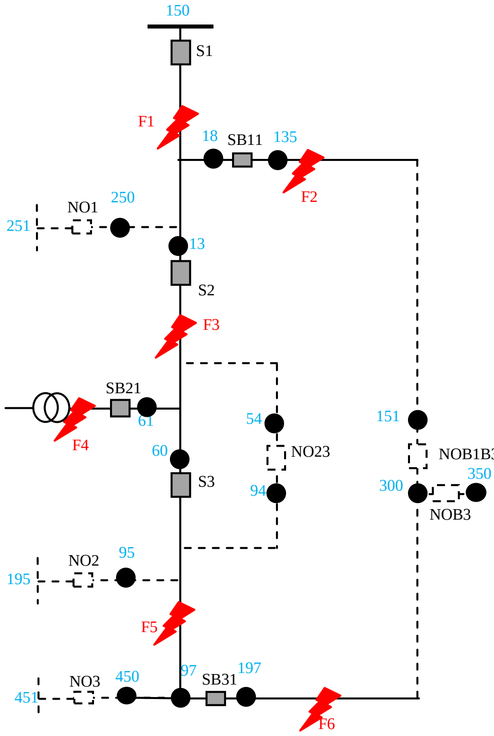

Fig.2. Potential faulty sections of IEEE 123 node test feeder.

In potential detection matrix, the sensed fault current is discriminated by digits 1 and healthy section is discriminated by digits 0 as shown in table [2]. For example, the DI equals to 100000000000 refers to faulty section (F1) which controlled by switch S1. The digital input for F1 is not repeated with the potential faulty sections. So that, the digital input are used as the fault code to discriminate the fault location. The fault section needs adequate action to isolate the faulty section.

Table 2. Detection matrix for IEEE 123 node test feeder

DETECTION MATRIX													
FAULT	S1	S2	S3	NO1	NO2	NO3	SB11	SB21	SB31	NO23	NOB3	NOB1B3	DIGITAL INPUT
F1	1	0	0	0	0	0	0	0	0	0	0	0	100000000000
F2	1	0	0	0	0	0	1	0	0	0	0	0	100000100000
F3	1	1	0	0	0	0	0	0	0	0	0	0	110000000000
F4	1	1	0	0	0	0	0	1	0	0	0	0	110000010000
F5	1	1	1	0	0	0	0	0	0	0	0	0	111000000000
F6	1	1	1	0	0	0	0	0	1	0	0	0	111000001000

The isolation matrix presents the proposal switching action to isolate the faulty sections as shown in table [3]. The controller is detecting the fault code and determines the equivalent digital output signals (DO). For example the DO equals to 110111000111 refers to isolate the faulty section (F1) which **is** limited by switches S1, S2 and SB11. In DO, the opening switches are discriminated by digits 1 and closing switches are discriminated by digits 0. The DO signals are meaning that the switches S1, S2 and SB11 are opened. In addition to the normally opened switches NO1, NO2, NO3, NOB3 and NOB23. And so on, the switches S3, SB21 and SB31 are closed. The digital output for every isolated fault case isolation not repeated in the others. There are isolated healthy section which is limited by switches SB11 and the normally opened switch NOB1B3. The isolated healthy feeder needs to alternative paths power flow from the selected feeder or alternative source to receive the isolated healthy sections.

Table 3. Isolation matrix for IEEE 123 node test feeder

ISOLATION MATRIX													
FAULT	S1	S2	S3	NO1	NO2	NO3	SB11	SB21	SB31	NO23	NOB3	NOB1B3	DIGITAL OUTPUT
F1	1	1	0	1	1	1	1	0	0	1	1	1	110111100111
F2	0	0	0	1	1	1	1	0	0	1	1	1	000111100111
F3	0	1	1	1	1	1	0	0	0	1	1	1	011111000111
F4	0	0	0	1	1	1	0	1	0	1	1	1	000111010111
F5	0	0	1	1	1	1	0	0	1	1	1	1	001111001111
F6	0	0	0	1	1	1	0	0	1	1	1	1	000111001111

The restoration matrix presents the number of available restoration solutions as shown in table [4]. The controller is remotely sending the DO signals to the control units which associated with distributed switches. The switches control units take action to restore the power to healthy sections according to the received signals.

Table 4. Restoration matrix for IEEE 123 node test feeder

RESTORATION MATRIX													
FAULT	S1	S2	S3	NO1	NO2	NO3	SB11	SB21	SB31	NO23	NOB3	NOB1B3	DIGITAL OUTPUT
F1	0	0	1	0	0	1	0	1	1	0	0	1	001001011001
F2	1	1	1	0	0	0	0	1	1	0	0	0	111000011000
F3	1	0	0	0	0	0	1	1	1	0	0	1	100000111001
F4	1	1	1	0	0	0	1	0	1	0	0	0	111000101000
F5	1	1	0	1	0	1	1	1	0	0	0	1	110101110001
F6	1	1	1	0	0	0	1	1	0	0	0	0	111000110000

For example, the DO equals to 001001011001 refers to restore the power to healthy section after isolation of the faulty section (F1) which is limited by switches S1, S2 and SB11. In DO, the closing switches are discriminated by digits 1 and opening switches are discriminate by digits 0. The DO signals are meaning that the switches S1, S2, SB11, NO1, NO2, NO23 and NOB3 are opened and the other switches are closed as shown in the Fig. [3]. There are other way to restore the healthy sections by the opening NO3 and closing NO2. Figure 3 demonstrates the restoration process when two alternative sources are available.

In the figure, the shaded rectangular refers to the closed switches. The unfilled rectangular refers to the opened switches. The control system will select the alternative feeder that has the most capacity. In the case of the self-healing constraints are satisfied, the controller may send the restoration matrix without isolation matrix for avoiding the unnecessary operation of switching and communication devices. When S1 is used as main circuit breaker, it should be blocked in the matrices. The main circuit breaker must be sustained open during the switching.

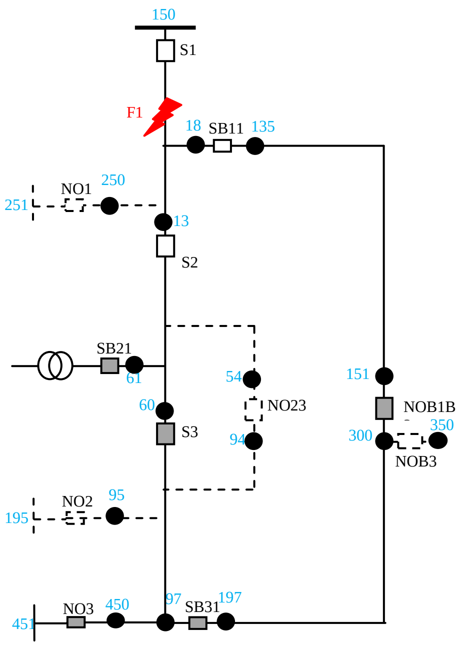

Fig. 3. The restoration process when two alternative sources are available

The mentioned control scheme, is economical and satisfying the fault management with significant fault current. In case of the fault through resistance, the fault current may be lower than the setting of controller at distributed switches. In this case advanced technique must be used. In proposal technique, the fault current and residual voltage values at the distributed IEDs must be recorded. Then, the IEDs are sending the recorded values to the control center.

In other word, the fault data are received from the controller at the IEDs. Then, mathematical operations are applying to discriminate the faulty section. In this technique, the conditional probability is used for discriminating the faulty section using the equations (1, 2, 3 and 4) [20] and [21].

$$P_{ri}(NS_i, \ldots, NS_n) = \frac{\frac{f_1(NS_i)}{f_o(NS_i)}}{\sum_{j=1}^{n}\frac{f_1(NS_j)}{f_o(NS_j)}} \quad (1)$$

$$0 \leq Pr(Ns) \leq 1 \quad (2)$$

$$f_o(NS_i) = \frac{1}{\sigma_o\sqrt{2\pi}} e^{\frac{-(NS_i-\mu_o)^2}{2\sigma_o^2}} \quad (3)$$

$$f_1(NS_i) = \frac{1}{\sigma_1\sqrt{2\pi}} e^{\frac{-(NS_i-\mu_1)^2}{2\sigma_1^2}} \quad (4)$$

Where, Ns is Normalized value for the feeders, σo refers standard deviation for healthy case, μo is mean for healthy case, σ1 is standard deviation for faulty case and μ1 is mean for faulty case.

Table. 5. Detection of Faulty section (F5) using conditional probability.

F5(S3)		Pro (Vo*ΔIo)					
Rf (Ω)	If (A)	S1	S2	S3	SB11	SB21	SB31
20	102	0	0	1	0	0	0
40	52	0	0.12	1	0	0	0
60	35	0.01	0.57	0.99	0	0	0.01
80	26	0.08	0.59	0.94	0.03	0.02	0.05
100	21	0.16	0.56	0.84	0.09	0.07	0.16
σo = 0.4		μo = 0		σ1 = 0.8			μ1 =1

In potential detection matrix, the faulty and healthy sections are discriminated by the conditional probability criteria 0 ≤ Pr(Ns) ≤ 1. The higher value of Pr (Ns) refers to the faulty section and the other values refer to the healthy sections as shown in tables [5] and [6].

In table [5], the faulty section (F5) is controlled by the switch S3. The mathematical operation of conditional probability refers to S3. In the table, the higher value of Pro (Vo*ΔIo) is detected at S3 at the difference values of fault resistance as shown in the table.

Table. 6. Detection of Faulty section (F6) using conditional probability.

F6(SB31)		Pro (Vo*ΔIo)					
Rf (Ω)	If (A)	S1	S2	S3	SB11	SB21	SB31
20	102	0	0	0	0	0	1
40	52	0	0.09	0	0	0	1
60	35	0	0.34	0	0	0	1
80	26	0.07	0.3	0	0.03	0.02	0.99
100	21	0.16	0.35	0.01	0.08	0.06	0.99
σo = 0.4		μo = 0		σ1 = 0.8			μ1 =1

In table [6], the faulty section (F6) is controlled by the switch SB31. The mathematical operation of conditional probability refers to SB31. In the table, the higher value of Pro (Vo*ΔIo) is detected at SB31 at the difference values of fault resistance as shown in the table.

IV CONCLUSIONS

Self-healing may result overload conditions, excessive voltage drop, or power factor degradation and the control system should select the alternative feeder that has the most capacity. The complexity of configuration required to more complex process for achieved the self-healing.

Change protection settings groups in relays to preserve effective coordination after circuit reconfiguration.

The self-healing becomes more flexible with the proposed technique. There are many restoration ways according to system configuration and the constraints. The process of self -healing may stopped at the isolation of faulty sections to satisfy the system constraints or unavailable alternative source.

The multi level of the control system makes simplicity of network automation. The delegation between two controller levels avoids the communications saturation.

The proposal smart fault management scheme is achieved with the IEEE 123 node test feeder. In the feeder, the technique detects the faults, isolates faulty section, restores service to non-faulted sections and simplifies the system reconfiguration.

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