FAULT SECTION ESTIMATION IN POWER SYSTEMS USING THE PROTECTIVE DEVICES SETTINGS AND SEARCH ALGORITHM OF ISOLATED SECTIONS

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Abstract— Fault section location is a critical task when a severe disturbance is caused by a failure on a transmission line. In order to avoid further economic and social costs by load interruptions, intelligent systems have been successful in dealing with fault location problems. This paper presents a novel deterministic method to locate fault section on electrical power systems with the aim of assisting to command center operators to make decisions in cases of disturbances. The methodology proposed is based on the features of the electrical system, such as: state of relays and circuit breakers; impedance of transmission lines and transformers and adjustment of impedance relays. With the information provided by the expert system proposed, the operator has the advantage of making decisions more accurate in less time, based on information obtained from own electric system; unlike other methods already proposed, which were based on uncertainties and approximations.

Keywords— Fault section estimation, power systems protection, search algorithm, intelligent systems applications in power systems.

1 Introduction

Given that the electricity is an indispensable asset to a nation and even considered one of the indices of development of a country, it is essential that it be delivered to customers continuously, in other words, it is of utmost importance that the power system work full-time. Identifying the location of faults is an important process for promoting higher reliability of electric power systems. Such knowledge is especially important for faults on lines because lines extend over large geographical areas. Knowledge of the location of a permanent fault allows the utility to promptly dispatch personnel to the scene to make necessary repairs. The sooner the personnel arrive at the scene, the faster the service can be restored. Experience has shown that a significant portion of outage times are caused because of the time required in locating the failure.

To ensure these features, it is necessary a constant evolution in the protection systems. Currently this need has made the study of methods to fault location became a matter of great emphasis. Because of this, increasingly are developed computational tools able of identify or estimate the fault section.

A good computational tool should support the operator in the following phases: identify the system components (transformers, transmission lines, etc.) that were in operation before the contingency and were disconnected because of it; select the most plausible hypothesis for the event among the set of components found in the previous phase. If the faulted equipment needs maintenance, execute the necessary maneuvers to isolate it (G. & J. G., 2008), (J & O, 2012).

In recent years, several methods to estimate the fault section were developed (W, et al., 2013)- (P, et al., 2012) such as neural network (W, et al., 2013)- (Thukaram & Shenoy, 2006), genetic algorithms (Wen, 1997), neuro-genetic (Bedekar & Bhide, 2009), logic fuzzy applied on expert systems (Min, et al., 2004), (Chen, 2011), (Chen, 2012) and constructive heuristic combined with integer programming (P, et al., 2012).

The change in the network topology due to the operating of the protective devices must be considered with the uncertainties in the power systems. A change in the network topology generates changes on the protective areas of the devices. In the complicated case of multiple faults, consideration of the change in the network topology is necessary for an accurate fault diagnosis (Min, et al., 2004).

The proposed method here also needs consider these changes in the network topology to work correctly. This methodology is based on the real characteristics of the electrical system, such as impedance transmission lines and transforms, state of circuit breakers and adjusts distance relays.

Using parameters obtained from the electrical system this method identifies the fault location, given as a result, for each section the percentage of deviation from his reference fault built for the section pattern.The result of method shows to the control center operators a list of fault candidates ordered from largest to smallest probability occurrence.

The proposed methodology is novel and distinct from other methods already applied. The weights calculated to define a section as a possible fault candidate are taken from own electric power system. Therefore, we can affirm that fault candidates selections are defined by intrinsic information and not by uncertainties.

2 Power system protections

When there is a fault in a power system, protective relays detect the fault and trip the corresponding circuit breakers in order to isolate the fault section. In this procedure of protection, there are some uncertainties such as malfunctions, miss operation, and the false alarms of the protective devices. There are various protection systems based on the possibility that not all devices operate correctly.

Several analysis and simulations in specialized software are made on the power system before of adjust all the protection devices. In general, protection systems are composed of the main protection and some backup protection; which are usually composed of distance relays (Committee, 2008).

The zone 1 is normally adjusted to 85% of the section. Consequently, the distance relay is equipped with another zone, which deliberately overreaches beyond the remote terminal of the transmission line. This is known as zone 2 of the distance relay, and it must be slowed down so that, for faults in the next line, zone 1 of the next line is allowed to operate before zone 2 of the remote distance relay. This coordination delay for zone 2 is usually of the order of 0.3 s. The reach of the second zone is generally set at 120–150% of the line. Other mentioned that the zone 2 is adjusted from 115% to 150% of its own section according to the length of own section and its adjacent section. The zone 2 has more sets for consider, all it depends the power system composition.

In order to provide a backup function for the entire line, it is customary to provide yet another zone of protection for the relay at A. This is known as the third zone of protection, and usually extends to 120–180% of the next line section. The third zone must coordinate in time and distance with the second zone of the neighboring circuit, and usually the operating time of the third zone is of the order of 1 s.

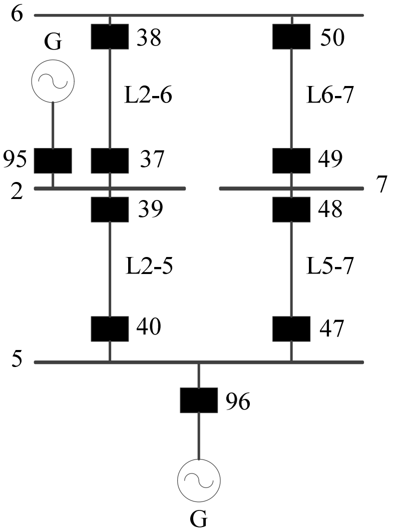

Fig. 1. Partial ieee-30 bus system

The zone 3 normally has a set like 120% of the own section and the shorter adjacent section (Committee, 2008)- (Siemens, 2012).

3 Expert system methodology

The methodology for fault section estimation on power systems depends of alarm groups and states of circuit breakers activates, associated for each section. For explain better the methodology was used the test system IEEE-30 Bus System. Fig. 1 shows the partial IEEE-30 Bus System.

The expert system is divided into four blocks; each block operates as a filter, where the latest block shows to the operator the summary with the fault candidates arranged for priority of analysis.

Fig. 2 shows the flowchart explaining step to step the process made.

2.1 Estimation of the fault reference

The value of the fault reference (FR) can be calculated creating a pattern for each section using the correlation between zones settings of the impedance relays and information of network topology. TABLE I presents the model of database of the expert system. In this paper this correlation generates a value that will be considered like a weight in terms of selectivity defined by the

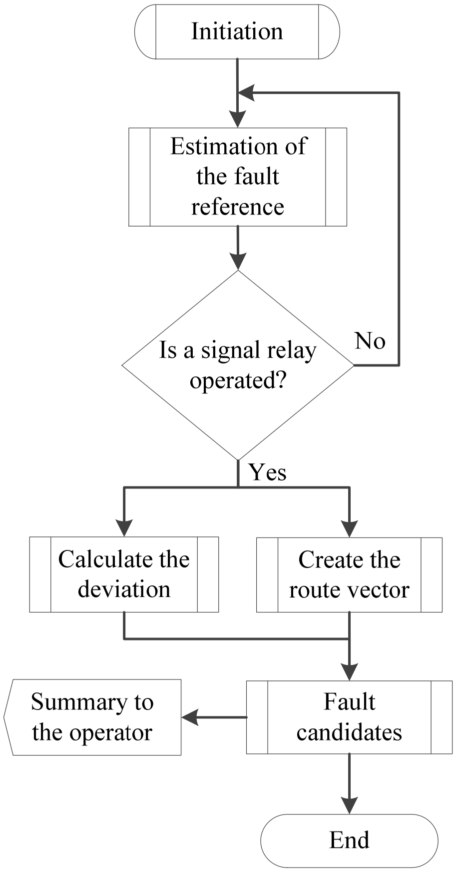

Fig. 2. Expert system flowchart.

TABLE I. Model of database.

Section	**Z(p.u)**	**Relay**	**Zone setting (p.u)**	**Weight**
Section id	Z(p.u) value	R1	Zone 1	W_{Z1}
			Zone 2	W_{Z2}
			Zone 3	W_{Z3}
		R2	Zone 1	W_{Z1}
			Zone 2	W_{Z2}
			Zone 3	W_{Z3}

TABLE II. Results with the Dijkstra algorithm for the section L6-7.

L_{LA}	N_{LA}	**Dijkstra algorithm**		
		Initial node	**Final node**	**Active pattern nodes inside the paths**
2	1	96	49	96-5-47-48-7-49
			50	96-5-40-39-2-37-38-6-50
2	1	95	49	95-2-39-40-5-47-48-7-49
			50	95-2-37-38-6-50

TABLE III. Database of partial ieee-30 bus system

Section	**Z(p.u)**	**Relay**	**Zone setting (p.u)**	**Weight**
L2-5	0,2038	39	0,1732	1
			0,2343	0,8449
			0,3943	0,4393
		40	0,1732	1
			0,2343	0,8432
			0,39	0,4441
L2-6	0,1856	37	0,1577	1
			0,2071	0,82
			0,2744	0,5748
		38	0,1577	1
			0,2092	0,86
			0,3681	0,4285
L5-7	0,1248	47	0,1060	1
			0,1435	0,8521
			0,2532	0,4189
		48	0,1060	1
			0,1435	0,905
			0,3943	0,26902
L6-7	0,0862	49	0,0732	1
			0,0991	0,8333
			0,1551	0,4722
		50	0,0732	1
			0,0991	0,8978
			0,2532	0,2893

protection reach corresponding to the settings of the associated impedance relays. In other words, it's defined the zone 3 as 1, thus are determined the zone 1, zone 2 and zone 3 as percent. Below are defined these percentages with reference to the protected section, determining weights for each protection zone in terms of selectivity.

This weight of each zone in terms of selectivity on the section can be calculated by:

$$W_{Z1} = \frac{Z_3}{Z_3} \tag{1}$$

$$W_{Z2} = 1 - \left(\frac{Z_2}{Z_3} - \frac{Z_1}{Z_3} \right) \tag{2}$$

$$W_{Z3} = 1 - \left(\frac{Z_3}{Z_3} - \frac{Z_1}{Z_3} \right) \tag{3}$$

Where:

Z_1 - Impedance relay setting for zone 1 (Ω).

Z_2 - Impedance relay setting for zone 2 (Ω).

Z_3 - Impedance relay setting for zone 3 (Ω).

In addition, with the information of network topology using the network configurator proposed by (Aécio L., et al., 2012), are obtained the states of circuit breakers and switchgears.

The objective in this section is identify all available paths from a generator node until the study node, using the Dijkstra search algorithm based on the impedance values of the elements of the electrical system (Loureiro, 2005), (Correia, 1999).

A generator node is one that has a generation plant connected.

In order to determine the number of paths to explore for the search algorithm is taken as base the quantity of lines in service associated with study node.

$$N_{LA} = \sum L_{LA} - 1 \tag{4}$$

Where:

L_{LA} - Quantify of lines in service associated with the study node.

N_{LA} - Quantify of paths to explore.

When defining the weights and the available paths is created a pattern for each section conformed for responsible nodes for the section at that moment.

TABLE II presents the results obtained for the section L6-7 using the Dijkstra algorithm.

Each relay is defined as a node and all element of electrical system is conformed for two nodes. With this information is built the database as show the TABLE III. With this pattern is built a database where are associated the reaches of main and neighbors relays responsible for the section.

The total weight of main and neighbors relays responsible for the section can be calculated by:

$$W_{TOTAL(\mathrm{N})} = W_{Z(\mathrm{N})} \times A_{NA} \times Z_{COV} \qquad (5)$$

Where:

$W_{Z(N)}$ - Weight of the zones in terms of selectivity.

A_{NA} - Active pattern node with values of 0 or 1.

Z_{COV} - Zone coverage of neighbors relays on the section (%).

The total weight for main protections not used the Z_{COV}, because those values were considered as a total in terms of selectivity on the section.

TABLE IV presents all the information obtained of database and determined for the expert system for calculate the fault reference value.

2.2 Calculate the deviation for each section

The deviation can be calculated using the fault reference and the value of the total weight is generated for each section according with the protection alarms activated for a fault. These weights are taken of the database.

The deviation is represented in percent as the difference between the total weight generated for protection alarms and the fault reference. This can be obtained as follows:

$$D_{SEC} = \frac{FR - W_{TSEC}}{FR} \qquad (6)$$

Where:

W_{TSEC} - Total weight of each section generated for protection alarms.

FR - Fault reference.

Using this deviation is organized a list of sections from smallest to largest value, thus being able to give priority to analysis of sections with the smallest deviation.

2.3 Create the route vector

The route vector is created with the signalizations of circuit breakers opened by protection of the section. The number of node is saved in order the reception in the route vector; these nodes are used as inputs for the search algorithm with the objective of determine that sections are in the route, which can be obtained as follows:

$$R = D_{i=1}^{n}(\mathrm{i}) \qquad (7)$$

Where:

D(i) - Nodes associated to circuit breaker trip activates for protection of the section.

These nodes are used as a guide, with the aim of create a route and associate the sections inside it. In the expert system database is stored and updated all information of electrical system.

TABLE IV. Value of fault reference for the section L6-7.

Section	**Relay**	**L6-7**		
		Active pattern node	Z_{COV} **(%)**	$W_{TOTAL(N)}$
L2-5	39	0	0	0
		0	0	0
		0	0	0
	40	0	0	0
		0	0	0
		0	0	0
L2-6	37	1	0	0
		1	0,25	0,205
		1	1	0,5748
	38	0	0	0
		0	0	0
		0	0	0
L5-7	47	1	0	0
		1	0,2172	0,1851
		1	1	0,4189
	48	0	0	0
		0	0	0
		0	0	0
L6-7	49	1	0,85	1
		1	1	0,8333
		1	1	0,4722
	50	1	0,85	1
		1	1	0,8979
		1	1	0,2894
			FR	5,8766

TABLE V. Results of route vector for a fault on the L6-7.

R	**Initial node**	**Final node**	**Path**	**Associated sections.**
48, 50	48	50	48-7-49-50	BUS7, L6-7

TABLE V shows as each node is associated with yours section and is created a list of sections that are physically within the area of the fault occurrence. It is simulated a case with occurrence of fault on the L6-7, where the circuit breaker 49 failure and the fault is isolated for the circuit breakers 48 and 50.

2.4 Summary of section estimation to the operator

After made the event classification and fault diagnosis, is presented to the operator a list with the possible fault sections, arranged from highest to lowest priority analysis, detail of activation or not of selective protection and type of selective protection.

TABLE VI. Fault case analysis

Fault Section	Operated relays	Tripped Circuit Breaker	Observation
L2-5	R39_1, R39_2, R39_3, R40_1, R40_2, R40_3, R31_3, R34_3, R36_3, R38_3, R48_3	39, 40	Fault isolated by main protection.
L2-6	R37_1, R37_2, R37_3, R38_1, R38_2, R38_3, R31_3, R34_3, R36_3, R40_3	37, 38	Fault isolated by main protection.
L6-8	R51_1, R51_2, R51_3, R52_1, R52_2, R52_3, R37_3, R45_3, R49_3, R55_3, R54_3	52, 56, 76, 74, 46, 38, 50	Fault isolated by breaker failure protection.

TABLE VII. Summary of fault section estimation.

Fault section candidates		Diagnosis result			
Section	D_{SEC} (%)	Priority	Fault section	Selective protection	Type of selective protection
L2-5	5,14	1	L2-5	Yes	Z1, POTT
L2-6	5,65				
L6-8	12,00				
L6-28	67,15	2	L2-6	Yes	Z1, PUTT
L2-4	68,14				
L4-6	68,78				
L6-7	69,22	3	L6-8	Yes	Z1, PUTT, 87L
L1-2-1	69,68				
L1-2-2	69,68				

4 Simulation results

The proposed methodology is tested on the whole IEEE-30 Bus System. It was simulated the fault case with triple simultaneous faults occurred on L2-5, L2-6 and L6-8 on the 50% of the section; as shows the TABLE VI. All starting signals of impedance relays are activated according to their adjustment, for sections L2-5 and L2-6 are activated the starting signals associated and then the fault is isolated by main circuit breakers. To the section L6-8 are activated the starting signals associated and the fault is isolated by remote circuit breakers, because one the main circuit breakers fail; in this case was activated the backup protection scheme (breaker failure) of the main breaker that do not operate. Some of the analyzed sections have alarms in common, which are jointly processed with a view to diagnose large-sized systems.

With the creation of the route vector is easy to remove several sections that are foreign to the fault and get a less candidates sample.

TABLE VII. shows the interface between the operator and the fault section estimation, which allows the option of a general list of sections associated to the alarms activated organized by analysis priority. Furthermore, the diagnosis result presents the sections confirmed as strong fault candidates.

For this simulation are shown the sections defined like fault candidates that generate a deviation value, then these candidates are filtered taken as reference the section found in the route vector reducing the number of fault candidates, making a diagnosis relating the alarm information and physical sections isolated of electric system. The candidates are organized by name, analysis priority and selective protection information enabled. This simulation shows that the sections L2-5(5,14%) and L2-6(5,65%) are approximate, thus this proposal is able to give more than one option of fault candidates with the objective to assist the operator.

Furthermore, this proposal presents of the detail of activated selective protection for each candidates, increasing the control center operator confidence at the time of the decision making based on selectivity criteria.

The simulation is performed on a Intel Core^{TM}i7 using MATLAB, the speed of the proposed methodology is satisfactory.

5 Conclusion

This paper presents a novel deterministic methodology for the fault section estimation in power system produced by the own features of electric system such as impedance lines and transformers, impedance relay settings and change in the network topology; unlike other methods already proposed.

The differential of this work is performs an analysis of intersections of protections zones with the purpose of estimating the fault section using the impedance relay settings. The changes of network topology reflect changes on the protection schemes, this work adapts a search algorithm to consider these changes and create an adaptive system of patterns. For each fault case, the estimation section depends of the relay setting information that at time are responsible by isolate, which enables to this methodology make a diagnosis based on the characteristics of the system itself. Were obtained satisfactory results for the simulations made, even with scenarios with multiple faults, erroneous signals and failures breakers.

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