An Assessment on Security and Reliability of Protective Equipment in Distribution System from Asset Management Perspective

Yousef Alirezalu[1], Reza Dashti[2]
[1]M.Sc. of Electronic Engineering, Jasb Branch, Islamic Azad University, Jasb, Iran
[2]PhD of Electronic Engineering

Abstract
In this paper, a cost index is proposed for protective relays in radial distribution networks. This index includes total cost of buying relay and interruption/outage penalty resulting from relay's incorrect operation. For this purpose, Markov trigon space is assumed for each relay. These three modes include correct operation, incorrect operation in the event of error and interruption with no error each of which will result in partly energy loss. In case of reasonless downstream network load interruption, the related relay is missed and in the event of non-operating upon an error, the network load will be lost totally since the main circuit breaker will interrupt entire the network as it is the support. Undoubtedly, with varied possibility for each of error functions, the loss energy value will be varied. Therefore, an analysis was conducted in this regard which shows that despite lost total network load due to non-operating of relays upon errors, the expected lost energy will not be significant since such a lost value is multiplied by the possibility value and is a small number due to low possibility.
Key-words:
security and reliability, protective equipment, asset management

1. Introduction

Power systems traditionally consist of three sections including generation, transmission and distribution. This system permanently is known as the greatest and the most complex system made by human and the energy engineers constantly try to improve such a set. The power systems are called as a set consisting of equipment, generation, transmission, distribution and subscribers which are together working regularly and seamlessly.

In terms of physical properties of power system (as we know, power networks are divided into three sections including generation, transmission and distribution), reliability study for power systems are conducted in three individual sections including generation (HL-1), transmission (HL-2) and distribution (HL-3).

Totally, four following steps are conducted to analytically study the reliability of distribution network:

- All possible error modes should be identified in the system.
- Impact of each mentioned mode on each load point should be evaluated.
- For each load point, reliability indices of the load points should be calculated through the total impacts resulted from diverse error modes.
- Using the indicators derived from previous step, reliability indices of entire the system are to be calculated.

Reliability of protective equipment means proper functioning to interrupt the error and their security is defined as the possibility for lack of correct operation. It makes sense to consider concepts of security and reliability of protective equipment for calculation of network reliability indices which will result in more realistic results. Also, these parameters are of high importance for capital managers from two angles: 1- Determination of an optimized maintenance strategy for protective equipment which are a part of assets and capitals of a distribution network, and 2- Determination of an optimized maintenance strategy for other components, considering impact of protective equipment on reliability indices.

Aging power grid is one of the main challenges of Iranian power industry [3]. Therefore, it is necessary to pay more attention on renovation or reconstruction of electricity network equipment. Therefore, an efficient asset management system is required for optimization of assets replacement costs.

Diverse definitions have been addressed for asset management in literature. Australian Asset Management Association defines asset management as "management of assets life cycle to reach specified organizational goals" [4].

Hesting believes that asset management is derived from an organizational/business objective and includes a set of activities associated with what assets are required, which assets should be provided and purchased, which ones should be supported, maintained or renovated or even be phased out in such a way all these activities lead to a proper and effective achievement of desired goals [4].

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CIGRE Australian Asset Management Advisory Group defines asset management in power industry as a set of business processes which are employed to develop, utilize and maintain assets of an organization to reach desirable requirements of subscribers and business stakeholders. These desirable requirements typically include cost, performance, safety and environmental results as well as reliable electricity supply [5].

Asset management is based on two following principles [6]:

1. Meeting requirements and expectations of all stakeholders including legislators, regulators, shareholders, subscribers and employees.
2. Meeting short-term industrial needs considering sustainability and environmental issues in long-term.

Regulators ask distribution companies to economically, efficiently and sustainably utilize and maintain power grid and if necessary, develop the grid. For this purpose, a good balance should be made by distribution companies among the following items [6]:

1. Assets and costs of the company
2. Assets and performance of the network
3. Future long-term strategies
4. Assets and risk of the network

Principles for the quantitative assessment of electric power systems reliability include fundamental terms and useful measurement topics of system reliability and the underlying data which are needed for the calculation of such indices [1]. For operation data processing, all types of errors are necessary to be studied and identified and then Necessary methods should be used to relieve their impacts. In doing so, the errors are divided into the following types [2]:

1. Exit according to the plan
2. Compulsory exit

The compulsory exit is divided into two categories of temporary and permanent. The main factors of temporary and permanent exit are as follows:

- Error of network equipment such as transformer and circuit breaker
- Error of subscribers' equipment including personal posts or power equipment of the plants
- Overload
- Ground connection or Phase connection by animals
- Planned exit for installation of new equipment
- Planned exit for maintenance
- Employees error
- Error resulted from unknown factors and environmental culture

Error of network equipment may be arisen due to lightning and wrong design, construction, installation and application or depreciation.

Objectives of present study are represented as follows:

1- Studying the protective equipment reliability model used in electrical power distribution network and extraction of a suitable model which can calculate reliability of such equipment, considering concepts of reliability and security.

2- Studying distribution network reliability model considering protective equipment reliability model and calculating conventional reliability indicators including SAIDI, SAIFI, CAIDI, CAIFI, ENS, etc.

3- Modeling impact of asset management strategies from maintenance perspective on distribution network reliability indicators, considering security and reliability of protective equipment

4- Optimization of asset management strategies in the distribution network from maintenance perspective based on conducted modeling items.

5- Presenting a framework for capital management from maintenance perspective in distribution network considering security and reliability of protective equipment

6- Conducting simulations and calculation of indices for a standard distribution network as a sample.

2. Distribution network reliability model

In order to evaluate reliability among distribution networks with an order of 3, some indices are defined and calculated same as other levels. The well-known reliability indices among distribution networks are as follows:

- System Average Interruption Frequency Index (SAIFI)
- System Average Interruption Duration Index (SAIDI)
- Customer Average Interruption Frequency Index (CAIFI)
- Customer Average Interruption Duration Index (CAIDI)

- Energy Not supplied

The index ENS is used from above indices according to the study type since such an index is evaluated for interruption and power outages penalties and thereby it is an important index. The required equations to calculate above indices include two steps where the former specifies indices of each load point:

$$\lambda_s = \sum_{i=1}^{n} \lambda_i \; (\frac{f}{yr}) \tag{5}$$

$$U_s = \sum_{i=1}^{n} \lambda_i r_i \; (\frac{h}{yr}) \tag{6}$$

$$r_s = \frac{U_s}{\lambda_s} \; (\frac{f}{yr}) \tag{7}$$

It is pointed out here that since the distribution system is radial, it functions like a series system and thereby for each load point, failure rate includes total sum of failure rate of all equipment located before the load point. The second step is to calculate each reliability index. Here, ENS index calculation way is presented:

$$ENS = \sum_{j=1}^{n} \sum_{i=1}^{m} \lambda_i \, r_{ij} P_j \tag{8}$$

n :number of bus bars

m :number of sections

3. Modeling

Reliability of protective equipment is defined as the capability of equipment to accomplish assigned mission. In present paper, correct operation rate method will be used. This rate is defined as follows:

$$R = \frac{n_c}{n_g} 100\% \tag{19-3}$$

$$F = \frac{n_f}{n_g} 100\% \tag{20-3}$$

Where R is reliability of protective relay, F is the failure possibility and nc, nf and ng are number of correct operations, number of incorrect operations and total protective equipment operations, respectively. A protective relay is more often in idle mode and it is expected to be operated only in calling time. Value of a relay is known as prevention of outage, interruption and damage in the event of incorrect operation.

The relay is assumed to have three types of independent operation including correct operation in the event of command, incorrect operation in the event of command and incorrect operation (reasonless interruption). These three modes include following items:

1- Intact: in this mode, relay does the interruption in the event of error and in case of no error, no interruption will be done. The prominent name of this mode is ENS0.
2- Non-operating upon error: in this mode, relay does not do interruption in the event of any errors and thus main circuit breaker of the network will interrupt entire the network. The prominent name of this mode is ENS2.

Beginning of each section is assumed to have the network relay. Therefore, if a relay does a reasonless interruption then the downstream functioning will be missed. Also, if a relay does not interrupt in the event of error, then the main circuit breaker will interrupt whole of a feeder. For each operating mode, one ENS is calculated and total ENS is derived from total sum of these three modes.

Therefore, the main equation of total lost energy is as follows according to the relay failure possibilities:

$$ENS = \sum_{i=1}^{n} \lambda_i r_i [(1 - P_{s,i}) P_i + P_{S,i} \sum_{i=1}^{n} P_i] + P_{R,i} \sum_{i=1}^{n} \lambda_i r_i P_i \tag{9-3}$$

Where the parameters are as follows:

P_i	Possibility of intact status
$P_{s,i}$	Possibility of non-operating upon error
$P_{R,i}$	Possibility of reasonless interruption

Hence, total target function includes relay purchase cost and outage/interruption penalty and is specified as follows:

$$F = ENS \times VOLL + Price \tag{10-3}$$

Where the parameters are as follows:

F	Target function
VOLL	Value of lost load
Price	Price

4. Case study

In order to evaluate efficiency of proposed algorithm, the presented model should be applied on a case study. In this section, the proposed model was applied for a distribution network with 9 IEEE buses (Figure-2). This network has a main feeder from which 4 subsidiary feeders are egressed.

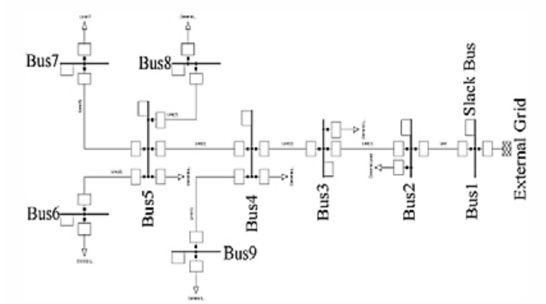

Fig. 2 a distribution network with 9 IEEE buses

The steps of previous study proceeded the proposed algorithm step-by-step. The results of each step are presented and an analysis was conducted on them. Three different relays are as shown in Table 4-2.

Table 4.2: Information of relays

Price ($)	Possibility of correct operation	Possibility of non-operating upon error	Possibility of reasonless interruption	Relay type
50	0.8	0.1	0.1	Type 1
400	0.9	0.05	0.05	Type 2
800	0.95	0.0025	0.0025	Type 3

In present study, values of the indices ENS0, ENS1 and ENS2 are presented in Table 3. Also, values of asset management index for each relay are pointed in Table 3-4.

Table 3.4: Values of reliability indices for the three studied relays

	Type 1	ype 2	Type 3
ENS0	6.498	6.156	5.814
ENS1	0.12905	2.581	4.51675
ENS2	2.225	44.5	77.875

Table 4.4: Values of indices for each studied relay

Type 1	Type 2	Type 3
26.55615	39.92775	33.07716

Sensitivity analysis was conducted on value of lost load and possibility of incorrect operation. Therefore, three diagrams are plotted in Figures 2-4 to 4-4.

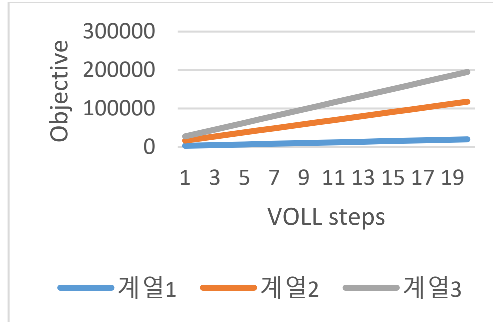

Fig. 4.2 Variations of target function in terms of variations of the value of lost load from 100 to 300 for three types of relay

Another analysis was conducted on variation of incorrect operations possibility in which possibilities were varied according to Table 5-4. In doing so, Figure 3-4 depicts calculated values of lost energy in terms of relay's increased incorrect operation steps in the event of error. Also, Figure 4-4 shows calculated value of lost energy in terms of relay's increased incorrect operation steps in the event of reasonless interruption.

Table 4.5: Variation of Ps possibility for three relays

Steps for PR possibility variation	Relay 1	Relay 2	Relay 3
1	0.0000	0.0000	0.0000
2	0.0056	0.0111	0.0167
3	0.0111	0.0222	0.0333
4	0.0167	0.0333	0.0500
5	0.0222	0.0444	0.0667
6	0.0278	0.0556	0.0833
7	0.0333	0.0667	0.1000
8	0.0389	0.0778	0.1167
9	0.0444	0.0889	0.1333
10	0.0500	0.1000	0.1500

Table 6.4: Variations of PR possibility for the three relays

Steps for PS possibility variation	Relay 1	Relay 2	Relay 3
1	0.0500	0.1000	0.1500
2	0.0444	0.0889	0.1333
3	0.0389	0.0778	0.1167
4	0.0333	0.0667	0.1000
5	0.0278	0.0556	0.0833
6	0.0222	0.0444	0.0667
7	0.0167	0.0333	0.0500
8	0.0111	0.0222	0.0333
9	0.0056	0.0111	0.0167
10	0.0000	0.0000	0.0000

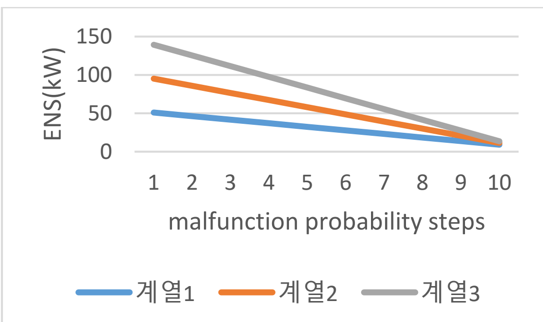

Fig. 3.4 variations of lost energy in terms of relay's incorrect operation changes in the event of error for the three relays

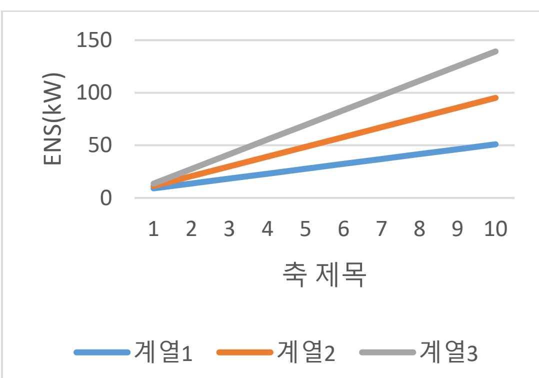

Fig. 4.4 variations of lost energy in terms of relay's incorrect operation changes in the event of reasonless interruption for the three relays

5. Conclusion

In this paper, a new index was presented for reliability of relays among distribution networks. This index is able to determine optimal type of relay. Also, the proposed model can calculate proper time of maintenance by changing possibility of relay's incorrect operation. According to what mentioned on objectives and principles of asset management science, the necessity of asset management implementation was discussed in power distribution network of restructured area in power industry. Accordingly, long-term and successful experiences of the countries with restructured power industry were addressed, as well. Undoubtedly, power market regulators ought to take advantage of asset management system to assure long-term sustainability of power distribution network.

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