Power Distribution System Improvement Considering Damage Cost Due to Voltage Sags

Poonsri Wannakarn
Department of Electrical Engineering, Faculty of Engineering
Rajamangala University of Technology Phra Nakhon, Bangkok, THAILAND
poonsri.w@rmutp.ac.th

Nitikorn Kesphrom
Department of Electrical Engineering, Faculty of Engineering
Rajamangala University of Technology Phra Nakhon, Bangkok, THAILAND
nitikorn-k@rmutp.ac.th

Supawud Nedphokaew
Department of Electrical Engineering, Faculty of Engineering
Rajamangala University of Technology Phra Nakhon, Bangkok, THAILAND
supawud.n@rmutp.ac.th

Nattachote Rugthaicharoencheep
Department of Electrical Engineering, Faculty of Engineering
Rajamangala University of Technology Phra Nakhon, Bangkok, THAILAND
nattachote.r@rmutp.ac

Abstract* - *This research article presents a decision-making guideline for the improvement of the power distribution system. By considering the damaging effects of voltage sags caused by faults in the power system. The damage can be estimated by estimating the number of voltage sags by simulating the occurrence of faults at various locations in the power system, namely industrial, commercial and large power users that are installing equipment that is sensitive to changes in voltage. From the test processing with the proposed technique, it was shown that the results of the damage assessment before and after the improvement of the power distribution system are compared with the cost of improving the power system to reduce the number of faults. It will provide information that can be used to make investment decisions to improve the power distribution system more efficiently and economically.

Keywords – Decision, Damage cost, Voltage sags, Faults, Distribution system

I. INTRODUCTION

Voltage sag occurs from many causes, such as starting a large motor, powering the transformer and faults in the power system. This can make various devices of electricity consumers that are sensitive to voltage changes, such as power electronic equipment that is malfunctioning or stopping working, causing various damages both directly and indirectly, such as cost of product damage, maintenance fee and opportunity cost in business competition, etc.

The estimate of damage cost by the voltage sag can be made at the desired location in the power distribution system [1]. The important information to know is the number of voltage sags in a year. This is usually obtained from recording events that occur by monitoring equipment installed in the electrical system [2]. And then use the statistical data to make investment decisions to improve the power distribution system to increase the efficiency of electricity distribution, build stability and Reduce the number of faults in the electrical system.

There are many ways to improve the power distribution system, such as changing the type of power cable, cutting trees near power lines and installation of animal protection equipment each method has different costs and the budget used in the operation each year is limited. The power utilities who are in charge of the power distribution system must have information to make decisions for such actions.

Therefore, this research paper presents a stochastic method for estimating the number of voltage sags per year caused by faults at different locations in a power system [3]. Then, the damage caused by the voltage sags before and after the improvement of the power distribution system was estimated. To compare it with the cost of reducing the impact of the voltage drop in a cost-effective way [4].

II. VOLTAGE SAGS EVALUATION

Voltage sag is reducing the magnitude of the voltage down to between 0.1 and 0.9 percent of normal voltage. Within a time of 0.5 cycles to 1 minute according to the IEEE 1159-1995 standard shown in Fig. 1. The method used to evaluate is the Fault position method [5], which is a simulation of the occurrence of faults at various positions, both symmetrical and asymmetrical. By using recorded statistical data namely magnitude, duration and number of voltage sags, details are as follows.

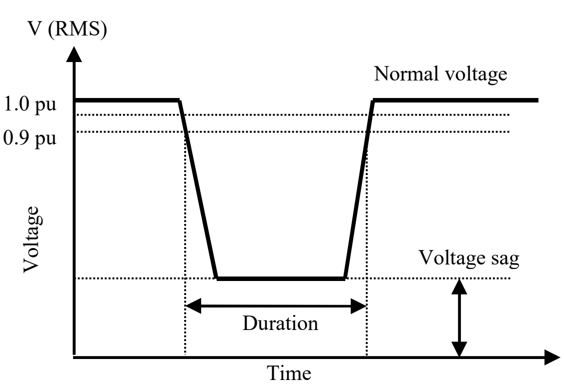

Fig. 1. IEEE 1159-1995 standard (Voltage sag)

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A. Magnitude of Voltage Sag Evaluation

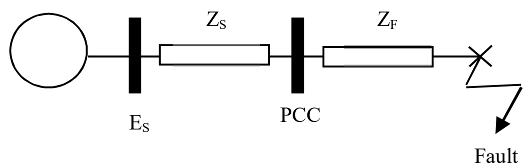

Fig. 2. Equivalent circuit of fault in the power distribution system

$$V_{SAG} = \frac{Z_F}{Z_F + Z_S} E_S \quad (1)$$

Where

V_{SAG} is Voltage sag at PCC
E_S is Source voltage
Z_F is Impedance between fault and PCC
Z_S is Impedance of source at PCC

The magnitude calculation of the voltage sags at the point of common coupling (PCC) when a fault occurs in the power distribution system is shown in Fig. 2 and can be obtained from the voltage division law, as in (1)

B. Duration of Voltage Sag Evaluation

The duration of each voltage sag can be estimated from the fault elimination time of the protective device. Each type will have a different removal time depending on the fault current flowing through the protective device. By taking the value of the fault current to calculate the operating time of the protective device from the time-current characteristic curve (IT Curve) of the protective device.

C. Number of Voltage Sag Evaluation

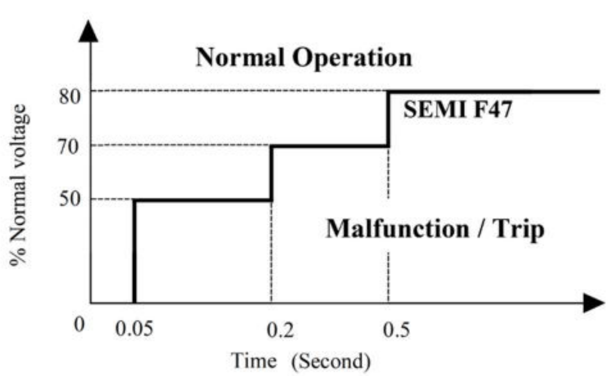

Fig. 3. SEMI F47 Voltage Tolerance Curve

The number of voltage sags is based on the SEMI F47 tolerance curve [6], which is characterized by the response to the voltage magnitude and duration of the voltage sags. Representing electrical equipment installed on various buses in the power distribution system is shown in Fig. 3 and the number of times electrical equipment malfunctions at any bus can be calculated according to (2).

$$NT = \sum_{i=1}^{m} F_i \cdot P_i \cdot R_i \quad (2)$$

Where

NT is Number of times equipment malfunctions
F_i is Faults rate per year of line i
P_i is Probability of fault type of Line i
R_i is Ratio of equipment malfunctions to faults
m is Number of Line

III. Damage Cost Evaluation

A. Cost of Damage due to Voltage Sags

Cost of damage incurred in that distribution system It is obtained by summing up the damage values of the bus that is sensitive to voltage sags. It can be calculated by multiplying the number of equipment malfunctions obtained from the system-wide faults simulation multiplied by the cost of downtime per event (CODT) for equipment or machinery that is sensitive to voltage sags according to (3).

$$C_{DS} = \sum_{j=1}^{k} CODT_j \cdot NT_j \quad (3)$$

Where

C_{DS} is Cost of damage due to voltage sags
$CODT_j$ is Cost of downtime per event
NT_j is Number of times equipment malfunctions
k is Number of customer bus

The cost of downtime per event comes from various causes, including loss of product, loss of labor, and hidden costs. These values can be determined by collecting data and interviewing employees working with downtime electrical equipment and employees who must perform the duties of restarting the system [1].

B. Damage Cost Simulation

The step for simulating faults in the distribution system determines the number of malfunctions of devices that are sensitive to voltage sags following as

Step 1: Enter the data on the distribution system, including the size and type of conductors, protective equipment, and fault rates for the cable conductors across all buses.

Step 2: Determine the bus location of interest.

Step 3: Simulate all types of fault events at different locations in the distribution system based on the information in Step 1 to calculate the magnitude and duration of the voltage sag that occurs at the interested bus.

Step 4: Compare the magnitude and duration of voltage sag with the SEMI F47 Voltage tolerance curve to record the device malfunction event according to (2).

Step 5: Calculate the total damage cost due to voltage sags according to (3).

Step 6: Repeat steps 2 - 5 to complete all interested buses.

IV. CASE STUDY

In this study, the 22 kV power distribution system of the Provincial Electricity Authority (PEA) will be used. Saraburi Substation 1(2005), feeder lines 1 and 2, 45 buses, details are as follows in Fig.4 and the probability of occurrence of each type of fault is shown in Table 1.

TABLE I. PROBABILITY OF FAULT TYPE

Fault Type	3PH	LL	LLG	SLG
Probability	0.15	0.5	0.10	0.7

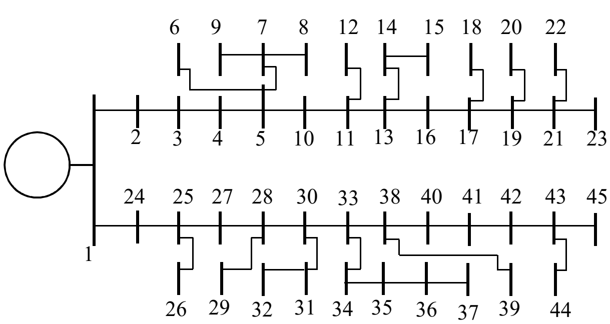

Fig. 4. PEA Saraburi Substation 1

A. Power Consumer for Study

TABLE II. POWER CONSUMER INFORMATION

Power consumer type	Feeder 1 BUS	Feeder 2 BUS	CODT (THB)
Industrial	14	39	500,000
Commercial	6,7,8,9,15	26,29,31,32,34	25,000
Residential	12,18,20,22,23	35,36,37,44,45	5,000

The study will categorize power consumers into 3 categories [7]: industrial, commercial and residential to study the effects of faults in the power distribution system and causing voltage sags to affect consumers. The information of electricity consumers showing type, location and assumed cost of downtime per event (CODT) can be shown in Table 2.

B. Improvement Case

The improvement of the distribution system in this study will compare the change of conductor type, namely
Change from partially insulated conductor cable (PIC) to Space Aerial Cable (SAC) and Change from All Aluminum Conductor (AAC) to Partial Insulated Conductor (PIC)

Simulating the modification of the conductor type in each feeder and both. A total of 12 cases was carried out in both feeders, with details of each case study shown in Table 3.

TABLE III. IMPROVEMENT CASE

Case	Feeder 1	Feeder 2
1	Base Case	
2	PIC to SAC	-
3	-	PIC to SAC
4	PIC to SAC	PIC to SAC
5	PIC to SAC	AAC to PIC
6	AAC to PIC	-
7	-	AAC to PIC
8	AAC to PIC	AAC to PIC
9	AAC to PIC	PIC to SAC
10	PIC to SAC AAC to PIC	-
11	-	PIC to SAC AAC to PIC
12	PIC to SAC AAC to PIC	PIC to SAC AAC to PIC

C. Improvement Cost

TABLE IV. REPLACEMENT CONDUCTOR INFORMATION

Conductor type (Old)	Fault Rate / km/yr.	Conductor type (New)	Fault Rate / km/yr.	Improve Cost / km (MTHB)
185 PICS	0.2	185 SACS	0.15	1.5
120 PICS	0.2	120 SACS	0.15	1.25
120 AAC	0.25	120 PICS	0.2	1.0

The cost of improving the distribution system studied in this study is the cost of changing both conductor types. Each type of conductor has different fault statistics. The information is shown in Table 4.

V. Results

Simulating faults in the distribution system using statistical data and calculating the total damage caused by voltage sags. Table 5 presents all the results in comparison to the cost of improving the distribution system by changing the type of conductor in different cases.

Considering the results obtained, it can be seen that improving the distribution system by changing the cable type from PIC to SAC can reduce the damage.

TABLE V. TOTAL COST

Case	Damage cost by consumer type (MTHB)			C_{DS} / yr. (MTHB)	Save Cost / yr. (MTHB)	Improve Cost (MTHB)	Improve Cost / Save Cost
	Industrial	Commercial	Residential				
1	4.63	1.16	0.23	6.02	-	-	-
2	4.28	1.07	0.21	**5.56**	**0.45**	**13.51**	**30.02**
3	4.62	1.16	0.23	6.01	0.01	9.6	960.00
4	4.03	1.01	0.20	**5.24**	**0.77**	**23.11**	**30.01**
5	4.23	1.06	0.21	**5.50**	**0.52**	**17.61**	**33.87**
6	4.59	1.15	0.23	5.97	0.05	5.2	104.00
7	4.58	1.14	0.23	5.95	0.07	4.1	58.57
8	4.54	1.13	0.23	5.90	0.12	9.3	77.50
9	4.58	1.14	0.23	5.95	0.07	14.8	211.43
10	4.28	1.07	0.21	**5.57**	**0.45**	**18.71**	**41.58**
11	4.57	1.14	0.23	5.94	0.08	13.7	171.25
12	3.97	0.99	0.20	**5.17**	**0.85**	**32.41**	**38.13**

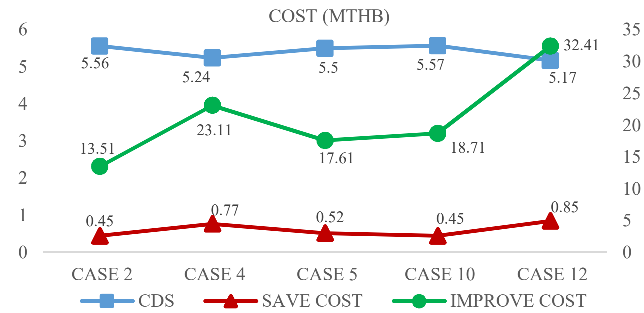

Fig. 5. Top 5 Case Studies

After considering the improved cost per saved cost values of all cases, it was found that the top 5 case studies are cases 4, 2, 5, 12, and 10, respectively, shown in Fig. 5. The simulation results can be analyzed as follows:

1)*Case 12*: This will cause the damage to be reduced the most. But it also requires the most investment in improvements because it is the replacement of both types of cables in the 2 feeder lines.

2)*Case 4th:* This will reduce the damage to the second place but requires less investment in improvement than case 12 at the amount of 9.3 million baht, changing only PIC cables to SAC in 2 feeder cables.

3)*Case 5th*: This will reduce the damage to the third place and require less investment in improvement than case 4th, amounting to 5.5 million baht.

So, if we have enough budget can choose case12 to improve. But if the budget is limited, it can be changed to choose case 4th and case 5th to suit the budget and cost-effectively.

4)*Case 2nd and Case 10th*: Both will reduce the damage to the fourth place but case 2nd requires less investment in improvement than case 10th at the amount of 5.2 million baht.

When comparing between these 2 cases, the Case 2nd should be chosen for investment.

VI. Conclusion

The method for decision-making to improve the power distribution system by considering damage cost due to voltage sags presented in this paper is a method that can be used to estimate damage from voltage sags for information in planning and Making investment decisions to improve the electricity supplier's distribution system cost-effectively and appropriately.

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APPENDIX

TABLE VI. CONDUCTOR INFORMATION

Conductor type	R1 (Ω / km)	X1 (Ω / km)	R0 (Ω / km)	X0 (Ω / km)
185 SACS	0.1805	0.2455	0.3285	1.7549
185 PICS	0.21435	0.33976	0.39186	1.5538
120 PICS	0.26643	0.34869	0.41443	1.57551
120 AAC	0.26643	0.36382	0.56243	2.70319

TABLE VII. INFORMATION OF FEEDER I

Bus-Bus	Distance (km)	Conductor type	Protective Curve
1-2	0.12	185 PICS	Relay
2-3	0.12	185 PICS	Relay
3-4	2.0	185 SACS	Relay
4-5	5.0	185 PICS	Relay
5-6	2.6	185 PICS	Relay
5-7	0.5	185 SACS	Relay
5-10	0.1	185 SACS	Relay
7-8	4.15	185 SACS	Relay
7-9	0.9	120 PICS	Relay
10-11	0.1	185 SACS	Relay

TABLE VII. INFORMATION OF FEEDER I (Cont.)

Bus-Bus	Distance (km)	Conductor type	Protective Curve
11-12	0.5	120 AAC	Relay
11-13	1.2	185 SACS	Relay
13-14	0.7	185 SACS	Relay
13-16	0.2	120 AAC	Relay
14-15	0.5	120 PICS	Fuse
16-17	0.3	120 AAC	Fuse
17-18	0.1	120 AAC	Fuse
17-19	0.2	120 AAC	Fuse
19-20	1.1	120 AAC	Fuse
19-21	0.3	120 AAC	Fuse
21-22	1.0	120 AAC	Fuse
21-23	1.5	120 AAC	Fuse

TABLE VIII. INFORMATION OF FEEDER II

Bus-Bus	Distance (km)	Conductor type	Protective Curve
1-24	0.15	185 SACS	Relay
24-25	0.15	185 SACS	Relay
25-26	0.3	185 PICS	Relay
25-27	1.5	185 PICS	Relay
27-28	0.1	185 PICS	Relay
28-29	0.2	185 SACS	Relay
28-30	0.65	185 SACS	Relay
30-31	0.75	185 SACS	Relay
30-33	1.15	185 SACS	Relay
31-32	1.5	185 PICS	Relay
33-34	0.5	185 PICS	Relay
33-38	0.5	185 PICS	Relay
34-35	0.2	120 AAC	Relay
35-36	0.8	120 AAC	Relay
36-37	0.1	120 AAC	Relay
38-39	0.2	185 PICS	Relay
38-40	0.5	185 PICS	Relay
40-41	0.1	185 SACS	Relay
41-42	0.2	185 PICS	Relay
42-43	1	185 PICS	Fuse
43-44	0.5	120 AAC	Fuse
43-45	2.5	120 AAC	Fuse