Calculating Feeder Fault Current with MATLAB Software Program

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ABSTRACT

The aim of this article describes the program of computerized how to calculate the feeder fault current in a distribution substation. This article adopts Thevenin theory as the basis of calculation, and narrates them in two ways: the artificial and the computerized algorithm. It leaves aside the artificial and delves the computerized algorithm. The latter is divided for two computerized algorithm - separate and all of equipment. In the computerized algorithm, all data inputting, procedure steps, and report form were carefully been designed by MATLAB application software. As for data inputting refers to the specification parameters of equipment component. The characteristics of this article are described with both text and Fig. to achieve operation simple and understanding easy. References include a representative textbook and several journal articles. Verify with real cases and reveal the pros and cons of artificial and program algorithms. The purpose of this article is to discard waste - an artificial calculation that is time-consuming, cumbersome and prone to clerical errors. The computer programs algorithm can compensates for defects and improves accuracy and timeliness. This method has been proven to be an economical design aid tool that is of great help to maintenance or designers in the field of electrical engineering.

Keywords: Single-line diagram, Interrupting current capacity circuit breaker, Fault current, MATLAB application software, Thevenin equivalent resistance.
1. INTRODUCTION

There have been actual cases in power distribution substations; one of the distribution transformers in the substation needs to be updated because of equipment failure do to relieve the pressure of the power supply. After consulting with the manufacturer, checking whether the manufacturer has spare parts that match the original design equipment parameters, after investigation, only the impedance percentage is different in the parameters and the rest are the same. To ensure the normal operation of the feeder circuit breaker. First, start to examine the relevant parameter values of equipment in the original design blueprint. From this calculation, the original design feeder line fault current value and feeder circuit breaker interrupting capacity value are calculated, correctly design the latter to be greater than the former (the breaking capacity value of the circuit breaker must be greater than the line fault current value), if the feeder line encounters an abnormal fault, the circuit breaker will be automatically opened under the operation of the protection relay to isolate the fault point. The feeder fault current value obtained by bringing in the parameter value of the new spare equipment, is it still within the breaking capacity value of the circuit breaker? If it exceeds, the breaking capacity value of the larger circuit breaker needs to be updated together. In the calculation process, in addition to the single-line diagram of the equipment connection of the substation and the parameter values of each equipment, the data is simplified into "Thevenin equivalent impedance," Then apply the skills of MATLAB application software to replace the tedious manual calculation to prevent trouble caused by clerical errors.

In addition to the introduce, the structure of this article includes paragraphs such as literature review, single-line diagrams of distribution substations, handwritten calculation steps, application calculation descriptions, verification, and conclusions.

1.1 Literature Review

In the field of power engineering, there are countless books and articles of related published in journals to illustrate the system fault current and breaking capacity of circuit breaker equipment. This article only lists one electric engineering teaching book and several representative articles as a reference review.

From reference [1] Interpretation theorem and application for the basic textbook of academic theory, as for [2-9], they are based on theoretical integration and applied were published on journal within actual power systems. The content is from the power system - positive, negative, zero sequence and the relationship between the three-phase wiring of the first and second side coils of each transformer equipment and the neutral point grounding of the generator to the change of the system impedance value, next to connect the transmission line impedance to draw the "Thevenin equivalent" impedance value of the power system, then find the fault current value of each section in sequence.

As for the reference [10], in addition to integrating the above-mentioned references data and using the specification parameters of the equipment components of the distribution substation (including the impedance value between two devices). To calculate the fault current value of the feeder to design the interrupting capacity value of the feeder circuit breaker, In order to achieve what the most economical and safe design is. And because the above [6] calculation process is carried out manually, the links are too cumbersome and easy to make clerical errors. So start research and development to replace written calculations with programs. The steps of the development process are explained as follows.

1.2 Design Program

Continuing the background, and then developing computer programs to replace artificial algorithm. This chapter reiterates the artificial algorithm steps and programming skills, and the corresponding comparison methods are used to show the advantages and disadvantages.

1.3 Artificial Algorithm

The one-line diagram of the power system equipment of a distribution substation, each equipment specification is transformed into the impedance value those are shown in Fig. 1. Taking 20MVA for base, the equipment specifications and design parameter values and codes are calculated and the impedance values are obtained, as shown in Table 1 and Table 2. Those transformers (T1, T2, and T3) and a generator (G) in Fig. 1 are all designed with Y-
type neutral point directly grounded; the interrupting capacity specification of the feeder circuit breaker was originally designed to be 20000 amperes (A).

- In the original design blueprint, each equipment component is transformed into impedance and then simplified into the "Thevenin equivalent" impedance value from the system impedance distribution diagram.
- Then calculate the feeder fault current value (SC), and the power supply terminal must be short-circuited in the "Thevenin equivalent" impedance calculation process. As for the "Thevenin equivalent" voltage, the voltage at the feeder end is used.

The calculation steps are as follows:

\[
\begin{align*}
Z_{12} &= Z_1 + Z_2 \\
Z_{34} &= Z_3 + Z_4 \\
Z_{13} &= Z_{12} + Z_{34} \\
Z_{54} &= Z_5 + Z_4 \\
Z_{67} &= Z_6 + Z_7 \\
Z_{57} &= Z_{54} + Z_{67} \\
Z_{811} &= Z_{81} + Z_{91} + Z_{101} + Z_{12} \\
Z_{581} &= Z_{57} + Z_{811} \\
Z_{th} &= Z_{581} + Z_{8} + Z_{9} + Z_{10} \\
Z_{th} &= 0.5417 + j1.2907 \\
SC &= \frac{1}{\frac{Z_{th}}{MV} \times \frac{1.73 \times 480V}{20 \text{ MVA}}} \\
SC &= \frac{0.5417 + j1.2907}{11865} \text{ A.}
\end{align*}
\]

The calculation result of the feeder fault current value is less than the interrupting capacity of the feeder circuit breaker, this is in line with the original design blueprint specifications, and otherwise it is unqualified.

Another hypothetical situation, if the T2 equipment in Fig. 1 needs to be updated due to a fault, its parameters are 4.8kV on the primary side, 480V on the secondary side, capacity 1MVA, impedance %3, X/R 4:1 and other parameters. Substituting the above calculation steps to obtain the Zth equivalent impedance value of 0.4917 + j1.0907. The generated feeder fault current is 13881 A (SC).

The feeder fault current exceeds the interrupting capacity of the feeder circuit breaker (20000A), so the new spare parts can be replaced. In other words, when the equipment is updated, the equipment parameters are different, the calculated fault current value shall not exceed the interrupted current value of the feeder circuit breaker, to ensure stable power supply and safe operation of the system and protect equipment safety.

### 1.4 Programming

After the above-mentioned artificial algorithm steps, the process are very cumbersome and can easily cause clerical errors and affect accuracy. Lead to wrong equipment specification design. In order to prevent the shortcomings of artificial algorithm, an easy-to-operate programming algorithm was developed to replace manual work. So that to shorten the design time and efficiency and reduce operating costs. The parameters of the related of this article are taken from [10].

- Importing the artificial algorithm program into the MATLAB application software only needs to establish the parameter input method and calculation skills and cooperate with the grammar. To integrated into a simple, accurate and time-saving calculation tool.
- The program part of this article is divided into two aspects: the specifications of each equipment component of the substation and the impact of the specifications of individual equipment components on the feeder line fault current.
- The operation process only needs to install the MATLAB application software operating environment in the personal computer to execute the various programs (.case1 or case2) Input the corresponding "related parameter value" in Table 2 in the main screen to accurately obtain the fault current value of the feeder line, as shown in Fig. 2 (case1) and Fig. 3 (case2).

### 2. VERIFICATION

From Fig. 2 and Fig. 3, it is easy to operate and only need to enter the parameter value of each equipment or individual equipment of the power system. The fault current value of the feeder can be accurately calculated, and then it can be judged whether the interrupting capacity of the feeder circuit breaker is within the qualified range.

In order to illustrate the special case for instance, a distribution transformer in a distribution substation needs to be updated due to a failure. However, there are three distribution transformers for primary and secondary side voltages, which are the same as the original equipment.
**Fig. 1. Single-line diagram of system equipment of distribution substation**

The equipment parameters of a distribution substation for the original design supply 500MVA transmission line impedance ratio X/R 6:1 under 16kV.

The parameter values of each equipment based on 20MVA are as follows:

- Z3 = [Capacity (MVA)]: Impedance (%) X/R: = [3.06 0.8];
- Z4 = [Voltage (kV)]: Impedance (%): X/R: = [4.8 0.06 0.03];
- Z5 = [Voltage (kV)]: Impedance (%): X/R: = [4.8 0.05 0.02];
- Z6 = [Capacity (MVA)]: Impedance (%): X/R: = [0.2 0.1 0.1];
- Z7 = [Voltage (kV)]: Impedance (%): X/R: = [4.8 0.06 0.03];
- Z8 = [Voltage (kV)]: Impedance (%): X/R: = [4.8 0.1 0.04];
- Z9 = [Capacity (MVA)]: Impedance (%): X/R: = [1.04 0.1];
- Z10 = [Voltage (kV)]: Impedance (%): X/R: = [0.04 0.04 0.04];
- Z11 = [Voltage (kV)]: Impedance (%): X/R: = [0.04 0.002 0.002];

**Feeder fault current (3C)A**

- 1.1865e+04

**Fig. 2. Program execution results of various equipment components in the substation**

The equipment parameters of a distribution substation for the original design supply 500MVA transmission line impedance ratio X/R 6:1 under 16kV.

The parameter values of T2 changed on 20MVA base:

- Z9 = [Capacity (MVA)]: Impedance (%): X/R: = [1.04 0.1];

**Feeder fault current (3C)A**

- 1.1865e+04

**Fig. 3. Execution results of individual equipment programs**
Table 1. Equipment name and code and various parameters

| Code | Section name                                      | Capacity(MVA) | Impedance % | X/R | Remarks   |
|------|---------------------------------------------------|---------------|-------------|-----|-----------|
| Z1   | Between 161 kV line and T1 primary side           | 500           | -           | 6:1 |           |
| Z2   | T1                                                | 3             | 6           | 8:1 |           |
| Z3   | Generator                                         | 1             | 15          | 10:1|           |
| Z4   | Between Generator and 4.8 kV bus                  |               | 0.03/0.06   | cable |          |
| Z5   | Between T1 secondary side and 4.8 kV bus          |               | 0.02/0.05   | cable |          |
| Z6   | Motor                                             | 0.2           | 10          | 10:1|           |
| Z7   | Between motor and 4.8 kV bus                      |               | 0.03/0.06   | cable |          |
| Z8   | Between 4.8 kV bus to T2 primary side             |               | 0.04/0.1    | cable |          |
| Z81  | Between 4.8 kV bus to T3 primary                 |               | 0.04/0.1    | cable |          |
| Z9   | T2                                                | 1             | 4           | 4:1 |           |
| Z91  | T3                                                | 1             | 4           | 4:1 |           |
| Z10  | Between T2 secondary side and 480 kV bus          |               | 0.002/0.002 | cable |          |
| Z101 | Between T3 secondary side and 480 kV bus T3      |               | 0.002/0.002 | cable |          |
| Z11  | Direct grounding impedance value of feeder circuit breaker | | | | |
| Zth  | Thevenin equivalent impedance value of the feeder end to ground | | 25 | | |

Table 2. Equipment code and each parameter and impedance standard per unit value

| Equipment code | Related parameter values | Impedance per unit value |
|----------------|--------------------------|--------------------------|
| Z1             | 500:20:6                 | Zpu=0.0067+j0.04         |
| Z2             | 3:0.06:8                 | Zpu=0.005+j0.4           |
| Z3             | 1:0.15:10                | Zpu=j3.0                 |
| Z4             | 4.8:0.06:0.03            | Zpu=0.052+j0.026         |
| Z5             | 4.8:0.05:0.02            | Zpu=0.043+j0.017         |
| Z6             | 0.2:0.1:10               | Zpu=j10.0               |
| Z7             | 4.8:0.06:0.03            | Zpu=0.052+j0.026         |
| Z8             | 4.8:0.1:0.04             | Zpu=0.087+j0.035         |
| Z81            | 4.8:0.1:0.04             | Zpu=0.087+j0.035         |
| Z9             | 1:0.04:4                 | Zpu=0.194+j0.8           |
| Z91            | 1:0.04:4                 | Zpu=0.194+j0.8           |
| Z10            | 0.48:0.002:0.002         | Zpu=0.174+j0.174         |
| Z101           | 0.48:0.002:0.002         | Zpu=0.174+j0.174         |
| Z11            | 480/20000                | Zpu=0.025               |
| Zth            | ---                      | Zpu=0.5473+j1.3946       |
Their parameter values (capacity (MVA) | impedance (%) | X/R) are (1 0.03 4) and (1 0.04 5) respectively. And (1.5 0.04 4) into the program, due to the difference between the parameters and the original specifications, the fault current values of the feeder are calculated to be 13881 A, 11993 A and 14712 A, respectively.

The program execution results are shown in Fig. 4, Fig. 5, and Fig. 6. From the above, it is known that only the parameter value (capacity (MVA)|impedance (%)|X/R) is (1 0.04 5). This equipment is suitable for replacement, because the feeder fault current value is still in the feeder circuit breaker interrupting capacity specification within (less than).

In addition, in order to verify the relationship between the feeder fault current and the three parameters of the distribution transformer (T2) equipment. Take any one of the three parameters as a variable with five values and the other two parameter values are fixed. In addition, the other two parameters are changed to find the corresponding feeder fault current value, as shown in Table 3. From the data and parameters in Table 3, the relationship between the distribution transformer parameters and the fault current value of the feeder is summarized as shown in Table 4. It is known from Table 4 that the change of parameter value will affect the feeder fault current vary greatly. Therefore, when updating spare parts, you must re-calculate according to the new parameter value to ensure that the value is within the interrupting capacity value of the feeder circuit breaker, so as to provide stable, reliable and safe operation.

Looking at the artificial and program calculation process descriptions, it is verified that the latter is superior to the former, especially from the equipment parameter input method and the calculation results are presented in graphics, and then the simple, accurate, and time-saving calculation skills are displayed.

Fig. 4. Execution results of individual equipment parameters (1 0.03 4)

Fig. 5. Execution results of individual equipment parameters (1 0.04 5)
The equipment parameters of a distribution substation for the original design
Supply 500MVA transmission line impedance ratio X/R 6:1 under 161kV
The parameter values of T2 changed on 20kVA base
$Z_{F} = \frac{\text{Capacity (MVA)}}{\text{Impedance (\%)} \cdot \frac{X}{R}}; \quad \text{Feeder fault current (SC)}$

Table 3. Transformer (T2) parameters and feeder fault current value

| Capacity (MVA) | Impedance % | X/R ratio | SC (A) |
|---------------|-------------|-----------|--------|
| 1             | 0.04        | 3         | 11639  |
|               | 0.04        | 4         | 11865  |
|               | 0.04        | 5         | 11993  |
|               | 0.04        | 6         | 12075  |
|               | 0.04        | 7         | 12132  |
| 1.1           | 0.04        | 4         | 12527  |
| 1.2           |             |           | 13138  |
| 1.3           |             |           | 13702  |
| 1.4           |             |           | 14226  |
| 1.5           |             |           | 14712  |
| 1             | 0.03        | 4         | 13881  |
|               | 0.04        |           | 11865  |
|               | 0.05        |           | 10355  |
|               | 0.06        |           | 9183   |
|               | 0.07        |           | 8249   |

Table 4. Relationship between transformer parameter values and feeder fault current

| Fixed parameter       | Variation parameter | Feeder fault current | Figure          |
|-----------------------|---------------------|----------------------|-----------------|
| Capacity and X/R      | The impedance greater | Less                 | As shown in Fig. 7 |
| Capacity and          | The X/R greater      | More                 | As shown in Fig. 8 |
| impedance             |                      |                      |                 |
| Impedance and X/R     | The capacity greater | More                 | As shown in Fig. 9 |

Fig. 7. The relationship between fault current and impedance
3. CONCLUSION

In addition to avoiding the trouble of human clerical errors, the characteristics of this article can also calculate the feeder fault current value by entering the parameter value of equipment in the MATLAB software program in a short time, and it can be used repeatedly without professional operation.

As for the parameter changes that maintain the relationship between the feeder fault current and the interrupting capacity of the feeder circuit breaker, if the fault current value of the feeder is greater than the interrupting capacity of the feeder circuit breaker, it will affect the abnormal operation of the feeder circuit breaker, resulting in the expansion of the power outage area.

Therefore, it is necessary to recalculate and review any equipment parameter those are been changed to ensure that the equipment operates in a qualified state. Therefore, this method is an indispensable auxiliary tool for electrical engineering design or maintenance technicians to design calculations.

COMPETING INTERESTS

Author has declared that no competing interests exist.
REFERENCES

1. Dunchan Glover J, Mulukutla S. Sarma, Thomas J. Overbye. Power system analysis & design, fifth edition, Global Engineering. 2012;90 -158.
2. Ming-Jong Lin. Applied the software of MATLAB to calculate the balanced three-phase fault using impedance matrix. 2020 International Symposium on Computer, Consumer and Control (IS3C);2020. Taichung. Taiwan.
3. Ming-Jong Lin. Advantage to short circuit current of calculation on power system by the MVA Method. Asian Journal of Research in Computer Science. 2020;6(1):28-36. Article no.AJRCOS.58344
4. Liu Wen Yan. Power system protection coordination design. ZTE engineering consulting corporation, ZTE engineering quarterly. 2008;101:55-64. Available: https://www.sinotech.org.tw/journal/pdfview.aspx
5. Thomas E. McDermott. A test feeder for DG protection analysis. IEEE PES Power Systems Conference and Exposition, PSCE;2011.
6. Ehab M. Esmail, Nagy I. Elkalashy, Tamer Kawady, Abdel-Maksoud I. Taala. Impact of current transformer saturation on fault location algorithms for parallel distribution feeders 2017. Nineteenth International Middle East Power System Conference;2017.
7. Jingwen Chen, Enliang Chu, Yingchun Li, Baoji Yun, Hongshe Dang, Yali Yang. Faulty feeder identification and fault area localization in resonant grounding system based on wavelet packet and Bayesian classifier. Journal of Modern Power Systems and Clean Energy, Vol. 8, No. 4, July 2020.
8. Lazar Z. Velimirovic, Aleksandar Janjic, and Jelena D. Velimirovic. Fault Location and Isolation in Power Distribution Network Using Markov Decision Process. TELSIKS;2019, Serbia.
9. Shu Hongchun, Wang XU, Tian Xincui, Wu Qianjin Peng Shixin. On the use of S-transform for fault feeder detection based on two phase currents in distribution power systems. 2010 2nd International Conference on Industrial and Information Systems;2010.
10. Industrial and commercial power systems fault calculation methods. Available: https://electrical-engineering-portal.com/.../fault-calculation-methods
APPENDIX

Executive program

Case 1.

>> clear;
fprintf('The equipment parameters of a distribution substation for the original design
The equipment parameters of a distribution substation for the original design
Supply 500MVA transmission line impedance ratio X/R 6:1 under 161kV
The parameter values of each equipment based on 20MVA are as follows :
Input
b = input(' Z2 = [Capacity (MVA) | Impedance (%) | X/R] ; = '); c = input(' Z3 = [Capacity (MVA) | Impedance (%) | X/R] ; = ');
d = input(' Z4 = [Voltage (kV)] Impedance (%) | X/R] ; = ');
e = input(' Z5 = [Voltage (kV)] Impedance (%) | X/R] ; = ');
f = input(' Z6 = [Capacity (MVA)] Impedance (%) | X/R] ; = ');
g = input(' Z7 = [Capacity (MVA)] Impedance (%) | X/R] ; = ');
h = input(' Z8 = [Voltage (kV)] Impedance (%) | X/R] ; = ');
s = input(' Z9 = [Capacity (MVA)] Impedance (%) | X/R] ; = ');
w = input(' Z91 = [Voltage (kV)] Impedance (%) | X/R] ; = ');
k = input(' Z10 = [Voltage (kV)] Impedance (%) | X/R] ; = ');
fprintf('Feeder fault current (SC)A

a1 = 500; a2 = 20; a3 = 6; a4 = 1/(a1/a2); a5 = a4/a3;
a6 = a5 + 'a'4;
b5 = b(2)'a2(b(1)); b6 = b5/b(3); b7 = b6 + 'i' b5;
c5 = c(2)'a2(c(1)); c6 = c5/c(3); c7 = c6 + 'i' c5;
d5 = d(1)'d(1)/a2; d6 = d(2) + 'i'd(3); d7 = d6/d5;
e5 = e(1)'e(1)/a2; e6 = e(2) + 'i'e(3); e7 = e6/e5;
f5 = f(2)'a2(f(1)); f6 = f5/f(3); f7 = f6 + 'i' f5;
g5 = g(1)'g(1)/a2; g6 = g(2) + 'i' g(3); g7 = g6/g5;
h5 = h(1)'h(1)/a2; h6 = h(2) + 'i'h(3); h7 = h6/h5;
s5 = s(2)'s(1); s6 = s5/s(3); s7 = s6 + 'i' s5;
w5 = w(2)'a2(w(1)); w6 = w5/w(3); w7 = w6 + 'i' w5;
k5 = k(1)'k(1)/a2; k6 = k(2) + 'i' k(3); k7 = k6/k5;
y11 = (a6 + b7)'c(7) + d7;
y12 = (a6 + b7) + c7 + d7;
y = 11/y12;
y1 = y + e7;
y2 = (1 + f7 + g7)/y1 + f7 + g7;
p = 480/20000;
y21 = y2*(h7 + w7 + k7 + p)/(y2 + (h7 + w7 + k7 + p)); y3 = y21 + (h7 + s7 + k7);
y4 = abs(y3);
y5 = (1.73'480)/y4;
v = 20/1;
SC = y5'v

Case 2.

>> clear;
fprintf('The equipment parameters of a distribution substation for the original design
The equipment parameters of a distribution substation for the original design
Supply 500MVA transmission line impedance ratio X/R 6:1 under 161kV
The parameter values of T2 changed on 20MVA base
Input
s = input(' Z9 = [Capacity (MVA)] Impedance (%) | X/R] ; = ');
fprintf('Feeder fault current (SC)A

...
fprintf('*****************************************************')

a1=500;a2=20;a3=6;a4=1/(a1/a2);a5=a4/a3;
a6=a5+i*a4;
b1=3;b2=0.06;b3=8;b5=b2*(a2/b1);
b6=b5/b3;b7=b6+i*b5;
c1=1;c2=0.15;c3=10;
c5=c2*(a2/c1);c6=c5/c3;c7=c6+i*c5;
d1=4.8;d2=0.06;d3=0.03;
d5=(d1*d1)/a2;d6=d2+i*d3;d7=d6/d5;
e1=4.8;e2=0.05;e3=0.02;
e5=(e1*e1)/a2;e6=e2+i*e3;e7=e6/e5;
f1=0.2;f2=0.1;f3=10;
f5=f2*(a2/f1);f6=f5/f3;f7=f6+i*f5;
g1=4.8;g2=0.06;g3=0.03;
g5=(g1*g1)/a2;g6=g2+i*g3;g7=g6/g5;
h1=4.8;h2=0.1;h3=0.04;
h5=(h1*h1)/a2;h6=h2+i*h3;h7=h6/h5;
s5=s(2)/(a2/s(1));s6=s5/s(3);s7=s6+i*s5;
w1=1;w2=0.04;w3=4;
w5=w2*(a2/w1);w6=w5/w3;w7=w6+i*w5;
k1=0.48;k2=0.002;k3=0.002;
k5=(k1*k1)/a2;k6=k2+i*k3;k7=k6/k5;
y11=(a6+b7)*(c7+d7);
y12=(a6+b7+c7+d7);
y=y11/y12;
y1=y+y7;
y2=(y1*(f7+g7))/(y1+f7+g7);
p=480/20000;
y21=y2*(h7+w7+k7+p)/(y2+(h7+w7+k7+p));
y3=y21+(h7+s7+k7);
y4=abs(y3);
y5=(1.73*480)/y4;
v=20/1;
SC=y5*v