CALCULATION OF GRID CURRENT AT A STATION USING ALTERNATIVE TRANSIENT PROGRAM

J. K. Arora
Department of Electrical Engineering
Punjab Engineering College, Chandigarh

Hans R. Seedher

Abstract: When a ground fault occurs at a substation, the part of fault current that flows between the earthing system and the surrounding earth is known as grid current. This current determines the magnitude of the dangerous voltages within and around the station. It may vary from a few percent to almost 100% of the earth fault current. It is necessary to make an accurate estimate of grid current for an economical and safe design of earth electrode. In this paper use of PC version of the Electromagnetic Transient Program (EMTP), also known as Alternative Transient Program (ATP), for computation of grid current is presented. Data about all transmission lines, feeders and cables terminating at the station, where grid current is to be calculated, is required. The data file for running the ATP is to be in the specified format and its preparation is laborious. To facilitate preparation of the input data file for running the ATP, an interface program is presented. Results of grid current obtained with ATP for a number of cases are given.

I. INTRODUCTION

Earthing system of a generating station or a substation is designed with the prime objective of providing safety to personnel during an earth fault. The fault current during an earth fault has several alternate paths for returning to the sources which feed the fault. A part of the current flows between the earthing system and the surrounding earth for returning to the sources of origin. The remaining current may return through earth wires or may flow through a metallic path consisting of the conductors of the earthing system and its connections to the neutrals of the sources of supply. The component of the fault current that flows between the earthing system and the surrounding earth is called grid current. The dangerous voltages, within or around the station are proportional only to this component of the fault current. Evaluation of grid current is thus of paramount importance for the design of an earthing system. The grid current may vary from a few percent to almost 100% of the earth fault current depending on the location of fault, configuration and parameters of earth wires and phase conductors, earth resistance of the station and tower footing resistances. Several researchers have dealt with the problem of determination of grid current and a number of analytical methods have been reported [1-5]. Recently a simplified analytical method having simpler data requirements has been reported [6]. In this method the component of fault current supplied by each of the transmission lines is assumed to be known.

A number of approximate simplified methods have also been proposed [7-9] for evaluation of grid current. In the method proposed by Thapar and Madan [7,8], the current diverted by aerial earth wires has been divided into two components namely, one diverted by conduction and the other by induction. The method, however, may give erroneous results for many situations [6]. In case of two circuits, which are coupled conductively and inductively, it is not appropriate to calculate the current in one circuit as two separate components, because of conduction and by induction, and then use superposition to obtain the total current as done by Thapar and Madan. Garrett, Patel and Myers [9] have prepared a number of graphs drawn on logarithmic scale for obtaining ratio of grid current and earth fault current. These graphs, obtained by using computer program of [5], however, do not fit into all practical situations. Interpolation and approximation have to be used in most cases. Graphs only provide a rough estimate of the grid current. As in [6], in these approximate methods also, the currents supplied to the fault from various lines connected to the station are assumed to be known.

In a survey conducted by IEEE [10], it was found that majority of utilities the world over did not appropriately account for current diversion by the alternate paths to determine the maximum grid current. The maximum value of the earth fault current or an arbitrary fraction of it was being used in place of the maximum grid current. A design based on an arbitrary value of grid current is either uneconomical or unsafe. The use of arbitrary value of grid current by the designers may be because of the unavailability of a suitable computer program for its determination. The approximate methods [7-9] suffer from the limitations described in the previous paragraph.

In this paper, use of PC version of Electromagnetic Transient Program (EMTP), called Alternative Transient Program (ATP), for computing grid current at a station is presented. The Alternative Transient Program (ATP) is a public domain program and is freely available to EMTP user groups. This program is being used by engineers for a number of power system computational applications [11]. The data requirements of this program for computation of grid current are similar to those of analytical methods [1-5]. However, the data file which is needed for running ATP has to have distinct bus names for
the ends of a large number of sections of the transmission lines
and feeders connected to the station in the specified format.
Preparation of the data file is difficult and error prone. A
computer program to generate this data file has been developed;
the input data file for this program is simple and is in format
free form. The authors have used ATP for determining grid
current for a number of test problems. The results obtained are
similar to those obtained with the computer program SMECC
developed at Electric Power Research Institute, USA, (EPRI)
[5].

II. RELATION BETWEEN FAULT CURRENT AND GRID
CURRENT

The grid current \( I_g \) at a station can be expressed as a product
of four factors [12] as

\[
I_g = I_f D_f C_p S_f
\]  

(1)

where

\( I_f \) = Symmetrical value (without taking into account d c
offset) of earth fault current for the fault case resulting
in the maximum grid current, A

\( D_f \) = Decrement factor to take into account d c offset

\( C_p \) = Corrective projection factor accounting for future
increase in fault current during the substation life span

\( S_f \) = Current division factor, fraction of total earth fault
current that flows between the earthing system and the
surrounding earth

Values of factors \( D_f \) and \( C_p \) are discussed in IEEE Standard
80 [12]. For design of earth electrode, the value of fault
duration is usually taken 0.5 second or more for which \( D_f \)
may be assumed as 1.0. The corrective projection factor \( C_p \)
takes into account the increase in the fault current due to future
growth. Its value can be estimated from the available
projections. The value of fault current at a station depends on
the type of fault and the fault location. \( I_f \) in (1) should
correspond to such a fault location and fault type as result in the
greatest flow of current between the earthing system of the
station and the surrounding earth. From a parametric study in
[5], it is concluded that

i) for a given fault location, the maximum grid current is
generated from single line to earth or double line to earth
fault, and

ii) for practical power systems, the grid currents for single line
to earth fault and for double line to earth fault are
approximately equal.

For much higher probability of occurrence, only a single line to
earth fault may be considered for computation of maximum
grid current.

The current division factor \( S_f \) depends mainly on location
of fault and on overhead earth wires connected to the station.
The former determines contribution to the fault current from the
remote stations via a vis that from the local sources. If the fault
occurs at a station, the current supplied to the fault by the local
sources flows through a metallic path consisting of the
conductors of the earthing system and connections to the
neutral of the sources of supply, and does not contribute to grid
current. Irrespective of the location of a fault, the fault current
supplied through a transmission line has two paths for returning
to the source. A part of it returns to the source through earth
wires and the rest of it flows between earthing system of the
station and the source through earth. The part that returns
through an earth wire of a transmission line depends on the
following factors - namely, impedance per span of earth wire,
tower footing resistance, number of spans between the fault
point and the substation on the supply side and mutual
impedance between earth wire and phase conductors of the
transmission line [6]. In case of earth wire of a feeder, the
current diverted by it depends only on the first three factors.
The grid current is equal to the difference of the current fed to
the fault through transmission lines and the current diverted by
earth wires. Generally for a power station forming part of an
interconnected system, the maximum value of grid current is
obtained when the fault is inside the station [7-9]. When grid
current is computed with ATP, the division of fault current in
various paths can be obtained directly in the output.

III. COMPUTATION OF GRID CURRENT

A single line diagram of the station at which grid current is
to be determined is required. This diagram would show all the
transmission lines and feeders connected to the station along
with the transformers interlinking them. The network behind
each transmission line is represented by an equivalent generator
at the far end of the line. ATP is used to calculate the fault
current at the station under consideration. The type of fault and
its location can be selected. ATP has the facility to display
currents at selected points in the circuit in the output file. Thus
the grid current is obtained by appropriate selection of the
nodes at which the current is output. Even the current in earth
wires can be included in the output file.

To assemble the input data file, the required data includes
self and mutual impedances per span of the lines and feeders
terminating at the station under consideration, length of each
transmission line/feeder, average length of span, average
footing resistance of the towers of the lines and feeders near the
station end, earth resistance at the station under study, the
sequence impedances of equivalent sources at the far end of
transmission lines which shall feed fault current in the event of
an earth fault at the station, and data about transformer/s which
are connected between buses of different voltages at the station
under study. The self and mutual impedances per km of the
transmission lines and feeders can be generated with the LINE CONSTANTS subroutine of ATP. This subroutine requires data about configuration of phase conductors and earth wire/s of all transmission lines and feeders terminating at the station and their resistance per km, and average soil resistivity under the transmission line/feeder. For generating data to be used for determining grid current, a transmission line/feeder is assumed to have three phase conductors and one or two earth wires. In case of double circuit line or a line with bundle conductors, the self and mutual impedances are determined with one equivalent conductor per phase. Self and mutual impedances per span of each transmission line or feeder can be calculated by multiplying their respective values per unit length by span length of that line or feeder.

In the data file to be used for determining grid current, self and mutual impedances of 20 spans on the substation end are distinctly represented if the line/feeder has more than 20 spans. In case of a transmission line the impedances of the rest of the length of the line are represented in lumped form. For the purpose of determining grid current, generally 20 spans of the line are sufficient to represent a line of infinite length [7]. It is necessary to include the lumped impedance of the rest of each transmission line to correctly calculate the fault current. If the number of spans is less than 20, data of the actual number of spans is used. In the data file, the two ends of each span are treated as two buses with distinct names. Thus the data file to be prepared for computing grid current can become quite voluminous when there are a number of transmission lines and feeders terminating/originating at the station where grid current is to be calculated. An interface program with symbolic name ATPGRD, which prepares its output file in the form required to run ATP for determining grid current, has been developed. A copy of the program ATPGRD can be obtained free of cost from the authors.

In ATPGRD it is assumed that there are two buses in the station at different voltages interconnected by one or more transformers. A number of lines are connected at each of the buses. A line, which can feed the fault, is termed a transmission line and the one, which does not, a feeder. The system at the far end of each transmission line is represented by an equivalent generator. The earth fault is assumed to occur at the HT bus. The input data file for the interface program ATPGRD can be prepared once the self and mutual impedances of the lines/ feeders have been determined. This file is easy to prepare and is in format free form. Preparation of the input data file for ATPGRD is explained in Appendix A where the data file for one test problem is given for illustration. The input data file required for ATP is automatically generated by ATPGRD.

IV. TEST PROBLEMS

Computer program ATP has been tested by using it to determine grid current for three test problems. Results for these test problems as obtained by computer program SMECC [5], which was developed at (EPRI), are available in literature [5,9]. The results obtained by ATP for the test problems are compared with those obtained with SMECC.

Single line diagram of the system of first of these test problems is shown in Fig. 1. The test problem is from EPRI report [5]. The substation feeding the 115 kV transmission line is represented by an equivalent source. At the substation under study, the voltage is stepped down to 12 kV with a delta/star transformer. A 12 kV feeder supplies a three phase load. The grid current would be the maximum for a single line to earth fault on the 115 kV bus in the station. The input data file of ATPGRD for this problem is given in Appendix A in which the load connected at the end of the feeder has been ignored. The value of grid current obtained by using ATP is 738 A with fault current of 1503 A. In the EPRI report [5], the fault current and the grid current obtained with computer program SMECC for single line to earth fault at 115 kV bus are 1492 A and 742 A respectively.

The second problem is taken from IEEE Tutorial Course [9]. A single line schematic diagram of the substation of this problem is shown in Fig. 2. The part of the power system

![Fig. 1. Single line diagram of the system for test problem 1](image1)

![Fig. 2. Single line diagram of the system for Test Problem 2](image2)
feeding each of the 115 kV lines is represented by an equivalent source. A delta/star transformer supplies the 12.47 kV bus to which three feeders are connected. A single line to ground fault occurs at the 115 kV bus. The grid current obtained by SMECC is reported to be 2515 A and that by ATP is 2390 A. The third problem [5] describes the results of a test carried out on the system shown in Fig. 3. A tap line from a 115 kV main line supplies the Texas Valley substation, where the fault is simulated. At the station, a star/delta transformer steps down the voltage and feeds a 12 kV feeder. The feeder consists of a section of overhead line and a cable followed by another section of overhead line. To reduce the operating voltage during the test a mobile delta/star transformer was connected at the feed end of the 115 kV main line. This transformer was rated at 2 MVA and had voltage ratio of 22/4.16 kV; the actual tap used was 18.7/4.16 kV. In the EPRI report, the computed value of fault current is 98.2 A and that of grid current is 62.0 A. With the method described in this paper the grid current is found to be 64.1 A. The grid current measured by creating a single line to ground fault at the Texas Valley substation was 73.2 A [5]. The report [5] ascribes the discrepancy in measured and computed values to variations in the assumed values of tower footing resistance and their actual values.

For comparison, the test problems are also solved by using computer program PAG developed in [6], by the approximate methods of Thapar et al [7,8], and by that of Garrett et al [9]. The value of grid current for the three test problems as obtained by the program SMECC [5], the method of this paper, and by the methods of [6], [7,8] and [9] are summarized in Table I. The results obtained by ATP are close to those obtained by SMECC. The values obtained by PAG are also similar to those by SMECC. However, the values of grid current obtained by approximate methods of [7-9] differ considerably from the first three methods.

<table>
<thead>
<tr>
<th>Method</th>
<th>Problem 1</th>
<th>Problem 2</th>
<th>Problem 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATP</td>
<td>738</td>
<td>2390</td>
<td>64.1</td>
</tr>
<tr>
<td>Program SMECC</td>
<td>742</td>
<td>2515</td>
<td>62.0</td>
</tr>
<tr>
<td>Program PAG</td>
<td>745</td>
<td>2527</td>
<td>62.6</td>
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<td>Thapar et al</td>
<td>989</td>
<td>4992</td>
<td>68</td>
</tr>
<tr>
<td>Garrett et al</td>
<td>438</td>
<td>2763</td>
<td>43</td>
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V. CONCLUSIONS

To obtain a good estimate of dangerous voltages when an earth fault occurs at a station, it is essential to calculate grid current. Use of Alternate Transient Program (ATP), which is a public domain program, for computing grid current is presented. An interface program ATPGRD, which facilitates preparation of the elaborate data file required for running ATP is developed. The data requirements of the program are similar to those of other computer-based methods described in literature. The program can prepare input data file required for ATP for a station to which a number of transmission lines/feeders are connected at two buses linked by transformer/s. Grid current can be calculated for a single line or double line to earth fault at the station. The results obtained by using ATP are comparable to those obtained by other computer-based methods.

VI. REFERENCES

APPENDIX A

The input data file for the program ATPGRD is in format free form. The data file required for ATPGRD in case of first of the test problems is illustrated below in Table A1. The first line of the data file is a line identifying the problem. The next line gives the system frequency. On the third data line, the number of transmission lines and feeders connected to HT bus are given. After this there is one set of data for each transmission line and feeder. The first line of this set specifies whether there are two earth wires or one. Next few lines contain the lower triangle of the self and mutual impedance matrix of the line in ohm per kilometre as obtained by using LINE CONSTANTS subroutine of ATP. The values of the matrix are given row by row. In the output of LINE CONSTANTS each row of the lower triangle of impedance matrix first lists resistance components of all elements of the row on one line followed by reactance components of all elements on the next line. The impedance data is followed by a data line giving the total length of line in km, span length in km, number of distinct spans to be modeled and average tower footing resistance. The data of the generators connected to the lines follows next, with one data line per equivalent generator. Data on each line consists of zero sequence resistance and reactance of the generator, positive sequence resistance and reactance of the generator, and per phase voltage of the line or the equivalent generator in volt; if any of these resistances is not available, it may be given as zero. All resistances and reactances are in ohm. After the requisite sets of transmission line/feeder and generator data, the data for transformers connected between the buses follows.

The first line of transformer data gives the number of transformers. The second line specifies the transformer connection, which is one of the three namely 'D/Y', 'Y/Y' or 'Y/D'. This is followed by two lines of data per transformer: the first of these carries the word ‘ACTUAL’ if the data to be given for the transformer is actually available or ‘DEFAULT’

<table>
<thead>
<tr>
<th>Problem from EPRI Project EPort</th>
<th>Data</th>
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<tbody>
<tr>
<td>PROBLEM FROM EPRI PROJECT EPORT</td>
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<tr>
<td>1.0</td>
<td>1</td>
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<tr>
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<td>0.47709,0.91261</td>
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<td>0.44487,0.44431,0.91273</td>
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<td>0.46767,0.42363,0.43988,0.10499</td>
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<tr>
<td>1.04416</td>
<td>0.05818,0.75414</td>
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<td>0.05818,0.05821,0.75414</td>
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<td>0.49289,0.51722,.51722,1.03535</td>
<td>4.023,0.134,20.50</td>
</tr>
<tr>
<td>SLTE</td>
<td></td>
</tr>
</tbody>
</table>
otherwise. If ‘DEFAULT’ is given, approximate values specified for power transformers shall be assumed. The actual data about the transformer, to be given on the next line, is transformer excitation current in ampere peak, percentage copper loss, percentage iron loss, percentage impedance, primary voltage per phase, secondary voltage per phase and transformer MVA rating. If this data is not available only primary voltage per phase in kV, secondary voltage per phase in kV and transformer MVA rating are to be given. On the next line after the transformer data, the earthing resistance of the substation is given. After this the total number of transmission lines and feeders connected to LT bus are given. This is followed by one set of data for each transmission line and feeder in the same format as is described above for the lines connected to the HT bus. After this one line of data for each of the equivalent generators connected at the ends of transmission lines connected to the LT bus is given; this data is also in the same form as the data for generators at the end of lines connected to the HT bus. The last line is a mnemonic specifying the type of earth fault; it is ‘SLTE’ in case of single line to earth or ‘DLTE’ for two phase to earth fault.