GIC calculation of Gansu power grid based on Power World

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Abstract. The geomagnetic induced current (GIC) caused by the geomagnetic storm flows into
the transformer, which will saturate the transformer. It will cause the system's reactive power loss
and harmonic increase, which will adversely affect the operation of the transformer. Therefore,
it is of great significance to study the impact of GIC on the power grid. In this paper, the
calculation method of grid GIC and the transformer equivalent circuit model are given. The
Gansu power grid GIC is calculated by using Power World Simulator. Finally, based on the
contour plot, the distribution law of GIC in Gansu Power Grid is analyzed.

1. Introduction

As the scale of China’s power grid continues to expand, the voltage level continues to rise. It is
increasingly susceptible to interference from geomagnetic storms[1]. The geomagnetic induced current
caused by geomagnetic storm flows into the power grid from the grounding neutral point of the
substation, which saturates the transformer[2], which leads to the system's reactive power loss, harmonic
increase, and also causes the vibration of the transformer main body to be intensified and overheated[3].
Therefore, the computing system GIC is necessary to study the safe operation of the power grid.

For the GIC calculation[4] considering the quasi-DC characteristics of GIC, a model based on the
resistive parameters of the grid is proposed, but this model only considers the highest voltage level. The
literature[5] uses the node admittance matrix based on the full-node model. The law calculates the GIC
programming of Sanhua Power Grid. When the grid is complicated, the former has to establish a large
number of grid node admittance matrices. In this paper, Power World power system visualization
software is used to build the grid model in the simulator. By inputting the corresponding parameters and
GIC module, the GIC in the network can be calculated.

Power World Simulator (PWS) is a power system visualization simulation software package
developed by the University of Illinois, USA. Its design features user-friendly interface and excellent
interactive performance. It is also a rare simulation software with GIC function. When calculating GIC,
the programming process of MATLAB is reduced. Simply construct the corresponding network model
in the simulator and input the parameters to visually see the calculation result of GIC. In this paper, the
Gansu power grid is taken as the research object, and the GIC value under the corresponding electric
field is calculated in power world and the result is analyzed.

2. GIC calculation principle

2.1. Flow mechanism of GIC in transformer

Since the frequency of GIC is 0.0001 Hz~0.01 Hz, it can be regarded as quasi-direct current with respect
to the power frequency of 50 Hz, and the grounding neutral point of the transformer and transmission
line provides the GIC with a circulation path, which is injected into the system and flows through it. When the transformer is used, a bias magnetic flux is generated on the winding, which is superimposed on the main magnetic flux, causing the transformer to saturate and jeopardize the normal operation of the power grid. The circulation mechanism is shown in Figure 1.

![Figure 1 GIC circulation path in the system](image)

As shown in Figure 1, the GIC flows from the left-hand transformer grounded neutral point into the system and flows back to the ground through the transmission line through other transformers to the neutral point. In the voltage level of China’s power grid, the neutral point is directly grounded in the system of 110KV and above. Therefore, only the system of 110KV and above should be considered in the GIC modeling.

2.2. GIC calculation method

2.2.1 Node admittance

The value of the equivalent voltage source on the ground of the geoelectric field is as follows:

\[ V_{AB} = E_N \cdot L_N + E_E \cdot L_E \]  

(1)

\( E_N, E_E \) they are the unit values of the north-south component and the east-west component of the induced geoelectric field (V/km). \( L_N, L_E \) In order to consider the objective shape of the earth and use the latitude and longitude of the earth to correct the north-south and east-west distances, the calculation formulas of the two are as shown in equations (2) and (3):

\[ L_N = [111.133 - 0.56 \cos(2\phi)] \cdot \Delta L_{ad} \]  

(2)

\[ L_E = [111.5065 - 0.187 \cos(2\phi)] \cdot \cos(2\phi) \cdot \Delta L_{ong} \]  

(3)

![Fig 2 GIC node admittance matrix DC model diagram](image)

According to the node voltage method, for any node, there is:
\[
\sum_{k=1}^{N} i_{ki} = i_i, \quad k \neq i
\]  
\( (4) \)

\( I_i \) Current flowing to the node \( i \) from the node \( k \); \( i_i \) The sum of the nodes flowing to the earth current.

\[
i_{ki} = j_{ki} + (v_k - v_i) \cdot y_{ki}
\]  
\( (5) \)

For a node \( i \), the sum of the current sources of all the branches of the transmission line connected to it is expressed as:

\[
J_i = \sum_{k=1}^{N} j_{ki}
\]  
\( (6) \)

Organize and use matrix representation to be writable as:

\[
U = Y^{-1} J
\]  
\( (7) \)

\subsection*{2.2.2 Transformer component model}

The transformer provides the main path for the GIC when the magnetic storm occurs. Since the type of the transformer is different from the connected group, the flow path of the GIC is also different. Therefore, different transformer models need to be built according to the different types of transformers. It is usually divided into two different transformer models: an ordinary transformer model and an auto-transformer model.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{transformer}
\caption{Equivalent circuit diagram of the transformer}
\end{figure}

\section*{3. Basic parameters of Gansu Power Grid}

Figure 4 shows the geographical connection diagram of Gansu 750kV ultra-high voltage power grid. The content of this section calculates the GIC of the Gansu 750kV power grid, and its transformer resistance value is 0.3 \( \Omega \).
4. Simulation result analysis

The northward electric field is applied: 0.063 V/km; the eastward electric field is 0.17 V/km. The construction of the grid DC model and the results are shown in Figure 5.

The result shown in Figure 5 is the size of the inflow (outflow) of the GIC of the node. It can be seen from the calculation results in Table 2 that the electric field component is the data calculated under the same magnetic storm, but from the direction of the GIC flowing into the node. The GIC flowing into a node under the northward electric field may flow into the same node or may flow out of the node under

| Number | Starting node | Ending node | Number of loops | Line length | Equivalent resistance |
|--------|---------------|-------------|-----------------|------------|-----------------------|
| 1      | 1             | 2           | 2               | 82.22      | 0.405                 |
| 2      | 2             | 3           | 2               | 307.23     | 1.513                 |
| 3      | 3             | 4           | 2               | 316.65     | 1.559                 |
| 4      | 4             | 5           | 2               | 220.67     | 1.087                 |
| 5      | 5             | 6           | 2               | 113.53     | 0.559                 |
| 6      | 5             | 8           | 2               | 159.33     | 0.785                 |
| 7      | 6             | 7           | 2               | 195.04     | 0.961                 |
| 8      | 8             | 9           | 1               | 70.13      | 0.691                 |
| 9      | 9             | 10          | 2               | 220.29     | 1.085                 |
| 10     | 6             | 10          | 1               | 148.31     | 1.461                 |
| 11     | 10            | 11          | 2               | 230.38     | 1.135                 |
| 12     | 11            | 12          | 2               | 170.56     | 0.840                 |
| 13     | 12            | 13          | 1               | 87.85      | 0.865                 |
the eastward electric field. Moreover, from the perspective of the GIC value, the GIC of each node in the eastward electric field is substantially larger than the GIC value in the northward electric field, and the node with the largest difference is 30 times eastward GIC, which is the node 11 of the northward GIC.

In Table 2, whether in the north direction electric field or the east direction electric field, node 1, node 7, and node 3 have larger GIC in the calculation result. Looking at the geographic wiring diagram of Gansu Power Grid, we can see that these nodes are all at the end of Gansu Power Grid. The larger GIC value is due to the ‘end effect’ of the power grid. In the GIC calculation result (north direction), the GIC of node 4, node 6, and node 11 is smaller than that of other nodes, and the distribution of the substation connected thereto is symmetric in the north-south direction of the geoelectric field, so that GIC can cancel each other out.

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Figure 5 Gansu power grid model and GIC results

| Table 2 GIC calculation results of Gansu Power Grid in Power World |
|---|---|---|
| Node | GIC calculation results (N) | GIC calculation results (E) |
| 1 | 9.47 | -43.33 |
| 2 | 3.13 | -32.149 |
| 3 | 5.9 | -1.783 |
| 4 | 0.79 | 4.404 |
| 5 | -3.02 | 11.007 |
| 6 | 1.58 | 19.265 |
| 7 | 7.81 | 54.31 |
| 8 | -2.27 | -43.749 |
| 9 | -6.12 | -41.098 |
| 10 | -5.88 | -1.912 |
| 11 | 0.83 | 24.799 |
| 12 | -8.17 | 47.129 |
| 13 | -4.04 | 3.108 |

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Figure 6 Schematic diagram of GIC contours of various nodes in Gansu Power Grid

(a) GIC northward horizontal component  (b) GIC eastward horizontal component
In order to facilitate the visual observation of the distribution law of GICs in each node (bus bar) in the power grid, the contour map of GIC of Gansu Power Grid is drawn in Power World. As shown in Fig. 6, the figure is divided into several regions according to the absolute value of the GIC flowing into a node. The darker color represents the larger the GIC amplitude flowing into the corresponding node. It can also be seen from the figure that although all of them belong to the Gansu power grid, however, the distribution of GIC is extremely uneven. Under the eastward electric field, the absolute value of the GIC flowing into Bus1 is large, but the adjacent bus 2 has a small GIC value, so it can be seen that the size of the GIC and the substations’ geographical distribution has a certain relationship, and there are large GICs at the end points and inflection points of the grid. In the geographical location, the values of the nodes GIC with symmetric distribution of adjacent substations are small.

5. Conclusion
This paper introduces the PWS visualization programming software, and builds a model for the Gansu power grid based on the grid parameters given in this paper, and gives the GIC calculation results. Analyze the distribution law of GIC in Gansu power grid by plotting contour lines in software. And it is concluded that the distribution of GIC has a certain relationship with the geographical position of the substation in the power grid and the direction of the geoelectric field component. Under normal circumstances, the geomagnetic induction current has a larger east-west component than the north-south component.

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