Research on Urban Power Grid Harmonic Source Location Based on Harmonic Transmission

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Abstract. Based on the analysis of parameter identification of harmonic state estimation and harmonic source localization on fundamental theory, urban power grid harmonic transmission model is established, and by using harmonic transmission rule, preliminary determine the harmonic source area, effectively reduce the dimension of harmonic state estimation and calculation workload. Then using intelligent methods and data reliability security strategy, automatic identification and acquisition of harmonic currents, improve the quality of data, effectively prevent the harmonic current of nonlinear and measurement noise vector's influence on the harmonic state estimation. Finally, a case is given to prove the correctness and feasibility of the theory in this paper.

Introduction

Harmonic source location is the basis for solving the harmonic power flow calculation, dividing each harmonic sources’ harmonic responsibility, using economic means to punish the harmonic problems. However, in the common connection point, harmonic is often the result of multiple harmonic sources interaction, and it is vulnerable to the impact of the background harmonics, resulting harmonic source localization difficult. It is very necessary to locate the harmonic source quickly and efficiently.

The Theory and Algorithm of Harmonic Source Localization Based on Harmonic State Estimation

The Basic Principles of Parameter Identification in Harmonic State Estimation

Least squares method is more popular way of parameter identification algorithm, the expression is as follows:

\[ Z = HX + V \] (1)

Suppose there are \( n \) complex harmonic power sources in big cities grid, including \( i \) in high-voltage power grid, \( j \) in the medium-voltage grid, \( k \) in the low-voltage grid, the equation (1) can be written as:

\[
\begin{bmatrix}
Z_i \\
Z_j \\
Z_k
\end{bmatrix} =
\begin{bmatrix}
H_{i1} & H_{i2} & H_{i3} \\
H_{j1} & H_{j2} & H_{j3} \\
H_{k1} & H_{k2} & H_{k3}
\end{bmatrix}
\begin{bmatrix}
X_i \\
X_j \\
X_k
\end{bmatrix}
+ 
\begin{bmatrix}
V_i \\
V_j \\
V_k
\end{bmatrix}
\] (2)

Ignore the effects of measurement noise on the calculation, so formula (2) is further simplified to:

\[ Z_w = H_w X_w \] (3)

where \( w = i \) or \( j \) or \( k \), depending on the harmonic source at voltage levels or areas.

Harmonic Source Localization Principle

Assuming the use of harmonic state estimation techniques we can obtain the information of each harmonic injection sources in the whole grid:
\[ I_i(h) = \sum_{j=1}^{n} Y_{ij}(h)U_j(h) \]  

(4)

In the formula (4), \( I_i(h) \) indicating that the h-th harmonic injection in the i-th bus-bar; \( Y \) represents a power grid node harmonic admittance matrix; \( U \) represents the estimated net harmonic voltage state.

The definition of the i bus of the h harmonic nodes inject hard power:

\[ P_i(h) = \text{Re} \left[ U_j(h)I_i(h) \right] \]  

(5)

Solving Two City Power Grid Model and Harmonic Transfer Coefficient

Schematic Diagram of City Power Grid

To analysis facilitate, the city power grid schematic diagram is simplified as shown in Figure 1.

![Schematic diagram of city high voltage power grid.](image)

Figure 1. Schematic diagram of city high voltage power grid.

![Equivalent circuit of transmission line.](image)

Figure 2. Equivalent circuit of transmission line.

Transmission Line Modeling and Harmonic Transfer Coefficient

According to the city grid diagram of Figure 1, the use of π-type equivalent circuit of the city power lines, power lines to get the equivalent circuit shown in Figure 2, the line impedance can be expressed as follows:

\[ Z_{lh} = Z_{ch} \sinh(\gamma_h l) \]  

(6)

\[ Y_{lh} = \frac{\cosh(\gamma_h l) - 1}{Z_{ch} \sinh(\gamma_h l)} \]  

(7)

where: line features respectively corresponding to the h-th harmonic impedance and propagation constant, are complex; \( l \) is the line length, corresponding to the harmonic h, has the following circuit equation:

\[
\begin{align*}
U_{oh} &= U_{ih} \cosh(\gamma_h l) - Z_{ch} I_{ih} \sinh(\gamma_h l) \\
I_{oh} &= I_{ih} \cosh(\gamma_h l) - \frac{U_{ih}}{Z_{ch}} \sinh(\gamma_h l)
\end{align*}
\]  

(8)

where in the beginning of the line, respectively, the end of the h harmonic voltage and current. If the circuit has h beginning of the harmonic current sources \( I_{ih} \), through the line after the transmission distance \( lh \) flow into the circuit at the end of the harmonic current sources \( I_{oh} \), so you can get the transmission line harmonic transfer coefficient:
\[ K_{th} = \frac{I_{oh}}{I_{ih}} = \cosh(\gamma_h l) - \frac{U_{oh}/I_{oh}}{Z_{Ch}} \sinh(\gamma_h l) - \frac{Z_{th}}{Z_{Ch}} \sinh(\gamma_h l) \]

where \( Z_{th} \) in \( h \) harmonics corresponding transmission line impedance.

**Transformer Modeling and Harmonic Transfer Coefficient**

For two-winding transformer, harmonic impedance is available to the series impedance between the first bus and the second bus, its value is:

\[ Z_{Tn} = R_{Tn} + jX_{Tn} \quad (10) \]

where in \( R_{Tn} = \sqrt{n}R_{T1} \), \( R_{T1} \) the fundamental wave resistance of the transformer primary and secondary winding’s; \( X_{Tn} = nX_{T1} \), \( X_{T1} \) is the fundamental anti-leak between the first and the second winding of the transformer.

According to the equivalent circuit of the transformer, the transformer can be obtained the harmonic transfer coefficient for:

\[ k_{th} = \frac{I_{oh}}{I_{ih}} = \left( \frac{Z_{T1}^*}{Z_{T1}^*} + Z_{T1-k}^* \right) \left( \frac{Z_{T1-k}^*}{Z_{T1}} \right)^{k-1} = \frac{Z_{Th}^*}{k-1} \quad (11) \]

where, \( Z_{Th}^* \) is the transformer corresponding the \( h \)-th harmonic transmission conversion impedance.

**Load harmonic Source’s Equivalent Circuit and Harmonic Transfer Coefficient**

Due to the higher power equivalent impedance is far less than the lower grid equivalent impedance, it is generally only considered superior to subordinate power grid harmonic transfer, therefore, load harmonic source circuit equivocate as shown in Figure 5.

Figure 5 C equivalent to the sum of the transmission line and the user to install the reactive compensation device capacitance, \( I_x \) is the load harmonic currents, \( I_{sx} \) is harmonic current injection system, \( I_{cx} \) is the injection capacitor current. According to Figure 5, injection the relationship between harmonic currents \( I_{sx} \) and harmonic source current \( I_x \) can be expressed as:

\[ k_{Lh} = \frac{I_{sx}}{I_x} = \frac{U_{sx}/Z_{Tx}}{U_x/Z_{Tn} + U_x/X_{cx}} = \frac{X_{cn} + Z_{xn}}{X_{cn} Z_{xn}} \quad (12) \]

According to equation (10) (16) (17) harmonic transfer coefficient shows that urban power transfer coefficient

\[ K_{hx} = k_{Th} \cdot k_{hh} \cdot k_{Lhx} \quad (13) \]

**Based on Harmonic Conduction Mechanism Initial Impression of the City Harmonic Source**

For the urban grid, consider different voltage levels of harmonic impact coefficients \( K_{hjm} \) \((K_{hjm} \text{ expressed in paragraph j bus transfer to the harmonic impact on the para m bus}), you can get on the bus voltage harmonic emission permit para m values harmonic relationship between the emission levels of planning:
\[ G_{\text{hbm}} \leq \frac{S_{m}}{\sqrt{\sum_{j=1}^{n} K_{hjm}^\alpha S_j}} THD_m \]  

(14)

\( S_m \) is the m para bus power capacity; \( G_{\text{hbm}} \) is the sub-h total harmonic voltage emission levels for all users by the substation power supply allowed values; \( \alpha \) is overlay index;

\[ \sum_{j=1}^{n} K_{hjm}^\alpha S_j \leq S_m \left( \frac{THD_m}{G_{\text{hbm}}} \right)^\alpha \]  

(15)

Due to the higher power equivalent impedance is far less than the lower grid equivalent impedance. Therefore, when during the early break the harmonic source, but also only consider the impact of the higher power after conducting the corresponding levels of harmonic power. According to the city grid diagram of 2, assuming that X-1 Power Network for X-rated power transfer, you can of formula (15) turn into:

\[ K_{hX}^\alpha (S_{X+1} + S_{X}) \leq S^\alpha \left( \frac{THD_X}{G_{hBX}} \right)^\alpha \]  

(16)

So by comparison \( K_{hX} \) and \( K_{hX}^* \), we can determine that the initial impact of harmonics is delivered by a higher power, or because of the level of harmonic impact of the grid itself, its judgment of the following principles:

- \( K_{hX} > K_{hX}^* \), need to consider the impact of the higher harmonic power grid, power grid and the higher harmonic source retrospective.
- \( K_{hX} \leq K_{hX}^* \), the level grid load caused by large harmonic probability, in this level of harmonic power source retrospective

**Conclusion**

Based on the harmonic transfer law, by using harmonic transmission rule, preliminary determine the harmonic source area or voltage grid, effectively reduce the dimension of harmonic state estimation and calculation workload. At the same time, using intelligent sampling algorithm automatically adjusts the measured variable sampling frequency, and establish data reliability model, which can ignore measurement noise vector's influence on the positioning calculations, and provide a quick and effective positioning of the harmonic source.

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