Power Quality Evaluation of Electrified Railway's Impact on Wind Farm Electric and Its Engineering Application

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Abstract. As electrified railway is an unbalanced load with random fluctuations, and its non-linearity will affect the power supply quality of the power grid near the access point of the traction power supply system, causing various power quality problems; When electrified railway is connected near wind farms, the power quality problems may affect the safe operation of grid-connected wind farms, even caused a large-scale wind farm cut off the grid. To assess the impact of electrified railway access on the power quality of wind farms at the Point of Common Coupling (PCC), combining the characteristics of electrified railways and the actual operation of the power grid, this paper proposes a method for quantitatively evaluating the impact of electrified railways on the power quality of wind farms, and the negative-sequence current conditions is calculated at the grid-connected points of wind farms that tightly operated on one side of the electrified railway and tightly operated on both sides from engineering practical perspective, providing a basis for the comprehensive management of power quality.

1. Introduction
Power quality of power grid will be influenced by the development of electrified railway, by the reason of electrified railway load with the characteristics of nonlinear, single-phase. Since more and more electrification railway are arranged intensively, when electrified railway is connected to the grid of wind farm, it will influence the operation of wind farms. Therefore, it is necessary to research the quantitative assessment method for the influence of electrified railway with the power quality of wind power plant, in addition, the evaluation result can provide reasonable suggestions for the planning construction and safe operation of the regional power grid [1-3].

Equivalent of a two-port network for electrified railway and wind power centralized access to the regional power grid has been shown in Literature [4]. In the PSCAD/EMTDC, the simulation of wind power negative sequence has been influenced by the insert of electric railway. However, the lack of harmonic impact analysis is obviously. The models of electric railway and wind power units were built respectively in PSCAD/EMTDC [5-7]. Due to the difficulty in collection of equipment parameters and the huge workload, which is not be applied to the practical project. Voltage and frequency deviation, voltage fluctuation, and the harmonic which has been caused by operation of electrified railway has been Calculated and simulated by Literature [8]. In addition, it focuses on analysis the impact of wind power unit which is caused by the traction substation connected to the electricity grid.

This paper will propose on the evaluation method of impact of electrified railway on power quality of wind power which is based on PSASP, an electrified railway in and operation of the wind farm in Liaoning province. This method would evaluate the influence of power quality of wind farm caused by
the access of electrified railway load. Combined with background of wind power quality harmonic test, quantified the main harmonic pollution could provide a theoretical basis for power grid management and non-linear load division.

2. Load characteristics analysis of electrified railway.

Electrified railway is a kind of transportation mode which consists of traction power supply system, locomotive system and electric locomotive. Traction power supply system mainly provides the electrical energy required. Traction transformer is a core device. The difference of connection mode would affect the performance of the transformer and harmonic current of electrified railway.

The electrified load of this paper uses the single-phase frequency (50Hz) AC system and the traction power supply system uses a rated voltage of 25kV. The main transformer of traction substation is in a fixed standby mode, one main and one standby operation. The traction transformer adopts 220/27.5kV, V/V connection type, and the impedance voltage (%) is 10.5. Related parameters, recently, forward power consumption and load case has been shown in table 1. The average current, short time maximum current of fundamental wave and low voltage side without the filter every harmonic average, short-time current of each traction station are shown in table 2.

| Traction substation | Rated capacity/MVA | Rated voltage/kV | Average power/MW | Maximum power/MW |
|---------------------|-------------------|-----------------|-----------------|-----------------|
| Traction substation A | 2× (20+20) | 220/27.5 | 13 | 56 |
| Traction substation B | 2× (50+40) | 220/27.5 | 29 | 135 |
| Traction substation C | 2× (40+50) | 220/27.5 | 29 | 135 |

3. The power grid model of the traction station and surrounding wind farm

This paper is based on the power system analysis program PSASP. The modeling of electrified railway and wind farms is according to the plan of traction station access. As shown in figure 1, a large number of wind farms has been accessed into the ZhangWu substation. The Dalintai wind power plant has been accessed into high voltage side of the Zhangbei wind power plant main transformer. In addition the line between Zhangbei 220 and Zhangwu 220 has been the public line. At the same time high voltage side of the Zhangbei wind power plant main transformer has been accessed into the Gumen switching station. The capacity of each wind farm is: Zhangbei wind power plant is 430.5MW, Zhangdong wind power plant is 400MW, Dalintai wind power plant is 100MW. Power grid with the characteristics of large capacity and concentrated interconnection of wind farm, which the traction station would be accessed into. Therefore, electrified railway into grid three-phase unbalanced load harmonic current will be injected into wind farm, and it would influence transformer, current commutation device, compensation device, wind turbines and other power equipment. At the same time, harmonic currents of wind farms would affect the electrified railway. As a result, it is important to determine the harmonic source of wind farm.
4. Harmonic analysis of grid connection point of wind farm

4.1. Harmonic allowable values
According to electrified railway system substation and wind farm and short-circuit capacity in grid connection point (table 3), according to, harmonic current value of grid connection point in 220 kv busbar of traction and wind farm has been calculated and shown in table 4 with small operation way of the grid.

| Traction substation / wind farm | Substation / PCC | Recent Normal way | Forward Normal way |
|---------------------------------|------------------|------------------|-------------------|
| Traction substation A           | Zhangwu Substation | 2585.2           | 3916.9            |
| Traction substation B           | Gutun Switch Station | 5151.0           | 7804.4            |
| Traction substation C           | Gutun Switch Station | 5151.0           | 7804.4            |
| Zhangbei Wind Farm              | PCC               | 2613.9           | 3960.4            |

| Traction substation / wind farm | Substation / PCC | 3 times allowable value | 5 times allowable value | 7 times allowable value |
|---------------------------------|------------------|-------------------------|-------------------------|-------------------------|
| Traction substation A           | Zhangwu Substation | 9.54                    | 9.54                    | 6.76                    |
| Traction substation B           | Gutun Switch Station | 19.01                  | 19.01                  | 13.46                  |
| Traction substation C           | Gutun Switch Station | 19.01                  | 19.01                  | 13.46                  |
| Wind Farm                       | PCC               | 9.65                    | 9.65                    | 6.83                    |

4.2. Harmonic Current Analysis
Based on the analysis of the load characteristics of electrified railway, the calculation of harmonic current in primary side is used by the method of V/V connection mode and its working principle is shown in figure 2.
Figure 2 The working principle and vector relationship of V/V traction transformer

According to the vector relationship in FIG.2, and no-load current has been ignored. The current relationship between primary side and secondary side of the single-phase V/V transformer is shown below.

\[
\begin{align*}
I_x &= \frac{I'}{K} \\
I_y &= \frac{I'}{K} \\
I_c &= -(I'_x + I'_y) / K \\
I'_x &= -I' / K = -\frac{a^2 I'}{K} \\
I'_y &= I' / K = I' \\
I'_c &= (I'_x - I'_y) / K = \frac{1}{K}(a^2 I' - I')
\end{align*}
\]

Evaluation and analysis of harmonic current and harmonic voltage are according to the characteristics of railway load and harmonic superposition. Consideration of the traction power supply arm through the average current and short time maximum current, the calculation of the short maximum current injection system with maximum current in working conditions of every harmonic current is shown in this paper. The harmonic current of each traction station is shown in Table 5. Comparing the 3rd, 5th, and 7th harmonic effective values and allowable values for each phase, it is obviously that the harmonic current produced by traction on the system side is less than the allowable values. Therefore, it is satisfied the requirement of national standard.

| Traction substation / wind farm | Substation / PCC | Each phase | Three  | Five   | Seven  |
|---------------------------------|------------------|------------|--------|--------|--------|
| Traction substation A           | Zhangwu Substation | A phase | -1.51+1.08i | -0.72+0.51i | -0.54+0.38i |
|                                 |                   | B phase | 2.55   | 1.21   | 0.91   |
|                                 |                   | C phase | -1.03-1.08i | -0.49-0.51i | -0.37-0.38i |
| Traction substation B           | Gutun Switch Station | A phase | -0.77+0.55i | -0.37+0.26i | -0.27+0.19i |
|                                 |                   | B phase | 0.94   | 0.45   | 0.34   |
|                                 |                   | C phase | -0.16-0.55i | -0.0836-0.2613i | -0.06-0.19i |
| Traction substation C           | Gutun Switch Station | A phase | -2.08+1.48i | -0.97+0.69i | -0.74+0.53i |
|                                 |                   | B phase | 2.11   | 1.01   | 0.75   |
|                                 |                   | C phase | -0.04-1.48i | -0.04-0.69i | -0.01-0.53i |

If all of the harmonic current injected into system by Traction substation A, Traction substation B, and Traction substation C are flow into the line of Zhangbei wind power plant. The sum of each...
harmonic vector is that of harmonic of flowing out of Zhangbei wind power plant. However, out-of-limit could not happen. As shown in table 6.

Table 6  Traction Stations Harmonic Currents into Wind Farm PCC

| Substation /PCC | Each phase | Three     | Five      | Seven     |
|-----------------|------------|-----------|-----------|-----------|
| PCC             | A phase    | -4.36+3.11i | -1.17+0.51i | -1.55+1.10i |
|                 | B phase    | 5.6       | 2.67      | 2         |
|                 | C phase    | -1.23-3.11i | -0.6136-1.4613i | -0.44-1.10i |

4.3. harmonic voltage analysis
The limit value of the harmonic voltage (phase voltage) of the public power grid with the nominal voltage of 220 kV is: the odd harmonic voltage has a rate of 1.6%, and the even harmonic voltage has a rate of 0.8%. In the analysis and evaluation of harmonic current caused by harmonic current, its simulation principle is same as harmonic current. With the condition of short circuit, and the current is maximum, and the harmonic voltage in grid connection point of wind farm are shown in the chart. It is obviously that the harmonic voltage of grid connection point is less than the allowable values. Therefore, it is satisfied the requirement of national standard.

Table 7  Harmonic voltage distortion of Wind Farm PCC

| Substation /PCC | Each phase | Three     | Five      | Seven     |
|-----------------|------------|-----------|-----------|-----------|
| PCC             | A phase    | -4.36+3.11i | -1.17+0.51i | -1.55+1.10i |
|                 | B phase    | 5.6       | 2.67      | 2         |
|                 | C phase    | -1.23-3.11i | -0.6136-1.4613i | -0.44-1.10i |

4.4. Negative sequence current analysis
When the negative sequence current is injected into the contact line of the wind power station after the traction station is connected, the following two situations are considered.

(1) The electrified railway tightly operated on both sides, and the current calculation of short-time maximum current is selected on both sides of the supply arm current;

(2) The electrified railway tightly operated on one side, and the current of one side of the supply arm is selected for short time maximum current and the current of the other side is 0.

Model of electrified railway and wind farm are simulated in PSASP. In the condition of power grid with small load, hydro turbine shutdown, coal-fired power plants to arrange a certain capacity of maintenance spare, select grid contact line of wind farm as a monitoring point of negative sequence current. The ratio of negative sequence current and rated current of the power plant after the traction station access system in two conditions is shown in table 8, and the negative sequence current of wind farm grid connection point is less than 8% of the rated current.

Table 8 Negative sequence current of wind farm contact line

| wind farm contact line | Rated current (kA) | Negative sequence current/rated current (%) Both sides close | One side close |
|-----------------------|--------------------|-------------------------------------------------------------|---------------|
|                       | 1.129              | 0.76                                                        | 0.49          |

5. conclusion
Electrified railway access would mainly influence on negative sequence and harmonic of wind farm power quality. Based on the analysis of negative sequence characteristics of traction load and the working principle of V/V traction transformer, an engineering application evaluation method is proposed in PSASP Software for electrified railway impacting wind farm electric power quality. This
evaluation method can provide theoretical foundation for planning and coordination of regional grid, wind farm site selection and main harmonic source responsibility defined. The calculation results could provide certain reference of power quality management for electrified railway of unbalanced load.

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