Analysis of Harmonics Infiltration Produced by Electrification Railroad on 220kv and 35kv Network

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Abstract

Through analysis of measure data on three 220kV transformer substation in Shanxi China, the results show that harmonic current produced by electrification railroad injects into power system in a proportion through 110kV point of common coupling, and the infiltration coefficient is closed to 1 if harmonic current direction is 110kV to 35kV, this phenomenon coincides with usual law; but there has strong infiltration in harmonic voltage between 110kV and 220kV system, and the infiltration coefficient could be not negligible, it does not coincide with usual law. Therefore, 110kV harmonic distortion produced by electrification railroad not only infiltrates to 220kV system thought coupling transformer, but also disseminates even hundreds of kilometres thought electric fence.

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1. Introduction

Beginning from the 1980s, power harmonic has been researched by China electric power specialist [1]. Especially electrification railroad and high energy consumption enterprises, more and more nonlinear load has been used and led to harmonics problems seriously with developing of power system and increasing of power supply. Now, the problem of harmonic infiltration has been concerned by electric power corporation and power consumers, and studied by scholars of all worlds [2]. Generally, harmonic current produced by electrification railroad injects into power system in a proportion through 110kV point of common coupling, then infiltrates into the lower load branch. If harmonic current direction is high voltage side to low voltage side, the infiltration coefficient is closed to 1; on the contrary, the infiltration coefficient is quite small and negligible [3]. Ref. [4] considered: there has strong infiltration in harmonic
voltage between 500kV and 220kV system, and the infiltration coefficient is closed to 1 when harmonic current direction is 220kV system to 500kV system. Ref. [5] considered: if voltage drop less than 5 percent between supply voltage and load voltage, the infiltration rate of total voltage harmonic distortion (THDV) is 0.75 between 110kV system and 0.4kV system. Ref. [6] considered: if harmonic current direction is high voltage side to low voltage side, the infiltration coefficient is reduced and transmission resistance makes greater while active load increases and reactive load diminishes. Ref. [7] only discusses the problem of infiltration from high voltage system to low voltage system. But when infiltration relation is studied carefully, we can find particularity in infiltration characteristics of electrification railroad.

Harmonics in 110kV system produced by electrification railroad can infiltrate to 220kV and 35kV systems through coupling transformer, and be spread in power system. Consequently harmonics effect has been aggravation. The paper analyzes two facts of harmonics infiltration: high voltage bus and low voltage bus.

2. Infiltration theory analysis

110kV bus is the point of common coupling between electrification railroad and power system, and 110kV voltage distortion produced by electric locomotive could be infiltrated to 220kV and 35kV systems. The order of severity depends on load and capacitor parameter.

2.1. Case one: no capacitor in power system coupling with electrification railroad

\[ U_{n35} (\%) = K_{vn} U_{n110} (\%) \]  

\[ K_{vn} = X_{Fn}/((X_{Tn} + X_{Fn}) = nX_{F1}/(nX_{T1} + nX_{F1}) \]

\[ K_{vn} \] is infiltrated coefficient of harmonics voltage; \( X_{Fn} \) is harmonics inductive of equivalent load; \( X_{Tn} \) is harmonics inductive of equivalent transformer.

We can know from formula 1 and formula 2:

- (A) \( X_{Fn} \) and \( X_{Tn} \) are inductance, so \( K_{vn} < 1 \);
- (B) \( X_{Fn} \gg X_{Tn} \) , so \( K_{vn} \) closed to 1.

Obviously formula 1 and formula 2 are suitable for harmonics voltage infiltration between each voltage class coupled by transformer.

2.2. Case two: contain capacitors in power system coupling with electrification railroad

\[ K_{vn} = \frac{1}{1 + \frac{X_{Tn}}{X_{Fn}} - \frac{X_{Tn}}{X_{Cn}}} = \frac{1}{1 + \frac{X_{T1}}{X_{F1}} - n^2 \frac{X_{T1}}{X_{C1}}} \]
\[ n_0 = \sqrt{\frac{X_{C1}}{X_{T1} + X_{C1}} + \frac{X_{C1}}{X_{F1}}} \]  

(4)

Analysis:

(A) if \( n = n_0 \), because of \( X_{Fn} \gg X_{Tn} \), \( K_{vn} \to \infty \), then resonance status;

(B) \( \frac{X_{Tn}}{X_{Fn}} \ll 1 \), so \( 1 + \frac{X_{Tn}}{X_{Fn}} \to 1 \), then harmonics inductive of equivalent load influence on \( K_{rn} \) and \( n_0 \) is very small. If approximate compute:

\[ K_{vn} = \frac{1}{1 - \frac{X_{Tn}}{X_{Cn}}} = \frac{1}{1 - n^2 \frac{X_{Tn}}{X_{Cn}}} \]  

(5)

\[ n_0 = \sqrt{\frac{X_{C1}}{X_{T1}}} \]  

(6)

All analysis mentioned does not consider the influence of load impedance. When load impedance has been considered, \( K_{vn} \) should be lower and had the damping function for resonance phenomenon; \( K_{vn} \) is affected clearly by \( X_{Cn} \):

No mentioned \( X_{Fn} \) and think \( X_{Tn} \) and \( X_{Cn} \) to be algebra quantity:

When \( |X_{Cn}| > |X_{Tn}| \),

\[ K_{vn} = \frac{X_{Cn}}{X_{Cn} - X_{Tn}} \frac{\partial K_{vn}}{\partial X_{Cn}} = \frac{X_{Tn}}{(X_{Cn} - X_{Tn})^2} > 0 \]  

so \( |X_{Cn}| \) is increased with \( K_{vn} \);

When \( |X_{Cn}| < |X_{Tn}| \),

\[ K_{vn} = \frac{-X_{Cn}}{X_{Cn} - X_{Tn}} \frac{\partial K_{vn}}{\partial X_{Cn}} = \frac{-X_{Tn}}{(X_{Cn} - X_{Tn})^2} < 0 \]  

so \( |X_{Cn}| \) is increased with \( K_{vn} \) rising.

terms of \( K_{vn} > 1 \) (not considered the influence of \( X_{Fn} \)):

If \( |X_{Cn}| > |X_{Tn}| \), formula 5 can obtain \( K_{vn} > 1 \); if \( |X_{Cn}| < |X_{Tn}| \) and \( |X_{Cn}| > \frac{|X_{Tn}|}{2} \), can obtain \( K_{vn} > 1 \). To sum up the two cases, there is the term of \( K_{vn} > 1 \)
\[ |X_{Cn}| > \frac{|X_{fn}|}{2} \] 

(7)

3. Harmonics infiltrated to low voltage power system

We can use the measurement data in Yang Cheng transformer substation to demonstrate and analyze the harmonics infiltration problem of electrification railroad and 35kV power system. Measurement time was from 0 o’clock at July 10 to 0 o’clock at July 12 2010. Measurement apparatus was power quality online monitor system produced by FLUKE Company.

Table 1. Relative harmonic voltage content of 3th–13th

| Harmonic (frequency) | Relative harmonic voltage content of 95% probability value (%) | Infiltration coefficient |
|----------------------|---------------------------------------------------------------|-------------------------|
|                      | 110kV bus A phase | B phase | C phase | 35kV bus A phase | B phase | C phase | A phase | B phase | C phase |
| 3                    | 1.644             | 1.047   | 0.9368  | 1.010           | 0.6714  | 0.6569  | 0.6144  | 0.6413  | 0.7012  |
| 5                    | 2.244             | 1.335   | 1.955   | 1.975           | 1.528   | 1.811   | 0.8801  | 1.145   | 0.9263  |
| 7                    | 1.241             | 0.7973  | 1.258   | 0.8057          | 0.4308  | 0.9257  | 0.6492  | 0.5403  | 0.7359  |
| 9                    | 0.9766            | 0.7267  | 1.071   | 0.3655          | 0.2680  | 0.4275  | 0.3743  | 0.3688  | 0.3992  |
| 11                   | 1.281             | 0.8251  | 1.328   | 0.5405          | 0.3336  | 0.5518  | 0.4219  | 0.4043  | 0.4155  |
| 13                   | 0.7929            | 1.306   | 1.041   | 0.3111          | 0.5493  | 0.4149  | 0.3924  | 0.4206  | 0.3986  |
| THDV                 | 3.590             | 2.975   | 3.451   | 2.444           | 1.893   | 2.194   | 0.6808  | 0.6363  | 0.6358  |

Thought analysis we can know: 110kV voltage distortion can be response to 35kV coupled with its, and the order of severity depends on load and capacitor parameter. While not mentioned capacitor influence, the infiltration coefficient is closed to 1; while mentioned capacitor influence and capacitor reactance greater than half of equivalent transformer harmonics inductive, the infiltration coefficient is greater than 1, on the contrary smaller than 1. Load influence can diminish infiltration coefficient and have the damping function for resonance phenomenon.

4. Harmonics infiltrated to high voltage power system

Thought test point 1 we can know that the THDV is 2.22% on 220kV bus voltage in Fang Cheng transformer substation, and 5th harmonic voltage distortion is 2.07%, and both not satisfied of Nation Standard (GB/T 14549-1993). But we not find the harmonic sources on 220kV and 110kV system in Fang Cheng transformer substation, and can not find harmonic in test point 2 and test point 3, so can obtain harmonic of 220kV system must be introduced from other 220kV system.

Seen from the Fig 3 and Fig 4, we can know: Firstly, the harmonic quotas of 110kV bus in Yi Jing transformer substation (Test point 4) is exceed standard seriously because of electrification railroad. When electrification railroad stops function, the harmonic quality gets well soon; Secondly the harmonic quotas of 220kV and 110kV bus in Fang Cheng transformer substation is exceed standard because electrification railroad. When electrification railroad stops function, all quotas is better and meets to national standard; thirdly, we can determine that the harmonic quality of 220kV and 110kV bus in Fang Cheng and Yi Jing transformer substation is directly related to the function manner of electrification.
railroad, and to exceed the harmonic standard of 220kV system in Fang Cheng transformer substation is due to had lots of nonlinear loads in Yi Jing power system. Finally, Fang Cheng transformer substation is about 100 kilometers away from Fang Cheng transformer substation. So 110kV harmonic distortion produced by electrification railroad not only can infiltrate to 220kV system thought coupling transformer, but also disseminate even hundreds of kilometers thought electric fence.

![Main wiring diagram of Fang Cheng and Yi Jing transformer substation](image1)

**Fig 1** Main wiring diagram of Fang Cheng and Yi Jing transformer substation

![A phase voltage on 2200kV bus in Fang Cheng transformer substation](image2)

**Fig 2** A phase voltage on 2200kV bus in Fang Cheng transformer substation (a) Total e harmonic distortions ;(b) 3th~17th relative harmonic voltage content
Fig 3 Total e harmonic distortions of A phase voltage on 2200kV bus (a) Yi Jing transformer substation; (b) Fang Cheng transformer substation

Fig 4 5th harmonic current of 182# feeder in Yi Jing transformer substation

5. Conclusion

Harmonic current produced by electrification railroad injects into power system through 110kV point of common coupling, and the infiltration coefficient is closed to 1 if harmonic current direction is 110kV to 35kV; the infiltration coefficient could be not negligible if harmonic current direction is 110kV to 220kV, and 110kV harmonic distortion can disseminate even hundreds of kilometers thought electric fence

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