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# Analysis of Electromagnetic Immunity Experiment for Field Installation of Intelligent Equipment in Substation

Ji Jianfei[1], Wang Lihui[2], Yuan Yubo[1] and Yang Yifei[3]

[1]*Jiangsu Electric Power Research Institute Co., Ltd, Nanjing, China (jijianfeisgcc@163.com)*
[2]*School of Instrument Science and Engineering, Southeast University, Nanjing, China (wlhseu@163.com)*
[3]*Department of Automation, Nanjing University of Science and Technology, Nanjing, China (15850548121@163.com)*

***Abstract***

*With the increase of voltage level and more and more secondary devices are located in field, the secondary circuit of substation is in a strong electromagnetic environment. Because the secondary circuit is affected by the interference of switch operations, there are many trip accidents happened in substations without any fault in recently years, which constitutes a serious threat to the power network and harms the safe operation of the electric power system. It is of great theoretical significance and practical value to study the Electromagnetic Compatibility problem of the transformer substations substation secondary circuit. In this paper, the abnormal phenomenon of one 110kV intelligent substation merging unit is described. And the reason of the abnormal phenomenon is analyzed. Firstly, the Electromagnetic Compatibility experiments specified by the IEC61000-4 standard are carried out. Furthermore, to verify the anti–interference performance of the merging unit, the Electromagnetic Compatibility experiments above the standard are carried out. The structure of merging unit is improved until the merging unit operates normally. Secondly, to quantitatively analyze the disturbance strength, the electromagnetic disturbance signal is recorded, and the characteristics of amplitude and time-frequency of the recorded signal are analyzed. Thirdly, the characteristics of the logged signal are compared to the IEC61000-4 standard. Finally, this paper puts forward some suggestions about improving the Electromagnetic Compatibility performance of merging unit.*

***Keywords****: Intelligent substation; Field installation; Electromagnetic transient disturbance*

## 1. Introduction

Along with the construction of intelligent substation, the electromagnetic compatibility problems of the substation become more outstanding. In 2011, because the Rogowski coil electronic current transformer is affected by the interference caused by the switch operation, the output waveform is abnormal, the No. 58 supplementary document published by the capital construction department of State Grid Corporation regulates that before the electronic current transformer is well established, the newly-built substation adopts the conventional transformer with the merging unit but not electronic transformer to realize field digital-to-analog converters. At the same time, as the voltage class of substation becomes higher, the capacity of substation becomes larger, the number of control objects becomes more, the field installation of secondary intelligent devices becomes a trend. But the working mode and installation position of field installation intelligent devices is very different from that of local installation intelligent secondary

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devices, the distance from field installation intelligent secondary devices to the disturbance source is nearer, so the intelligent devices suffer greater electromagnetic disturbance[1-2].

In this paper, the abnormal operation of merging unit of the 110kV intelligent substation is analyzed. Firstly, the reason of the abnormity of merging unit is analyzed. Secondly, the EMC (Electromagnetic Compatibility) experiments specified by the IEC61000-4 standard are carried out. Furthermore, to verify the anti–interference performance of the merging unit, the EMC experiments above the standard are carried out. And the structure of merging unit is improved until the merging unit runs normally. Thirdly, the electromagnetic disturbance signal is recorded, and the characteristics of amplitude and time-frequency of the recorded signal are analyzed. Finally, some suggestions to improve anti-interference performance are put forward.

## 2. Background

The primary electric wiring diagram is shown in Figure 1. The substation adopts single bus section, two 110kV return circuits in this term, one main transformer, and no 10kV outgoing lines. As shown in Figure 2, the substation adopts GIS (Gas Insulated Switchgear) combined electrical apparatus and conventional transformers, the merging units and the intelligent terminals are installed in GIS cabinets. One day, the substation went into operation, when the disconnecting switch operated, the computer monitoring system alarmed ’ line protection lock’ signal, the merging unit restarted and the data acquisition equipment of merging unit lost data points.

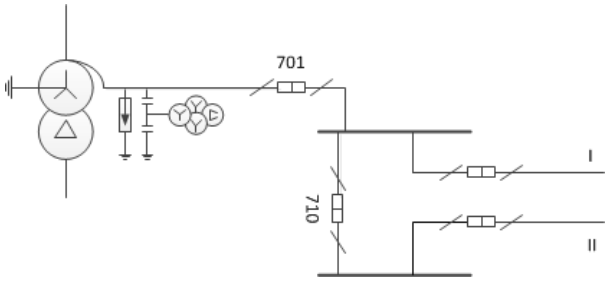



**Figure 1. One 110kV Substation Primary Electric Wiring Diagram**

**Figure 2. One 110kV Substation Single Bus Section GIS Equipment**

## 3. Processing Steps

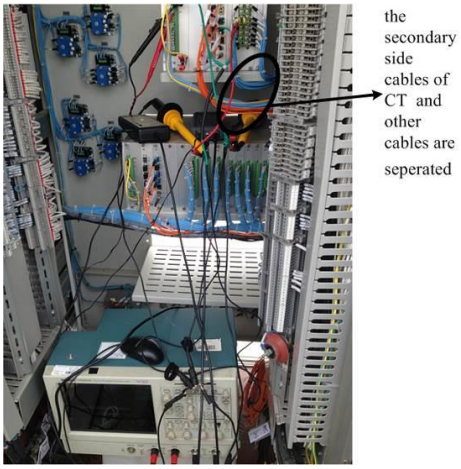
### 3.1. First Step

At first, suspecting that the abnormal condition is caused by the damage of merging unit circuit board, after the program of merging unit is upgraded and all circuit boards are replaced besides the AC (alternating current) sampling circuit board, the abnormal condition still happened. So the problem of circuit boards of merging unit is excluded.

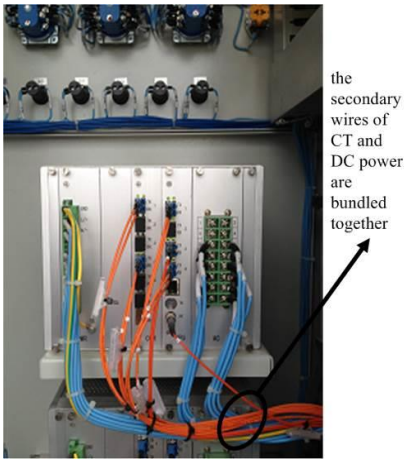
 

Because the merging unit restarted, it is necessary to examine the DC (direct current) power module. When closed the disconnection switch, the voltage of merging unit backplane's electric power dropped from 220v to 110v transiently, so it is suspected that there are problems in the external DC power. But when the substation was powered off again and the DC power system was examined (during the power off, the GIS device is covered by rain cover, the switch journey is adjusted, which are all not related to merging unit electrical circuit). It is found that the DC power system which is properly grounded worked well, and there was no AC wave interfused.

### 3.2. Second Step




(a) The secondary side cables of CT(current transformer) and other cables are separated




(b)The secondary side cables of CT and other cables are bundled together

**Figure 3. Measuring Transient Disturbance Signal by Oscilloscope**

Furthermore, in order to find the reasons, the substation plans to transmit again. The main reasons can be found from the two aspects: DC power and EMI (Electromagnetic Interference).

**1. Monitoring the DC Power Voltage.**

When operating switch, the working DC power voltage of merging unit and line cabinet are monitored. The record time is 500ms. When close the switch, the merging unit restarted, and there is no voltage dropping wave in oscilloscope. The millimeter reading is stable.

**2. Using Independent DC Power.**

At the condition of using the independent DC power, when operating the switch again, the abnormal phenomena still exists. So the DC system of substation is normal, and the DC system is not why the merging unit restarts.

Firstly, after disconnecting VT (voltage transformer), the abnormal phenomena still exists. Secondly, after pulling out AC sampling cables, the abnormal phenomena also exists. Finally, after disconnecting all wires (including ground wires) of the power panel, using independent DC power, and pulling out AC sampling board, the electrical circuits between the merging unit and primary equipment are cut off, then operating the switch enough times, the abnormal phenomena doesn't happen. It is considered that the EMI is why the merging unit restarts.

**3. Searching the EMI Path**

Reconnecting the wires step by step, the power panel connection wires are recovered firstly. The AC sampling boards are still pulled out. When operating the switch, the abnormal phenomenon happens again.

**4. Searching the EMI Coupling Mode**

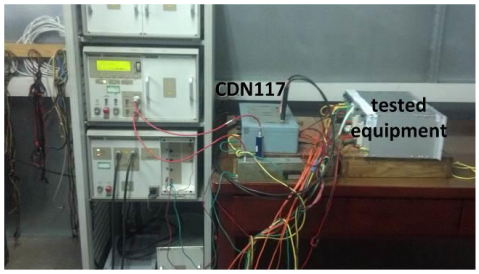
At the condition of AC sampling board are pulled out, the secondary sides of CT are shortened. When operating the switch, the abnormal phenomenon of merging unit doesn't happen again. It is found that the secondary wires of CT and DC power are bundled together. The EMI can couple into the DC power cables, which causes the abnormal phenomenon.

**5. Cutting off the EMI coupling path**

The all connection wires of merging unit are recovered. The AC sampling wires and DC power wires are separated. After operating the switch enough times, the abnormal phenomenon of merging unit doesn't happen again.

So, the EMI produced by the switch operation couples into the DC power is why the merging unit restarts. After the secondary wires of CT and DC power wires are separated, the abnormal phenomenon of merging unit doesn't happen again, but the data acquisition equipment of merging unit still loses data points.

### 3.3. Third Step




(a) Surge experiment


(b) EFTB experiment

**Figure 4. EMC Experiment**

Because the data acquisition equipment of merging unit still loses data points, the EMC experiment for merging unit are carried out. As shown in Figure 4, based on the EMC experiment, the rectification measures for merging unit are performed. Experimental records and rectification measures are as follows:

**(a) Experimental Records**

I conventional experiment

EFTB (electrical fast transient burst) interference experiment: when IV level interference wave (4kV, 5 KHz/100KHz) is applied on device power, the input and output unit and the analog circuit, the merging unit works well. The data acquisition equipment of merging unit doesn't lose data points.

Surge experiment: when IV level surge wave (4kV, 8/20us) is applied on device power, the input and output unit and the analog circuit, the merging unit works well. The data acquisition equipment of merging unit doesn't lose data points.

II unconventional experiment

EFTB (electrical fast transient burst) interference experiment: when interference wave (above 4.5kV, 5KHz/100KHz) above IV level is applied on device power, the input and output unit and analog circuit, the merging unit works well. The data acquisition equipment of merging unit occasionally loses data points.

Surge experiment: when surge wave (4.4kV, 8/20us) above IV level are applied on device power, the input and output unit and analog circuit, the merging unit works well, and the data acquisition equipment of merging unit doesn't lose data points.

**(b) Rectification Measures**

I The original design adopts that two DSP (digital signal processor) plug-in boards to realize MU functions; inner communication between two DSP plug-in boards is realized through bus motherboard.

The new design adopts that two DSP (digital signal processor) modules are integrated into one plug-in board. So the communication mode through bus motherboard is cancelled, which can improve the device's anti-interference ability.

II Cabinet processing adopts conductive processing methods to improve the integrity of cabinet, and electrical connection among the various parts of the cabinet is more reliable. And the whole anti-electromagnetic disturbance performance of device is improved.

After improving the cabinet structure of merging unit, the whole conductive performance of cabinet and the connection mode of two DSP (digital signal processor) plug-in boards, the EFTB interference experiment and surge experiment mentioned above are carried out again. The merging unit works well, and the data acquisition equipment of merging unit occasionally loses data points.

### 3.4. Forth Step

After rectifying the merging unit, the substation plans to transmit again. The merging unit works well, and the data acquisition equipment of merging unit occasionally loses data points. For quantitatively analyzing the electromagnetic disturbance intensity the merging unit is subjected, the electromagnetic transient disturbance signal is recorded when operating the switch [5-6].

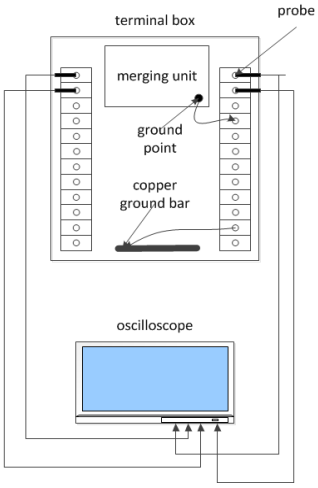



**Figure 5. Recording Electromagnetic Transient Disturbance Signal**

As shown in Figure 3 and Figure 5, When operating the switch, the electromagnetic transient disturbance signal from the channel of the A phase current of the secondary sides of CT, the A phase voltage of the secondary sides of CT, the channel of DC power (differential mode interference), the positive pole of DC power (common mode interference), the voltage of the ground wire of merging unit to the copper ground bar is recorded.

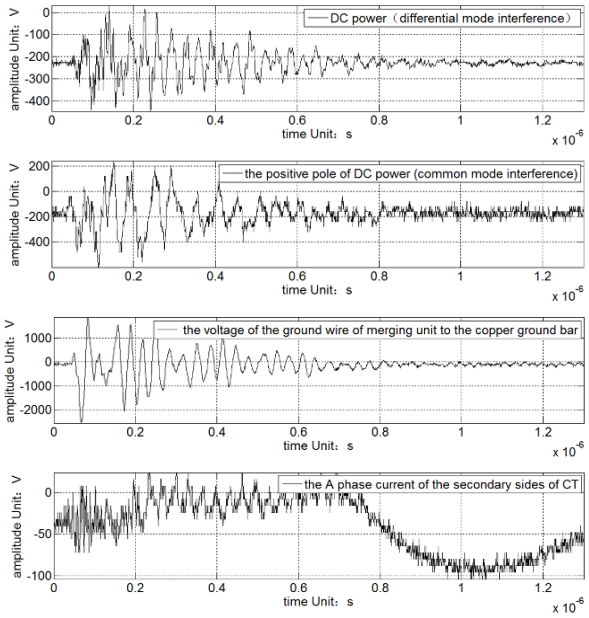



**Figure 6. When the switch is closed at the third time, and the DC power wires and secondary wires of CT are bundled together, the electromagnetic transient disturbance time-domain waveform of the channel of DC power (differential mode interference), the positive pole of DC power (common**

**mode interference), the voltage of the ground wire of merging unit to the copper ground bar, and the A phase current of the secondary sides of CT**

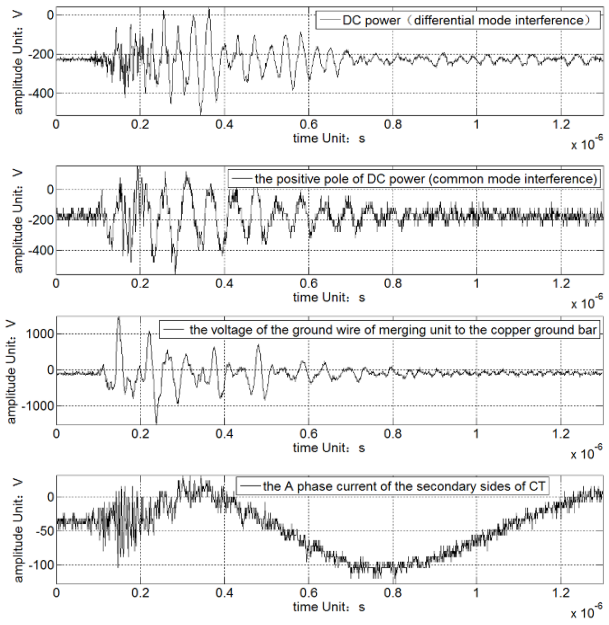


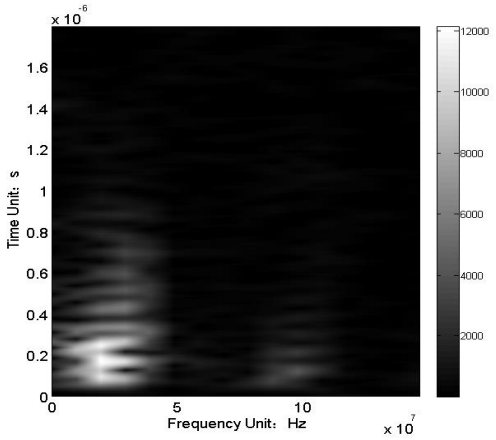

**Figure 7. When the switch is opened at the second time, and the DC power wires and secondary wires of CT are separated, the electromagnetic transient disturbance time-domain waveform of the channel of DC power (differential mode interference), the positive pole of DC power (common mode interference), the voltage of the ground wire of merging unit to the copper ground bar, and the A phase current of the secondary sides of CT**

As shown in Figure 6 and Figure 7, when the DC power wires and secondary wires of CT are separated, the peak value of the electromagnetic transient disturbance in the channel of DC power (differential mode interference) is 300V, the peak value of the electromagnetic transient disturbance in the channel of the positive pole of DC power (common mode interference) is 700V, the peak value of the electromagnetic transient disturbance in the channel of the positive pole of DC power (common mode interference), the peak value of the A phase voltage of the secondary sides of CT is 1000V, the peak value of the electromagnetic transient disturbance in the channel of the A phase current of the secondary sides of CT is 200A, the peak value of the electromagnetic transient disturbance in the channel of the voltage of the ground wire of merging unit to the copper ground bar is 3000V.

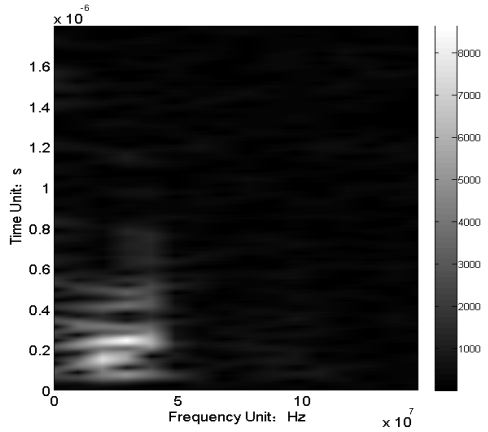
When the DC power wires and secondary wires of CT are bundled together, the peak value of the electromagnetic transient disturbance in the channel of DC power (differential mode interference) is 500V, the peak value of the electromagnetic transient disturbance in the channel of the positive pole of DC power (common mode interference) is 700V, the peak value of the electromagnetic transient disturbance in the channel of the voltage of the ground wire of merging unit to the copper ground bar is 4000V, the A phase voltage of the secondary sides of CT is 1000V, the peak value of the electromagnetic transient disturbance in the channel of the A phase current of the secondary sides of CT is 200A.

It is obviously that in the second step, when the DC power wires and secondary wires of CT are separated, the merging unit doesn't restart. As shown in Figure 6-Figure 10, after the DC power wires and secondary wires of CT are bundled together, the peak value of the electromagnetic transient disturbance in the channel of DC power (differential

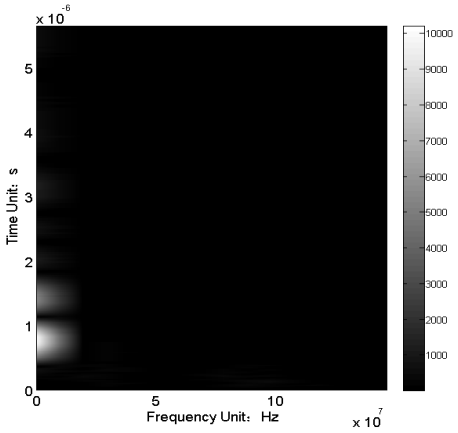
mode interference) increased by 200V, and the peak value of the electromagnetic transient disturbance in the channel of the voltage of the ground wire of merging unit to the copper ground bar increased by 1000V. The electromagnetic transient disturbance in the secondary wires of CT couples into the DC power wires and the ground wire of merging unit. When the DC power wires and secondary wires of CT are bundled together, the intensity of coupling electromagnetic transient disturbance in the channel of DC power and the ground wire of merging unit becomes stronger.




(a) The channel of the A phase voltage of the secondary sides of CT

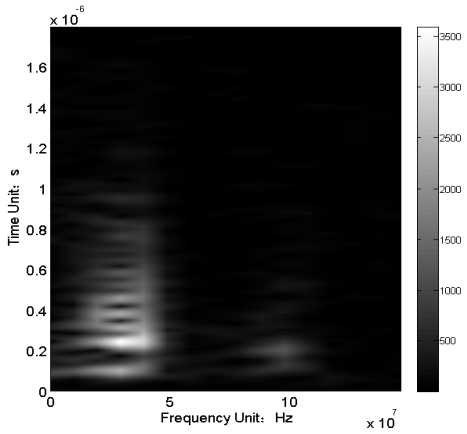



(b) The channel of the positive pole of DC power (common mode interference)




(c) The channel of the A phase current of the secondary sides of CT




(d) the channel of the DC power (differential mode interference)

**Figure 8. When the switch is closed at the first time, and the DC power wires and secondary wires of CT are separated, the time-frequency spectrum of the electromagnetic transient disturbance**

The STFT (short-time Fourier transform) can provide time and frequency information at the same time[4-5]. To be economic, the representative time-frequency spectrums of electromagnetic transient disturbance in the channel of DC power (differential mode interference), the positive pole of DC power (common mode interference), the A phase voltage of the secondary sides of CT, and the A phase current of the secondary sides of CT are shown in Figure 8.

The abscissa represents frequency, the ordinate represents time, and the depth of the filled color represents power spectrum strength[6]. The time-frequency spectrums of electromagnetic transient disturbance in the channel of DC power (differential mode interference), the positive pole of DC power (common mode interference), the A phase voltage of the secondary sides of CT are similar to each other. Within 0.5 microseconds after operating the switch, the main component of frequency is distributed between 0 and 40MHz. Within the frequency band, the waveform is stronger, and the waveform is strongest at 20MHz. For the channel of the A phase current of the secondary sides of CT, there are several continuous strong pulses, and the main component of frequency is distributed between 0 and 20MHz.

## 4. Conclusion and Suggestion

### 4.1. Conclusions

1. The electromagnetic interference generated by the switch operation may couple into the field installation intelligent device by CT circuit and the device's other wires, so the field installation intelligent device may work abnormally.

2. When carrying out IV level electrical fast transient burst (EFTB) experiment and IV level surge experiment regulated in IEC 61000-4 standard for merging unit, the device operated normally. When carrying out above IV level EFTB experiment and Surge experiment for the device, the device operated abnormally. The recorded disturbance signal shows that the peak value of disturbance signal of the merging unit's ground wire can reach 4600V, which is larger than that of IV level of EFTB experiment and Surge experiment regulated by IEC61000-4 standard, so the peak value of interference signal produced by the switch operation of substation is larger than that regulated by IEC61000-4 standard.

3. From the analysis of the recorded electromagnetic disturbance signal, after about 0.5 microseconds the switch operation, the strength of waveform is more strong, the frequency distribution are mainly between 0Hz to 40MHz, and at 20MHz, the spectrum amplitude is the strongest.

4. It means that the electromagnetic transient disturbance in the secondary wires of CT couples into the DC power wires and the ground wire of merging unit. When the DC power wires and secondary wires of CT are bundled together, the intensity of coupling electromagnetic transient disturbance in the channel of DC power and the ground wire of merging unit becomes stronger.

Author names and affiliations are to be centered beneath the title and printed in Times New Roman 12-point, non-boldface type. Multiple authors may be shown in a two or three-column format, with their affiliations below their respective names. Affiliations are centered below each author name, italicized, not bold. Include e-mail addresses if possible. Follow the author information by two blank lines before main text.

### 4.2. Suggestions

1. When carrying out EMC test for field installation intelligent equipment, it is necessary to improve the strength of EMC test above IV level regulated in IEC61000-4 standard.

2. Improving the cabinet structure of merging unit, the whole conductive performance of cabinet and the connection mode of two DSP (digital signal processor) plug-in boards.

3. It is suggested that the DC power wires and secondary wires of CT must be separated to avoid that the electromagnetic transient disturbance in the secondary wires of CT couples into the DC power wires and the ground wire of merging unit.

## Acknowledgements

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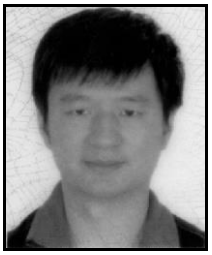
## Authors



**Ji Jian-Fei**, male, He was born in 1982. He is currently an postdoctoral in Jiangsu Electric Power Company, China. His major research interests are EMC, and relay protection and automation.