Impact of Third Harmonic Current to Earth Fault Protection System

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Abstract

The building installing a lot of dimmer load and using earth fault protection relay to detect the earth fault, there are a nuisance circuit breaker trips cause by the operation of earth fault relay. This event happens when a lot of dimmer load which is the source of third harmonic current operate together.

This paper proposes the case study of the impact of third harmonic current from dimmer load which disturb the operation of the earth fault protection relay and cause a nuisance trip of circuit breaker. In order to analyze the cause of the problem, the operation principle of earth fault protection system is analyzed, the harmonic content of dimmer circuit current is measured and the current flow analysis (divide into 3 categories: normal load current flow, earth fault current flow and third harmonic current flow) is also implemented.

The nuisance circuit breaker trips, when dimmer loads operate, are caused by third harmonic current. This current, which is generated by dimmer, does not cancel each other but sum up together causing a significantly higher current flow in neutral conductor, ground conductor and ground loop. And this higher ground current cause the total summation current, which earth fault relay detects, exceeds the operation setting of relay. Thus earth fault relay incorrectly detects earth fault event and command circuit breaker to trip out.

Finally, the several mitigation methods are proposed and analyzed. Including the installation of harmonic filter to reduce the third harmonic current flowing in the system and the installation of 4 poles automatic transfer switch (ATS) to block the unwanted current (normal load current and third harmonic current) flowing in ground path in normal operating condition. The advantage and disadvantage for each method are also summarized.

Keywords : third harmonic, earth fault protection, dimmer, nuisance trip.

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1. Introduction

In MEA customer's theater building, there are a lot of dimmer installations uses for control the lighting that shine to the stage when the performance is showing. This theater receives the electricity from MEA at 24 kV and step down to 400 V by the distribution transformer supplying all loads inside the theater. They also install a low voltage backup generator for supplying electricity to important load (including dimmer circuit) in emergency (outage from MEA). Normally the generator will not synchronize to MEA power system. When outages occur, the automatic transfer switch (ATS) transfers an important load in emergency distribution board (EDB) to receive the power from backup generator instead. Figure 1 show the schematic wiring diagram of power supply system of this theater. (Note: to simplify the diagram, the 3 line conductors are shown in only one line).

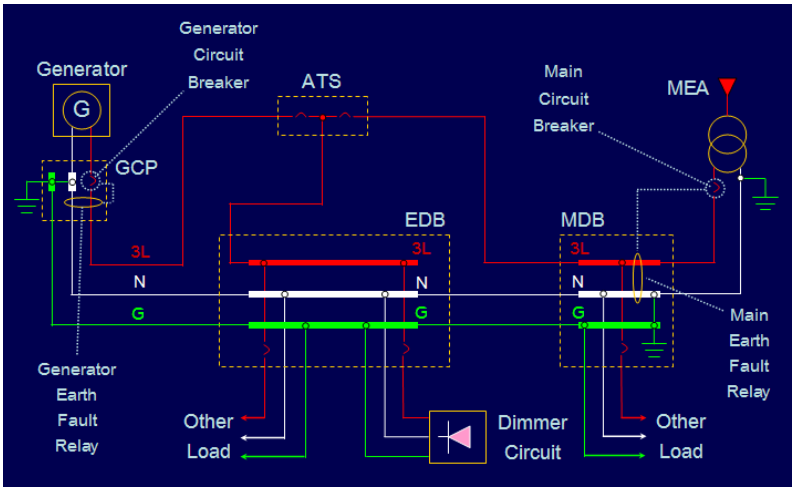

Figure 1: Schematic diagram of theater's power supply system

The backup generator has an earth fault protection system to detect the earth fault current and open generator circuit breaker to protect the damage to the generator from overcurrent. The earth fault protection relay operates by detecting the summation of current in all phase conductors and neutral conductor.

This system has a multiple ground connection points that are 1) neutral point of the distribution transformer, 2) ground bus in main distribution board (MDB) and 3) ground bus in generator control panel (GCP). The neutral bus and ground bus are also bonded together in MDB and GCP.

In case of supplying from utility (MEA), there is no nuisance circuit breaker trip event. Anyway when ATS transfer loads to receive the power from backup generator and if in that time there are a lot of dimmer load usages then the generator earth fault protection relay incorrectly detect the earth fault event and command the generator circuit breaker to trip out.

2. Equipment Operation Analysis

2.1 The operation of dimmer load

Dimmer loads can generally consider as the significant source of third harmonic current. The harmonic current measurement at dimmer circuit (line conductor) is shown in Figure 2. It is obviously found that magnitude of third harmonic current is about 40% of fundamental current (50 Hz). Native characteristic of third harmonic current is a zero sequence component. That means third harmonic current in each line conductor will not cancel at neutral point (like normal 50 Hz load current) but they will sum up and increase their magnitude significantly in neutral conductor (see Figure 3).

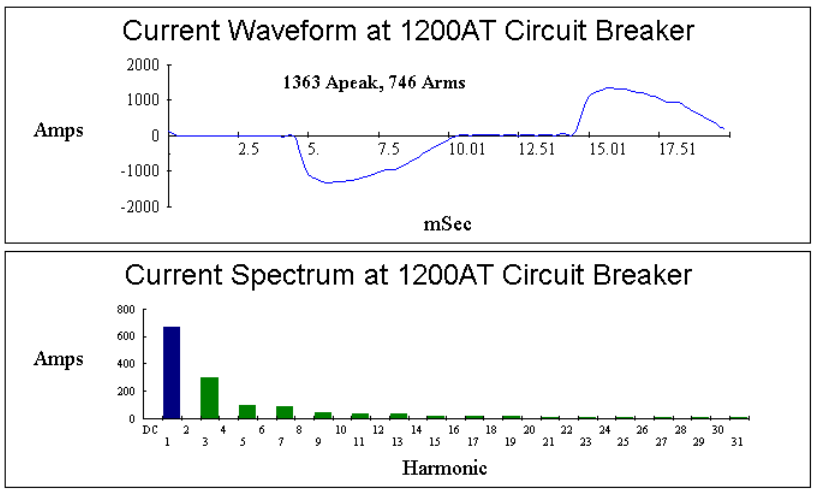

Figure 2: Current waveform and harmonic spectrum of dimmer circuit

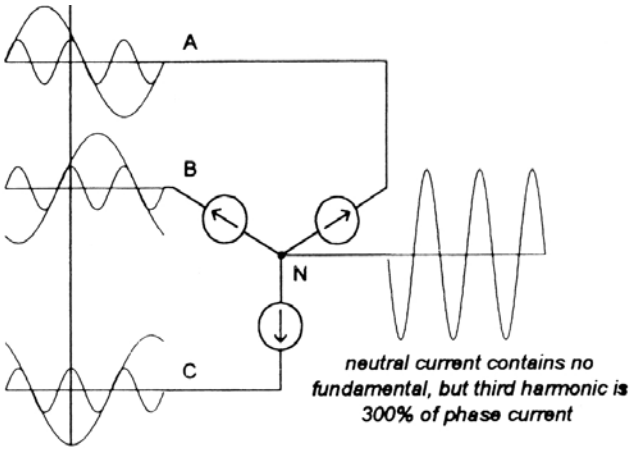

Figure 3: The summation of third harmonic current in neutral conductor

2.2 The operation of earth fault protection system

In this case, the operation of earth fault protection system uses the concept of total current summation of 3 line currents and neutral current (see Figure 4). In normal operating condition (no earth fault), the summation of 3 line currents and neutral current is equal to zero that mean no current flow through relay A. When earth fault occur, there is a leakage current to the ground so the current summation now is not equal to zero. That means there is some current flow through relay A depends on the magnitude of earth fault current. Earth fault protection system use this current to detect the earth fault condition.

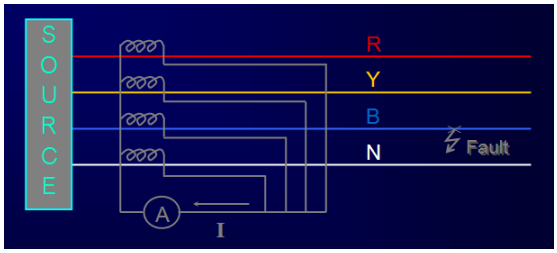

Figure 4: The diagram of earth fault protection system

However the neutral bus and ground bus in MDB are bonded together. Furthermore the neutral point of generator is also connected to ground. When supply power by generator, even in normal operating condition, if loads in each phase are not balance then there still be a current flow through neutral conductor and ground conductor (also ground loop). The magnitude of this current depends on degree of load unbalance in each phase. Normally, in three phase power system, degree of load unbalance is rather small. So this normal operating ground current magnitude is not quite high. The operation setting of earth fault relay must concern this ground current and set the tripping current at some value higher than zero to avoid the nuisance trip in normal operating condition. In this case, they set the tripping current at 20% of full load current of generator which is 600 A. That is why there is no nuisance generator circuit breaker trip when dimmer load (which can cause more current flow in ground conductor) does not operate.

3. Current Flow Analysis

In order to analyze the cause of nuisance circuit breaker trip, the current flow analysis is implemented in 3 situations. All 3 situations are analyzed in case of power is supplied by generator since this problem occur when load receive power from generator only.

3.1 Flow of normal load current (50 Hz)

If normal load current (50 Hz) is balance in each phase, there is no current flow back to the generator via neutral conductor. But if normal load current is unbalance, there is some current flow back to the generator via neutral conductor also in ground conductor and ground loop (see Figure 5). This ground current can cause the total summation current that earth fault relay detect not equal to zero and lead to incorrectly detect earth fault event. However current setting of earth fault relay is 600 A. That mean total summation current magnitude must be greater than 600 A then relay will operate. So in normal operation which degree of unbalance is not quite high, earth fault relay still not operate and there is no nuisance circuit breaker trip event since the total summation current is less than operation setting of relay.

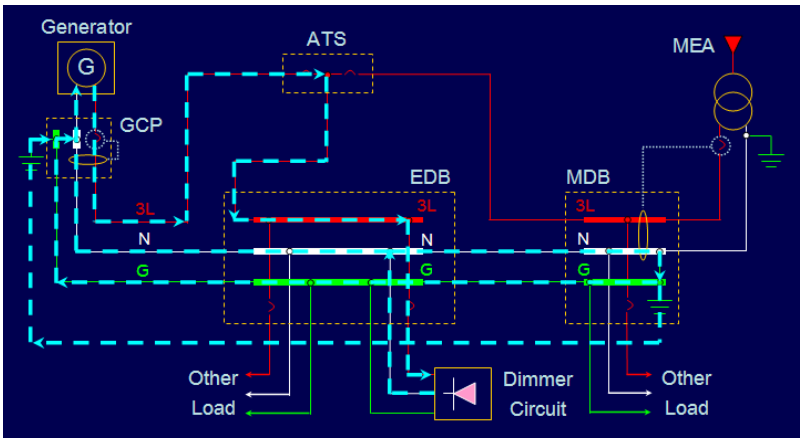

Figure 5: Flow of normal load current (50 Hz) diagram

3.2 Flow of earth fault current

When earth fault occur, earth fault current will flow back to the neutral point of generator via several path. The highest magnitude current will flow in lowest impedance path. Almost earth fault current will flow back to generator at ground connection point in GCP since this is the lowest impedance path. Anyway there is some earth fault current flow back to generator through ground connection point at MDB, ground conductor and neutral conductor (see Figure 6).

Since almost earth fault current will flow back to generator at ground connection point in GCP, so there is just small earth fault current flow back through neutral conductor. Earth fault relay can detect a high magnitude of total summation current which exceeds the operation setting of relay and command the generator circuit breaker to trip out for protecting the generator. This is a correct operation of earth fault protection system.

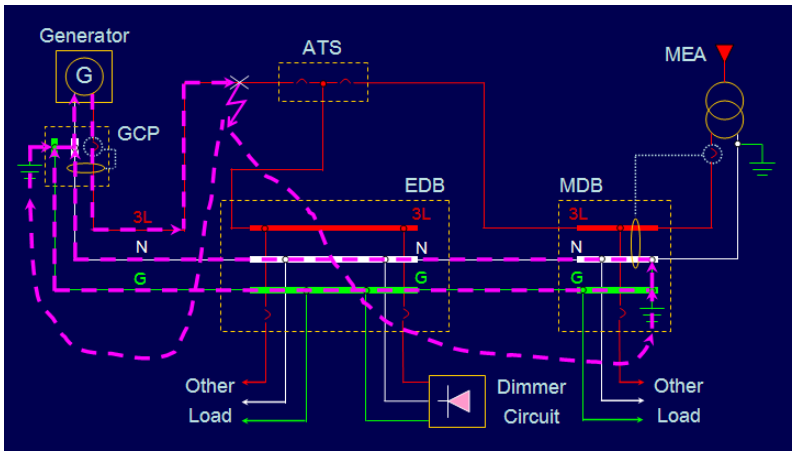

Figure 6: Flow of earth fault current diagram

3.3 Flow of third harmonic current

Concerning the flow of harmonic current, we can consider harmonic producing load (dimmer) as a harmonic current source. Dimmers generate a high quantity of third harmonic current which is the zero sequence component. Almost of this current will flow out from line conductor of dimmer circuit through the lowest impedance path (in this case is generator). When each third harmonic current in 3 line conductors reach the neutral point of generator, they will not cancel each other but sum up together and increase their magnitude significantly. This third harmonic current tries to return to the source which is the neutral point of dimmer circuit via several paths. These paths are neutral conductor, ground conductor and ground loop (see Figure 7).

The quantity of ground conductor and ground loop current increase significantly causing the total summation current exceed the operation setting of relay. So earth fault relay misunderstand and command circuit breaker to trip out.

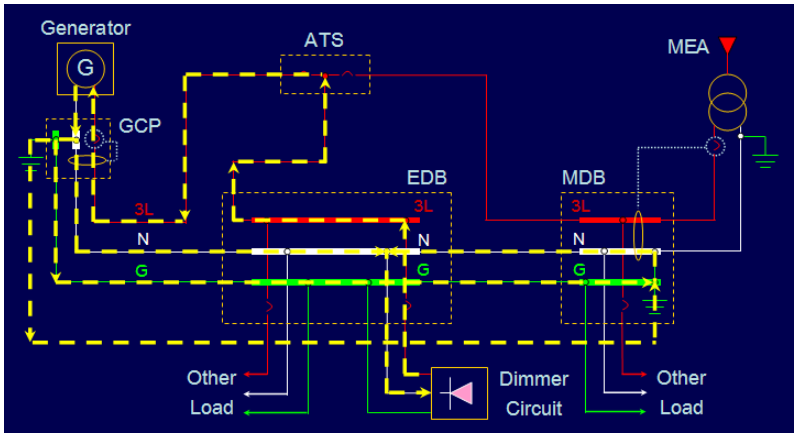

Figure 7: Flow of third harmonic current diagram

4. Analysis Result Conclusion

The nuisance generator circuit breaker trips, when dimmer loads operate, are caused by third harmonic current. This current, which is generated by dimmer, does not cancel each other but sum up together causing a significantly higher current flow in neutral conductor, ground conductor and ground loop. And this higher ground current cause the total summation current, which earth fault relay detects, exceeds the operation setting of relay. Thus earth fault relay incorrectly detects earth fault event and command circuit breaker to trip out.

5. Proposed Solutions

The proposed solutions for this problem can be divided into 2 categories. First solution is the reduction of third harmonic current flowing in the system. This can be implemented by using the dimmer device which specially design to reduce the harmonics or installing an additional harmonic filter nearby the dimmer circuit. The purpose of this method is to limit the third harmonic current from the dimmers not to flow to the other part of the system that can cause the problem to earth fault relay.

The other solution focuses on the control of normal load current (50 Hz) and third harmonic current in ground path. This can be done by blocking the current path in ground conductor and ground loop by changing the current ATS (3 poles type) to the new one (4 poles ATS). This implementation is for control normal load current (50 Hz) and third harmonic current flowing to generator through neutral conductor between GCP and EDB only. These currents can not flow to generator via ground connection point in GCP. Only earth fault current can flow back to the generator via ground connection point in GCP and can not flow back through neutral conductor between GCP and EDB (see more detail in part 5.2).

5.1 Installing third harmonic filter

This third harmonic filter should be installed in EDB nearby dimmer circuit. Harmonic filter normally consists of inductor and capacitor connected in series. The impedance of each inductor and capacitor must be equal at harmonic frequency which wants to filter. In this case, the total impedance of harmonic filter is very low for third harmonic current (see Figure 8). Thus almost third harmonic current from dimmer circuit will circulate inside harmonic filter and not flow through other part of power system. The ground path currents do not increase by the addition third harmonic current from dimmer and no adverse effect occur to earth fault protection relay.

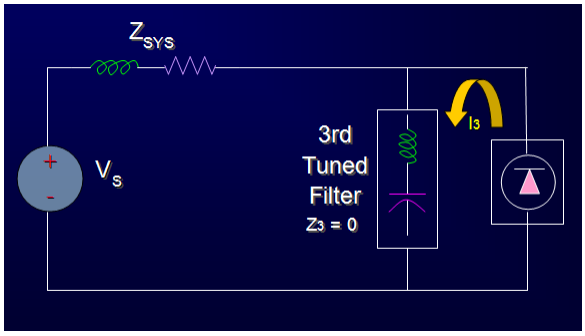

Figure 8: Third harmonic filter diagram

5.2 Installing 4 poles automatic transfer switch

The current ATS is 3 poles type which has only 3 phase switches (not include switch for neutral). This type of ATS can not separate neutral system between utility side and generator size. On the other hand, 4 poles ATS has 3 phase switches and also include switch for neutral so it can perfectly separate neutral system between utility and generator side (see Figure 9).

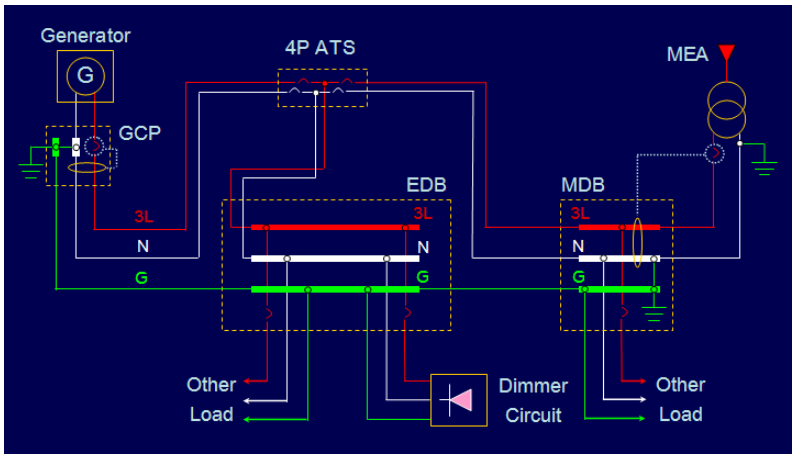

Figure 9: Wiring diagram of 4 poles ATS

To analyze the effect of 4 poles ATS in blocking normal load current and third harmonic current in ground path, we again separate the analysis into 3 parts which are 1) normal load current flow 2) earth fault current flow and 3) third harmonic current flow as followings.

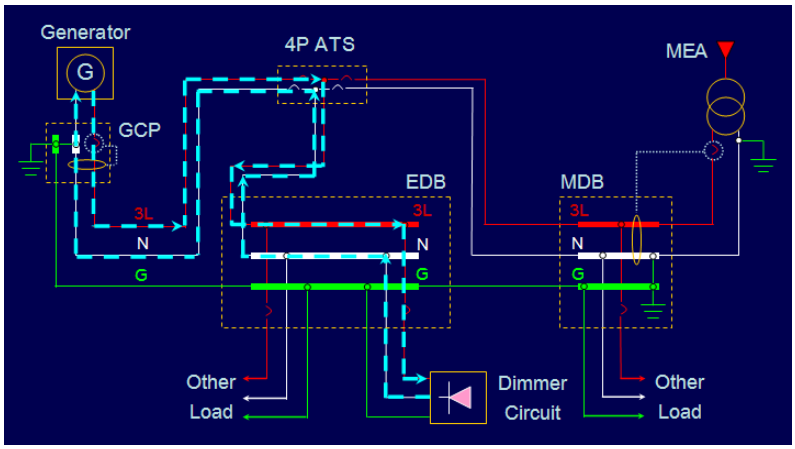

Figure 10: Effect of 4 poles ATS to the flow of normal load current (50 Hz)

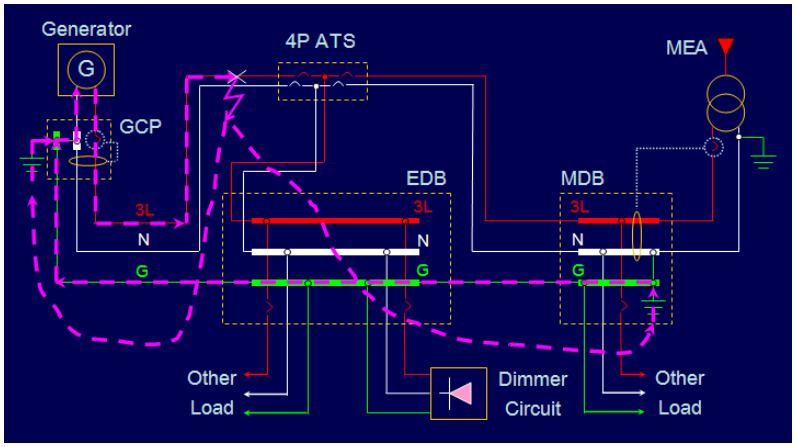

Figure 11: Effect of 4 poles ATS to the flow of earth fault current

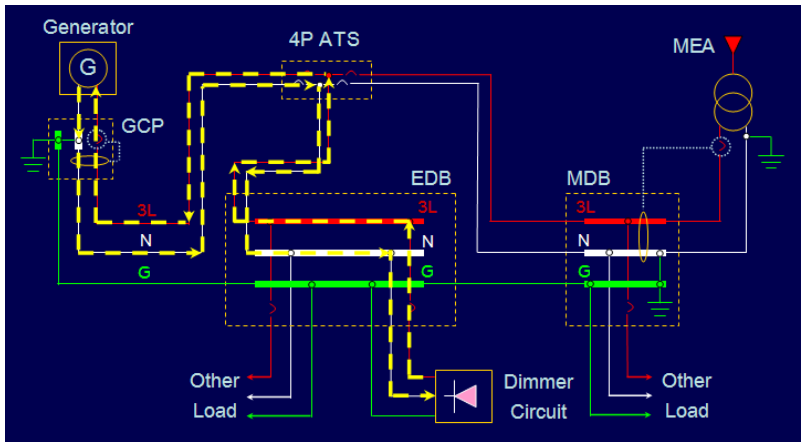

Figure 12: Effect of 4 poles ATS to the flow of third harmonic current

In case of normal load current (50 Hz), 4 poles ATS can block this current from flowing back to generator through ground conductor and ground loop (see Figure 10). This implementation can also increase the sensitivity in earth fault detection of earth fault relay. The normal load current (50 Hz) can not disturb the operation of earth fault relay even though there are unbalanced loads in the system.

In case of earth fault current, 4 poles ATS can block this current from flowing back to generator through neutral conductor. All of earth fault current can only flow back to generator via ground loop and ground

conductor (see Figure 11). So the earth fault relay can detect a high quantity of total summation current and command circuit breaker to trip out quickly.

In case of third harmonic current, 4 poles ATS can also block this current from flowing in ground conductor and ground loop. The third harmonic current can only flow in line conductor and neutral conductor (see Figure 12). Nevertheless how much third harmonic current from dimmer flowing in the system, this current can not disturb the operation of earth fault relay. Since the total summation current which relay detect still not change.

6. Conclusions

The change of dimmer device to the new one which is specially designed to reduce harmonic emission can mitigate the disturbance occurring to the earth fault protection system. Moreover, this method also reduces the losses and other problems due to the flow of harmonic current in power system.

Installing harmonic filter is another solution. Anyway special care must be concerned for this implementation because of filter overload from future harmonic load and additional harmonic current from neighborhood.

For 4 poles ATS solution, not only the misoperation of earth fault relay can be solved, it can also improve the sensitivity of earth fault relay. However the space and modification of present installation must be concerned for installing the new ATS.

Finally, the most suitable solution must concerns the total cost of owner and economic aspect. This also needs the furthermore investigation.

References

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