Protective Relays with Individual Breaker CT Inputs Help Detect Ring Bus Loose Connection Problems

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Abstract: This paper presents and discusses the benefits of connecting individual breaker CT inputs into the protective relays in a ring bus configuration. A real life case study of identifying loose or high impedance connections on a breaker disconnect in a ring bus configuration is presented. Furthermore, this paper also proposes a simple and novel ring bus open phase detection technique to prevent potentially expensive damage and outage to the high voltage equipment.

Keywords Ring Bus Configuration, Individual Breaker CT input, CT, Split Core CT, Loose Connection, Open Phase Detection

1. INTRODUCTION

1.1 The Ring Bus Configuration

The ring bus system configuration is widely used in power system switching stations. Figure 1 shows a typical ring bus configuration of a typical switching station with four power system elements, in this case with two transformer banks and two transmission lines.

Loose connections or open phases on the ring bus can be left undetected if not given special consideration. The loose connections or open phases can lead to substantial high voltage station equipment damage due to thermal or arcing affects and may cause major system outage if left undetected.

1.2 Relay Connection for the Ring Bus Configuration

Traditionally, due to the limitation of available current inputs of the relays, currents from any terminal's two breakers in the ring bus configuration were combined (paralleled) before they were connected to the relay as shown in Figure 2. With this CT arrangement, the relay would not have the ability to detect an open ring configuration (one breaker open) from the currents, nor can it detect any open or stuck phase(s) or loose connection on the buswork.

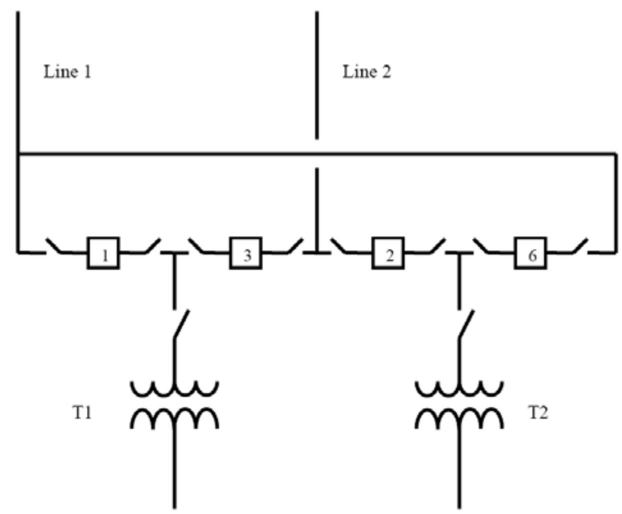

Figure 1, Ring Bus Configuration

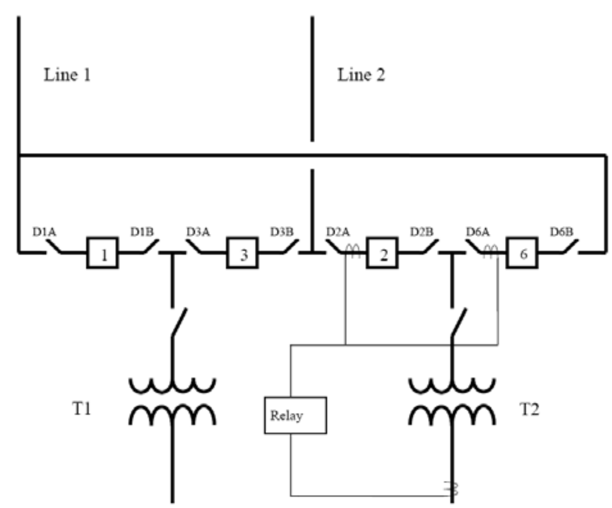

Figure 2, Conventional CT Arrangement for Transformer Protection

In modern microprocessor based protective relays, most relay manufacturers can provide multiple current inputs for both line and transformer relays. Therefore, it is now possible to connect the relay with the CT arrangement shown in Figure 3.

One obvious advantage of connecting individual CT inputs to the relay is that breaker failure protection can be implemented from within the element protection relays without the need to install separate breaker failure relays. Additionally, with this CT arrangement, an open phase(s) or loose connection on the ring bus can be identified through examination of the relay records and through custom programmed current logic functions. Furthermore, a simple technique can be implemented to generate an alarm to warn the system operators when a loose connection is present on the buswork, hence prevent possible major high voltage equipment damage and outage.

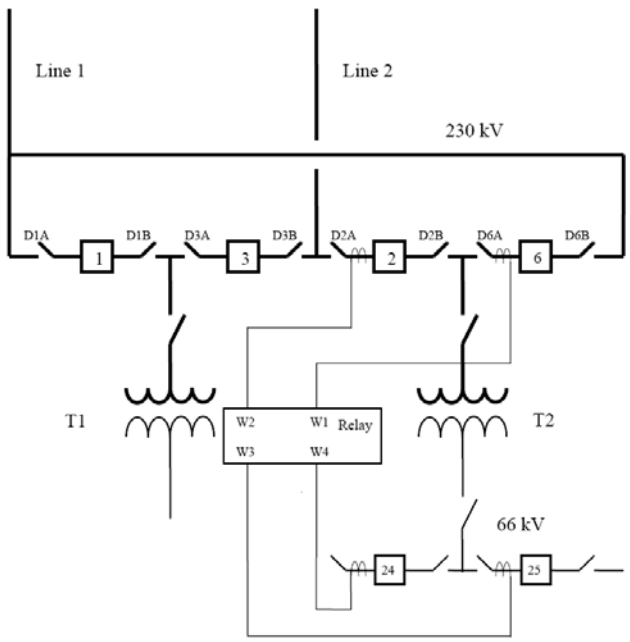

Figure 3, Individual Breaker CT Input Arrangement

2. A REAL LIFE CASE INVESTIGATION AND STUDY

In the process of the final commissioning checks of a new transformer bank and its associated protective relays, a loose connection of a breaker disconnect was unexpectedly identified through the analysis of the relay recordings. This was possible due to the fact that individual CT inputs were brought into the relays. This loose connection could have been left unidentified, developed into a more severe problem, caused more equipment damage and resulted in more significant power system outage.

2.1 The Problem

As shown in Figure 3, a new 230/66 kV transformer T2 and its associated breakers and disconnects had been installed at one of Manitoba Hydro's substations. One of the relays for this transformer protection is a four current input transformer differential protection relay connected as shown in Figure 3.

As part of the commissioning tests, the transformer current circuits were checked individually by opening each ring breaker and ensuring that the relay received the correct balanced currents. These tests and all of the other usual tests had passed, thus allowing the transformer to be placed into service.

Prior to analyzing the relay recordings, we had no reason to suspect that there was any problem since transformer load metering was correct and the relay was not showing any differential operating current.

As a final check, with the system fully intact, the technician triggered a recording in one of the differential protection packages to confirm that a previously identified CT connection problem had been corrected. Upon inspection of this record, we immediately realized that something was not right. It was observed that one of the current inputs showed significant unbalance (zero sequence and negative sequence) and the other breaker current input had only one phase current. Figure 4 is the record that shows the current waveforms. This diagram shows the three phase currents of all four windings: W1, W2, W3 and W4, which correspond to current sources from breakers 6, 2, 25 and 24 respectively.

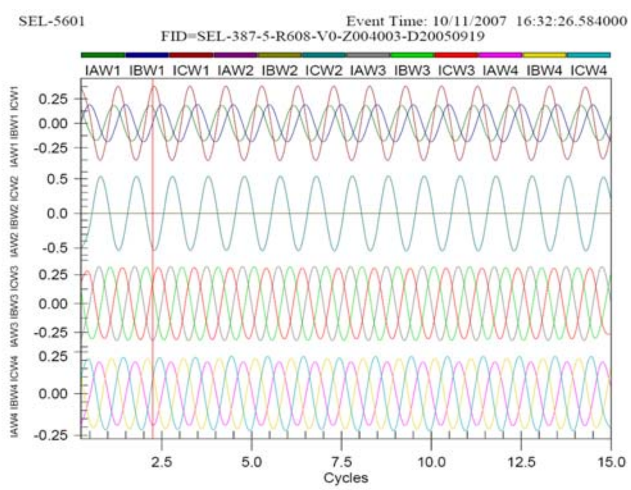

Figure 4, Breaker Current Waveforms, Ring Closed

Notice that the currents in both breaker 24 (W4) and 25 (W3) from the Low Voltage (66 kV) side of the transformer are well balanced, indicating that the loading of the transformer itself is also balanced. However, on the High Voltage side, the C phase current of breaker 6 (W1) is much higher than the other two phases. Meanwhile, on breaker 2 (W2) only C phase current is present and it is 180° out of phase with C phase current of breaker 6.

2.2 The Analysis

Upon closer examination of these waveforms, we initially suspected that there may still be an incorrect CT connection to the relay because of a connection error that had been identified and addressed earlier in commissioning. To confirm (or rule out) any problem with the CT connections, we asked the system operators to open the high voltage side breakers one at a time. Figure 5 and Figure 6 show the current waveforms with 230kV breakers R6 and R2 opened and closed alternately, leaving only one 230kV breaker closed at a time.

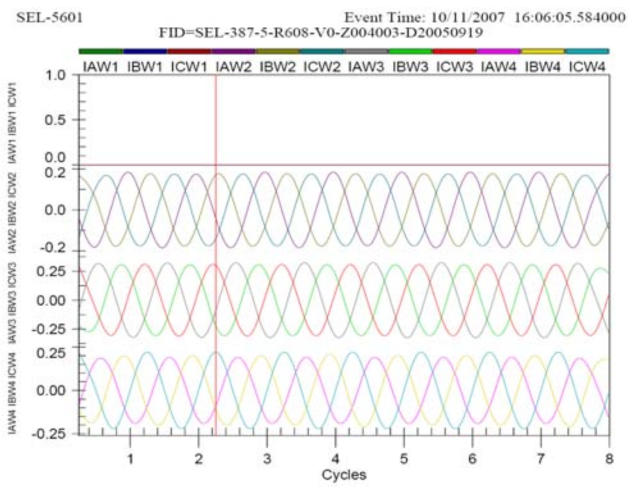

Figure 5, Breaker 6 Open, Breaker 2 Close

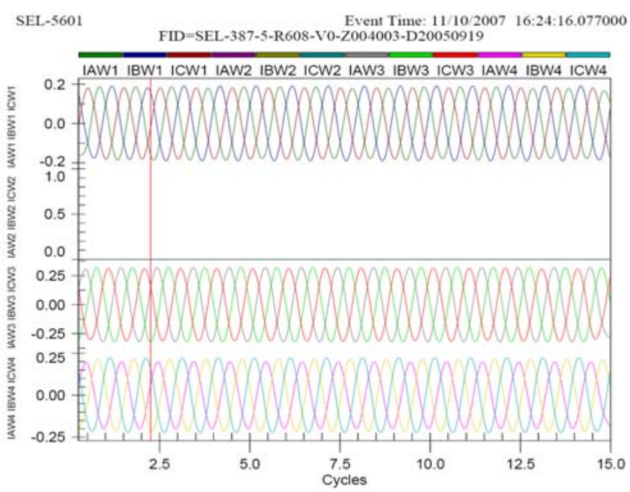

Figure 6, Breaker 2 Open, Breaker 6 Close

The open breaker tests confirmed that there was no problem with the relay setup, or CT connections since the three phase currents were balanced and the currents from high and low voltage sides of the transformer were matched. This led us to believe that the problem must be somewhere in the primary connections.

From Figure 4, it appears that there was a two phase open condition on breaker 2 since there was no measured A and B phase current. However, why did the current waveform not show any problem when breaker 6 was open?

We then suspected that there must be a loose (high impedance) connection on both A and B phases of the primary equipment associated with breaker 2. This can be explained as follows:

In a simplified hypothetical three phase diagram shown in Figure 7, with one source and one load, if the ring bus connection is healthy we assume a fairly even current split of current in the two breakers. Then we would see balanced three phase current of 20A going through each breaker, for a total of 40A going into the transformer.

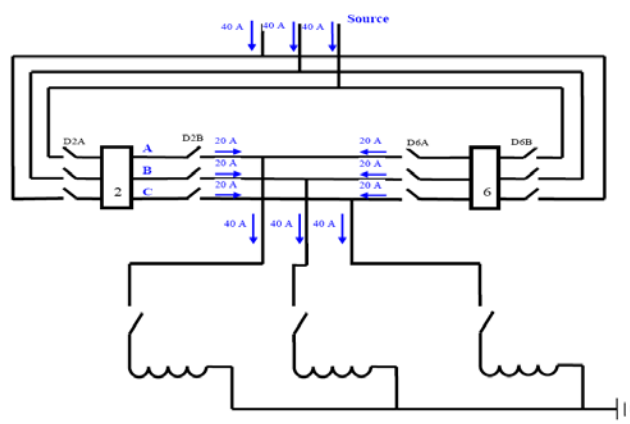

Figure 7, Current Distribution When Ring Bus is Healthy

If the ring bus is not healthy as shown in Figure 8, similar to our case where breaker 2 has loose connections on both A and B phases; all of the A and B phase current will take the "path of least resistance" through breaker 6. This was exactly as shown in the current waveforms of Figure 4. Note that the current going into the transformer HV side is the same whether the ring bus is healthy or not.

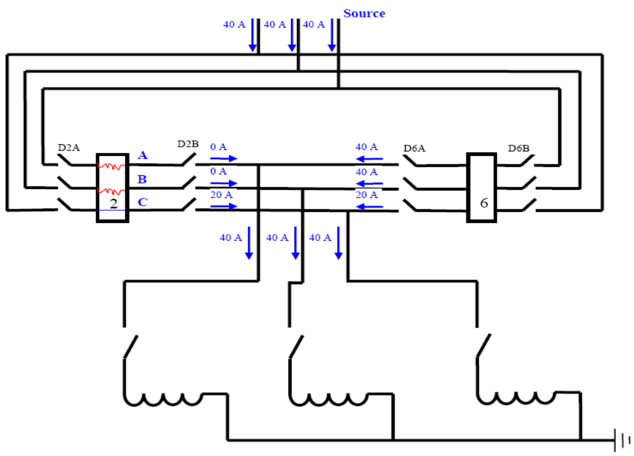

Figure 8, Current Distribution When Ring Bus Has Loose Connections

Also note that the unbalance current (consider the zero sequence current), merely circulates in the ring and appears equally in all breakers. This is true as long as the ring has at least one phase intact and there are not multiple open points on any of the other phase(s).

2.3 The Findings

With the preliminary conclusion that there was a loose connection on both A and B phase on the ring bus section associated with breaker 2, we requested the maintenance personnel carry out a Thermography Inspection of the ring bus. They used an infrared camera to scan the bus section to locate any hot spots, hence determine if there is any loose connection. Figure 9 shows a sample picture of a Thermography Inspection. The hot spot indicates that there is a loose or high impedance connection.

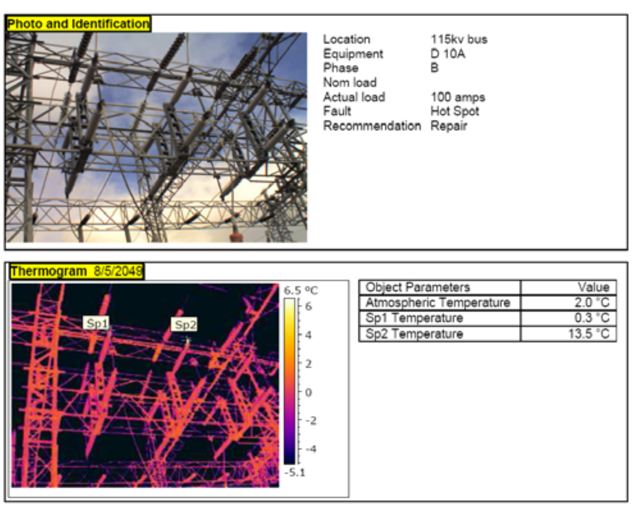

Figure 9, Sample Picture of a Thermography Inspection

In this particular case, after the Thermography Inspection, the maintenance personnel quickly located two hot spots on the bus section and upon further investigation they found out that there were loose bolts on the connecting plate of the breaker disconnect D2B. Figure 10 is a picture that shows that damage to the bolt and the plate due to the loose connection.

Figure 10 Damage to the Connector Due to Loose Connection

After the two loose connecting plates were replaced and the system was placed back into service, the current waveforms look perfectly normal again as shown in Figure 11. Problem solved!

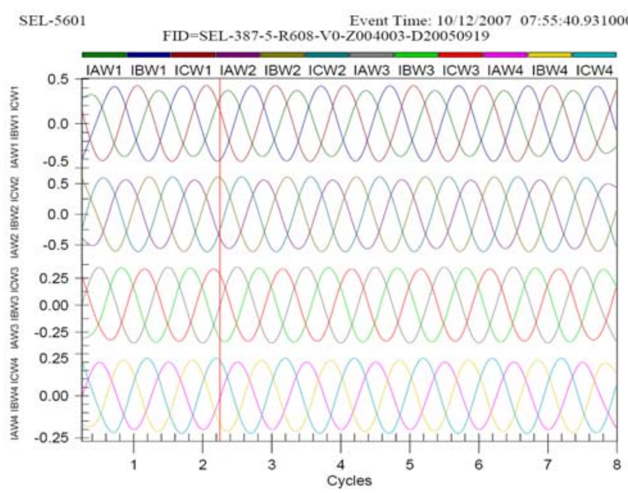

Figure 11-Breaker Current Waveforms after Problem Fixed, Ring Closed

2.4 The Conclusion

Loose connections or open phases on the ring bus can occur at any time and may be left undetected unless given special design consideration such as we have detailed here, or unless someone carefully reviews and analyzes the current waveforms on a routine basis. The load reading on the transformer would appear to be perfectly normal. If the CT connection is implemented in the traditional way, as shown in Figure 2, no relay information can provide any indication that there is a loose connection or open phase on the ring bus.

The individual CT inputs connected into the relays make it possible to indentify loose connections or open phases on the ring bus configuration through examination of the breaker current waveforms or sequence components.

3. RING BUS OPEN PHASE DETECTION TECHNIQUE

In recent years, a few other incidents similar to the above case have occurred in the Manitoba Hydro system. In a couple of cases, the open phase condition was not identified and it is presumed that it may have been in that state for a long time. The problem was only found when a second open point was created in the ring bus by opening another breaker in the ring and the element subsequently tripped by protective relays due to the presence of unbalance current.

As a specific example, a few years ago, in the process of clearing one of the two transformer banks in one of our substations as shown in Figure 12, the other bank tripped. This resulted in a major extended power outage to all the customers connected to the 66 kV lines from this substation.

It was later found out that one phase of breaker 4 had been open and undetected for an indeterminate time. As soon as the ring bus was opened by breakers 1 or 8, which were opened to clear bank 1, the unbalance current could no longer circulate in the ring and was forced to go through breaker 4. The unbalance current going through bank 2 neutral was high enough to cause the neutral overcurrent relay connected to the 230 kV neutral of transformer bank 2 to operate and trip the bank.

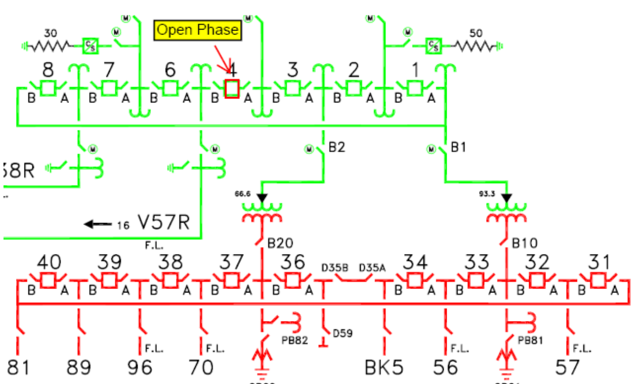

Figure 12 - Another Station Where Open Phase Occurred

3.1 The "Ring Bus Open Phase Detector" Technique

To provide some early warning for open phase in the ring bus configuration, we have implemented a "Ring Bus Open Phase Detector" technique at a few stations where individual breaker CT inputs to the relays or disturbance fault recorders (DFR) are available.

In the DFR, this technique uses an inexpensive "Split Core" CT clamped around the secondary three-phase conductors of an individual ring bus breaker CT circuit. This "Split Core" CT current is connected to a station DFR where a trigger threshold and alarm contact are configured. If there is any unbalance current circulating in the ring, it will appear equally in all breakers, so we only need to measure the current in one breaker. When unbalance current is detected, the recorder will send an alarm to the system operators indicating there is a suspected loose connection or open phase condition in the ring bus.

Figure 13 shows the arrangement of this technique and Figure 14 shows an actual installation.

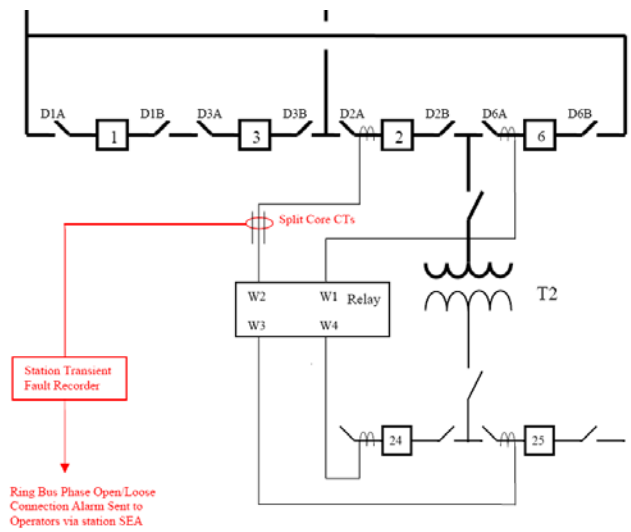

Figure 13 - Ring Bus Open Phase Detection Arrangement

Figure 14 - An Actual Installation of Open Phase Detection

This technique has since helped in the early detection of open phase and loose connections in some cases before more severe damage to the bus work had developed.

3.2 Benefits of the “Ring Bus Open Phase Detector” Technique

This technique offers the following benefits:

- **Inexpensive**
  If a transient fault recorder is already at the station and if it contains a spare channel, only a single split core CT is required (approximate cost is $150). Added to this cost would be the cost of running a 2 conductor cable to the location of the nearest un-summated breaker CT secondary along with labour costs.
- **Non-Intrusiv**e
  This arrangement is non-intrusive in nature since the Split Core CT does not need to "break into" any current circuits; no outages are required to make the connections.
- **Easy to Implement**
  The configuration of the recorder is straight forward and there is not much study required to set the threshold. Generally a minimal setting of 0.25A to 0.5A secondary should be sufficient to detect a problem in the ring, yet not operate for normal unbalance conditions which should be very small. Selecting CTs with the lowest ratio if possible is preferable to achieve maximum sensitivity, but this is generally not imperative. A time delay of 2 - 5 seconds should be used to ensure the alarm doesn't operate for transient fault conditions.
- **Can provide an advance alarm to System Operators**
  If the alarm is active, the Operators can have technicians investigate and resolve the problem before severe damage occurs and before they risk a forced outage by opening the ring.
- **Split Core CT can be run a long distance from the recorder**
  For this application, 1000 meter run between the Split Core and transient fault recorder would not be a problem. Usually we would not be looking at a distance of more than a few hundred feet.
- **It detects 3 types of ring problems:**
  Three types of ring problems can be detected; Open Phase, Stuck Phase or High Resistance connected Phase.
- **Works on Grounded (Wye) or Ungrounded (Delta) busses**
  The technique can be easily implemented on grounded (wye) or ungrounded (delta) busses

3.3 Limitation of the “Ring Bus Open Phase Detector” Technique

This technique has the following limitations:

- The detector cannot detect problems with a defective breaker which is at a balance point (i.e. if the problematic breaker normally contains only a small amount of current due to the equal transfer of current from sources to loads on either side of it.) However, in this case the alarm may appear intermittently coincidentally with load shifts in the ring.
- The detector cannot pinpoint the location of the defective high resistance point since the unbalance occurs equally in all of the ring breakers. A technician must measure the currents in each phase of every breaker's CT secondary to pinpoint the problem (i.e., find the CT with one or two phases of zero current.).
- Since it is necessary to clamp the CT on one breaker only and CTs are often summated in zone boxes in the switchyard, we may sometimes require several hundred feet of cable (prefer two-conductor, shielded, twisted) to access a single breaker's current.
- The actual high resistance point will usually be invisible to the human eye so an infrared scanner is usually necessary to pinpoint the exact "hot spot". The problem can be inside the breaker or at any of its surrounding buswork.

4. CONCLUSIONS

1. One obvious advantage of connecting individual CT inputs into the relay is that breaker failure protection can be implemented from within the element protection relays without the need to install separate breaker failure relays.
2. Protective relays with individual CT inputs provide the possibility of early detection of loose connections or open phases on the ring bus configuration.
3. Loose connections or open phases on the ring bus can be left undetected if not given special consideration. The loose connections or open phases can lead to substantial primary station equipment damage and cause major system outage.
4. A simple and inexpensive technique proposed in this paper can detect loose connections or open phase condition in the ring bus and provide an alarm to the system operators before further equipment damage is materialized.