Protection Scheme for the HK Electric's New 132kV and 22kV Busbar Configurations

C.W. Chiu † and K.W. Yeung *

Abstract – New 132kV and 22kV GIS / Insulated busbar configurations will be adopted for HK Electric’s MRS Substation. Unit busbar protection is used to ensure prompt and discriminative isolation of the faulty busbar and to minimize the supply interruption to customers. Traditional high impedance differential protection is applied as main protection for the busbars of the new 132kV and 22kV busbar configurations because it is simple, reliable and well-proven in HK Electric. This paper describes a non-conventional design of the busbar protection system for the new 132kV busbar configuration with an aim to enhancing the protection availability while maintaining adequate selectivity and discrimination. For the new 22kV busbar configuration, special features like feeder common overcurrent and earth fault (OCEF) protection, rough balanced back-up OCEF protection and cross-tripping of bus-interconnector circuits are introduced to minimize the impact of abnormal conditions such as protection / circuit breaker failure during fault in the 22kV system.

Keywords: Unit busbar protection, High impedance differential protection, Feeder common OCEF protection, Rough balanced feeder / Busbar backup OCEF protection, Cross-tripping of bus-interconnector

1. INTRODUCTION

The Hongkong Electric Co., Ltd. (HEC) generates electricity at Lamma Power Station on Lamma Island and transmits the electricity from Lamma Island to various parts of Ap Lei Chau Island and Hong Kong Island where the load centres reside. The voltage levels of the transmission networks are 275kV and 132kV. At primary zone substations, i.e. the load centres, the transmission voltage is stepped down to 11kV or 22kV for feeding the distribution networks nearby.

Electricity is then distributed from the primary zone substations to over 3,600 distribution substations on Hong Kong Island, Ap Lei Chau Island and Lamma Island through the 11kV and 22kV distribution networks. Although the majority of HEC’s distribution system is supplied at 11kV level, it has been HEC’s intention to migrate some load from 11kV system to the 22kV system progressively [5], [6]. In this connection, new zone substations are designed to distribute electricity at 22kV level.

To cope with the load growth in the Central and Wan Chai areas, following the commissioning of the new MRS 275kV Switching Station in 2008, a new 132kV switching station and a new 275/22kV zone substation are required to be put into service in the Wan Chai area in 2010. Due to scarcity of land, the two new substations are housed together with the MRS 275kV Switching Station in a multi-storey building.

To further enhance HEC’s supply reliability, new GIS / Insulated busbar configurations with fault tolerant capability [1] are adopted at the new 132kV switching station and 275/22kV zone substation. The following
sections describe the protection schemes to be used at these two new substations with new busbar configurations.

2. MRS 132KV SWITCHING STATION

The new MRS 132kV Switching Station injects power to the existing 132kV transmission network in Wan Chai area so as to relieve the load congestion in adjacent areas. Due to the crucial role and special location of this switching station, it was decided to adopt a design with higher fault tolerant capability for the 132kV busbar configuration and the associated busbar protection.

2.1 MRS 132KV GIS BUSBAR CONFIGURATION

MRS 132kV Switching Station comprises a 6-busbar GIS with 20 bays (viz. 12 outgoing circuits, 2 275/132kV interbus transformer circuits, 4 bus-sections and 2 bus-couplers) in double-busbar configuration as shown in Fig. 1.

![Fig. 1. MRS 132kV Busbar Configuration.](image)

In HEC's existing 132kV switching stations, GIS with separate isolators and earth switches have been adopted with proven reliability and performance. During the market search inquiry for the supply of MRS 132kV GIS, it was found that most GIS manufacturers only offered 3-position switches (Fig. 2), which integrate an isolator with an earth switch, as their standard products in the 145kV class GIS.

![Fig. 2. 3-position Switch Adopted in MRS 132kV Switching Station.](image)

The reliability of the busbar isolator has always been a concern for GIS with double-busbar configuration because a single busbar isolator fault may lead to the loss of two busbars, or half of the substation load for a 4-busbar GIS. It was decided in the design stage to take a prudent approach in adopting a 6-busbar design for MRS 132kV Switching Station. Any busbar isolator fault in this new GIS configuration will at most affect 1/3 of the substation.

2.2 BUSBAR PROTECTION FOR MRS 132KV GIS

In HEC system, fully duplicated busbar protection systems of different operating principles with fault clearance time within 0.14s are employed as a standard arrangement in transmission substations to clear a busbar fault. The burn through time of 0.5s is stipulated for the GIS because of the following considerations:

i. For the best dependability, a 132kV GIS is usually protected by two independent busbar protection systems (namely the 1st and 2nd Busbar Protection), each comprising check zone and discrimination zone protections. Tripping of a busbar will be initiated by a busbar protection system if both its check zone and discrimination zone protections detect a busbar fault.

ii. In case there is a mismatch in status between the main and auxiliary contacts of a busbar isolator, the discrimination zone protections of the two busbar protection systems for the respective busbar may be disabled by the CT supervision scheme and as a result both busbar protection systems will become inoperative.

iii. Under such circumstances, the busbar fault has to be cleared by Distance Zone 2 Backup Protection with operating time of around 0.4s at the remote ends. As a result, the faulty GIS may be burnt through by the fault energy even though the busbar fault is successfully cleared by the backup protection.

The burn through time requirement of HEC’s existing 132kV GIS and related specification in IEC62271-203 “High-voltage switchgear and controlgear – Part 203: Gas-insulated metal-enclosed switchgear for rated voltages above 52kV” are summarized below:
HEC Requirement for Existing GIS

<table>
<thead>
<tr>
<th>Requirement extracted from IEC62271-203:</th>
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<tbody>
<tr>
<td><strong>Standard requirement</strong></td>
</tr>
<tr>
<td><strong>Rated short circuit current</strong></td>
</tr>
<tr>
<td><strong>Protection start</strong></td>
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<tr>
<td><strong>Duration of current</strong></td>
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<tr>
<td><strong>Performance criteria</strong></td>
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<tr>
<td>&lt; 40kA r.m.s.</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>0.2s</td>
</tr>
<tr>
<td>No external effect other than the operation of suitable pressure relief device.</td>
</tr>
<tr>
<td>≥ 40kA r.m.s.</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>0.1s</td>
</tr>
<tr>
<td>No external effect other than the operation of suitable pressure relief device.</td>
</tr>
<tr>
<td>≥ 40kA r.m.s.</td>
</tr>
<tr>
<td>2</td>
</tr>
<tr>
<td>≥ 0.3s</td>
</tr>
<tr>
<td>No fragmentation (burn-through is acceptable)</td>
</tr>
</tbody>
</table>

The enclosure should be able to withstand, without burning through, an internal arc fault of 40kA r.m.s. of not less than 0.5s.

However, most European suppliers can only provide GIS in accordance with the IEC requirements. In order to ensure that at least one of the busbar protection systems can operate within 0.14s under all circumstances so that the standard IEC requirement of 0.3s can be adopted in the new system, the following design of the 2nd Busbar Protection system using high impedance differential principle is adopted:

i. Installing additional check zone protections so that each pair of main and reserve busbars will have its own check zone protection, instead of one check zone for the whole GIS. This will require additional check zone CTs on the bus-section circuits but the overall size and capacity of the 132kV GIS are not affected.

ii. Modifying the trip logic so that the check zone protection alone can initiate the busbar tripping to clear the busbar fault if the discrimination zone protection is locked out, say due to a mismatch between the status of the main and auxiliary contacts of a busbar isolator.

iii. Modifying the trip logic so that the discrimination zone protection alone can initiate the busbar tripping to clear the busbar fault if the check zone protection is locked out, say due to open circuit of check zone CT wiring.

Under the new design, the availability of the 2nd Busbar Protection system will be improved although its security may not be as good as the conventional design. However, it will be acceptable from system viewpoints because with the adoption of the 6-busbar design, at most one pair of main and reserve busbars (i.e. about one third of the circuits) will be tripped should the check zone protection operate under the above-mentioned scenario; on the other hand, four busbars will still remain in service.

### 3. MRS 275/22kV Zone Substation

The new MRS 275/22kV Zone Substation which is directly fed from MRS 275kV Switching Station steps down the system voltage from 275kV to 22kV to supply the 22kV distribution network in Wan Chai area. Similar to MRS 132kV Switching Station, most manufacturers only offer 3-position switches as their standard products in 22kV class GIS. Therefore, the reliability of the busbar isolator is also a concern to 22kV GIS since a busbar isolator fault will lead to tripping of the respective busbar causing significant supply interruption to the customers.

In order to achieve world class electricity supply [2], typical 22kV closed-ring network [3], [4] similar to other 22kV zone substations in HEC is adopted in principle with enhancement on the 22kV busbar configuration to allow better fault tolerant capability. Details of the protection schemes for the new busbar configuration are described in the following sections.

#### 3.1 MRS 22kV Busbar Configuration

MRS Zone Substation is equipped with 4 x 50MVA 275/22kV zone transformers. To improve the fault tolerant capability of the zone substation, the 22kV winding of each zone transformer is connected to two 22kV busbars via separate incomer cables. As a result, in total there will be eight 22kV busbars which are connected in ring configuration via bus-interconnector cables. The rating of the 22kV busbars, incomer cables and bus-interconnector cables is 1250A. Fig. 3 shows the simplified 22kV busbar configuration of MRS Zone Substation.

![Fig. 3. MRS 22kV Busbar Configuration.](image-url)

Normal-open (N/O) points will be arranged on appropriate bus-interconnectors so that two zone transformers are normally operated in parallel. When one zone transformer is switched out, the remaining three will be connected in parallel by rearranging the N/O points so that no zone transformer will be left operating alone.

With the new busbar configuration, should a 22kV busbar (say Busbar 1) trip upon busbar / switchgear fault, the zone transformer (say Tx 1) connecting to the faulty busbar can still output power through another busbar (say Busbar 2) seamlessly. Supply interruption to customers

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due to 22kV busbar fault can be avoided, if the two source ends of a closed-ring feeder pair are connected to the two busbars being fed by the same zone transformer.

It should be noted that connecting the two ends of the closed-ring feeders to different transformers should be avoided because unwanted load transfer current from one busbar to another may flow in the closed-ring feeders under certain busbar configurations with possible overload of the feeder cables. In addition, extreme care should be exercised during busbar reconfiguration and / or parallel switching of 22kV feeders to avoid parallel operation of multiple Z/Tx’s through the additional interconnections amongst busbars / substations in order to contain the 22kV fault level to the fault rating of primary equipment.

3.2 22KV FAULT LEVEL

3.2.1 22kV 3-Phase Fault

22kV 3-phase fault level largely depends on the zone transformer impedance and the number of zone transformers operating in parallel. Besides, the 22kV fault level will also be affected by the system voltage, zone transformer tap position and cable length to the fault point. For safety reason, the 22kV system fault level must not exceed the 22kV switchgear’s short-time withstand capability and fault breaking capacity (i.e. 25kA).

To meet the system operation requirement, the impedance of the 275/22kV zone transformer at MRS Zone Substation is carefully selected in the design stage so that the maximum 22kV fault level will not exceed the 22kV switchgear’s fault rating even when three zone transformers are connected in parallel. In addition, the advanced Distribution Management System (DMS) in HEC’s System Control Centre will continuously monitor the fault level of the distribution network.

On the other hand, the minimum 22kV fault level may occur if a zone transformer is in single operation which is very unlikely during normal operation mode. Protection systems shall be designed to cater for all possible busbar configurations at the whole range of system fault levels from the minimum up to the maximum value of 25kA.

Due to the high X/R ratio of the zone transformer impedance, the 22kV circuit breakers (CB) may need to break large 3-phase fault current with strong DC component, if high speed protection is employed to protect 22kV switchgear fault which is close to the zone transformer. To ensure that the 22kV CB will not be damaged during breaking of the maximum fault current of 25kA with high DC level, high speed unit protection (e.g. high impedance differential busbar unit protection) is intentionally delayed by some tens of milliseconds. For calculation of the appropriate CB opening time, please refer to IEC62271-100 (previously IEC60056) “High-voltage switchgear and controlgear – Part 100: Alternating-current circuit-breakers”.

3.2.2 22kV Single-Phase-To-Earth Fault

As the 22kV windings of the zone transformer are delta-connected, a zig-zag connection earthing transformer connecting in series with a neutral earth resistor is installed on the 22kV side of each zone transformer to allow single-phase fault current to flow; otherwise, the earth fault protection may not be able to detect an earth fault in the 22kV system effectively. The combined impedance value of the earthing transformer and neutral earth resistor is so selected that the earth fault current should be kept below the full load current of the zone transformer while it should be sufficiently large to drive the protection systems to operate firmly. In addition, this earthing design ensures that any 22kV single-phase-to-earth fault in the system shall not cause a voltage dip in the LV supply to customers exceeding 10% (i.e. voltage retained ≥90%).

It is worth mentioning that most of the 22kV primary live conductors (except those in the gas tank of GIS) are screened by earthed layer. Should they be interfered with or the insulation break down, a 22kV single-phase-to-earth instead of phase fault is most likely to occur. With such design, voltage dip caused by most 22kV fault, i.e. single-phase-to-earth faults, will have little impact (i.e. ≤10% voltage dip) to the LV customers.

3.3 PROTECTION ARRANGEMENT

Protection arrangement for MRS 275/22kV Zone Substation is illustrated in Fig. 4 and detailed design is described in the following sections.

![Fig. 4. Protection Arrangement at MRS Zone Substation.](image-url)
3.3.1 22kV Busbar Protection

In HEC’s traditional zone substations, an 11kV or 22kV busbar is protected by rough balanced OCEF protection (i.e. detecting the summation of all in-feed currents of a busbar) and backed up by respective OCEF protection on bus-interconnector and transformer incomer circuits. Fault discrimination is achieved by time grading with upstream and downstream protections. Such protection arrangement is simple and effective for single 11kV busbar with open-ring feeders or 22kV busbar with closed-ring feeders connecting to the same busbar.

For the new busbar arrangement at MRS Zone Substation, fault current may be contributed not only from the transformer incomer and bus-interconnector circuits, but also from the feeder circuits. Therefore, rough balanced busbar OCEF protection may not be able to provide satisfactory fault discrimination due to the additional interconnections between busbars through the feeder circuits. To ensure that only the faulty busbar is isolated upon a 22kV busbar fault with other healthy circuits remaining stable, high impedance differential unit busbar protection is added as main protection while the rough balanced busbar OCEF protection is still used as a backup protection.

As mentioned in Section 3.2.1, the high impedance differential unit busbar protection should be properly delayed so that the DC component in the fault current will not exceed the maximum allowable level at the time of CB opening. Duplicated delay timer relays are employed to improve the protection reliability.

To mitigate the impact of bus-interconnector CB failure during busbar fault or blind spot fault on interconnector circuit, both ends of the associated bus-interconnectors will be tripped at the same time upon busbar protection operation. In addition, for rough balanced busbar protection, to mitigate the impact of possible grading problems with zone transformers 22kV OCEF protection due to prolonged busbar fault clearance caused by feeder CB failure or abnormal fault current distribution in the interconnectors and feeders, cross-tripping of outer bus-interconnectors (e.g. B/I 2-3 and B/I 8-1 for Busbar 1 or Busbar 2 in Fig. 3) is required such that the zone transformer connecting to the faulty busbar will be separated from other healthy transformers immediately after operation of the rough balanced busbar protection. With such cross-tripping arrangement, should any grading problem exist, only the zone transformer connecting to the faulty busbar will be lost without affecting other transformer(s) in parallel.

3.3.2 22kV Bus-Interconnector Circuit

Like other 22kV zone substations in HEC, it may be required to connect the eight 22kV busbars in closed-ring configuration during contingency conditions. Proper time grading may not be achievable should a fault occur in the 22kV interconnector cable during busbar closed-ring operation as the current distribution in the ring may be uneven. Similar to other 22kV zone substations, unit protection is adopted for 22kV bus-interconnector circuit to ensure that only the faulty bus-interconnector will be isolated while other healthy circuits should remain stable under busbar closed-ring operation. Bus-interconnector OCEF protection is still used as a backup protection.

In the event of CB failure during bus-interconnector fault, the fault will be cleared by backup OCEF protection on outer bus-interconnectors and zone transformer incomer circuit with longer fault clearance time.

3.3.3 22kV Transformer Incomer Circuit

Similar to other HEC’s zone substations, standard transformer main protection and backup protection are employed to protect the zone transformer. In the event of incomer cable fault, transformer unit protection should see the fault and trip the 275kV source CB and both 22kV incomer CB’s.

In the event of incomer CB failure during transformer fault, the fault may still be fed from other zone transformer(s) via the 22kV busbar after tripping of the 275kV CB. The fault will then be cleared by backup OCEF protection on outer bus-interconnectors and zone transformer incomer circuit with longer fault clearance time.

In the event of incomer CB failure during 22kV busbar fault, the fault may still be fed from the zone transformer after tripping of the 22kV busbar. The uncleared fault will then be cleared by the transformer backup OCEF protection with longer fault clearance time.

3.3.4 22kV Closed-Ring Feeder Circuit

It is HEC’s current practice to arrange the 22kV feeders in closed-ring configuration and install unit cable protection on all 22kV cable sections along the feeder route. Therefore, in the event of 22kV cable fault in the outgoing feeder, only the faulty cable section will be isolated by the unit cable protection at the two ends of the cable section. All other parts of the feeder shall remain stable during the fault. Therefore, supply to customers will not be affected.

On the other hand, 22kV switchgear fault at distribution substation is protected by OCEF protection relays installed at zone substation feeder circuits. In addition, directional
fault indicators are installed at each distribution substation to pin-point the fault location after tripping of zone substation feeders. Therefore, supply to customers can be restored within a few minutes with the assistance of remote indications and switching.

It is worth mentioning that depending on the fault location, the fault current in a closed-ring feeder may not be evenly distributed from the two source ends. In the extreme case, over 90% of the fault current may initially be fed from one end and less than 10% from the other. After tripping of the strong source end CB at zone substation, the fault current will continue to flow from the other source end CB until it is also tripped by OCEF protection. The sequential tripping action will prolong the fault clearance time and thus may lead to grading problem with upstream protection.

To solve the possible grading problem, a common OCEF protection relay is installed for the two source end CB’s of each pair of closed-ring feeder at the zone substation. It detects the summation current of the two source end CB’s while tripping of the respective CB is guarded by an instantaneous OCEF relay on it.

4. CONCLUSION

New 132kV and 22kV busbar configurations with higher fault tolerant capability are adopted at MRS 132kV Switching Station and MRS Zone Substation respectively to render a better supply security. The paper briefly introduces the protection schemes which are designed to suit the new busbar configurations as well as to cope with the withstand capability of the switchgear to IEC62271-203 for 132kV and IEC62271-100 for 22kV. MRS 132kV Switching Station was energized successfully in early March 2010 while the commissioning of MRS 275/22kV Zone Substation is scheduled for August 2010 tentatively. As the protection schemes at MRS 132kV Switching Station and 275/22kV Zone Substation employ proven protection principles but with some improvements, it is expected that the reliability of the protection schemes will increase when compared with the conventional design at other existing substations; however, the actual protection performance will be reviewed after gaining more operating experience in the coming years.

5. ACKNOWLEDGEMENT

The authors are grateful to the senior management of The Hongkong Electric Co., Ltd. for permission to publish this paper.

6. REFERENCE


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