EXECUTIVE SUMMARY OF IAP REPORT

LTA convened the Independent Advisory Panel (IAP) for Power Supply to seek guidance and advice from specialists on the resilience of the Power Supply System for Rapid Transit System (RTS) Lines. The IAP made its assessments and recommendations based on meeting deliberations, site visits and interactions with LTA, SMRT and SBST engineering staff over a 5-day intensive programme, together with desktop assessment of the LTA's advance documents.

Deliberations of the IAP are presented in this report in accordance with the following main focus areas:

- Careful study of recent power-related disruptions to put in place comprehensive contingency plans and measures to prevent any repeat, and to ensure speedy recovery should there be a recurrence. In addition, to apply lessons learnt across to other RTS lines where relevant.
- Assessment of the resilience of the power supply system.
- Identification of potential gaps and their mitigating measures in the design, operations and maintenance of the power supply system.
- Determine the timing for the next power supply system upgrade.

The IAP made the following main observations regarding the power supply system:

1. The power supply system has achieved a high availability rate close to or exceeding the designed availability rate. While high availability is important, the power system performance should be assessed using resilience metrics of foresight, robustness and rapid recovery. Availability alone is insufficient to provide a holistic view of the performance of the system as a whole, and other established industry reliability indices should be used to facilitate performance tracking and benchmarking against other jurisdictions.

2. Equipment failure within the power supply system has largely been confined within the DC power supply system, in particular DC switchboards, DC power cables and third rail. These and other critical high-risk parts of the RTS require additional maintenance attention. The specifications of such equipment must allow for their use in the harsh local operating conditions such as heavy rainfall and water ingress, high temperatures and humidity, lightning, and damage from oil and termites. As hazards from the environment and those resulting from equipment failure/damage cannot be completely eliminated, operating and maintenance efforts will need to ensure that incidents are kept to as low as reasonably practicable.

3. System interdependencies with adjoining systems (trackways, rolling stock, signalling and upstream power grid supply) require the (designed) activation of power trips for personnel safety and equipment protection. Power can only be turned on after isolation, bypass or rectification of faults. Such power outages affect train operations as trains currently do not have alternative means of traction power. Rules governing the operation of interfaces between adjoining systems can delay the rapid recovery from power outage.

4. Optimal (unconstrained) system design should provide for 0-5mins and <20mins recovery from outage to prevent the propagation of knock-on effects that can cause severe disruption to train services. This may not be realisable in the near term, but should be a design intent or consideration for future lines and in the upgrade of existing lines.

5. Effective maintenance is challenged by the diversity of systems, technology levels and equipment types; as well as by the competing demands of efficiency and thoroughness given the limited maintenance hours available.

Whilst the IAP found many areas of good practice, there are areas where improvements are required. The IAP focused its recommendations on enhancing the resilience of power supply system in three aspects without compromising safety:

- **Foresight** – the ability to anticipate, prevent, mitigate potential problems. The IAP noted that measures to improve anticipatory capabilities and adaptability are being introduced in existing lines and are part of the requirements for newer lines.
- **Robustness** – the ability to absorb disruptions without sacrificing system performance, or to suffer graceful degradation while performing recovery actions. The IAP is of the view that the RTS is reasonably robust. However significant improvements can still be made especially in the identification and management of system interdependencies and mitigating their impact on train operations.
- **Rapid Recovery** – the ability to restore full system performance before this results in a high impact event. It also encompasses the resourcefulness of the operators in the event of an incident. The IAP is of the view that rapid recovery is a critical area for improvement.

The recommendations of the Panel are provided in the report and are organised under three categories:

1. Those that require immediate/ near-term attention.
2. Those that require longer term attention.
3. Those that should be considered and requiring further study.

The IAP recommendations that require immediate / near-term attention are presented below in this executive summary.

IAP RECOMMENDATIONS REQUIRING IMMEDIATE / NEAR-TERM ATTENTION

1. Operation and Maintenance, Asset Replacement

a) Inspect equipment planned for replacement more frequently. Inspect DC cables, 3rd rail and 3rd rail insulators every 6 months until these assets are replaced. If necessary, implement interim measures to mitigate further deterioration.

b) Consider the criticality of the component to revenue service when planning for asset replacement. Mission critical systems within 5 years of their specified lifespans should be considered for replacement. Reliability-Centred Maintenance (including FMECA) practices are to be comprehensively implemented.

c) Apply equipment specifications and codes of practices in the context of Singapore's unique operating environment. These requirements have to be in addition to existing international standards and codes of practice.

d) Replace MM74 DC switchgears due to weak trip coil and trip rod.

e) Conduct detailed operational risk assessments to facilitate the decision on ZX1 AC switchgears replacement at an appropriate LTA/SBST forum.

f) Allow in-house certification and authorisation of qualified operator personnel to perform electrical switching and isolation. This will also in rapid fault recovery in the event of incidence.

g) Conduct exercises to prove the adequacy of operational response measures and recovery plans in the event of a potential recurrence of previous power-related incidents. In particular, given the severe system-wide impact of the 7 July 2015 incident, the IAP considers that it would be important to consider the conduct of a mock exercise in a simulated live operating environment (conducted after revenue hours with traction power on and trains running) to affirm and validate the readiness and effectiveness of contingency measures and the readiness of equipment and personnel.

h) Review the touch voltage protection scheme and its existing settings until its replacement by voltage-limiting devices with intelligent and fault locating functions as the existing touch voltage protection tripping scheme during a future component failure can result in a repeat of the 7th July 2015 incident.

2. Lessons Learnt from Past Incidents

a) Examine all incident recovery measures in various failure scenarios to improve system recovery time as much as possible. Recovery measures are to be streamlined across all system boundaries.

b) Conduct root cause analysis on faults and apply lesson learnt to modify or replace unreliable equipment.

c) Create sub-categories to further classify faults currently under "Other" category in fault database.

d) Establish a 'trouble-shooting' knowledge database to assist in fault diagnosis during incidents.

e) For future new line roll-out, put in place measures to ensure tighter specification and quality control on the contractors and manufacturers. This is because of CCL DC cable failures, despite being a new installation, the traction cables failed and caused tripping, resulting in train disruption.

3. Introducing New Technologies

a) Establish intelligent fault identification system (iFIS) to pinpoint exact fault location, especially for the DC system.

b) Establish condition monitoring for early fault detection/prevention. Pre-emptive capabilities enhance resiliency and therefore should also be considered for retrofit implementation into existing older lines.

Recommendation:

- Online partial discharge monitoring for high voltage equipment, e.g. transformer and switchgears
- Online condition monitoring of high voltage cables.
- Online condition monitoring of traction cables.
- Online monitoring of running rail voltage with respect to earth.
- Online monitoring of UPS batteries banks health condition

c) Explore more extensive usage of energy storage to ride through voltage dips or maintain interim power supply during changeover when there is a loss of an RTS line's main intake power supply from power grid.

d) Install online real-time thermal imaging equipment in substations to check on the thermal profile of the switchgear, transformers, cables and power electronic converters. Currently, periodic thermal imaging using portable setup has been proven useful for condition monitoring.

4. Improve the 22KV AC System

a) Enable automatic switchover to alternative 66kV power supply intake, in the event of a loss of primary 66kV intake. (subject to further discussion with EMA/SPPG)

b) As far as possible, design a 22kV cable bottom entry termination to the transformers to eliminate the risk of working at height.

c) Ensure the installation of all indicators, instruments and name plate of transformers is at visible and convenient locations for easy maintenance checks.

d) Position drain valve of transformer away from any obstruction.

e) Review the NEL AC protection study.

f) Install 22kV GIS plugs at the rear of the switchboard to facilitate easy access to the cable ends, therefore cable insulation resistance tests can be easily conducted at the switch room. Carrying out of insulation resistance test at the cable chamber for the TWE Siemen gears is not recommended for future installations.

g) Provide pilot wire relay supervision to monitor the mal-function of the relay by OCC for future lines and asset replacement.

h) Adopt removable plug and socket 22kV cable terminations for GIS to fixed cable terminations (to permit access to cable ends for insulation resistance tests).

i) Equip Voltage Transformers (VT) of the 22kV cables with a switch for isolation and to facilitate easier carrying out of insulation tests of the cables.

5. 750V DC System

a) Install cables instead of bus duct between transformer (RT) and rectifier as well as between rectifier and DC switchboard, and between inverter transformer, inverter and DC switchboard.

b) Design the bus-bar and cable shutter in the switchboard with separate shutters that can be individually locked instead of one single shutter to ensure staff safety.

c) Review and identify a protection system that does not have wide spread traction power tripping when triggered unlike the 64P touch voltage protection.

d) Monitor and control depot traction system function should also be conducted by Operation Control Center (OCC), in addition to Depot Control Center (DCC).

e) Study the feasibility of using DC shielded cables. Existing DC cables health status could not be exhaustively checked by insulation resistance tests as there is no cable shield to serve as reference.

f) Co-ordinate feeder breakers protection relay with downstream equipment E.g. Trains CCD fuse should be such that the fuses interrupt the fault instead of the feeder breakers.

g) Design the train CCD that could be lowered by just a single command from the train drive cabin by the train operator when faulty train prevents the tripped traction breakers to close due to failed line test measurement.

h) Install disconnector switch between the DC switchgear and the 3rd rail.

i) Explore energy storage at the 750V DC switchboard for emergency traction power, besides wider use of UPS functions at 400V AC for service loads.

Glossary (provided by LTA)

Term	Full name
CCD	Current Collector Device
EMA/SPPG	Energy Market Authority/ SingaporePower PowerGrid Limited
FMECA	Failure Mode Effect and Cost Analysis
GIS	Gas Insulated Switchgear
OCC	Operations Control Centre
RT	Rectifier Transformer
RTS	Rapid Transit System
UPS	Uninterrupted Power Supply