The need of enhancing the quality and performance of the distribution network is ever increasing. This poses various challenges before the utility in terms of improving reliability and availability of the network, reducing life-cycle costs, reducing the losses and most importantly enhancing the safety and use of eco-friendly technologies.

Medium Voltage (MV) switchgear forms the backbone of the distribution network. A reliable and efficient MV switchgear system translates to a high quality distribution network. The reliability and efficiency of the MV switchgear can be addressed firstly in the design and later on during the operation & maintenance phase.

This paper describes a few case studies at Tata Power and the corrective actions taken in terms of change in design and change in maintenance practices.

Index Terms—MV Switchgear, Condition Monitoring, Retrofitting & Refurbishment

I. INTRODUCTION

The medium voltage (MV) switchgear is the critical component of distribution network and its failure may have a significant impact on power supply reliability to the end consumer. Though a lot of stress is given in designing and thereafter maintaining the switchgear for achieving the highest level of reliability, the measures are not adequate to prevent failures. The failures can be attributed to both inadequate design or more often due to inadequacy of the maintenance practices which fail to prevent and detect mechanical and electrical problems that lead to failures.

Increasing load densities is also putting a lot of pressure on the existing aging MV switchgear infrastructure. Solutions have to cater to often conflicting requirements of maintaining high reliability and availability while keeping the costs low and achieve highest levels of safety. With the space constraints in the existing Receiving Stations, retrofitting and refurbishment actions offer a feasible solution to enhance the life of the existing switchgear without adversely affecting the supply to the connected consumers. It is experienced that refurbishment actions has its own weak links in terms of operational flexibility, rating and requires special attention in terms of safety aspects & integration.

The paper describes a few of the occurrence on the MV switchgear, analysis of the root causes and corrective and preventive action taken thereafter to avoid the failures or mitigate the effects of failures.

II. TATA POWER’S PRACTICES FOR IMPROVING RELIABILITY OF MV SWITCHGEAR:

A. Design Practices

The design practice adopted by Tata Power is to achieve a techno-commercial optimal solution while fulfilling the following objectives:

- Reduce equipment failure
- Reduce the risk of operator error
- Reduce the risk of injuries to O&M personnel
- Reduce the maintenance effort
- Reduce the size / space requirement
- Compliance to Standards

Modern day switchgear have modular design with compartments. This enables faster isolation of the faulty compartment and also the scalability by enabling flexibility of expansion of the panels. In case of a fault, the damage is limited within the faulty compartment and hence down time is greatly reduced.

Compartment doors and barrier plates are designed to withstand pressure surge due to internal arcing. To determine the degree of protection that the switchgear provides to personnel and equipment in close proximity to the switchgear, internal arcs are initiated at specific locations inside the various switchgear compartments and area around the switchgear is monitored.
The design incorporates a pressure relief vent to direct hot gases and molten particles away from the operating personnel to protect the operator from injury and limit damage to equipment. Features like racking in/out the circuit breaker with doors closed and completely segregated low voltage compartment provide added safety.

The equipment also incorporates on-line monitoring facilities for Load Current (Overload and Under-current limits set on SCADA System), SF6 Pressure, Trip Circuit healthiness, spring charging etc. Breaker Monitoring Systems are connected to frequently operated breaker like breaker controlling capacitor banks for monitoring and trending of Load Current, Timings, Coil Currents and velocity. Numerical relays provide disturbance records for fault analysis and information about trip counters and \( I^2t \) that can be used as inputs for Condition Based Maintenance.

### B. Condition Monitoring & Maintenance Practices

Tata Power till recently followed a periodic maintenance schedule for the MV switchgear. The maintenance frequency was decided on the type of technology. More recently, there is a shift towards Condition Based Maintenance approach. The need to optimize manpower utilisation and maximise equipment availability are the main drivers for extending maintenance intervals for MV switchgear. This means greater reliance on condition monitoring techniques, particularly on on-line systems to provide information on the condition of assets. Information on trip counters, \( I^2t \) and breaker operation counter from the numerical protection relays and the SCADA system is used for scheduling maintenance on the switchgear. Majority of failures on the MV switchgear has been observed on the circuit breakers and hence special attention has to be given to its monitoring. A ‘Breaker Monitoring System’ has been developed which records and trends the breaker timings, coil currents, load current, velocity, counter etc. These are being installed on critical breaker and frequently operated breakers like transformer incomers and breakers controlling capacitor banks.

The off-line condition monitoring includes periodic visual Inspection for overheating, smoke marks, cracks on insulator, dust / moisture accumulation and foreign particles. The power circuit connections are tested for their tightness. Tests on circuit breaker such as Contact Resistance (condition of main contact); Coil pick-up voltage and current measurement; Close, Open and Trip-free time measurement; Contact Wipe measurement etc. are carried out. More recently, Dynamic Contact Resistance Measurement technique has been introduced which records the signature of the contact assembly during breaker operation and gives condition of the arcing contact. In addition to this, protection and controls test & trials are carried out. This includes relay pick-up and timing test, calibration of meters and checking of annunciations.

### C. Retrofitting and Refurbishment

The need for upgradation of the MV switchgear was felt due to the increased failure rate of the components of the switchgear that had lived its useful life, increasing fault levels, obsolescence of technology and lack of OEM support. Considering the unavailability of space for new switchgear commissioning and also taking into account factors like minimising shutdown time to the existing customers and quick restoration during emergencies; refurbishment and retrofitting was considered to be optimal solution for life enhancement and upgradation of the existing MV switchgear.

Though retrofitting solutions offer advantages like lower capital costs, lower time for retrofitting, use of existing cabling and terminations etc., there are also certain disadvantages. The main demerit is that the type tests conducted by manufacturers on their original switchgear are not valid for retrofitted cubicles. The suppliers of the new breaker and other equipment restrict their scope to type tests & routine tests conducted only on their equipment and not on the complete switchgear as a whole. Also, since the retrofitting is done at site, special attention needs to be paid in terms of assembly, integration and alignment.

III. CASE STUDIES

**Case Study – 1**

Occurrence: A feeder breaker was taken out for performing condition monitoring tests. The wires for timing test was connected to the breaker arms and the breaker was racked in the ‘test’ position for performing the operations. The breaker flashed over while inserting in ‘test’ position.
due to the failure of the mechanical interlock and the metallic clamp of the test equipment connected to the breaker came into arcing distance of the live bus bar causing the flashover.

Corrective & Preventive action taken: Plug-in connections are specified instead of sliding finger contacts for auxiliary connections. The circuit breaker is tested in 'Isolated' position. An extension lead enables extension the auxiliary contacts and racking in the breaker is avoided.

**Case Study – 2**

Occurrence: MV Breaker failed during fault clearance causing extensive damage to doors and windows of the switchgear room

Observations & Analysis: The pressure wave caused due to the arc produced during the breaker failure could find no way to escape causing damage to door and windows

Corrective & Preventive action taken: Outlets for the pressure wave in the form of hinged louvers have been installed at various locations in the switchgear room. These louvers remain closed normally and do not allow the outside dust to enter the room. In case a pressure wave is caused due to electrical arc, the pressure is released through these louvers, thus preventing damage to the switchgear room and also injury to the operating personnel present in the room.

**Case Study – 3**

Occurrence: A flashover occurred in Breaker compartment of a feeder which was charged and was carrying no current.

Observations & Analysis: The space heater in the breaker compartment was found to be defective. The matter was referred to the OEM. After analysis it was recommended by the OEM that to avoid condensation in the breaker compartment, the breaker should carry minimum 30% of rated current. In case the current was less than 30%, it was mandatory for the space heater to be in service. As the load current was zero in this case and the heater was off, there was water condensation in the compartment which resulted in flashover.

Corrective & Preventive action taken: Taking into consideration criticality of space heater healthiness, heater current monitoring circuit was introduced. A relay monitors the space heater current continuously and contact of the relay is connected for annunciation.

**Case Study – 4**

Occurrence: 22KV, 2500A Vacuum Circuit Breaker which had been retrofitted failed during service.

Observations & Analysis: It was suspected that the current carrying part of the breaker was getting overheated while carrying the nominal load current. It was decided to carry out heat run test on a similar breaker at Manufacturer’s works. Heat run test was carried out with breaker outside the cubicle (in open air) by passing rated current of 2500A through the breaker. The temperature rise in the current carrying path was measured by means of thermocouples and with thermovision camera.

The maximum temperature reached was 117 degC on connector assembly at the bottom of the vacuum bottle. The allowable end temperature according to IEC 600694 and...
62271-100 is 115 degC (i.e. 75 degC rise over an ambient of 40 degC). The OEM informed that the breaker rating was guaranteed only with breaker in open air conditions and the rating of the breaker inside the retrofitted switchgear cubicle needs to be derated by about 20%.

Conclusions: The breaker failure was attributed to overheating during normal load service as the temperature rise was more than allowable limits during heat run test. To prevent overheating with breaker inside the cubicle, a derating factor of 20% has to be applied. Thermal scanning can be effective predictive method especially for feeders that carry more than 70-75% of the breaker / switchgear rated current.

Case Study – 5

Problem: SF6 gas leakage was observed from 11kv Ring Main Units (RMUs). Five instances of SF6 gas leakage was reported in a short span.

Observations & Analysis: It was observed that in one RMU, there is safety membrane failure and in 4 RMUs the leakages was from resin cast tank of the RMUs. The matter was taken up with manufacturer. The root cause identified was that the high temperature variation between the day and night temperature resulted in over-pressure and subsequent leakage. It was suggested by the manufacturer to reduce the working pressure from 0.8bar to 0.55bar.

Corrective Actions: The RMU was type tested at KEMA with lower SF6 pressure (@1.3bar abs.). The SF6 gas pressure on all RMUs of that particular make and type was reduced to 1.55bar abs. @ 20 deg C as suggested by the manufacturer. No leakages have been experienced since last 2-3 years.

IV. CONCLUSIONS

A great emphasis is laid on the design practices and condition monitoring practices adopted for MV switchgear as it is a critical component in the distribution network. The challenge is to adopt new methodologies to minimise the faults and also to mitigate the impact of failures.

Tata power has carried out many changes in terms of their installation and condition monitoring practices over the years based on their experience. Personnel safety is of paramount importance and safe testing methods like testing of breaker in ‘Isolated’ position have been adopted. Lot of stress has been given to design of the switchgear room and features like hinged louvers and ‘pressurised’ room ensure safety and reduce the probability of faults.

Information from numerical protection relays and SCADA systems are used for data to support Condition Based Maintenance approach. New monitoring systems like space heater monitoring, Dynamic Contact Resistance measurement, and On-line Breaker Monitoring System have been introduced recently and can be used as effective tools for extending the maintenance cycles. Thermovision scanning has limited use in metal clad MV switchgear as the infra-red rays cannot penetrate the metal sheet. But it can be effectively used during heat-run tests or when a direct line of sight to the current carrying parts is available.

Retrofitting and refurbishment of the existing switchgear offer a feasible solution for enhancement of life and uprating of the switchgear. While this approach has advantages in terms of lower capital costs and completion time, care has to be taken in terms of the safety aspects with respect to the validity of the type tests after retrofitting.