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Key Performance Index for Overall Substation Performance

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Abstract*: Performance of electrical distribution utilities depends on substations which are serving the end consumers. Consumer demands are mainly focused on the uninterrupted supply of quality power at low cost. These requirements are met by the effective and efficient operation of substations. Substations adopt various asset management strategies and effective maintenance management techniques to improve their overall performance to meet the utility level customer related targets. Focused index to measure the effectiveness these measures are required for performance monitoring and improvements. In the literature reliability based indices are proposed to measure the substation performance. These indices even though provide some insight to the overall substation condition, but do not provide the overall performance centric index depicting the operational (maintenance) effectiveness and efficiency of a substation. In this paper a new performance index called as Overall Substation Effectiveness (OSE) based on Total Productive Maintenance (TPM) and Overall Equipment Effectiveness (OEE) is presented for measuring the substation performance. OSE will provide such a data which enables the organizations to identify the opportunities for improvement in the process.

***Index Terms*: Substations, OEE, TPM, KPI.**

I. INTRODUCTION

Distribution utilities performance depends on substations which are serving the end consumers. Consumer demands are mainly focused on the uninterrupted supply of quality power at low cost. These requirements are met by the effective and efficient operation of substations. Substations adopt various asset management strategies and effective maintenance management techniques to improve their overall performance to meet the utility level customer related targets. Aggregate performance of all the substations will decide the extent of meeting the targets. In general degree of customer satisfaction is measured by number of reliability indices. In the literature many performance indices are proposed to measure the substation performance. Performance based asset management proposed by EPRI [1], indicated number of secondary or low level performance indicators based on the field level controlling parameters are required along with primary indicators which are directly related to the utility objectives.

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Reliability indices are result oriented indices based on the various actions taken for improving the performance of the substations which will in turn affect the overall reliability. Many types of performance indices are available which will measure the effectives of various strategies or actions undertaken for the improvement of substation performance [2]. The combined effect of all these indices will decide the overall effectiveness of the substation. In the literature, integrated or unified or overall index for measuring performance of a utility is reported [3] for comparing and rating the distribution utilities. Credit Rating Agency of India Limited (ICRA) explained the integrated rating methodology for power distribution utilities [4]. This methodology is based on operational and reform parameters, external parameters and financial parameters. Credit Rating Information Services of India Limited (CRISIL) proposed rating criteria for the power distribution utilities [5]. The rating criteria is based on various risk factors of the distribution utilities and they are industry risk, regulatory risk, market position and service area, economics and track record of operating efficiency. Unified index methodology based on the normalization of selected indices was reported in the literature [3]. In this method, critical reliability indices are selected and normalization is carried out with necessary weightages to arrive at a unified index. In the same way, overall performance index calculation for the substations is also required for comparing the performance of various substations and ranking of substation for quick analysis of performance results as well for suggesting the improvements or to encourage for better results [6]. In the literature not many publications are reported about the overall performance index for substations.

Substation ranking based on the past performance data was reported by Anders [6]. In this methodology, history of reliability, security and safety indices for the critical components in a substation are analyzed for ranking the substation. Finally, all the factors are combined to form a single parameter for grading the substations. In this process not only the past data, component contribution to the substation was also considered using mathematical model. Based on this model, structural importance factor and criticality importance factors were calculated using the Birnbaum's Importance measure. This method uses the past data based on the standard reliability indices which do not depict the real operational (maintenance) performance of the substation. Eskom proposed a Plant Health Index (PHI) as an overall substation performance index [7].

In this method Substation Plant Health Index model is proposed by considering critical components in a substation. Critical components are shortlisted based on their capex cost, duration
of repair times and failure rates. In the publication circuit breakers, transformers and tap changers are considered for the PHI model. For each equipment certain equipment specific tests are conducted and results are summarized by assigning the weightage for each test and score for results. Then the substation PHI is evaluated by adding up all the scores of equipment by assigning the weightage to each equipment category. Finally using the weightage to equipment, weightage to each test for equipment and the scores are added to get the substation PHI. These methods even though provide an insight to the overall substation condition, but do not provide the overall performance centric index depicting the operational (maintenance) effectiveness and efficiency of a substation. In this paper a new performance index based on Total Productive Maintenance (TPM) concept and Overall Equipment Effectiveness (OEE) is presented for measuring the overall substation effectiveness.

II. TPM AND OEE

It is a well-established fact that TPM and its principles yield significant performance improvement across multiple industries. TPM is popularly implemented in many manufacturing industries to achieve high quality products. TPM focus on the maintenance process and recognize it as a critical activity which enhances the business. TPM aims improvement at all levels of organization through the integrated effort across the organization. TPM presents a set of procedures that ensures every equipment in a manufacturing process is able to perform its designated tasks so that the production of final output of the process is uninterrupted. TPM exerts push on various fronts of the industry for continuous improvement and to meet end customer satisfaction. TPM focus on customer satisfaction, continuous process improvement, decision making based on facts, complete involvement of an employee, system integration, systematic and strategic approaches for process management, effective communication and extending the quality consciousness to third party suppliers. TPM improves the equipment performance, improved equipment availability, first-time through or FTT quality levels, reduced un-panned equipment breakdowns, increased return of investment, increase in the operator skill development and enhanced employee overall job satisfaction.

TPM can be defined as an organization wide, collective team effort to inculcate quality into the equipment and reducing the equipment breakdowns to achieve enhanced productivity levels. It is a structured and systematic continuous process on the equipment which optimize the effectiveness of production by increasing the efficiency by reducing the production losses throughout the life cycle of the product with the collective effort of team. In the literature main activities of TPM are described as 'pillars'. Widely referred model is based on Nakajima's [8] eight pillars are given below:

- Autonomous maintenance - Involvement of operator in day-to-day equipment maintenance
- Planned maintenance – Un-interrupted production
- Focused Equipment and process improvement - Solving of recurring problems
- Maintenance Prevention Pillar (MP) - Planning new equipment, to reduce maintenance expenses and deterioration losses.
- Quality Maintenance - Improvement activities to address quality issues
- Administrative TPM – Identify and eliminate unwanted administration functions
- Education and training – Operator Skill development.
- Safety and environmental Management – Improve Safety at work place.

OEE is a feedback measurement tool in the process of TPM and an effective KPI for performance measurement. OEE is very popular performance measurement tool among industries for the quantitative measure of equipment performance [9]. The degree of TPM effectiveness is measured by OEE. The equipment design characteristics, installation condition and operating procedures along with its maintenance effectiveness will affect the OEE. It indicates how effectively and efficiently the equipment is maintained. OEE is calculated based on the indicators for equipment reliability and its performance. It is a key measurement of efficiency in manufacturing processes at all levels of the product. Availability, performance and quality are the three factors whose cumulative will impact the OEE. OEE will provide such a data which enables the organizations to identify the opportunities for improvement in the process.

- OEE = Availability x Performance x Quality

Where

- Availability = Actual Production time / Planned Production time
- Performance = (Total products/operating time) / Ideal Run rate
- Quality = Good Product / Total Product

Three types of losses which are having impact on OEE are Downtime Losses, Speed Losses and Quality Losses as shown in Fig 1.

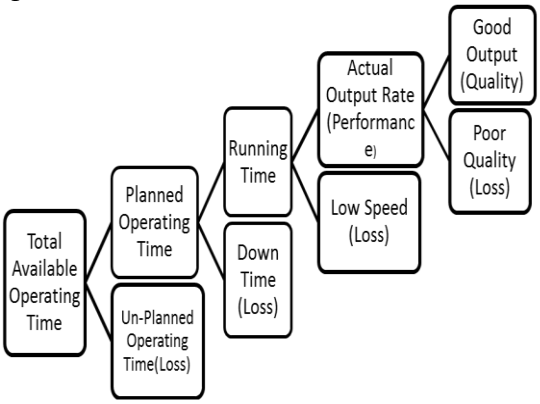

Fig. 1 OEE Components/Losses

These three types of losses are further divided into six types and they are called as Six Big Losses as shown in Fig 2. Elimination of these six losses is one of the main target of TPM/OEE.

Hence with right metrics for OEE, it will provide a very useful framework along with identification of areas for tweaking the performance. OEE will provide a quick status about the current equipment performance, at the same time it will enable to understand the effect of critical parameters on the complete process. OEE is a crisp and convenient dimensionless number which can be used to assess equipment performance in a systematic manner. OEE and TPM are popularly referred and adopted for the manufacturing industry. Application of TPM and OEE for non-manufacturing industries like service industry, process industry, etc. is reported in the literature [10] [11].

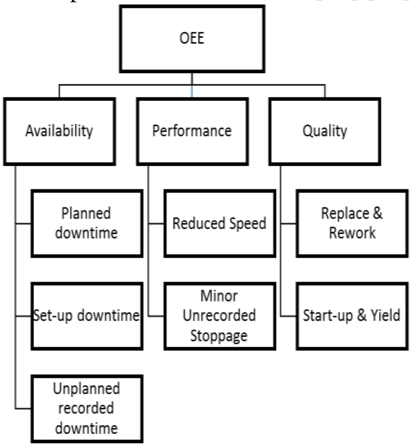

Fig. 2 Six Big Losses

In this paper focus is made on the evaluation of substation maintenance performance based on such a powerful concept. In the literature application of TQM concept for power distribution has been reported [12]. But, in this OEE is calculated based on the Loss Structure. OEE is computed based on the availability, performance rate and quality rate. The reported procedure did not provide the OEE based on the maintenance performance. In the present paper OEE approach is applied to calculate the overall substation performance and effectiveness with a focus on the maintenance management.

III. OVERALL SUBSTATION EFFECTIVENESS (OSE)

As explained above, OEE is product of availability, performance and quality. The terms are applied to a substation with clear focus on the maintenance function.

➢ Availability from manufacturing perspective =

$$\frac{\text{(Loading time} - \text{Downtime)}}{\text{Loading time}}$$

Where

Loading time = Planned time available per day (or month)

Downtime = Total time during which the system is not operating because of equipment failures,

➢ Availability from substation perspective

$$= \frac{\text{Total Substation availability}}{\text{(Total substation operating time) (Day/Month/Year)}}$$

$$= \frac{\text{Total Substation availability}}{\text{(Total Time – Incoming feeders down time)}}$$

(Day/Month/Year)

Total substation availability is calculated by considering all the connected load points along with their importance factor [13]. Substations operating time is the total time during which the downstream power is available from all incoming feeders.

➢ Performance from the manufacturing perspective

$$= \frac{\text{(Total pieces / Operating time)}}{\text{Ideal run rate}}$$

Where

Total pieces = Number of items processed per day (or month),

Operating time = loading time and downtime.

Substations operating time is the total time during which the downstream power is available from all incoming feeders.

➢ Performance from the manufacturing perspective

$$= \frac{\text{Total pieces}}{\text{Operating time}}$$

Where

Total pieces = Number of items processed per day (or month),

Operating time = loading time and downtime.

The performance in the present context is focused towards maintenance perspective. Maintenance performance mainly affects the substation downtime due to unplanned maintenance. An effective maintenance will reduce the failures thereby unplanned maintenance and increase the substation availability.

➢ Performance from the Substation maintenance perspective

$$= \frac{\text{Planned Maintenance duration}}{\text{Total maintenance duration (Month/Year)}}$$

$$= \frac{\text{Planned Maintenance duration}}{\text{Sum of Planned maintenance and un-planned maintenance duration (Month/Year)}}$$

➢ Quality from the manufacturing perspective =

$$\frac{\text{(Total pieces – Defective pieces)}}{\text{Total pieces}}$$

The defective pieces represent the number of items rejected due to quality defects.

➢ Quality from the Substation perspective

$$= \frac{\text{Total units of energy supplied to upstream}}{\text{Total units of energy received from downstream}}$$

(Month/Year)

$$= \frac{\text{Total energy supplied}}{\text{Total energy received}}$$

Hence Overall Substation Effectiveness (OSE)

= Availability x Performance x Quality

= ((Substation uptime or available Time)/ (Total substation operating time))

x ((Planned Maintenance duration)/(Total maintenance duration))

x ((Total units of energy supplied to upstream)/ (Total units of energy received from downstream)

OR

= ((Total Substation availability)/ (Total Time − Incoming feeders down time))

x ((Planned Maintenance duration)/ (Planned maintenance +Unplanned maintenance duration))

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x ((Total energy supplied)/ (Total energy received))

IV. CASE STUDY- OVERALL SUBSTATION EFFECTIVENESS (OSE)

OSE was evaluated for typical substations (4 nos.) Historical data for six years was collected OSE's were calculated and results are analyzed. OSE for Substation-1 for six years along with their corresponding A, P and E are shown in Fig. 3.

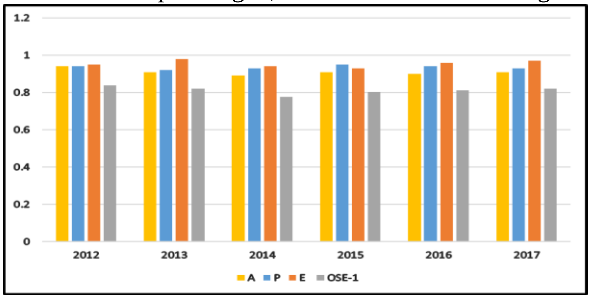

Fig. 3 OSE- Substation-1

OSE for Substation-1,2,3 and 4 for six years are shown in Fig. 4.

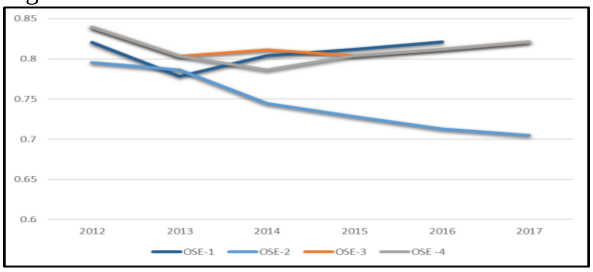

Fig. 4 OSE- Substation- 1 to 4

A. OSE Case Study – Analysis

The trend of OSE of all substations is showing steady which indicates that their overall maintenance performance is good. In case of substation-2 there is a constant declining trend, indicating that the maintenance function is to be reviewed. As a first step, which are the three factors availability, performance and quality is causing the decline in OSE as shown in Fig.5 is to be identified. Accordingly, remedial measures are to be implemented.

Availability: The trend of availability is upwards which shows that the equipment is healthy and performance of maintenance management is good.

Performance: The trend of performance is downwards which indicates that the unplanned maintenance duration is increasing. Even though availability is satisfactory, the unplanned downtimes are increasing indicating the equipment operating conditions. The operating regimes of equipment are to be verified with the manufacturer recommendations to reduce unplanned maintenance. The spares used for the maintenance are to be validated for the required duty cycle.

Efficiency: In line with the above due to more unplanned interruptions, the ratio of energy supplied and received is falling. Even though substation availability is maintained, the overall effectiveness is reducing due to the increase in the cost of energy not supplied. This will be improved by reducing the unplanned breakdowns. Hence among Availability, Performance and Efficiency, poor performance factor is the main reason for the poor OSE and is causing more unplanned breakdowns.

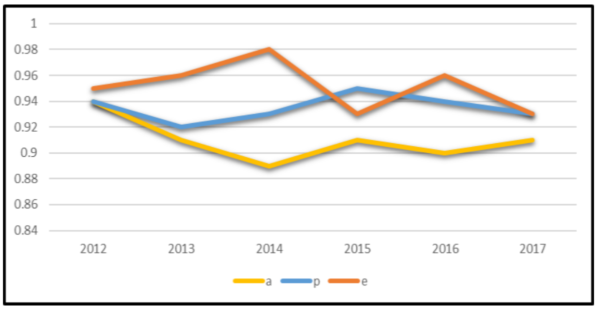

Fig. 5 OSE- Substation- 2

V. CONCLUSION

Substations adopt various asset management strategies and effective maintenance management techniques to improve their overall performance to meet the utility level customer related targets. Many types of performance indices are available which will measure the effectives of various strategies or actions undertaken for the improvement of substation performance. The combined effect of all these indices will decide the overall effectiveness of the substation. The overall performance indices reported in the literature do not provide the overall performance centric index depicting the operational (maintenance) effectiveness and efficiency of a substation. A new performance index called as Overall Substation Effectiveness (OSE) based on Total Productive Maintenance (TPM) concept and Overall Equipment Effectiveness (OEE) is presented for measuring the overall substation effectiveness. OSE is formulated as an overall performance centric index depicting the operational (maintenance) effectiveness and efficiency of a substation Case study considering the historical data of four substations has been presented.

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