INTEGRATED APPROACH FOR PLANNING AND CONTROLLING OF SUBSTATION MAINTENANCE PROGRAM

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1. Summary

Planning and scheduling of transmission substation maintenance activities represent one of the most significant stages of the maintenance program. The plan is intended to allow work to be completed using an estimated amount of time, material and manpower, taking into account all personnel and equipment safety concerns.

Effective maintenance plan integrates maintenance requirement with the network load forecast and shutdown schedules. This plan minimizes the impact of maintenance on equipment availability by reducing the equipment down time, the number of scheduled outages and equipment operation, and minimizing scheduled interruptions to customers. This plan also permit more accurate scheduling with effective utilization of resources.

Maintenance scheduling assigns resources and manpower for jobs to be accomplished, taking into consideration the operational constraints. These constraints represent transmission network behavior and maintenance resources availability along the considered calendar.

The maintenance plan objective can be met through the implementation of an integrated maintenance program that combines several maintenance approaches, such as predictive, operation-based and condition-based maintenance and failure mode and effect analysis. These approaches can eliminate the majority of unscheduled repairs and reduce the impact of contingencies and equipment failures on operations.

Effective computer applications such as Computerized Maintenance Management System (CMMS) and project packages are required to optimize the schedules, control the constraints, balance the workload and maximize manpower utilization. These packages provide effective performance indicators to assess the maintenance program, planning effectiveness, schedule readiness, equipment availability, and maintenance cost and quality.

This paper will begin by looking briefly at the integrated maintenance approach, and planning and scheduling of a transmission substation maintenance program. The rest of the paper will cover a number of important aspects associated with maintenance planning and scheduling as follows:

- Operational and Maintenance Constraints
- Computerized Maintenance Management System (CMMS).
- Assessment of a Maintenance Program and Planning Effectiveness
- Maintenance Performance Reports
- Maintenance Planner Functions and Training Requirements

Key Words

Predictive Maintenance - Integrated Approach - Substation Maintenance - Transmission - Planning - Scheduling - CMMS

2. Introduction

Preventive Maintenance (PM) is the scheduled inspection and maintenance carried out at predetermined intervals to maintain equipment

functional capabilities and to minimize the probability of equipment failure.

Corrective Maintenance (CM) is the unplanned repair of failed equipment to restore its functional capabilities. This approach alone is not sufficient to maintain equipment reliability and availability at minimum maintenance cost. Therefore, many approaches are combined and integrated to improve substation equipment reliability and optimize maintenance program. These approaches are predictive maintenance, operation-based and condition-based maintenance and failure mode and effect analysis (FMEA), which depend mainly on equipment condition, failure modes, failure characteristics and consequences that maintenance task are designed to prevent.

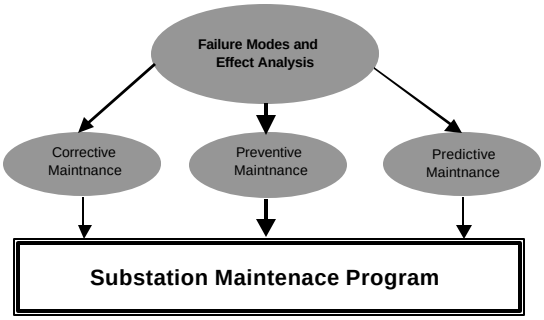

Figure-1: Integrated approach for a substation maintenance program.

There is a wide variety of condition monitoring and diagnostic expert systems that track the trend for various transmission equipment:

- Oil analysis techniques
- Vibration analysis
- Acoustic and ultrasonic analysis techniques
- Thermography
- Partial discharge.

The integrated approach acquires the patterns either on a continuous basis or on a routine basis to infer the equipment condition and interface to CMMS and expert applications that recognizes the pattern, classifies the nature of defects and provides advance warning so the predictive maintenance can be initiated and scheduled ahead of time to avoid further damage.

3. Planning and Scheduling of Substation Maintenance Program

Planned maintenance is an integrated effort to convert most of the maintenance work into scheduled maintenance. A planning team develops a comprehensive plan that integrates the maintenance requirements with the network load forecast and shutdown schedules, to minimize the impact on equipment availability and maximize labor productivity. This plan presents an overall picture of maintenance work with schedule milestones that act as a reminder to arrange parts requisition and shutdown schedules. A weekly and daily operation schedule is obtained from a master plan accordingly.

In this section, the main activities of maintenance planning and scheduling process will be described.

3.1 Maintenance Workload Forecasting

Maintenance Workload Forecasting comprises the estimation and prediction of the expected maintenance workload to achieve the desired level of effectiveness.

3.2 Maintenance Capacity Planning

Maintenance capacity planning determines the optimal level of resources to meet the forecasted maintenance work that consists of future forecast and existing backlog. Those resources include manpower, spare parts and tools. Maintenance capacity planning is needed to evaluate whether the current resources meet the maintenance demand, or overtimes and outsource maintenance contracts are required.

3.3 Maintenance Planning

Planning is the process of determining the quantity of work and resources required to achieve the desired level of effectiveness and efficiency, and interface operations plans with the maintenance plan and adjust planned maintenance due to changes in network load forecast and shutdown schedules.

3.4 Maintenance Scheduling

Maintenance Scheduling is the process of assigning resources and manpower for jobs to be accomplished at certain times with certain sequences and procedures, taking into consideration the operational constraints such as load season, availability of people, special tools and work priority.

4. Operational Constraints and Work Priority

4.1 Operational Constraints

Two operational constraint categories characterize a maintenance schedule:

4.1.1 Network-related category represents the network behavior; energy demand and power flow through the network along the considered calendar. This category also includes the continuity of power supply feeding customers, overload of certain section of the network, and the requirement to isolate the maintained equipment from the network.

4.1.2 Job-related category represents maintenance resources availability, work start and completion dates, precedence and priority constraints.

4.2. Maintenance Work Priority

Work priority is based on failure modes consequences and component condition. This system uses two rating scales: one is to rate the criticality of the substation and equipment and the other is to rate the importance of the maintenance work. When the equipment criticality code is multiplied by the work classification code, the resulting "Relative Ranking Importance of Maintenance Expenditure Index" (RIME) provides the priority for scheduling the maintenance work.

5. Computerized Maintenance Management System (CMMS)

CMMS is a work order computerized-based system that contains several basic modules for equipment, work orders, planning and scheduling, materials management, cost accumulation and performance reporting. It is able to integrate with purchasing, accounting, engineering, manufacturing, and the quality control system. The system performs a wide variety of functions to manage the maintenance program including forecasting, scheduling, tracking performance to improve reliability.

CMMS enhances preventive and predictive maintenance by providing a method to monitor failure trends that can eliminate root causes of failures, adjust preventive maintenance program, eliminate unnecessary preventive maintenance tasks and improve equipment reliability.

Integrating CMMS and the predictive maintenance approach can eliminate the majority of unscheduled outages for repairs. Work Orders are generated automatically whenever a specified parameter crosses a threshold value. These values may be manually entered into the CMMS or electronically obtained on a periodic basis from on-line condition monitoring or distributed control systems.

5.1 Equipment Management Module:

This module provides the initial entry of equipment information.

5.2 Work Order Management Module:

Work Order module provides the basis for work management, cost tracking, equipment history, and performance reporting. It supports controlling work requests, monitoring backlogs, determining priorities, and scheduling the maintenance work by assigning the best method to perform the work in the estimated time.

5.3 Spare Parts and Inventory Module:

During the work order analysis process, the planner lists the material required for the work. A separate request is used for each work order involved to accumulate cost information. Effective spare parts control is critical to the overall performance of the maintenance program.

5.4 Planning and Scheduling Module:

CMMS assists maintenance planners to optimize the schedules of the maintenance program by sorting the tasks according to craft, equipment type, due date, priority, shut down and resource requirements. Comprehensive scheduling features, such as critical path analysis, can be obtained by linking the work orders with the available hours to the project management software. The planner can change work order due dates, tasks sequence to avoid conflicts and combine tasks together to balance the workload, maximize manpower utilization and upload the optimized schedules to the CMMS.

The resulting schedule can be visualized on a Gantt chart representing the proposed maintenance schedule with a diagram showing the resource usage over the scheduled time.

Cost accumulation and maintenance performance reporting modules will be demonstrated in Section 7.

6. Assessment of Maintenance Program And Planning Effectiveness

The maintenance program and planning effectiveness can be assessed by implementing effective performance indicators and reporting structures. The performance indicators, such as workload, planning, equipment effectiveness and cost are used to monitor and control schedule readiness, equipment availability, work backlog, and cost and maintenance quality.

Performance reports are generated, analyzed and interpreted to measure the effectiveness of maintenance activities and initiate appropriate

corrective action into the maintenance program for further improvement. A monitoring and control cycle for maintenance program and planning effectiveness assessment is illustrated in Figure 2.

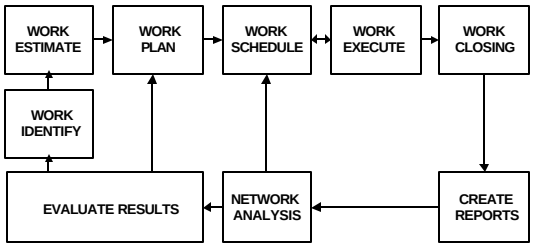

Figure-2: Monitoring and control cycle for maintenance program and planning effectiveness assessment.

7. Maintenance Performance Reports

There are many reports, which can be generated periodically or online, to evaluate the maintenance performance.

7.1 Cost Reports highlight areas of high maintenance cost and monitor contract, labor and material cost. This information is used for realistic forecasts and decisions on asset repair and replacement.

- Regular labor cost vs. overtime
- Percentage of maintenance labor costs to material costs
- Emergency maintenance costs
- Total maintenance cost per kilowatt hour (kWh)
- Maintenance cost effectiveness, estimated budgeted maintenance cost vs. actual cost

7.2 Utilization Reports: reduction process cycle time is an important means to improve productivity. These reports determine wasting time category with the root cause such as waiting for parts, approval and shutdowns.

- Manpower capacity utilization index indicates unallocated man-hours.
- Manpower effectiveness comparing actual versus planned times for completing work orders.
- Overtime vs. regular hours: a high value indicates high breakdowns, unplanned job and inefficient predictive maintenance program.
- Percentage of emergency repairs compared to total maintenance hours

7.3 Maintenance Quality Reports are used to highlight recurring problems on a piece of equipment.

- Maintenance rework measures the number of duplicate work orders generated to correct previously completed work orders within a certain period and determines the root cause.
- Equipment and spare parts history analysis is used to check spare parts quality.
- Percentage of PM versus CM.
- PM schedule compliance report compares the percentage of planned work to the total workload.
- Work Order status summary created by equipment type, classification and work type.

7.4 Equipment Downtime Reports:

- Downtime of major equipment, by area and by asset
- Unscheduled downtime
- Average downtime per breakdown

7.5 Equipment Reliability and effectiveness: how often the equipment does not fulfill its intended purpose. It is measured by interruption rate of particular equipment and for overall network per 100-circuit kilometer and per100 pieces of equipment.

Overall Equipment Effectiveness: indicates the usage effectiveness of the asset.

8. Maintenance Planner Functions and Training Program

The maintenance planner, who has sufficient technical experience on maintenance techniques, standards and procedures, plays an important role on the productivity of an effective maintenance program. The planner performs the following functions:

- Plans, coordinates and processes work orders by assigning the best and safe method to perform the work in the estimated amount of time and cost.

- Conducts deficiency analysis studies to determine incidents root cause and recommend actions to avoid reoccurrences.
- Performs maintenance audits to ensure that the maintenance procedures and quality are implemented.
- Evaluates maintenance by conducting periodic views of equipment history, prepares performance reports to examine the deviation from established measures and takes corrective action.

The maintenance planner is to be adequately trained on the following techniques and skills:

- Maintenance philosophies and techniques
- Forecasting and estimation techniques to estimate maintenance load, job time, manpower and spare parts requirements.
- Maintenance planning and scheduling tools, network demand and shutdowns scheduling.
- Computer software packages such as CMMS and project scheduling applications.
- Statistical process control tools.
- Communication and coordination skills.

9. Conclusions

This paper has presented the benefits of an integrated method that combines several maintenance approaches to improve equipment reliability, optimize maintenance schedules, and monitor failure trends that leads to eliminate root causes of failures and the majority of unscheduled repairs.

The paper has discussed the planning and scheduling of substation maintenance programs, operational constraints that represent transmission network behavior and maintenance resources availability.

Maintenance performance indicators and reporting structures have been also summarized to assess the maintenance program, planning effectiveness, schedule readiness, equipment availability, and maintenance cost and quality, in order to examine deviations from established measures and take the corrective action.

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