# Decision Support System and Integrated Asset Optimization (DSS & IAO)

### N.V.P.R. Durga Prasad, C. Radhakrishna

*Abstract: In order to achieve the target of substations maintenance at minimum cost and high reliability, a comprehensive maintenance management system which will enable the execution of maintenance activities incorporating the various optimization strategies and policies is required. In today's scenario for achieving effective maintenance number of systems, instrumentation technologies, etc. are in use to achieve the targeted benefits. At the substation level these systems are working independently and maintenance engineer is required to coordinate these systems for achieving the synchronization with the overall substation level. Computerized Maintenance Management System (CMMS) with built-in Decision Support System (DSS) are in use to address this issue. Present CMMS systems do not provide a comprehensive platform to implement DSS along with rule base expert systems for event based maintenance and other abnormalities management. In this paper a new platform DSS&IAO which is a comprehensive, integrated and expandable system for the substation maintenance management is proposed. Right from the preventive maintenance to condition based maintenance coupled with event based to equipment specific rule based expert system have been implemented. DSS&IAO is a platform wherein new optimization algorithms, new device interfaces, etc., can be easily incorporated.*

*Keywords: Substations, CMMS, DSS, Asset Management, Expert System.*

## I. INTRODUCTION

Distribution utilities are under constant pressure to provide un-interrupted supply of energy at lowest possible cost while satisfying safety standards for the improvement of customer satisfaction. Emphasis is on achieving higher system reliability and cost reduction. Immediate focus is on the reduction of operating and maintenance expenditure, and enhancing the equipment life to minimize the investments on replacement. First attempt is to reduce the system operating cost by optimizing the maintenance activities for the economic system operation. Accomplishment of these objectives is possible through an effective asset management with underlying efficient maintenance management. The structured process of an equipment (physical asset) life cycle right from design, manufacturing, operation and maintenance is termed as an asset management. Asset management in the operation and maintenance phase, monitors the asset for its deterioration or failure symptoms and appropriate maintenance activity will be planned to bring back the equipment condition to its original state or to avoid failure. These actions are appropriately recorded in the equipment

history and complete information is shared to the next level to support strategic asset management decisions. Information on the condition of assets and their deterioration due to aging will help in the effective maintenance of the asset throughout its life span which is the strategic asset management. Strategic asset management enables optimum use of resources to maintain better asset condition and reduce unplanned maintenance activities. The overall objective of asset management to optimize the system assets to perform the required functions of the overall distribution utility. Asset optimization is carried out through a structured business process consisting of planning, engineering, operations, maintenance and customers service. The optimization of maintenance is one possible technique to reduce maintenance costs while improving reliability. Utilities need to implement required and necessary maintenance strategies and Asset Management (AM) programs to manage inspections and maintenance activities to maintain the equipment condition. However, implementation of the above activities and making sound maintenance related decisions to improve equipment and system reliability at minimum maintenance expenditure is a challenge [1]. Maintenance Management Process is shown in Fig. 1.

## II. MAINTENANCE MANAGEMENT

Equipment maintenance is categorized into different levels based on the equipment characteristic and effects of different levels of maintenance on the condition of the equipment. Maintenance levels are inspections, minor maintenance and major maintenance. Various preventive maintenance methods that are employed in substations considering the condition and importance is shown in Fig 2. Maintenance management goals is to establish maintenance objectives, maintenance strategies, roles and responsibilities using a set of activities such as maintenance planning, control, monitoring and execution [2]. In order to accomplish this, it is required to have structured information from various sources and from various levels of the hierarchy at centralized location for taking a comprehensive decision. Information collected from various sources is made available as a strategic resource to all stake holders of an organization is essential to ensure smooth and coordinated actions among all related players. [3]. Such an information system which is used to support maintenance management functions is named as Computerized Maintenance Management Systems (CMMS). Apart from the basic functions, functionalities like condition monitoring data analysis, diagnosis of failures through a systematic analysis

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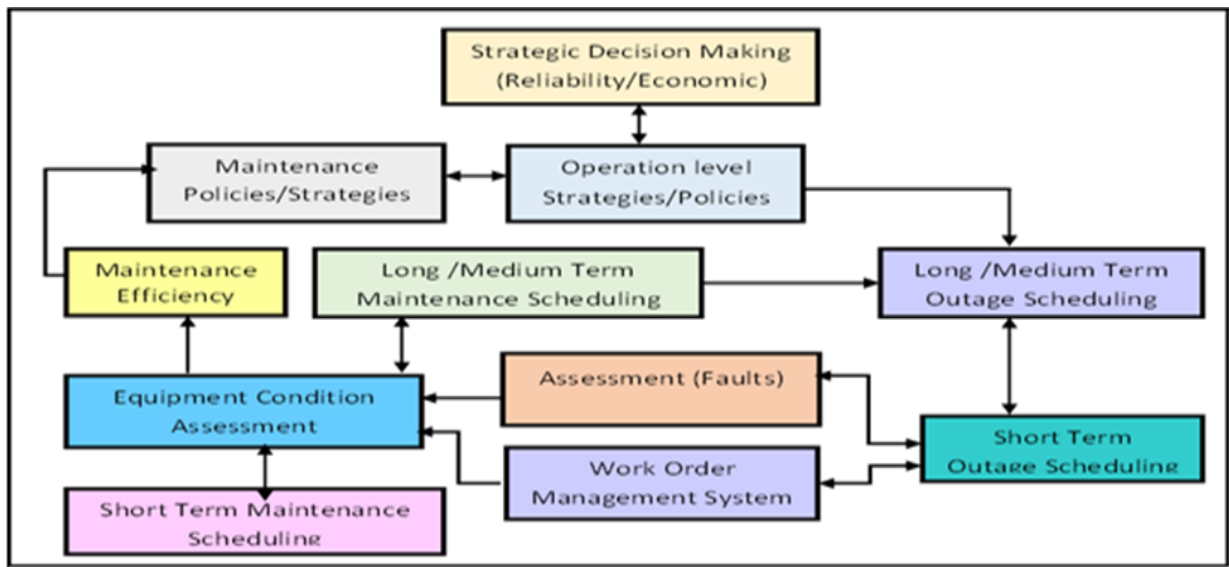*Blue Eyes Intelligence Engineering*
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**Fig. 1: Maintenance Management Process**

(FMEA), Maintenance resource allocation, tracking of spare parts availability, tracking of KPI for equipment performance, Decision Support System (DSS), Expert Systems and Integration to other information systems are incorporated in the advanced CMMS to meet the growing requirements of utilities. are incorporated in the advanced CMMS to meet the growing requirements of utilities.
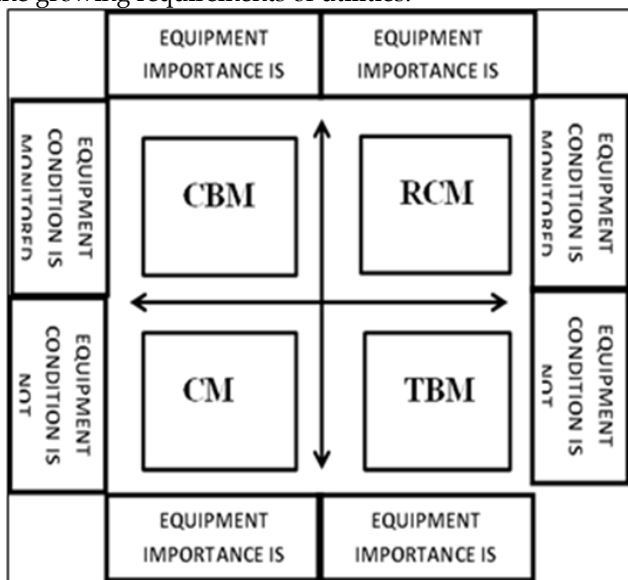


**Fig. 2: Preventive Maintenance Strategies**

### III. DECISION SUPPORT SYSTEM (DSS) FOR MAINTENANCE MANAGEMENT

Maintenance management of the substation and all substations within the utility requires information from number of independent sources. CMMS would provide the platform for handling such information and perform the various functions of the maintenance. However, making maintenance related decisions for effective maintenance management is very complex since it depends on various inputs like, maintenance schedule for daily, weekly and monthly, status of equipment deterioration, equipment condition, expenditure for maintenance resources and available alternate decisions along with their implications [4].

Decisions are required to be taken in a coordinated manner to achieve the system level maintenance effectiveness and requires seamless transfer of information from all the asset management levels of the utility. This requires a well architected Decision Support System (DSS) for assimilating and evaluating various options and alternatives to arrive at a best possible alternative [5]. DSS for maintenance management requires different types of information at different levels of asset management in the utility. With reference to maintenance management, the information system should provide equipment abnormalities, faults and service interruptions apart from the operational data to supports the decision making process. In order to make accurate and effective decision making in DSS, it is necessary to identify the common failure modes of the equipment or system and their detection process. DSS is the main component which is responsible for arriving at an optimal decision based on data from various sources like equipment specifications, design data, on-line monitoring system, maintenance history, work order execution and off-line testing system. DSS architecture mainly consists of three modules and they are database, model-base management system and user dialog management [6]. DSS is also architected by four modules and they are user interface, database, model and analytical tools [7]. In the literature, DSS in some applications described by five modules and they are data management system, model management system, knowledge engine, user interface, and user(s) [8].

### IV. EXPERT SYSTEM (ES) FOR MAINTENANCE MANAGEMENT

Many of the faults in the system requires a detailed analysis and investigation to find the reasons for the problem and it's remedial. For such situations maintenance engineer is required to possess enough expertise in arriving at a decision by analyzing the available data. Expert systems assist the maintenance engineer in such situations by utilizing the expert knowledge without having the physical presence of an expert. Expert Systems will aid

the problem solving process and increase the confidence in correct decisions (Clarke, 2005). Knowledge- based expert systems are computer programs for querying the expert rules (knowledge base) based on the current information and Inference Engine for generating outcomes. They provide a framework for the collection of system information, data organization and retrieval of specific knowledge. Knowledge base consists of set of rules and information used for the problem solving and Inference engine is responsible for making the final decisions or conclusions. The domain knowledge is captured in the form of expert rules which are utilized by inference engine for solving the problem. Inference engine is a control mechanism which applies the rules to the specific task using the context specific data for the arriving at a solution.

From maintenance perspective, apart from capability of integrating information from various sources and weighing them by the user intervention for the decision making process, DSS should also have the capabilities of expert system where the expert knowledge is acquired and applied for the precise decision making. The resultant system having DSS with expert system capabilities will enable utilities to make efficient and effective maintenance decisions and root cause analysis for faults by analyzing the equipment condition monitoring data, failure history, spares consumption, equipment maintenance models, equipment specifications and expert's personal knowledge.

## V. DSS AND ES FOR MAINTENANCE

Integration of DSS and ES allows to utilize the strong points of both DSS and ES to develop a powerful and accurate decision making system [9]. In the literature two frame works are available for the integration [10]. They are integrating ES into conventional DSS modules or components and ES as a separate and independent module interfaced with DSS. Combination of DSS and ES serves two district purposes using two types of information technologies. Maintenance engineer uses DSS for data acquisition, information processing and ES is used to get the expert intelligence for arriving at an optimized decision. Conceptual model of integrated DSS and ES is shown in Fig 3.
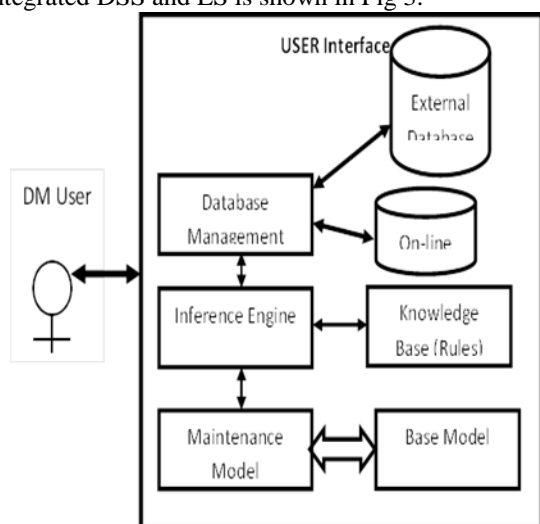


**Fig .3 Conceptual model of DSS & ES for maintenance**

Such DSS is called hybrid DSS driven by knowledge and models. An asset management solution having integrated and comprehensive CMMS with DSS brings overall effectiveness in the organization, reduces the equipment breakdowns, reduces maintenance expenditure and increases the customer satisfaction. DSS based on model and expert system will provide an efficient and versatile platform to achieve the asset optimization.

## VI. DISTRIBUTION AUTOMATION FRAMEWORK WITH DECISION SUPPORT SYSTEM AND INTEGRATED ASSET OPTIMIZATION (DSS & IAO)

As sated above, a comprehensive CMMS with DSS and ES is the required platform for the asset optimization. In the literature not many developments are reported with this combination for the maintenance management of substations. Condition based maintenance program for substation equipment to minimize the maintenance cost has been reported in the literature with DSS [11] [12] [13] [14]. However, many critical functions as listed below for achieving effective asset management are not included:

• Optimized maintenance scheduling based on the equipment models
• Maintenance management System at substation level rather than at equipment level.
• Equipment maintenance scheduling based on equipment importance and criticality.
• Interdependency of expert rules on equipment is not considered in the knowledge editor.
• Evaluation of KPI's with a feedback for fine tuning the maintenance activities is not implemented.
• Computation of equipment down time due to maintenance, breakdown, etc. is not captured.
• Computation of System level and equipment level reliability performance.

Addressing all the above requirements, a comprehensive DSS&IAO is proposed in this paper. The proposed framework has been developed with seamless integration to the distribution automation platform at the substations. Salient features of the proposed framework are:

• On-line data interface to the equipment condition related data
• Interface to the equipment RF-ID system for on-line maintenance integrity.
• Hierarchy based equipment Configuration at the Sub-station level
• Automatic generation of maintenance schedules based on configured periodicity. Automatic generation of maintenance task based various events generated by equipment alarms, equipment breakdown, major /minor overhaul, expert system, etc.
• Generation of optimized equipment maintenance /inspection schedules based on maintenance model of the equipment considering the equipment condition and importance.
• Provision for posting a maintenance task based on the

equipment break-down.

- Spares management as an integral part of the maintenance.
- Computation of maintenance cost at equipment level as well as overall substation level.
- Estimation of maintenance KPI.
- Computation of equipment downtime considering down time due to maintenance.
- On-line expert system for root cause analysis, condition based maintenance and fault diagnosis.
- Expert rule editor for managing the expert rules.
- Provision for capturing expert rules having interdependency.
- Creation of operational data base for creating experts with knowledge in maintenance.

## VII. DECISION SUPPORT SYSTEM AND INTEGRATED ASSET OPTIMIZATION (DSS& IAO)

DSS&IAO is an advanced and comprehensive maintenance management system developed for the substations using state-of-the-art software development tools. It incorporates best practices and result oriented methods followed in maintenance departments across various substations, thereby enabling quantum improvements in productivity levels and all the other key metrics of the maintenance function.

Proposed DSS&IAO is designed based on an open architecture with various interface methodologies for facilitating interface to external hardware and external software based systems. The system is capable of interfacing to up-stream for strategic decisions as well as downstream for effective maintenance actions. On-line Expert system is built-into the DSS&IAO as an integral part of the system for event analysis, fault diagnosis, rule management and knowledge assimilation for future. The present system is designed around the internet based technologies. The clients which are called as maintenance controllers (MC) are distributed geographically in the substation. All the clients are connected to the web server which can be an internet web server or an intranet web server. The users or clients are connected to the web server through a Local Area Network (LAN) as shown in Fig. 4.
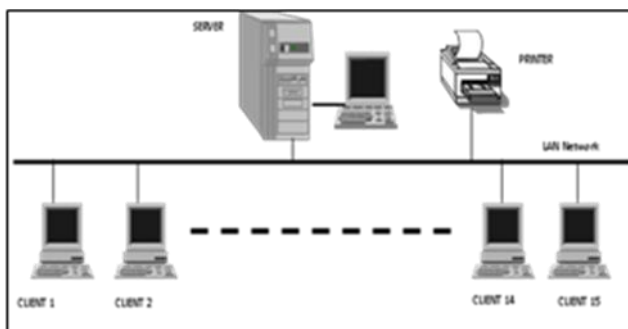


**Fig .4 Server client Architecture**

### 1.1 DSS&IAO System Architecture

DSS&IAO framework as shown in Fig. 5 is designed around the following building blocks executing in server as well as in MC:

•Equipment Configuration / Condition Data Management
•Abnormality/Event/Decision Support System & Expert System
•Schedule Generation for Maintenance / Inspection
•Breakdown/Shutdown Management
•Maintenance Management & Inventory Management
•Maintenance Performance Measurement.

**Equipment Configuration / Condition Data Management**:
DSS&IAO is configured with the various data related to substation configuration, equipment and other subsystems of the substation.

**Abnormality/Event Generation**
This module is the most critical and decision oriented module which makes the maintenance management as an intelligent system. Equipment condition data is analyzed and compared with the set threshold values and generate events to the scheduler for creating an action on equipment.

**Schedule Generation for Maintenance / Inspection**:
Apart from automatic time based preventive maintenance schedules, optimized maintenance task schedules based on the equipment condition, maintenance model and expert system are generated in this module.

**Breakdown/Shutdown Management:**
The equipment abnormality events which are generated in the earlier DSS module will be forwarded to this module if the equipment is diagnosed as breakdown or failed. Accordingly, the equipment shutdown maintenance which can be minor or major will be planned and scheduled.

**Maintenance Work Order Management & Inventory Management:**
Scheduled maintenance or inspection or shutdown jobs are executed in this module through work orders. These work orders are generated with complete details of the specific job to be carried on the equipment like scheduled start time and complete time, required spares, job instructions for guidance, etc. Work order closing is made automatic by associating with the RF-ID system attached to the equipment for accurate schedules and data integrity.

**Reports**: In this various maintenance KPI's are computed at the equipment level as well as at substation level to enable the user for tweaking maintenance activity performance. Completion of all work orders are concluded with the automatic data interface through the RF-ID enabled system.
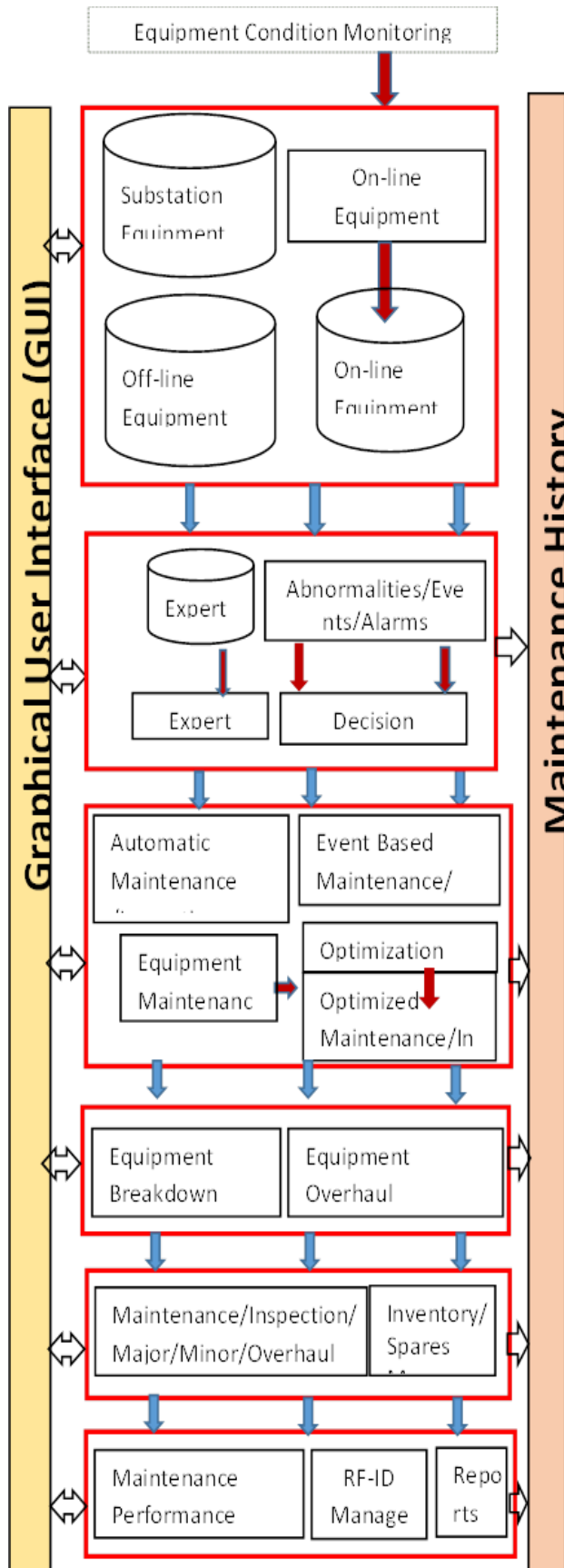
**Fig .5. DSS & IAO System Architecture**

**Maintenance Performance Measurement and**.

**Maintenance History:**

Complete history of the DSS&IAO is logged for future archival and analysis. History data is made available to upstream application for making effective strategic decisions. History is available by equipment wise, as well as substation wise for future analysis.

**Graphical User Interface:**

User is interfaced to DSS&IAO through this module. GUI is divided into a number of above module specific display pages.

## VIII. DSS&IAO SOFTWARE ARCHITECTURE

DSS&IAO building blocks are realized and integrated utilizing the various resources of information technology. Software architectural details of DSS &IAO are given in Fig 6.

There are five main components in the architecture diagram and they are Generic Data Concentrator (GDC), Maintenance Controller (MC), Equipment Deterioration Model, Maintenance Controller Interface and GDCInterface.

☐ **Generic Data Concentrator (GDC):**

GDC is a flexible framework for developing applications in the field of Monitoring, Control and Optimization, specifically for supervisory monitoring and control of processes. Applications can be built around GDC with control strategy. Control strategy is coded in the form of events.

☐ **Maintenance Controller Interface:**

It provides interface to Maintenance Controller for logging in the maintenance alarms and abnormality records into maintenance controller. Maintenance Controller Interface (MCI) is a client component provided as VB ActiveX DLL along with the Maintenance Controller Client to reference the methods required for sharing the data and executing operations on the Maintenance Controller application.

☐ **Expert Interface:**

Expert interface is used for supplying the data to the rule-based decision support system. In current system, the values of the tags used in the rules are directly obtained from the database.

☐ **Equipment Deterioration Model Interface:**

Equipment Deterioration Model will determine the optimized maintenance and inspections schedule for configured equipment in the substation for high reliability or minimum maintenance cost. This model is executed with the equipment data from the GDCInterface and other Database sources. It determines the optimized maintenance schedules.
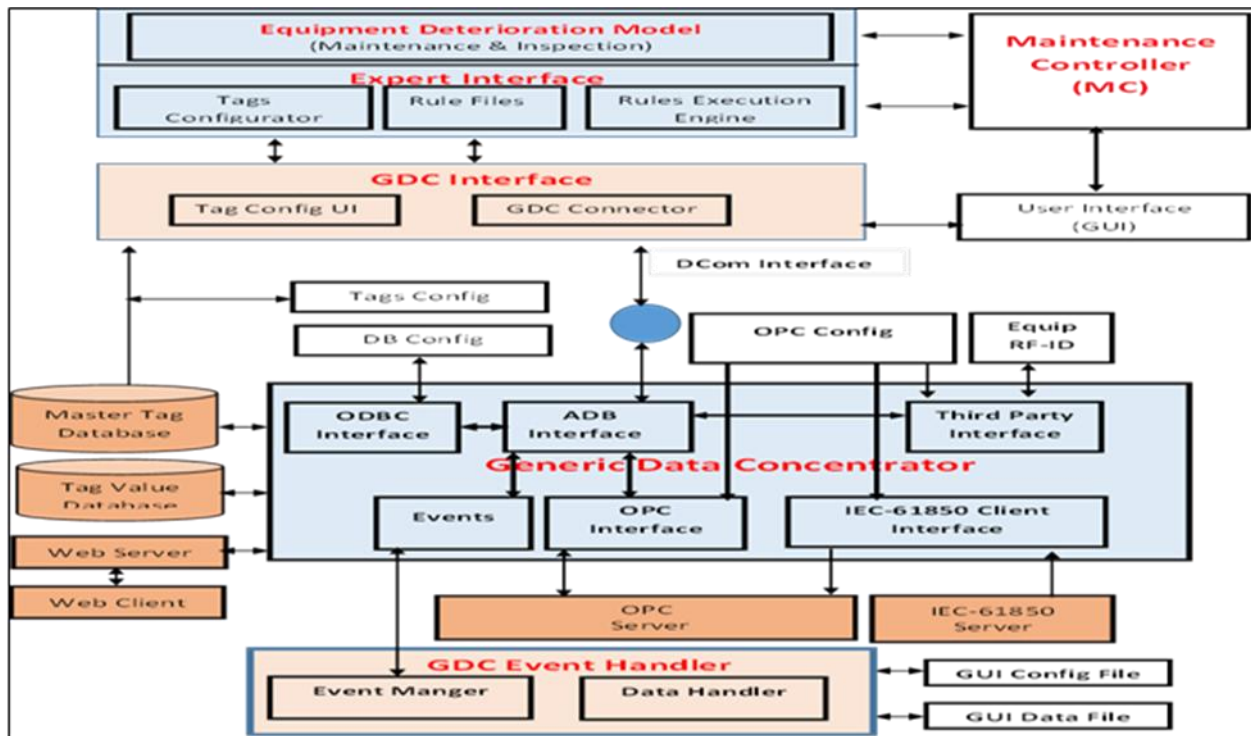
## Decision Support System and Integrated Asset Optimization (DSS & IAO)



**Fig.6. DSS&IAO Software Architecture**

Complete software of DSS&IAO is organized in the form of function specific modules as given below:

- Security
- Configuration
- Scheduling (Maintenance/ Inspection)
- On-line /off-line equipment related data acquisition
- Shutdown Management
- Abnormality /Events
- Expert system/Fault Diagnosis
- RF ID Equipment Management
- Inventory Management
- History    KPI/ Availability/Reliability / Reports

☐ **Security:**

The features in security allow the administrator to set user authorizations to various modules of the software.

☐ **Configuration:**

The Configuration module allows the user to set up the organizational framework, a one-time activity that enhances the success of implementation.

☐ **Scheduling (Maintenance/ Inspection)**:

Scheduling of maintenance and inspection tasks is carried out through three methods.
•Automatic Scheduling
•Event based Scheduling
•Optimized Scheduling

The Schedule module allows the user to schedule the inspection and maintenance tasks as per the above selection. In case of automatic generation, schedules are automatically generated for the specified period of time.  Schedule generation involves processing of the Preventive Maintenance and Preventive inspection information attached to the equipment and generation of work orders for the same.

**Abnormality module** in the ODC generates events or alarms by comparing the equipment data with the set data. User can configure a maintenance or inspection task for each event and alarm. Accordingly, whenever a configured abnormality is detected in the equipment, a pre-defined maintenance or inspection task is scheduled. Event driven maintenance is operated based on the built-in monitoring instruments of the equipment which will provide information to the maintenance controller to switch from the scheduled maintenance to event driven maintenance. Following are examples in substation where event driven maintenance is explored:

•Auxiliary contacts monitoring in Breakers.
•Calculation and integration of the breaker interrupted current
•Fault and trip operation counters
•Monitoring of the sequence components of the currents and voltages in transformer supervision logic

All of the above shows that the availability of the above advanced monitoring systems enables the user to implement the event based maintenance to reduce the maintenance cost and improving the maintenance efficiency.

In case the system is selected with the optimized scheduling, the maintenance and inspection tasks are generated based on the schedules provided by the deterioration model. The optimized module will determine the optimized schedules based on the pre-determined optimization strategy which is either maximizing reliability or minimizing maintenance cost.

Subsequently, work orders are generated for respective maintenance departments giving details of the task to be performed, manpower requirement, tools requirement, priority, and other task-related information. If the equipment is RFID enabled, then a check is made on the availability of on-line RF ID feedback for the work order closure. In other cases, it is closed manually.

☐ **On-line /off-line equipment related data acquisition:**

In this module the equipment condition monitoring data which are to collected on-line through ODC or offline are configured and monitored. These values are used for event generation as well as well as for the fault diagnosis.

☐ **Shutdown Management:**

The Shutdown module allows the user to eliminate repetitive maintenance planning activities such as maintenance and inspection tasks. It allows to group certain maintenance or inspection activities (planned or unplanned) as a shutdown job for better maintenance management.

☐ **Abnormality /Events:**

Equipment abnormalities or events are the abnormalities that had occurred during inspection. These are generated whenever the inspection values of the parameters cross the set threshold limits which are set in the configuration module. These abnormalities or events are the triggers for the fault diagnosis module which is driven by the expert module. Expert system will trigger a required maintenance task for the equipment. The user can view the abnormality-related job details and its fault diagnosis information.

☐ **Expert system/Fault Diagnosis:**

The rule-based engine helps in effective fault diagnosis. The aim is to get to the root cause of the fault or abnormality. Expert knowledge is to be configured as rules during configuration. The diagnosis of the fault is therefore independent of specific operator knowledge, as this is captured in the form of rules, and the system behaves as a 'learning' system.

☐ **RF ID Equipment Management:**

This module deals with the RF-ID enabled equipment. The main functions are RF-ID data acquisition, RF ID tag data identification and database update. The RF ID Tags are mounted on the equipment and their data is acquired into a stand-alone embedded reader called as RF-ID reader. The data from the RF-ID reader is communicated to the web server through a plant wide LAN. RF-ID enabled equipment will use the RF-ID tag feedback for its works management.

☐ **Inventory Management:**

The Inventory module will keep track of the all the materials (spares) received and issued. Continuous update of stock is done in the inventory based on the inputs from work orders completed, allocation of spares and issue of spares from open or reserved inventory to tasks.

☐ **History:**

This module maintains a history about the commissioning, movement, maintenance, inspection and stoppage of equipment. The history module is divided two parts such as complete history and critical spare tracking history which is re-usable for other equipment.

☐ **KPI/ Availability/Reliability / Reports:**

KPI analysis provides a snapshot of how assets are performing against the user-defined benchmarks. Asset performance via graphical indicators can be viewed directly to a Web browser. The ability to analyze the data captured in DSS&IAO about KPI's provides the knowledge to improve and optimize maintenance initiatives. Computation of KPIs

and its reports makes it possible to identify areas of maintenance that require improvement.

## IX. EXPERT SYSTEM

In Expert system is a rule based Decision support system proposed for substation maintenance management. The rules are created based on the possible problems in the substation. Whenever any problem arises, the corresponding rule gets fired. The description of the problem can either be given in text form or in the form of a picture clip. The expert can assess the problem and suggest a solution or directly solve it. Expert builds the diagnosis rules and they are protected by encryption. The events that rise in the system and came in to the notice of expert system are logged for future analysis. Main Features of Expert System are:

•Designed as an Expert System Shell for Building Rule Based Expert System for substation maintenance.

•Acts as Decision Support System.

•Rule based Domain Knowledge is protected by Encryption.

•User Friendly GUI for Building Rules.

•Creates Software Black Box for Future Analysis.

•Provision to create a rule whose output can be used as input to the other rule. It gives the facility to create new Tags (Memory Tags) that are not available in the tag database.

Data Interaction of expert system with the field tag values is shown in Fig 7.

DSS is targeted at two levels of users:

- The domain expert who will embed his knowledge in the system in the form of rules

- The plant operator who will be provided with guidance messages when these built-in rules fire during the operation of the plant

An important feature of the present expert system is the encryption capability which helps to protect the specific knowledge of the expert knowledge embedded in the system in the form of rules.
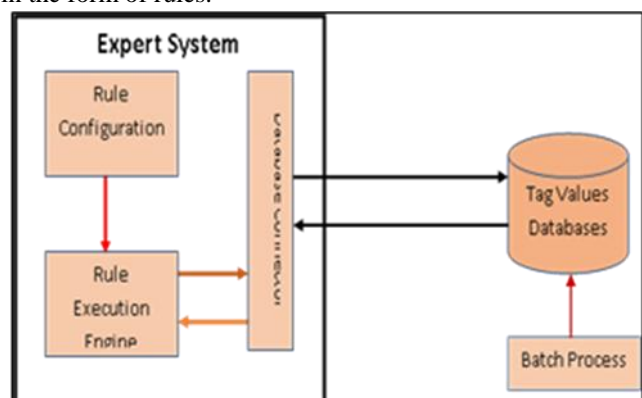


**Fig. 7. Data Interaction of Expert System**

## X. CONCLUSION

In order to achieve the target of substations maintenance at minimum cost and high reliability, a comprehensive maintenance management system which will enable the execution of maintenance activities incorporating the various optimization strategies and policies is required. In

today's scenario for achieving effective maintenance number of systems, instrumentation technologies, etc are in use to achieve targeted benefits. At the substation level these systems are working independently and maintenance engineer is required to coordinate these systems for achieving the synchronization with the overall substation level. Computerized maintenance management with decision support systems are in use to address this issue. Present CMMS systems do not provide a comprehensive platform to implement DSS along with expert systems for event based maintenance and other abnormalities management. In this paper a new platform DSS&IAO which is a comprehensive, integrated and expandable system for the substation maintenance management is proposed. Right from the preventive maintenance to condition based maintenance coupled with event based to equipment specific rule based expert system have been implemented. System is designed with highest flexibility for integration with other strategic tools and extensive substation history is provided about the maintenance. DSS&IAO is a platform wherein new optimization algorithms, new device interfaces, etc., can be easily incorporated in the future.

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