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Classification, Domains and Risk Assessment in Asset Management: A Literature Study

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***Abstract*— This paper presents a literature study on asset management in electrical power transmission and distribution system. Due to restructure and deregulation of electric power industry in recent times, the focus has been on transmission and distribution assets that include transmission lines, transformers, power plants, substations and support structures. The study aims to provide a first of its kind exposure to asset management classification, various interesting maintenance methods and theories developed in last two decades. In the end, it also discusses various risk assessment techniques in asset management developed and used for academic research and industries.**

***Index Terms*--Bibliography review, asset management, mid-term transmission planning, maintenance planning, risk assessment.**

I. Introduction

ASSET management is classified as an important activity in present day transmission and distribution system planning and operation. This is because of power market deregulation and competition among existing markets which forces the utilities to optimize the use of their equipment, while focusing on technical and cost-effective aspects. Also, it has encouraged power utilities to find optimal management of installed capacity while optimizing the cost of the current components over their life span which gave birth to asset management. Asset management, broadly, refers to operating a bunch of assets over the whole technical life cycle guaranteeing a suitable return and ensuring defined service and security standards [1]. CIGRE Joint Task Force JTF23.18 [2] defines asset management as:

"*The Asset Management of Transmission and Distribution business operating in an electricity market involves the central key decision making for the network business to maximize long term profits, whilst delivering high service levels to customers, with acceptable and manageable risks.*"

Complying with the needs, utilities are constantly striving to optimize the use of resources available for maintenance while ensuring system reliability is within satisfactory limits. In the electrical power industry, transmission and distribution components are capital-intensive assets and hence there is a requirement of utilizing them in the most efficient way.

Maintenance forms the crucial part of asset management. Literature survey shows there have been explicit studies on maintenance of various power system components, i.e. overhead lines, cables, transformers, etc. [3]-[10]. Secondly, risk assessment in asset management forms another integral part. As mentioned by Brown [11], asset management is the art of balancing cost, performance and risk. Since assets involve financial investment, there have been ample studies on asset management risk assessment [12]-[25]. Accurate, timely and reliable asset information results in better decisions and in the past, there has been quite much research on various aspects of asset management. But, till date, there has been no explicit literature study on asset management in power systems. This paper makes a maiden attempt of compiling various articles on asset management into a single literature study paper.

The rest of this paper is organized as follows: Section II describes the classification of asset management on time and information aspect. Section III presents the various domains of asset management, and related literatures. Section IV discusses on risk assessment in asset management. The conclusion of the present study is illustrated in Section V.

II. Classification of Asset Management

Since the late 1990's, electrical power industry has been substantially deregulated and the result is birth of "asset management." Asset management is also defined as the process of maximizing the return on investment of equipment over its entire life cycle, by maximizing performance and minimizing CapEx (Capital Expenditures) and OpEx (Operational Expenditures) [26]. CapEx contributes to the fixed infrastructure or new investment, and it depreciates over time while OpEx do not contribute to the infrastructure; rather it represents the cost of keeping the system operational and include costs of technical and commercial operations, administration, etc.

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Asset management is also referred to mid-term planning when classified under the time horizons of transmission and distribution system planning and operation, others being long-term (or system/grid development) and short-term (or system operation/operational) planning [27]. Thus, asset management is a link between long-term system development and short-term operation planning because it is a data-driven decision making process which aims at delivering the optimum result within the available budget (i.e., long-term) at the right time (i.e., short-term). CIGRE WG D1.17 gives a clear picture of how asset management relies on asset data and information extracted from this data that is to be used in future planning [28]. This is explained in detail when we classify asset management into its various segments.

A classification of asset management based on time-domain and activity-domain is shown in Fig. 1. The time-domain asset management is categorized into long-, mid-, and short-term asset management, explained below:

- *Long-term asset management:* The time frame ranges from a year and beyond and it aims at up-gradation of existing generation and transmission assets. In other words, it encompasses future planning, i.e., investment on new assets like phase-shifting transformers, reactive devices, investment on capacity expansion of existing connections or up-gradation of substation equipment. This involves greater financial risks, and hence proper planning can avoid the risks involved in time-delays, interest rates and long-term load diversity.

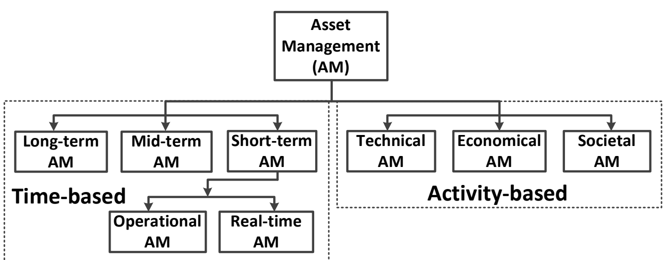

Fig. 1. Classification of asset management based on literature study

- *Mid-term asset management:* The time frame of mid-term ranges a few months and it involves optimal scheduling of equipment maintenance and allocation of available resources. The primary aim is to extend the life span of existing facilities through proper maintenance and optimally allocate the renewable energy resources as well as hydro/thermal units. Maintenance cost is the most crucial or driving factor since it is a function of outages, i.e., both planned and unplanned, and it can be greatly reduced when planned outages are scheduled according to availability of resources during seasonal load distributions. So, optimal maintenance scheduling greatly reduces the possibility of unplanned outages. It is also the task of asset managers to check that maintenance scheduling is planned based on system reliability and fuel constraints on the non-maintenance system, like the availability of water in-flows for hydro plants. Tor [26] explains the mid-term asset management as:
  - Minimizing corporate financial and physical risks based on planned and forced outages of assets
  - Reducing operation costs for supplying customers in a competitive era
  - Optimizing the allocation of volatile and limited natural resources for utilizing corporate assets
  - Extending the life span of assets through proper operational and maintenance schedules
  - Prolonging investment costs for the acquisition of new assets
- *Short-term asset management:* Short-term asset management is categorized into operational asset management (daily and weekly) and real-time asset management (outage management). Operational asset management aims at minimizing risks involved with assets, both physical and financial, due to load demand and hourly prices. Real-time asset management is also called the asset outage management. Contingency analysis forms a vital part. It helps in assessing the effect of unexpected outages due to change in weather conditions, any sudden breakdown or load fluctuations on the asset condition and performance. In recent times, due to technological advancements, real-time monitoring of assets is possible because of systems like Supervisory Control And Data Acquisition (SCADA), Remote Terminal Units (RTU), and Geographic Information System (GIS).

Based on activity aspect, Smit *et al.* [29] categorize asset management into technical-, economical- and societal-asset management. Technical-asset management deals with ageing, insulation and other physical conditions of assets. Socio-economic aspect is broken down to individual aspects, which deal with how asset management would be influenced by financial constraints and eventually its impact on society.

III. DOMAINS OF ASSET MANAGEMENT

Asset management covers aspects from technical issues like network planning to more economical themes like planning of investment and budgeting. On this aspect, the key points from Schneider *et al.* [1] can be summarized as:

- Maintenance strategies
- Determination of component condition
- Asset simulation
- Statistical fault analysis and statistical asset management approach (distribution)
- Life assessment (transmission)

Thus, it is important to analyze the dependency between maintenance and renewal actions, which gave birth to corrective maintenance and preventive maintenance. Corrective maintenance is the maintenance carried out after failures occur while preventive maintenance is the maintenance carried out before failures occur. Schneider *et al.* [1] presented their view about no existence of preventive maintenance. But, Bertling *et al.* [30] used preventive maintenance to develop a reliability based asset management called Reliability Centered Maintenance (RCM). The Electric Power Research Institute (EPRI) defines RCM as a systematic consideration of system functions, the way functions can fail, and a priority-based consideration of safety and economics that identifies applicable and effective preventive maintenance tasks. RCM is widely accepted in asset management which is evident from various published literatures [31]-[35].

The electric power transmission and distribution system assets include transmission lines, underground cables, transformers, breakers, power plant and substation support structures. With the integration of renewable energy sources, wind-farms, also part of asset management, have been extensively studied from the asset management point of view in [4][5], [33]-[36]. Other components in transmission and distribution systems widely studied are power transformers, overhead lines and circuit breakers, to name a few. The power transformer represents approximately 60% of the overall costs of the network, and is ranked as one of the most important and expensive component in the electricity sector [37]. Study reveals about substantial research on power transformers in various literatures about health monitoring, ageing, and oil-indicators [38]-[43]. Similarly, studies have been carried out for overhead lines [43]-[46], underground cables [43][47][48] and circuit breakers [43][49]-[51]. A real time case study on asset management in Singapore was conducted by Yoon and Teo [52], though it focused more on underground grid. With the advent of computational tools, Information Technology (IT) and Human Machine Interface (HMI) in the last decade, Kostic [53][54] made studies on the application of IT in asset management. [53] focuses on the aspect of integrating IT in asset management by utilizing process data (e.g., SCADA, EMS/DMS) in back-end tools such as Enterprise Resource Planning (ERP), GIS, Computerized Maintenance Management System (CMMS) and other analysis tools. A framework of data management used in asset management is shown in Fig. 2.

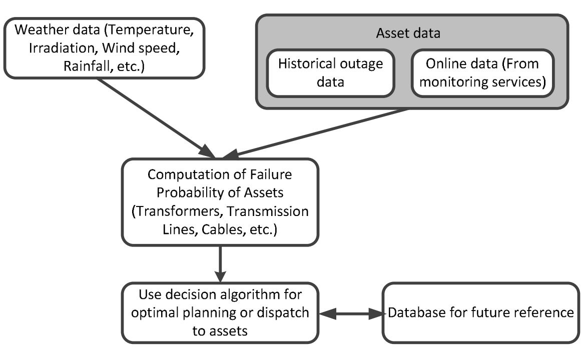

Fig. 2. A framework of data management used in asset management

Leaving aside IT and HMI in asset management, various computational models and optimization techniques have been developed for maintenance, refurbishment, ageing and monitoring techniques in asset management, like state diagram [55], fuzzy technique [34][42][56], neural networks [39], PSO [35], linear programming [46][57], branch and bound technique [58] and other optimization techniques [36][59][60]. Anders *et al.* [61] combined engineering and financial aspects of asset management into software tool called Risk-Based Asset Management (Ri-BAM).

IV. Risk Analysis in Asset Management

As Brown [11] discussed the relation of asset management and risk analysis, literature survey suggests the development of various risk models in the past two decades. The electric power transmission and distribution systems constitute the greatest risk to the interruption of power supply, and hence, risk analysis constitutes an important part of asset management. This is due to the huge investments on equipment, maintenance, up-gradation, etc. which has a direct impact on operational targets. The IEEE/PES task force analyzed the impact of maintenance on asset reliability [62], and the corresponding figure is shown in Fig. 3. Muhr [18] categorizes different kinds of risk into a cube called Risk Management Cube (RMC). The three faces of RMC are risk categories (market, financial, etc.), typical of trade risks (industry, utilities, etc.) and structure specific risks (international or regional). It explains how any decision taken will be based not only on the technical information but also on socio-economic aspects.

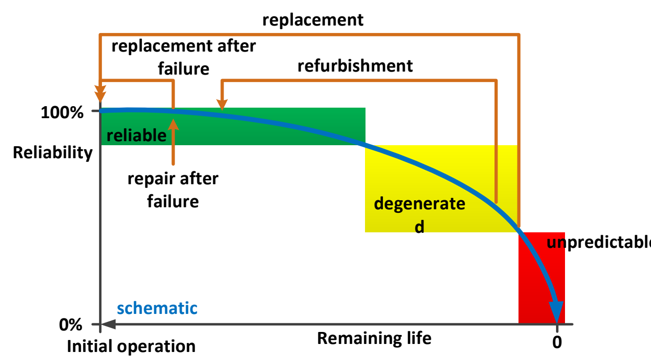

Fig. 3. Ageing model for asset simulation [1]

A large number of methods has been developed to tackle risk associated with asset management. Value at Risk (VaR) [19], Life Cycle Cost (LCC) [20], Run-Refurbish-Replacement (3R's) [17], and various probabilistic approaches [21]-[23] to name a few since citing all papers would be out of the scope of this paper. The VaR method, as defined in [19], measures the worst expected loss over a given time-horizon under normal market conditions at a given confidence level. It explores the maximum loss incurred in a specific time-frame with an appropriate confidence level. Similarly, LCC calculates the total operation cost of the system (which includes planning, purchase, operation and maintenance, and liquidation) for the lifetime, and it aims in minimizing the total costs. LCC has been applied in asset management for e.g. photo-voltaic plants [24] and wind-farm plants [25].

A risk management system called IGMS (Intelligent Grid Management System) was proposed by Endo *et al.* [63] which looks into the equipment performance in the transmission and distribution system. It looks into economics, ageing and reliability issues in transmission and distribution equipment, evaluated using a Monte-Carlo method as well as non-linear programming. Mehairjan et al. [16] did a statistical life data analysis for distribution cables which aims at obtaining the future failure probability by considering limited or incomplete data sets of the various assets.

V. Conclusion and Discussion

This literature study on asset management in electric power transmission and distribution system is a first of its kind. The authors have tried the best to include classification and maintenance theories, while also focusing on risk assessment techniques all in one literature study. The study includes 65 articles published from 1996-2014, trying to keep the study updated with papers published in 2014 [4][41][65]. A table of publication listing is shown in Table 1. Aligned with the title, the paper only includes electric power transmission and distribution asset management study. The study would have been incomplete without learning about the implementation of different mathematical techniques evolved in the past two decades in real-time. Cases such as of Lucio *et al.* [64] and German *et al.* [65] on Brazilian and Colombian electrical energy utility respectively, quantify the importance of asset management in today's time thus fulfilling the scope of paper.

TABLE I. Publication Listing

Time-frame	No. of publications
1996-2000	4
2001-2005	17
2006-2010	34
2011-2014	10

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