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Asset management and maintenance programming for power distribution systems: A review

Mina Mirhosseini, Farshid Keynia

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Abstract

Security and continuous proper functioning of the power system is a vital issue for supplying demands. Providing an acceptable level of reliability and necessity of that in all parts of the power system, from generation to distribution, has always been, and remains a major concern for network managers. Asset management and performing regular and routine maintenance activities has a considerable impact on ensuring system reliability, reducing expensive crashes, and preventing shutdowns. Up to now, much research has been done on the proper planning of maintenance in different parts of the network with a focus on cost savings, improved system performance and reliability, and reduced shutdowns. The purpose of this article is to review the findings of the study and to provide a more comprehensive view of the maintenance planning issue.

1 INTRODUCTION

With the increasing population of the world, the development and expansion of technology and industries, the need for energy is increasing day by day and power generation must meet that need. Therefore, the place of reliability at the level of production, transmission and distribution has become more important. Managing assets and planning for their

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maintenance under severe economic, social, political and security constraints is the best way to ensure the required system reliability.

Asset management is an important factor in supporting and enhancing an organization through long-term and short-term management of resources, services and the work environment [1]. Maintenance management and planning is a part of facility management. Maintenance is essential to ensure the correct operation of equipment and system components [2]. The effectiveness of preventive maintenance programs is commonly limited by unsystematic budget setting. An inadequate budget can result in an increase in power interruptions due to lack of maintenance activities. On the contrary, an excessive budget will not efficiently improve the reliability in terms of cost effectiveness as shown in Figure 1 [3]. For all systems, preventive maintenance cost are an added burden to financial bills, so there is no desire to implement them more than as much as necessary for ensuring proper operation of system, preventing customer interruption and the staggering cost of corrective maintenance [4]. This unwillingness can delay the execution of essential maintenance programs, thereby reducing performance quality and preventing optimal capacity utilization. Maintenance activities are a compulsory expense and neglecting them can have severe consequences for the system [5]. According to [6], maintenance requires a large amount of resources and accounts for three-quarters of the total cost of an asset's work cycle. On the other hand, maintenance is a long-term commitment that occupies 90% of the life cycle of an asset and requires careful planning to perform it properly [7]. Disregarding maintenance is a non-economic decision as it can lead to higher costs and detrimental effects [8].

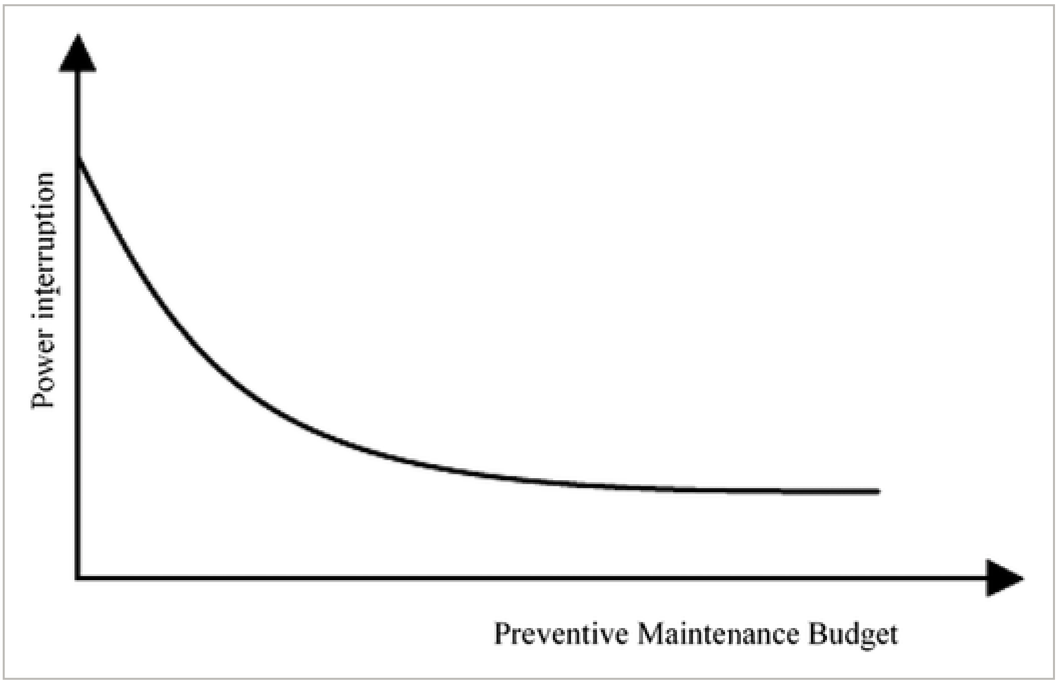

FIGURE 1

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Power interruptions versus preventive maintenance budget

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The subject of asset management is one of the economic and managerial concepts that were introduced in the last two decades in various fields of engineering, especially power systems engineering. The fundamental changes in power systems and the creation of a competitive environment by the electricity market have encouraged all practitioners of the power system to optimal operation and utilize their assets, focusing on the technical and the economic aspects. Different asset management techniques based on the local characteristics of each region are applied in different regions of the world that cannot be extended to all power systems [9].

Given the explanations given tothe importance of asset and maintenance management, as well as its limited and usually inadequate budget, one of the approaches discussed in numerous articles is 'prioritization'. Deciding which factors to prioritize is also a multi-criteria decision that requires a high level of understanding of the system.

The generation system as the starting point in both types of traditional and deregulated power systems is the first place to carry out maintenance activities. The generation system maintenance scheduling problem includes determining when to stop generation units for performing preventive maintenance to maintain system reliability and reduce overall operating costs such as the physical characteristics of the generating unit, providing load and maintaining minimum acceptable range of reliability etc. So, it is a kind of unit commitment problem with side constraints. This issue has been investigated and concluded for many years by considering the electricity market interactions with new optimization methods and there is not much progress in recent studies.

The transportation and distribution system includes a variety of assets for switching and protection at medium and low voltage levels, overhead and underground cables [10, 11] and transformers [12, 13] and distributed generation such as wind power plants [14] and solar. The specifications of the equipment will vary in number, size and complexity depending on the geographical position of the system. Research about asset management in the distribution sector is far less than studies in generation, and this may be because it has less impact on system reliability than other parts, but because of the important effects of proper performance of distribution assets on reducing the blackout times of consumers and thus guarantees the economic and profitable activity of distribution companies, should be considered.

This paper attempts to cover a full review on studies about the management and maintenance planning in the transmission and distribution system of the power system from 2000 to 2019. The structure of the research is as follows:

1. The first part has a comprehensive overview of all types of asset management planning.
2. The second part introduces maintenance activities and their types.

3. Section 3 reviews the methodology of studies in the area of asset management and maintenance planning.
4. Section 4 discusses about components of distribution systems.
5. In Section 5, reliability-cantered maintenance is explained completely.
6. Optimisation in maintenance problems is the subject of Section 6.
7. And in the last section, we summarize the discussion and present prospects for the future.

2 ASSET AND MAINTENANCE MANAGEMENT PROGRAMMING FROM A TIME PERSPECTIVE

To achieve the best level of capability and also to optimize equipment costs during their lifecycle, power system management is studied at three levels:

Network development (long-term)

Asset management (mid-term)

System operation (short-term)

As it is seen, asset management and maintenance plans are in the mid-term programming for the system. These plans are aimed at managing assets throughout their technical lifecycle and ensuring standard-based safe operation and service.

The asset management programs are categorized into two areas of time and field of activity and can be seen in Figure 2 [15]. Long-term asset management (AM) are for over one year and often aimed at bringing in new assets and developing a distribution system. Mid-term AM is from a few months to a year with the aim of optimally planning maintenance to extend the useful life of the equipment and reduce the risk of shutdowns. Short-term AM is divided into two categories of time-consuming activities (daily or weekly) to minimise physical and economic hazards based on the hourly price and demand, and of real-time (off-time) activities to deal with sudden events such as climate change using new online monitoring systems such as GIS.

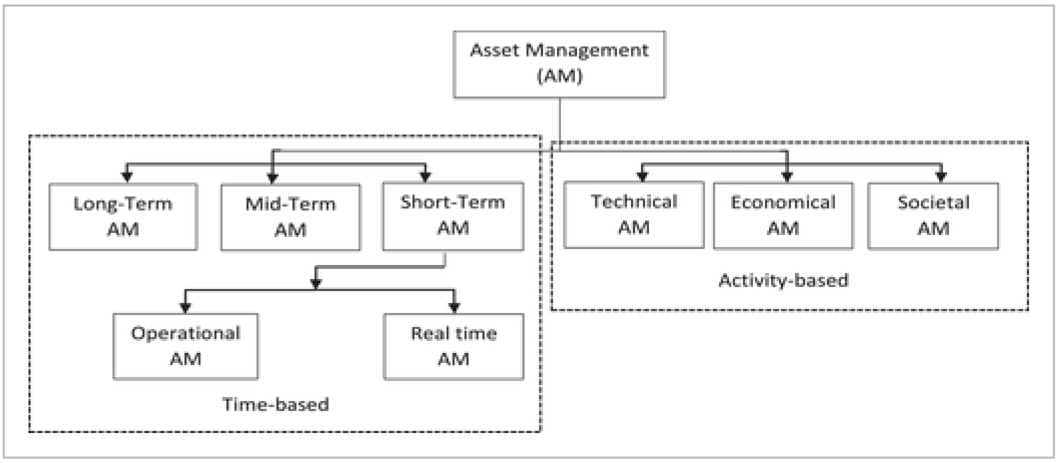

FIGURE 2

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Classification of asset management based on literature study

In the activity-based category plans, technical plans actually depend on the features of equipment such as lifetime effect, failure rate etc. Economic programs, as they are called, actually examine the economic aspects of a program, such as the cost of maintenance and supplying spare parts, and ultimately, social programs examining the impact of the use of assets on the environment and social life. For example, providing permanent, risk-free power to vital centres such as hospitals.

3 MAINTENANCE IN POWER SYSTEM

Maintenance is a commitment activity designed to ensure optimal performance of a component by remaining in the correct operation or returning to its previous performance level. Maintenance activities are divided into two categories:

1. **Corrective Maintenance**: Corrective maintenance and repair (CM) is performed after a component has been damaged. The purpose of CM is to restore the component to its operational state as quickly as possible by repairing or replacing a component that has been damaged.

2. **Preventive Maintenance**: A preventive maintenance and repair (PM) program is implemented to prevent premature failure and quality reduction of component. Preventive maintenance is performing pre-designated activities on system components to increase the reliability, availability, security and performance of those components; in other words, the PM can reduce the failure probability of a component. PM programs can be classified into the following three general categories [16]:

   Time based Maintenance: PMs are scheduled on a regular basis and are based on a staff component's background and experience. This method refers to routine maintenance tasks performed on an asset at fixed time intervals, regardless of its

Typesetting math: 100% The advantage of this method is that all pieces of equipment are checked intermittently but since it may be performed whether it is needed or not, it does not always strike a balance between risk and reward. If these intervals are not optimally programmed, the probability of system error is increased [17]. Similar to [18], two parameters of fixed time interval for PM measures and PM activity levels are introduced to minimize the overall cost of optimal PM activity over the minimum number of components. To find the minimum number of components, penalty of causing failure associated with each component is calculated and is specified by the virtual limit of the minimum penalty, number of components allowed to perform PM is determined.

The disadvantage of this approach is that firstly accessing the information about the components history is not an easy task and secondly, since the component performance conditions are subject to various factors such as environmental conditions, the decision-making based on the components information always has a percentage of error. Therefore, this method of maintenance is not able to minimize costs and the implementation of this procedure will result in high non-economic costs.

Condition-based maintenance: In this kind of PM, the erosion status (failure rate) of components is checked at specified intervals, and when the erosion rate of a component exceeds a certain limit, PM is performed on that component. This method helps in the continuous evaluation of the equipment, while helping to detect hidden system errors and bugs that may cause a global error [19]. Similar to what we see in [20], based on periodic visits, scoring on the status of repairable components (components such as fuses are excluded from the calculation because these components have to be replaced after a breakdown) is scheduled for annual maintenance. Markov transfer matrix was used to quantify the status of components in the visits and to determine the probability of component failure and the objective function is minimizing the annual cost, including repair costs, re-dispatching cost of repairing units, and cost of failures resolved with the constraint that visiting and repairing several components should not be in one block of time.

Note that this method is only based on the failure rate and does not include cost/benefit studies. This method is more efficient than the time-based PM but due to not considering the probability of failure and the consequent component failure, it cannot guarantee the optimal response

Reliability-centred Maintenance (RCM): It is superior to both previous approaches because it considers both the probability of failure and the result of component failure and can greatly guarantee to achieve optimal results based on cost/benefit analysis. This kind of PM is discussed in detail in Section 4. In the following, we review the methods for the implementation of the maintenance programs and the cost allocation associated with them in recent studies. There is a summary table with the advantages and disadvantages of the mentioned methods in Table 1.

4 METHODOLOGY IN STUDIES

As mentioned in the introduction, the cost of maintenance is an undesirable cost to the system and the budget allocated to it is never sufficient to carry out preventive activities on all components. For this reason, different decision-making methods are used to allocate a limited budget to critical and sensitive components. The first step is problem recognition and user priorities in problem solving. Assuming that the system and the user's expectations of the network are fully understood, accessing them is ensured by measuring reliability criteria. Various methods for determining the weight and prioritization of indices in performing of maintenance programs have been studied in various articles and we have provided here a categorization of these methods as seen in the following section.

4.1 Prioritize maintenance procedures

4.1.1 Sensitivity analysis

One of the simplest ways to determine the importance value of system components is using sensitivity analysis. In this method, we measure the impact of changing one or more inputs on output variables. In the maintenance scheduling and prioritizing system's components problem, outputs are mostly reliability indices, and failure/repair rates of each component are inputs, which is improved by performing maintenance. In [24] the rate of changes in reliability parameters (SAIFI, SAIDI) without performing any maintenance activities, in two consecutive time periods is measured to the failure rate changes over the same two periods. A weighting coefficient is considered for improving the quality of the solution for each component. This coefficient is the blackout cost due to the failure in each component. In [25], it first classifies the components of the distribution system under study (cables, circuit breakers etc.) and then each time the failure rate of one batch is assumed to be zero (ideal) and the rate of changes in the availability and shutdown factors calculates and compares in each case. Obviously, considering the location of each component is effective on the degree of criticality but that is not considered here and is a major disadvantage of this project. On the other hand, just checking for changes in a reliability index alone is not enough to determine the importance of the components, and which indicator should be tested is largely depended on the type of system and operator expectations. In general, the sensitivity analysis method is inefficient because of its inability to cover the effects of series and parallel components.

4.1.2 Multi-criteria decision-making

Multi-criteria decision-making (MADM) methods have become popular to consider more reliability indices and improve the quality of component prioritization methods. The overall process for multi-criteria decision-making is shown in Figure 2 [26]. The difference between multi-criteria decision-making methods is in the priorities that the user expects from the network.

For example, [19] Dempster-Schafer's theory of evidence was used to decide on condition-

Typesetting math: 100% e, and in [27] five indices were first defined to compare system components with each other. The fuzzy AHP formulates the decision matrix (components and indices) and finally the FAHP method determines the rating of each component. Another quantitative decision-making technique used in the field of maintenance is fuzzy logic. In [28] six important indicators of system reliability are defined and scored based on the system expert's opinion. The multiplication of fuzzy value of these indices determines the priority of each component for maintenance activities. In [29], using game theory, a factor measures the impact (on system reliability) of each component in partnership with other components by calculating the Shabbly value for each component. In the deregulated power systems that developed throughout the world today, interactions between market components and practitioners cannot be ignored, which is why one of the most recent studies [30] using the AHP method; in the first step, the importance weight of the market components (generation companies, distribution companies, regulators, independent system operators) is determined. In the next step, the decision-making on indicators relative to each other (for each of the market practitioners in the previous step) are determined. The other positive point of this project is to consider uncertainties for all market practitioners using the Monte Carlo iterative method, but the multi-criteria decision-making process is still based on the opinions and ratings of the technical experts.

In these methods, how to determine decision indicators is very important and it depends on the user's perspective. In addition, the decision-making process of weighting indicators are based on the personal preference of experts and specialist's opinion, which reduces the validity of the process. This objection is more or less observed in other multi-criteria decision-making algorithms. So, it is necessary to find the algorithm in which the weighing process becomes more reliable and human less.

4.1.3 Artificial intelligence

With the advances in artificial intelligence (AI), its use in maintenance management has expanded. One of the artificial intelligence techniques studied in this field is ANN (artificial neural network). In [31], using ANN, the amount of wind, solar and demand generation is estimated and the level of reliability in the system and budget is calculated. It estimates the amount of cost that can be allocated to maintenance.

Artificial neural networks are mostly used to solve the following tasks: association, classification, clustering, pattern recognition, image processing, control, optimisation, modelling and forecasting. The basic design of artificial neuron is very simple. The same feature is used in [32] to estimate the condition of the transformer using a special type of neural network called FFANN to predict when the transformer needs repairs and maintenance activity. In a newly published article [55], ANN is established to estimate the probable fault date and periods between to breakdowns by using 11-years fault data for power plants. This article uses MADM method (AHP and TOSIS) for organizing priority ranking list of power plant equipment and ANN for finding time and severity of maintenance [illegible]ly on critical equipment.

As all ANN using articles need comprehensive and complete type of data for long term in past, this method is not a good choice for distribution systems with great number of components which information of their repair/failure rate does not available or at least very hard to collect.

4.1.4 Definition of new combinational factor

The use of SAIFI and SAIDI factors in identifying important system components may not meet all the reliability dimensions required by the system. On the other hand, checking all standard reliability factors for the system is neither rational nor possible. Defining and creating a composite factor that has a multilateral view of the system's reliability level is a good idea to solve the problem. In general, the factors that are used to prioritize operations are divided into four categories: technical, economic, social and political [33]. Sometimes a suitable factor is a combination of these fields and is presented with a weighting coefficient that determines the importance of each factor to another one. This issue has provided good research ground in recent years. As can be seen in [34], a factor called the Risk Priority Index that is the product of failure probability, transmission line condition function and failure outcome function is introduced to prioritize maintenance activities. It is also presented in [35] to identify the most sensitive and critical circuit breaker in system, a weighted factor of reliability indicators is provided. Also, in [36] a new and interesting cumulative factor called weighted cumulative diagnostic impotence factor (WCDIF) is introduced which is based on calculating the system's unavailability in case of failure in each component. Obviously, the larger the factor, the upper the place in the priority list of maintenance for component and it means more budget should be spent for PM applying on them. In one of the new papers [37], the defined factor creates an interesting balance between important types of reliability indices including SAIFI, SAIDI and EENS. In the weighted factor (WI), the three important indices were each linked to their weighting coefficient that derived from the cost of losing load, while considering the feature of the series and the parallelism of the components. First, the most important feeder in the distribution system and, secondly, the most important load point in that feeder determines to focus on maintenance activities.

Preventive maintenance can be divided into two categories: Active PM and passive PM. Passive PM means those maintenance activities that are planned regardless of electricity market and price while Active PM follows price changing in the electricity market. Most research involves active PMs. However, in [38] the aim is to set up a plan for maintenance and operation that will minimize electricity cost and operating costs in a fully competitive electricity market (active PM) and maximize profits. This problem is optimized in GAMS software. Consideration of electricity market interactions and the impact of system failure on market operator decisions is discussed in [39]. A new factor is defined as the sum of expected costs of the generation and distribution company, and the maintenance cost of component in case of failure. Amount of changing in that factor is known as the criterion for determining the importance of the components. There is a summary of advantages and disadvantages of prioritization methods in Table 2.

TABLE 1. Advantages and disadvantages of the preventive maintenance methods

	Time based maintenance	Condition-based maintenance (CBM)	Reliability-centred maintenance (RCM)
5. Advantages	Lower long-term cost Easy to implement Predictable schedule Effective for continuously running assets	CBM is performed while the asset is working, which lessens the chances of disruption to normal operations. Minimizes unscheduled downtime due to catastrophic failure. Minimizes time spent on maintenance. Reduces the chances of collateral damage to the system.	Lower costs by eliminating unnecessary maintenance or overhauls. Reduced probability of sudden equipment failures. Able to focus maintenance activities on critical components. Increased component reliability. Incorporate root cause analysis.
6. Disadvantages	Ignores other causes of failure Too frequent schedule introduces risk Too infrequent schedule leads to excessive	Condition monitoring test equipment is expensive to install, and databases cost money to analyse. Fatigue or uniform wear failures are not easily detected with CBM measurements. Condition sensors may not survive in the operating environment.	Can have significant start-up cost, training, equipment etc. Savings potential not readily seen by management.

TABLE 2. Advantage and disadvantage of prioritisation methods

	Advantages	Disadvantages
Sensitivity analysis	This method can model the effect changing in one component condition in reliability indices easily.	Impossibility of examining several indices in one analysis Location of components is not considered This method cannot cover the effects of series and parallel components.

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	Advantages	Disadvantages
decision-making	component prioritisation methods with proper weights. Choosing proper method of decision-making according to problem pattern	process of weighting attributes and alternatives is based on the personal preference of experts and specialist's opinion
Artificial Intelligence	Accurate clustering and estimation of failure rate/repair time and failure cause	Need comprehensive and complete type of data for long term in past, this method is not a good choice for distribution systems with great number of components
Definition of new	Considering multi more than one reliability indices with appropriate weighting factors	–

The process of implementing an optimal maintenance plan does not finish with the prioritization of critical components. Rather, to achieve the highest level of reliability for the system and the least cost, it requires a rational and practical strategy from the beginning (problem and component recognition) to the end of the route, that is performing repairs and evaluating its impact on the network. This dynamic strategy is nowadays known as reliability-centred maintenance planning.

5 COMPONENTS OF DISTRIBUTION SYSTEMS

As distribution systems consists a large number of components, there are lots of studies which focus on important pieces of equipment of the system such as transformers [60], breakers [61, 62], switches and line branches (underground or overhead cables).

Transformers and circuit breakers as vital and most expensive components of distribution system have been noticed more than the other components [25, 26]. For example [63] used statistical estimates of failure probability and the expected economic impact of failures in multi-objective optimization, simultaneously minimising the maintenance costs and the predicted cost of unexpected failures to form an integrated framework of transformer maintenance management. In [64], Markov reliability and reward models are used to perform component failure and repair rates and follow the effect of parametric uncertainty in reliability and performability indices and the proposed method applied on sample system to apply preventative maintenance of an electric-power distribution transformer. Paper [65] determines the optimum maintenance strategy and optimum power flow control based on condition monitoring and diagnostic results of the operating power apparatus. Additionally, the risks are evaluated in the cost according to the impact of the failure rate for transformer and circuit breakers. In [66] multi-objective optimization is applied on components with high potential for improvement like transformer aims to create balance between PM and CM. One of the best references [67] using artificial neural system as a solution for solving the objective of reliability maximization with minimum cost and number of transformers and

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the required time by crews are considered as constraints of the problem. Many studies have investigated about failure mode and effect analysis with focus on transformer as a critical component of the system, some of them are [22, 23, 44]. In [71] transformers are the most critical component of the system by default and it proposed a model in which the micro grid exchanged power with the utility grid which is reshaped in such a way that the distribution transformer lifetime is maximized.

Other section of distribution system like overhead line is the subject of some studies. For example, in [70] proposes an efficient mixed-integer linear formulation for long-term overhead lines maintenance scheduling, utilizing the model of decoupled risk factors. Their effort establishes a precise description of time-dependent deterioration failure rate and provides the ability to determine the most cost-effective maintenance scenario while satisfying the reliability constraints.

6 RELIABILITY-CENTRED MAINTENANCE

RCM is a centralized strategy that create comprehensive links between preventative maintenance activities and network reliability and cost constraints. Reliability-centred maintenance provides a general framework for maintenance on the key prioritized components to provide the highest reliability at the lowest cost for the generating and transmitting units [40]. As it is completely described in [56] RCM is a statistical systemic application of historical data to apply the best possible maintenance program with least cost. According to the standards of the International Electro-Technical Commission (IEC), the basic steps in an RCM are as follows [21] and a detailed flow chart is shown in Figure 3:

1. Determining the boundaries of the system and its components
2. Determine the task of each system and its components in order to determine the critical subsystem in terms of performance
3. Identifying the causes of failure in important components
4. Forming a decision tree to categorise the failure causes in important components
5. Identify appropriate and effective maintenance strategies that constitute the initial repair plan
6. If proper maintenance activity is not found, repeat the designed routine.

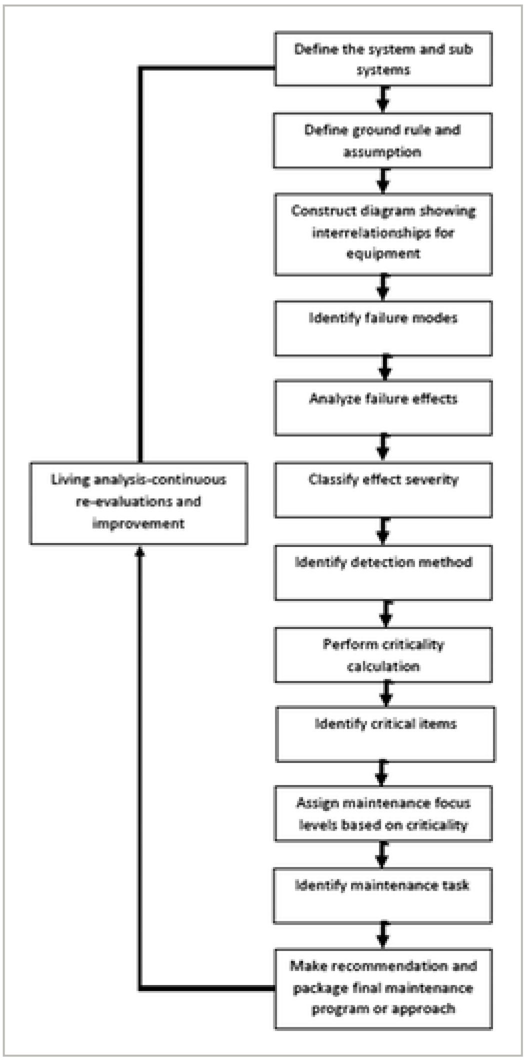

FIGURE 3

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RCM process

In completing the cycle of maintenance programming, proper maintenance activity should apply on important component. If reliability goals are not achieved by applying one PM, this process will be redone.

This method has been the model for many researchers in recent years. One of the first investigations in the power distribution system with RCM prospect is [22]. In this study, first, the failure modes and their effects analysis (FMEA) were tested for the components of the system, then the components within the critical permissible range (Criticality) are determined by the size of the critical value being prioritized and the type of activity they require (corrective or replacement activity, preventive action to improve efficiency, or at the highest degree, need to change in design principles). In [23], in completing the idea of [22] the reasonable reliability-centred maintenance (RRCM) method used on the same case, with a slight change to the cost-cycle modelling of components, the same results were obtained in reducing the total maintenance costs.

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The tendency to use RCM in electrical engineering evolved around 1980 after its successful operation in the aviation industry [41]. The conversion of aerospace RCM to its application in distribution systems caused significant changes in methodology. For example, in an aviation program, all types of system performance and possible failure scenarios should be identified, but in using RCM in distribution systems, a good case can be made for a simple system definition and failure modes analysis is likely to be sufficient [42].

In [43], a reliability-centred maintenance strategy is designed using the genetic algorithm for scheduling transformer maintenance in the system, and the impact of maintenance on the timing of transformer replacement is well specified. The best study to establish the basic framework for reliability-centred scheduling in the distribution system is [44]. This article covers all the principles of RCM implementation including problem definition and scope, determination of reliability factors according to problem type and needs, determination of a critical factor called component criticality, failure modes and effects analysis (FMEA), component failure rate modelling in the critical state of failure, and ultimately the proper execution of the most efficient and cost effective PM activity on the most critical component, using cost–benefit analysis. In addition, this process will continue until the reliability factor reaches the desired level of operator, so the execution cycle guarantees that the desired outcome is achieved. The second part of this paper is the implementation of the algorithm described in the first part on a sample test. [45] Somehow extends and improves the previous study. This paper shows the critical factor by which the components were categorized was improved in terms of adequacy and inclusivity because it has a weighted sensitivity analysis within it. Performing the best and most economical PM on the critical component and modelling its effect to observe the improvement of the reliability factors are the endpoint of this research. In [54] a multi objective function containing reliability index and economic risk function is defined. The reliability index function is created by defining new combinational factor, summation of SAIFI, SAIDI and ENS and the risk function is the amount of excess cost of maintenance to allowed budget. For more realistic modelling, the uncertainty of loads is considered and fuzzy triangular method is used. PM schedules will be proposed on overhead lines, underground cables, circuit breakers and remote-control switches and its gap of this study is because other important elements of the system are not considered and no prioritisation is done on network elements. The authors of [57] used MADM method, TOPSIS, for the selection of most critical transmission line for RCM. Values of reliability indexes (MAIFI, SAIFI, SAIDI, ENS and CAIDI) are first normalized, and multiplies to weights created by SHANON's method for each index to indicate criticality component index. Failure mode uses the probability of the past four years of the interruption statistics and preventive maintenance tasks considered by them are listed. The benefit to cost ratio (B/C) between SAIFI deviation and maintenance costs is calculated and the most economical task is selected. This study reveals that after performing nine maintenance activities, SAIFI is reduced by 88.84% and SAIDI is reduced by 86.13%.

Table 3 compares the existing literature around RCM implementation and prioritisation method used in the electrical industry.

TABLE 3. Classification of RCM literature

References	Critical component identification		Failure rate modelling	RCM framework	Maintenance cost optimising
	Method	Systematic approach			
Salar Moradi et al. [45]	MADM	√	√	√	×
Dehghanian et al. [44]	Combinational reliability factor	√	√	√	×
PiassoN D et al. [51]	Cost-based consequences	×	√	√	√
Ghorani R et al. [39]	×	√	×	√	×
Mazidi P et al. [38]	×	×	×	×	√
Afzali P et al. [37]	Combinational reliability factor	√	×	√	×
Rajesh Arya [36]	Combinational reliability factor	√	×	×	×
Jaganmohan Reddy et al.	×	×	×	×	√

7 COST OPTIMIZATION METHODS USING OPTIMIZATION ALGORITHMS

The common point in all the methods mentioned here is that the amount of budget allocated to maintenance activities is clear and only the division between critical components is studied. However, in real-world problems, the goal is to minimize the allocated budget for the sum of maintenance activities so that the CM cost for the system is zero or negligible. Therefore, the problem, in addition to properly allocating the budget among the important components of the system (prioritizing), is minimizing the amount of this budget. On the other hand, in all studies of RCM planning, some kind of optimization is Typesetting math: 100% ne the optimal amount of reliability indices and to compare them with the amount of them after PM to evaluate the effectiveness of the implemented maintenance strategy. Structure of objective function in to minimize the cost and maximize the reliability, these objectives have been introduced in various ways in different studies. The following classification can be provided:

A. To minimizing reliability indexes that their desirable nature is to be zero, like SAIFI, SAIDI, ENS.

B. To maximize reliability indexes that their desirable nature is to be 1 (normalized value), like ASAI.

C. Minimize total cost of production/generation (economical dispatch)

D. Minimize replacement cost (or corrective maintenance), repair cost

E. Operation and maintenance cost

F. Reliability cost, outage cost

G. Minimize risk function

According to the researcher concept, the process of optimization could be designed in the form of a single function or multi-functions.

Studies mentioned in the RCM section (45-46) this optimization is often done with deterministic methods such as Lagrange's, because the optimal value of the reliability index is always constant regardless of the changes in system status, while optimizing the cost of maintenance by deterministic methods is an old and inefficient way, because by changing the status of components due to various reasons such as exhaustion, the optimal amount of cost allocated to maintenance will change. In [46] the cost of operation and maintenance is minimized by the economic dispatch of load by the Gradient reduction method, and in [47] the optimal scheduling of circuit breakers replacement using the optimization function of the sum of maintenance and operation costs, replacement cost and the cost of reliability is implemented by the Branch & Bound method. Reference [68] proposes a mixed integer non-linear programming (MINLP) model to enhance the resilience of distribution systems exposed to hurricanes through an optimal preventive maintenance planning. For this purpose, a novel risk-based index called the Expected Outages (EO) is proposed and integrated into this MINLP problem. In fact, minimizing the EO directly enhances resilience of distribution systems. The resulting optimization problems are solved through the branch and bound algorithm. Researcher in [69] formulate a stochastic MINP model (SMINP) for optimizing the maintenance schedules in active distribution networks with the aim of reducing the total maintenance and operation cost, constrained by the reliability indices over a multistage planning horizon. Then they use Monte-Carlo tree search (MCTS) for solving distribution network maintenance scheduling problem. An optimal plan of actions for multiyear maintenance schedule based on the risk approach and the model of decoupled failure risk factors in distribution network is investigated in [72]. Defining new model of state transition leads to create new variables that are solved with dynamic programming method. To learn more about risk consideration in maintenance programming, [73] introduces an efficient risk-based maintenance management strategy for distribution system operator in the presence of PRM (penalty/reward mechanism). Decision tree and mixed-integer linear programming (MILP) formulation are used in the proposed approach to achieve a precise description of the time-dependent failure rates of equipment in the distribution networks and to evaluate the effectiveness of the various maintenance strategies.

Due to the complexity of maintenance problem and the expansiveness of its dimensions in the power system, the use of heuristic optimization algorithms has created greater flexibility and incorporates non-linear and complex constraints to the objective function. [53] Used a comparative view point in problem of maintenance facilities (depot) location in electric power distribution. It means that the problem was solved by two kind of algorithms, a Particle Swarm Optimization (PSO) algorithm and a Mixed Integer Linear Programming (MILP) model and the computational results show two approaches complete each other depending on the scale of the problem. What has led to a variety of research in this area is not only the variation in stochastic algorithms, but also the variations in the authors' view of constructing the objective function that has produced interesting results, while all of them seek to minimize the cost of maintenance. In [48, 49] the objective is to minimize the cost (total cost of generation, maintenance cost, replacement cost and blackout cost) for three components of the transmission system (overhead cables, underground cables and insulators) using the cumulative particle swarm optimization algorithm (PSO) and finally find the optimal PM strategy. The author used the Markov chain to simulate the effects of aging on the components. In [50] the failure rate of each component of the transmission system is modelled with the Weibull distribution function and the objective is to minimize the cost of maintenance (PM and CM) by maintaining an acceptable level of reliability. This function is solved by PSO optimization algorithm. The use of innovative optimization algorithms in maintenance problem has provided acceptable and reliable answers. The author of [58] tries to model the reliability level of distance protection equipment of system using Markov process and then minimize the function of SAIDI and cost (sum of maintenance cost and outage cost) by Improved Jaya Algorithm (IJA).

As in [51] multi-objective genetic algorithm used to minimize the cost of maintenance and inaccessibility of system components under the constraints of ‘System Average Interruption Frequency Index’ (SAIFI) and ‘System Average Interruption Duration Index ‘(SAIDI). As [54] is checked out in the previous section, for getting best trade-off between reliability index function and economic risk function in multi objective function, the non-dominated sorting genetic algorithm is employed. One of the pareto front solution should choose. Max-min operator is applied and the final selected result is one that the economic risk is about zero

Typesetting math: 100% x is higher than other solutions. It means economic constraints are very important and effective on final decision-making. Similarly, in [59] NSGA-II is used, but the multi objective function is composed of total cost of maintenance cost and system unreliability. What makes this article stronger and innovative is the modelling of maintenance cost and unreliability function and also the constraints of the problem. The following parameters are measured in periods of monthly, quarterly and yearly: system interruption duration per consumption unit (DIC) and system interruption frequency per consumption unit (FIC). These parameters have defined limitations. Average time of maintenance task, number of maintenance task and life cycle of each equipment are other constraint of this problem. As Markof and Weibul model for reliability modelling have been tested in many articles, Poisson have been used here. Proposed algorithm provides set of non-dominated solutions very close to optimal pareto frontier.

8 CONCLUSION

This study provides an overview of researches about asset management and maintenance planning methods in the area of distribution systems. Articles published from 2009 to 2019 were categorized and presented. Overall, the goal is to plan equipment to achieve optimal lifespan for assets, developing preventive maintenance activities, and ultimately minimizing replacement and substitute cost. To do this, we first need real information and proper functional analysis. Smart Grid infrastructure and online network monitoring devices are one of the most basic requirements and defaults of the system. Understanding of the system and its expectations of that will lead to the selection of the correct method of planning asset and system components management.

What can be found from the overview of the methods is that the correct asset management approach is actually to create the right mix of existing methods and build a comprehensive strategy for prioritizing components, minimizing costs and maximizing profits for all power system stakeholders. The method of asset/component prioritizing must be aligned with the user's goals in order to achieve the above objectives in the long term.

For more research in future, investigating and introducing a systematic management approach taking into account system uncertainties (caused by load changes, change in renewable power generation etc.) and studying its impact on maintenance programs and RCM patterns is suggested. Introducing a new hybrid factor that is both efficient in component prioritization and budget allocation is another interesting area that has not been studied extensively.

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