Overview On Role Of Asset Management Systems For Smart Microgrids

Y. V. Pavan Kumar

Abstract : Electrical energy demand of urban community buildings such as buildings of financial districts, industries, IT SEZs, greater communities, universities, etc., are increasing day-by-day resulting in frequent grid outages. Besides, in the modern smart grid era, the energy sector is looking for the load side management to deliver superior services to the consumers and also to manage their network effectively. To meet all the aforesaid objectives, "smart microgrids" are being deployed at distribution level by using information & communication technology (ICT) and instrumentation & control systems engineering. The fruitfulness of these systems depend upon how best it can manage all its individual assets, where, asset management systems (AMS) play a crucial role. An AMS facilitates monitored and coordinated activities in an organization to enable controlled environment to realize full potential value from the critical assets of the organization. Further, significant growth in technology and device protocols brings added value to AMS deployment. However, technology refresh problems, standard architectures, and suboptimal unified standards are creating difficulties for the users to deploy AMS for their assets. So, it is very important to understand all these aspects that are related to the AMS deployment for smart microgrids application. With this objective, this paper presents an overview of AMS and all its related aspects such as the architecture and its components, objectives, fault analysis, risk management, etc., along with a practical case study of a smart power system network.

Index Terms : Asset Management Systems (AMS), AMS architecture, Key drivers of AMS, Key goals of AMS, Plant assets, Smart microgrids, Urban community buildings.

1. INTRODUCTION

THE INCREASING supply-demand gap of the electricity for the present and future needs is a foremost concern in the current energy sector. Besides, the issues of environmental pollutions, fossil fuel depletions, and rapid economy growth of the developing countries are driving the design of local power systems, namely "microgrids", based on alternative sources of energy [1], [2]. These are further growing as smart electric systems by the use of advanced automation and control philosophies, which typically contains sensing technology for the continuous monitoring of electrical operational parameters (such as voltage, current, frequency, etc.), maintenance parameters (such as device temperature rise, equipment health conditions, etc.), business growth planning (mainly based on forecasting), and all other key parameters that have major impact on the business [3]. These measurements activate the human machine interfaces or actuators for taking the necessary control actions based on the pre-defined logics. All these modules (e.g., energy sources, loads, monitoring and control equipment, devices used for planning, maintenance and management equipment, etc.,), which takes a part of aforesaid operations are integrated to realize a smarter distribution power system called "smart microgrid" and each of these modules are called as an "asset" of the smart microgrids [4]. The fundamental objective of smart systems/networks is to create "an interactive environment to all the plant assets for better monitoring, management, and control" [5]. An asset is "an essential element/entity/device in the plant, whose operation majorly impacts the performance of the whole plant". It should be commendably regulated to yield a value that shows positive impression on the plant's economy [6], [7]. Further, the whole plant is an asset from organizational viewpoint which is in turn an addition of many small distinct assets. Thus, a distribution system exemplifies the integration of many different assets. General assets of a smart distribution power network are shown in Fig.1. These assets may be electrical equipment (circuit breakers, transformers, power electronics, machines, etc.), process equipment (pneumatic devices, valves, etc.), measuring equipment, instrumentation and control equipment, automotive equipment, etc. Different plants may have different type of assets, but, all these require proper management in order to have better control over the plant [8]. Hence, the use of "asset management system (AMS)" is very crucial in the fruitful operation of any asset's life cycle which typically impacts the efficiency of the smart network.

Major aspects of technology advancements and refreshing problems were described in detail in [6]. However, the major focus on technology advancements and adopting those for the capability enhancements of AMS were not addressed. As per the contemporary trend of energy efficient and smart grid era, it is very much intended to introduce AMS technologies into the energy sector. The development of chronological asset management in a power system leads to its superior operation and management for achieving enhanced business options and consumer satisfaction. It also provides decision support tools that helps the energy utilities to develop convincing and clear business cases by using modern technologies. This includes plant automation, new feeders' design, fault forecasting or prediction, etc. [4], [6], [9]. With the intent of AMS deployment, some attempts were made in the literature for various applications as mentioned follows.

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***Fig. 1**. General assets of a smart power system network.*

AMS implementation process and objectives of various distribution system stakeholders along with the approaches of securing their rights was presented in [9]. The roles and rights of each stakeholder were considered to find asset constraints and efficiency activities, also, presented a comprehensive framework for decision making and management (planning, operations, supervision, etc.) of a distribution system. Ossai et al., [10] presented a scheme for asset interaction management for renewable energy based power generation plant application. A structured procedure was developed for facilities management by combining environmental and socio-economic demands. Payman et al., [11] discussed an AMS for distribution power system using fuzzy analytical hierarchical process to address the system uncertainties. The effectiveness of this method in terms of its applicability and efficiency in managing distribution systems was validated using a practical case study. Fuzzy sets helped to address the judgment vagueness and uncertainty in the existence of many quantitative and qualitative aspects. Colson et al., [12] presented a decentralized control architecture for real-time and agent-based decision-making for a multi-asset microgrid. It also discusses the capability and feasibility of distributed agent-based control to achieve the smart grid goals. With the use of condition monitoring and diagnostic results of the power apparatus, Hanai et al., [13] presented a power flow control and optimal maintenance strategy to manage the grid intelligently. This decides the optimum power flow control and maintenance strategies. Love et al., [14] presented a framework for the asset owners to ensure that they can obtain values from investigating building information system. Similarly, short-term and mid-term asset management strategies for power distribution systems was presented in [15]. Ma et al., [16] discussed an AMS framework based on multi-agent technology, modern modeling techniques and reasoning procedures based on the probability analysis. It performs real-time asset condition monitoring and aggregation of the useful information for power plant asset management. This helps in improvement of condition monitoring, automation maintenance, and system reliability. Jahromi et al., [17] discussed a 2-stage management model for mid-term and short-term maintenance of power grid transformer asset's maintenance by considering transformer failure rate dynamics. This model was validated in [18] with various case studies. Similarly, Yan et al., [19] developed a probabilistic diagnosis framework for transformer diagnosis under various uncertainties in the system using refined Bayesian network graph concepts. Raghavan et al., [20] presented a state diagram for the plant's optimum maintenance that helps in analyzing the overall system cost and reliability. Probabilistic tools were designed to evaluate life cycle management model that helps for further optimization. German et al., [21] presented a brief review of asset management application in electrical sector of Colombia. It describes the importance of the tools for implementing AMS in the power systems and also highlights the inadequacies of the existing methods in Colombia. Andrusca et al., [22] presented an AMS design for a power system substation. It includes the design of AMS tools that analyze asset's technical condition, deterioration indexes, maintenance requirements, and schedules. Kelly et al., [23] developed AMS using logic scoring of preference method. This is done by optimizing the preferences such as mission role, fuel type, age, cumulative mileage, and miles per gallon to reduce overall cost. Giustolisi et al., [24] presented multi-objective optimal asset design for water distribution networks. The idea was implemented by testing the sensitivity of each solution with respect to the demand pattern. Similarly, [25], [26], [27], [28], [29] explains AMS design aspects for an enterprise, college, civil road, mobile, etc., respectively. In summary of the abovementioned literature review, it is understood that there were some attempts made by various researchers to develop asset management systems for different applications. However, the detailed description about feasible AMS architecture and its other developmental aspects for "smart microgrids", is yet substandard. This has to be analyzed for its suitability and improvisations as it is the emerging trend as part of the current smart grid initiatives. In this view, this paper presents the detailed developmental aspects of AMS for "smart microgrids", which includes key drivers, goals, responsibilities, maintenance and operational life cycle activities, fault detection and diagnosis, etc. Further, to understand the AMS cycle, a case study of power plant economizer is presented.

2 PERSPECTIVES OF ASSET MANAGEMENT SYSTEMS

AMS is a hardware-cum-software application used to manage and maintain assets in a plant for their efficient and optimum utilization. It enables the plant to achieve the excellence in operation and maintenance. There are many AMSs deployed for different applications, which facilitate continuous monitoring, prediction, analysis, and error reporting of an asset's functioning at the plant level. For example, the microgrid of a typical industrial building located in an urban community is shown in Fig.2. The sub-segments of this building are primary (priority) load, secondary (deferrable) load, grid supply, and local energy. All these segments are integrated to central monitoring and control station for their continual tracking. This integrated system builds an onsite power system, termed "smart microgrid". Instrument automation technology is involved in the operation of each and every asset of this smart microgrid system. Automation of the system using AMS helps in remote monitoring, control, and regulation of all the associated assets to optimize the plant's operations. This ensures an effective supply of reliable power to the respective consumers. In general, an AMS manages workflow, maintenance schedules, purchase, analysis, and inventory activities of assets, which includes corrosion monitoring of fixed assets, management of host and field devices, and network of automation assets. In essence, there will be numerous applications or systems used for asset monitoring and management, which forms an integrated plant facility for managing all the plant's assets and work processes. As an overall, the plant's asset management activities are provided for handling sustainable risk over plant's life cycle, which lengthens effective life of typical assets. 2.1 Organization and Management of System AssetsThe assets of a plant can be arranged in a pyramid type layered schematic as shown in Fig.3 in view of importance of each asset in the total plant operation. The management of these assets and features of each layer are given in Table. I.

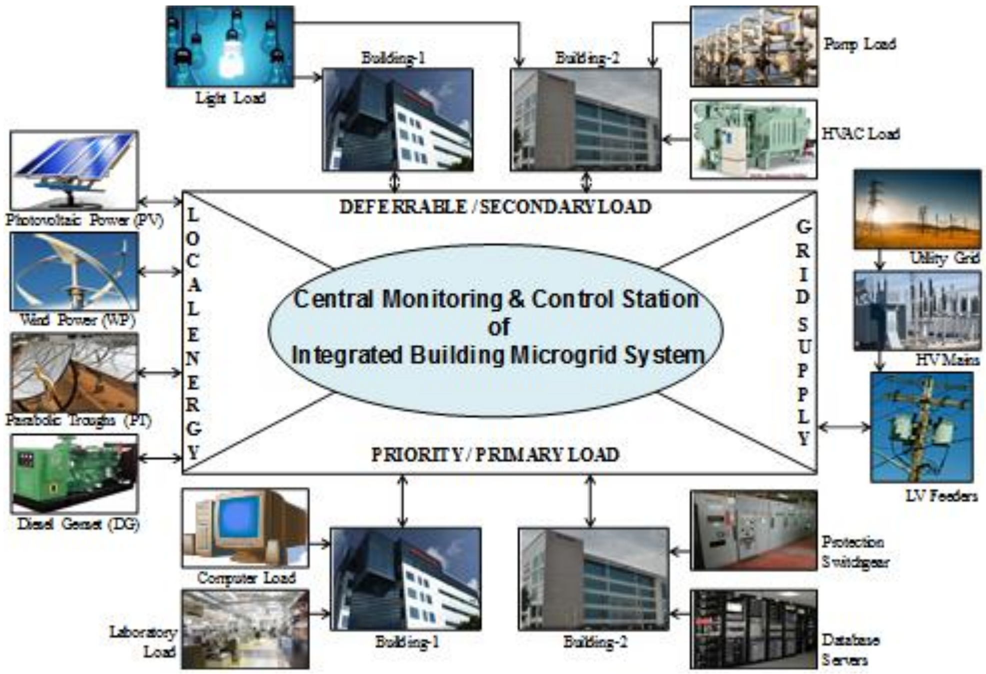


Fig. 2*. Smart microgrid schematic for an industrial building.*

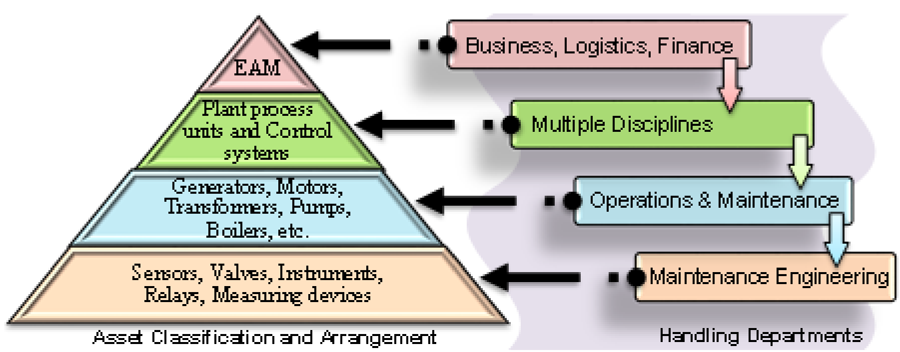


Fig. 3*. Arrangement of distribution plant assets.*

TABLE 1 *ARRANGEMENT OF ASSETS AND THEIR FEATURES*

Layer Number (Bottom to Top)	Features of the Assets	Management Strategy of the Assets
Layer-1	▪ This layer consists relatively more number of assets. ▪ However, these assets have relatively less value and impact on the plant's production when compared to the assets located in upper levels.	▪ Individual maintenance departments usually manage these assets. ▪ There are multiple AMSs available to manage the assets located in this layer. ▪ All these AMSs are integrated with the central monitoring and control station of the plant.
Layer-2	▪ Assets such as motors, pumps, boilers, etc., present in this layer. ▪ Consists relatively less number of assets than the lower level, but the cost of these assets is high and damage of these assets has an effect on the plant's production.	▪ These assets are usually managed by the plant AMS, where, the database of the AMS is converted to fault models to understand the issues and diagnose them. ▪ This knowledge database of AMS help the maintenance people to early predict and do maintenance for the asset issues.
Layer-3	▪ This layer consists of plant assets and process	▪ Management of the assets situated in this layer is carried

	units, which are small in number compared to first two layers. ▪ Maintenance of issues related to these assets has not only impacts the plant's production, but also the plant's business operations.	by multiple people from various respective departments or disciplines. ▪ For example control system engineers will manage the issues with plant processes and instruments.
Layer-4	▪ Top of the pyramid (i.e., Layer-4) consists of Enterprise AMS (EAM). ▪ EAM is the main interface between the plant operators and the external stakeholders. ▪ The EAM implements the total plant's purchase philosophies, cost control, maintenance strategies, auditing, and other critical operations.	▪ The EAM manages the plant by facilitating, - Advanced detection or prediction of any critical asset's malfunctioning in the plant. - Mechanism to inform the respective engineers when an issue is predicted, thus helps for its prevention. - Maintaining knowledge repository by collecting database of various AMS located in the plant. - Continuous learning facility to optimize and further improve troubleshooting ways for various issues.

2.2 Key Drivers for the Deployment of AMS

A typical industry may have thousands of assets to manage. Tracking and managing these assets manually is no longer possible. Software diagnostic tools are the basic requirements to identify and diagnose problems. Nowadays, various plants have gradually deploying AMS to improve their operational proficiency. The use of AMS for the optimum use of resources in a distribution network is highly encouraged by smart grid initiatives [30]. The fundamental drivers for AMS deployment are shown in Fig.4. The importance of these key drivers for AMS deployment are given follows.

- Reliability is a competitive business issue, which effects success of plant's run. Any unintended shutdowns will have considerable impact on the plant's productivity.
- Quality is an endurance point in the commercial market for better products and sales.
- Increased production on aged assets delays new capital investment though sustaining the existing production.
- Reduction of manpower demands to do more with less.
- Cost reductions motivates operations and maintenance.
- More stringent requirements of the customers on product specifications, precision, reliability, etc., affects the business.
- Environmental safety concerns have become an overall plant's issue to take suitable management decisions.

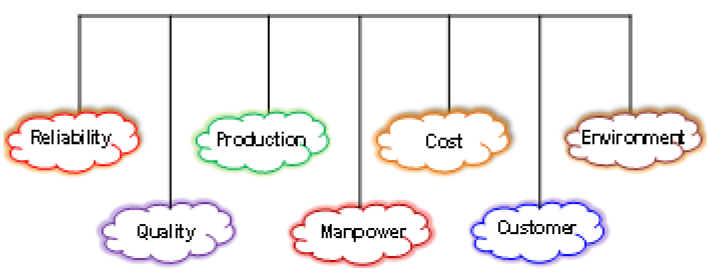


Fig. 4*. Key drivers of AMS deployment.*

2.3 User Perspectives on Asset Management

In the earlier days, the asset management was focused on forecasting the management and maintenance issues, diagnosing the failures, etc. In the current scenarios, it is intended to find system difficulties and ways to increase system capabilities. AMS tools such as performance tracking, diagnostics, and maintenance planning helps in the prioritization, automatic identification, and resolution of asset performance issues. Success in AMS comes from using the right tools and practices. Tools alone may not solve the problems, and, practices without the tools are very ineffective. User's primary interests are on measurement accuracy, predictive maintenance, and diagnostics which, today, are largely built into the field device itself. The hardware, operating system, applications, field device communication technologies, display rendering technologies, etc., becomes secondary to the user. Obsolescence on such secondary elements is becoming a key concern. The available standards are ineffective in controlling the upgrades of the enabling technologies. While these technologies bring competitive differentiation for the vendors, it is essential to control it within a general framework. Today, the major challenge faced by solution providers is to keep pace with migrations, compatibility, and interoperability rather than enhancing and adding value to the existing system to provide more meaningful data to the user to take correct and timely actions. If there are situations where a device in a plant of certain technology would not work properly, then the trouble shooting will become a big challenge. The host could be from a different vendor and device could be from other. Communication technology might be digital and rendering technology might not necessarily be the technology natively supported by the host. Troubleshooting such cases with multiple vendors with different technologies is very challenging and costly. There are numerous advantages of using the advanced technologies such as intuitive and cognitive user interfaces, nice displays, comprehensive representation of information, better user experience, seamless interoperability between devices from various vendors providing diagnostics and prognostics data, etc. There are lots of variants in the system and each of them are developed and governed by different organizations. Change in any of them makes the whole system to be incompatible with each other and results in partial or complete loss of functionality of the system. All or some of them may not directly yield the value for an operator or technician of the plant. Changing those results in loss of the system for the operations for some time and also cost effective. It is very hard to justify these migrations in the plant for the control system which is expected to run for large time without any disruptions. The fact that needs to be elevated is that, if everything works well, these technologies bring very good and intuitive information with proper displays. Engineers like to operate over these without physically reaching the device in these cases.

2.4 Key Goals of an Asset Management System

The success of plant's AMS depends on the role of three elements: technology, expertise (diagnostics), and work process as shown in Fig.5. The plant needs the adoption of technologies that are ready to perform asset management functions and needs expertise from systems and maintenance personnel to diagnose and carrying proper work process that can constantly evolve. Key goals of an AMS are shown in Fig.6. In order to achieve these goals, an AMS mainly requires clear accountability of the actions and ability to perform audit on those actions, ability to measure the performance of the assets and personnel managing the assets, and ability to create and present the report for taking the management decisions.

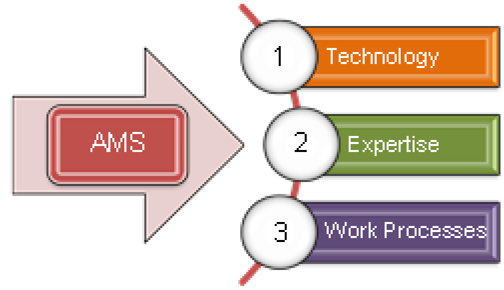


***Fig. 5**. Fundamental segregation of an AMS.*

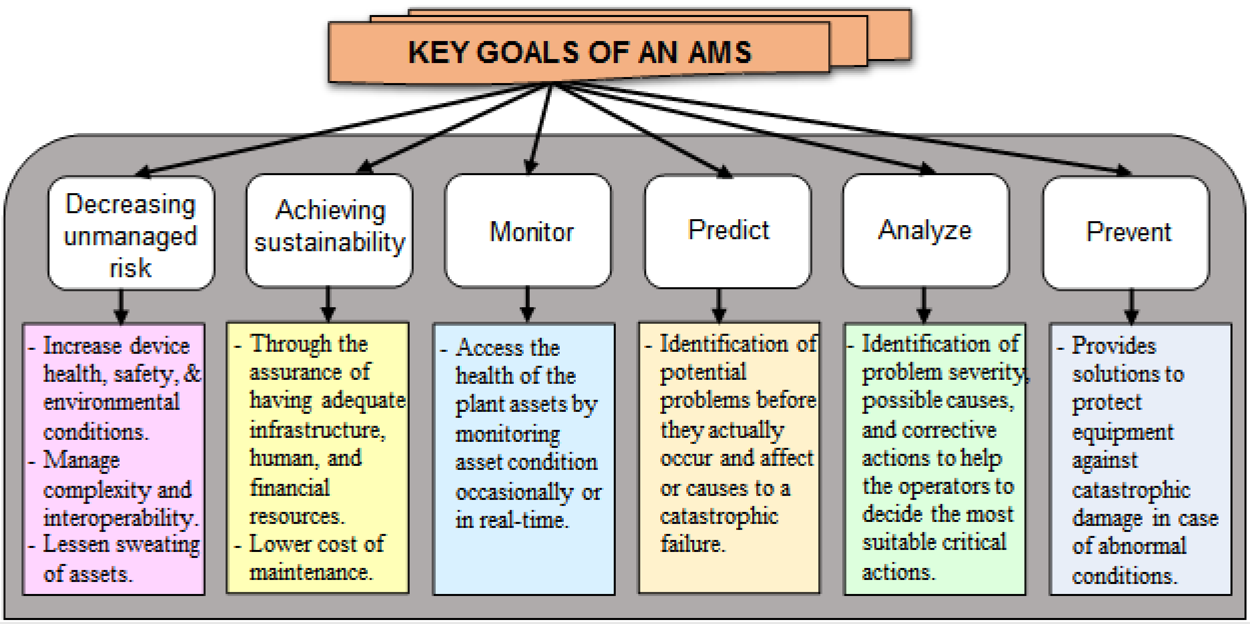


***Fig. 6**. Key goals of an asset management system.*

2.5 Fault Models

In order to achieve the goals and expectations, the AMS is provided with information in the form of models which acts as a blue print for the system while detecting the current and future failures. A model based approach is widely used across many manufacturing plants to reduce the amount of energy and time spent on the low performing equipment. Fault is a state or condition at which a functional failure is identified. A fault model is a model that discovers how the system handles some common failures that contribute to unsafe situations. Fault models are more abstract than the models of normal behavior. They are easy to construct, comprehend, and customize. They can easily capture interactions between the root cause (symptoms) and their effects (faults) without requiring a detail model to simulate the normal behavior. Fault models are classified as fault-symptom models and calculation models.

- A fault-symptom model is used to identify the failures and the symptoms in an asset. This information is fed to AMS to take the decisions for correcting the failures. Various reliability tools like “root cause analysis (RCA) and failure mode and effects analysis (FMEA)” are used for identifying faults and symptoms.
- A calculation model defines calculations on the asset's attribute values. The attribute values are updated based on
- the logic defined in the application. This is followed for both physical and logical entities.

3 ASSET MANAGEMENT SYSTEM ARCHITECTURE

The typical AMS architecture in a smart distribution system describes the integration of various assets through individual networks or communication technologies to form as a single centralized system. It is monitored by various clients for the analysis and control actions to maintain and protect the assets.

3.1 Constituents of an AMS Architecture

The typical AMS architecture includes the server, clients, networks, and smart devices as shown in Fig.7. The responsibility of each of these modules is explained as follows.

3.1.1 AMS Server

The AMS server is implemented by a supervisory control and data acquisition system (SCADA) to communicate with various clients for the monitoring and taking control actions. The detailed objectives of the AMS server are as follows.

- It has to maintain the database of all devices' information such as history, manufacturer, device type, audit trail reports, offline tasks, service and calibration status, etc.
- Performs centralized management of the data, namely, the list of devices, inspection schedule and reports, user-

created documents or manuals (e.g., procedures, bill of materials, parts list, etc.).
- Generates maintenance alarms for necessary actions.
- Follows diversified networks, viz., FDT, safety systems, modem, DCS, hardware multiplexers, etc.

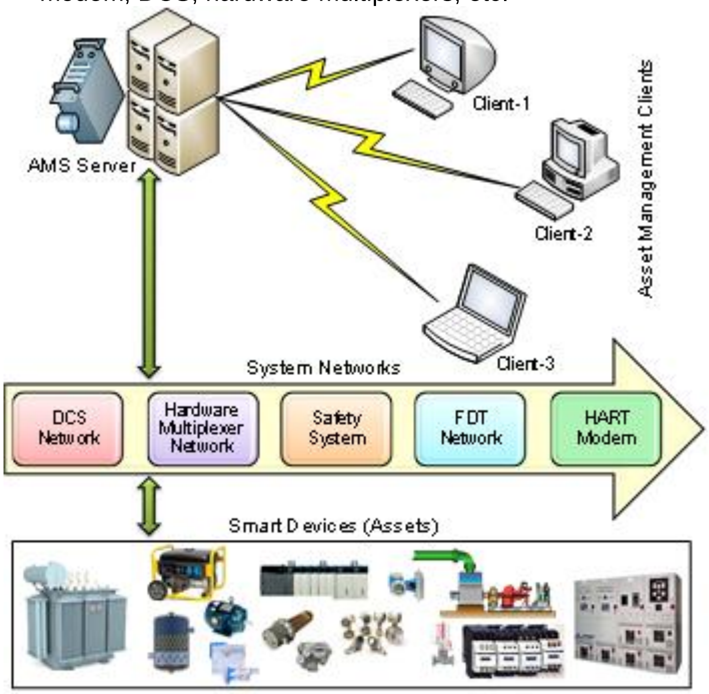


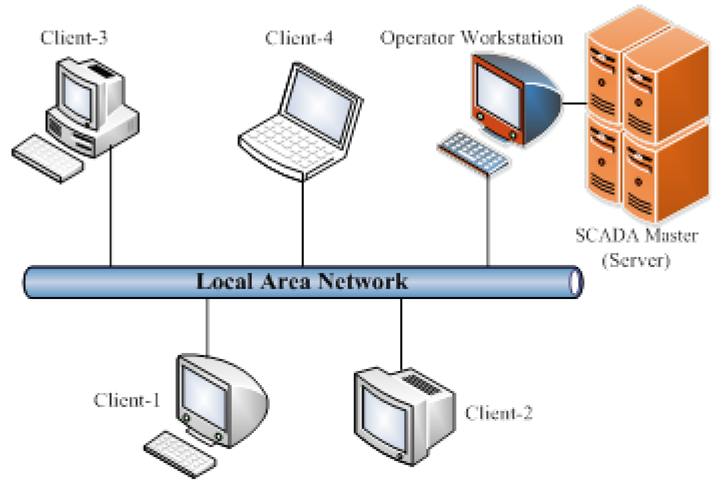
***Fig. 7**. AMS architecture to form a smart distribution system.*

The advancements in SCADA networks facilitate the AMS architecture deployment for wide area monitoring and control applications. Fig.8(a) to Fig.8(c) represents the architectures of SCADA, evolved from first-generation to third-generation respectively. First generation SCADA supports local area network based communication, which limits the connectivity of the devices within a limited area. The next generations two and three supports wide area network based communications, which enhances the use of SCADA. This leads to the more sophisticated and enhanced AMS systems' deployment.

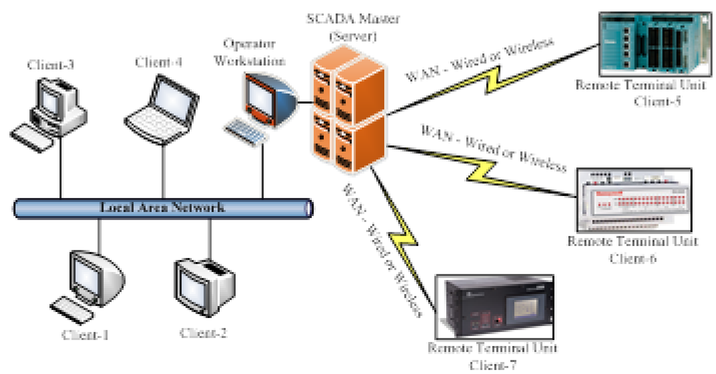
3.1.2 AMS Clients

Clients facilitate the user interface and enables remote server connectivity. The objectives of clients are as follows [31].

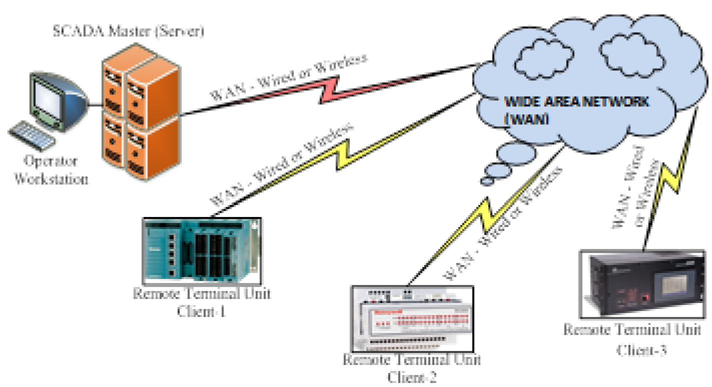
- It has to identify a device and distinguish device-to-device to check their health status and communication errors. This helps to release maintenance alarms, diagnosis alerts (unit diagnosis and process interface diagnosis), etc. to a device.
- Provide windows based user-friendly working platform with a navigation facility to select any specific device. This also helps the user to configure and calibrate any devices, that are generally operating on protocols such as HART (highway addressable remote transducers), FF (foundation fieldbus), PB (profibus), etc.
- Assign identification marks to the devices to recognize their maintenance status. It shares the device information (such as operation and maintenance status) across various engineering and operational personnel.
- Indicating device health status in a simpler way. (e.g. using a status display icon on the user interface to indicate device communication status, etc.).



(a). First generation architecture.



(b). Second generation architecture.



(c). Third generation architecture.

***Fig. 8.** SCADA architectures.*

- Along with the abovementioned standard diagnostic tasks, modern AMS possess tools such as FDT (field device tool), DD (device description), DTM (device type manager), EDD (electronic device description), etc. These tools provide innovative diagnostics as well as smooth user experience.

3.1.3 System Networks

System network layer provides the required technologies and standards for the smart devices to communicate with the server. However, the fruitful deployment of AMS network depends on accurate information rendering. To make these deployments more effective and mature, various technology standards are being continuously developed by reputed consortiums over the years. Some common technologies or standard communication languages such as DD, FDT, EDD, and DTM have been developed by these consortiums. These help to increase the compatibility of the devices supplied by multiple sellers to common systems. Besides, these guidelines help to homogenize the functional parameters of all such devices. The usual user scenario in the perspective of these new initiative is that; the devices should be delivered with any of DD/FDT/EDD/DTM technology while procuring them. It provides a facility to the end user to import/dump all these files into the local AMS of the respective device to make the device compatible with the other devices of the user, thereby operates as intended. So, these files will be subjected to only periodical versioning updates. These updates help to develop rich user-device interface and provides better diagnostics. Network connection to connect an asset to the server is shown in Fig.9. The key objective of these technologies is to perform device self-diagnostics, device integration to central server or control room, and troubleshooting the device during failures.

3.1.4 On-field Smart Devices

On-field smart devices provide essential information such as, health of its own operations and the health of the devices that are connected around them. These diagnostic features are facilitated by modern digital communications (e.g. HART, FF, etc.). Recently, IEC-61850 protocol is extensively developed for the interoperability of the devices [32], [33], [34]. Devices featuring such diagnostics are treated as data servers which are the basis for managing abnormal/faulty situations, process control and optimization, etc.

3.2 Maintenance and Role Based Diagnostics

The capabilities of the smart devices can be realized when these are maintained properly. The AMS maintenance is a cycle as shown in Fig.10. In this cycle, the work plan that is generated for an asset becomes a source for its work schedule. Again, this work schedule becomes a source for the work execution. The work execution becomes a source for work history. Further, this work history becomes source for the future work plan. This way, the work process maintenance cycle will operate continuously to achieve superior operation from an asset. Proper work history and work plan suggests the following maintenance strategies for any plant asset.

- Preventive maintenance: This type of maintenance is carried out at a predefined interval of time. This time interval is usually defined by the plant maintenance strategy or plant work history or the user. The report consists of the analysis on the type of maintenance executed, next milestones, issues found during maintenance, etc., The advantages of this preventive maintenance strategy are as follows.
  - Protect assets and extend the life of an asset.
  - Improves the reliability and reduce replacement cost.

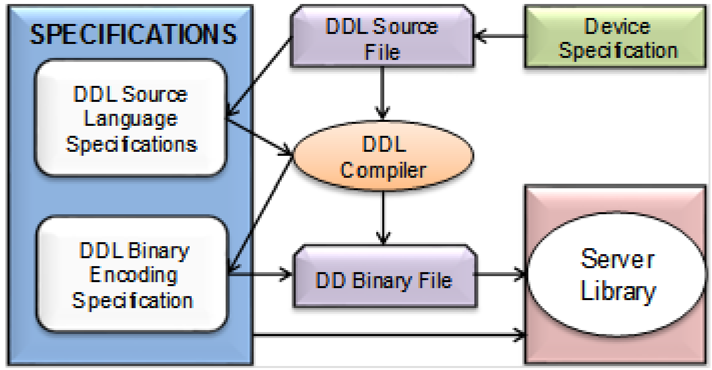


Fig. 9. *System network layout to connect an asset to server.*

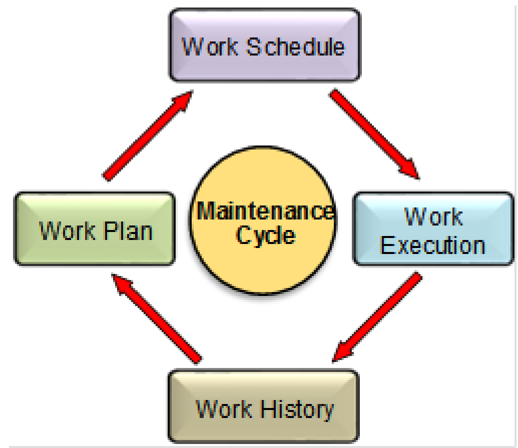


Fig. 10. *Work process maintenance cycle.*

- Predictive maintenance: This is an intellectual way of doing asset maintenance by considering production schedules, risk, and failure histories. It uses RCA and FMEA of the previous failures. This type of maintenance strategy is widely accepted by users in real-time due to the less break down and judicious strategies.
- Condition based maintenance: This type of maintenance has to be performed based on the following factors.
  - Present condition of the asset observed through the predictive maintenance.
  - Based on the asset models developed using the past information or knowledge.
  - Based on the real-time analytic data.
  - Number of variables to be controlled for an asset and type of smart device that is used.

In general, different users have to run different diagnostics. The same diagnostics maybe repeated differently in different situations. Typical roles and responsibilities of different users such as hardware engineer, operator, maintenance technician, manager, and electrical engineer are given in Fig.11. All these diagnostic procedures are continuously updated according to the technology updates in software (operating system and application software), device hardware upgrades, device protocol upgrades, data rendering technology updates, etc., as explained in [31].

4 ACTIVITIES OF AMS IN AN ASSET'S LIFE CYCLE

The life cycle activities of the AMS involves in the design and configuration of the asset. In general, there are two phases exists in any asset's life cycle named as "maintenance life cycle" and "operations life cycle" [35]. The operations life cycle is given by Fig.12, which includes operation plans for the production, operations schedules, product operations, and production history, such that one phase is a source of next phase cyclically as shown. Among all these maintenance life cycle and operations life cycle activities, fault detection and diagnosis is the key activity, which is described as follows.

4.1 Fault Detection and Diagnosis
There are two important methods available to perform fault detection and diagnosis namely, statistical fault analysis and risk assessment as described follows.

4.1.1 Statistical Fault Analysis
The statistical fault analysis is a failure and damage analysis that is developed with the use of the database of fault and damage occurrences. Along with the database, the other units participate in this analysis are, enterprise resource planning (ERP) software, SCADA system, and geographical information system (GIS) as shown in Fig.13.

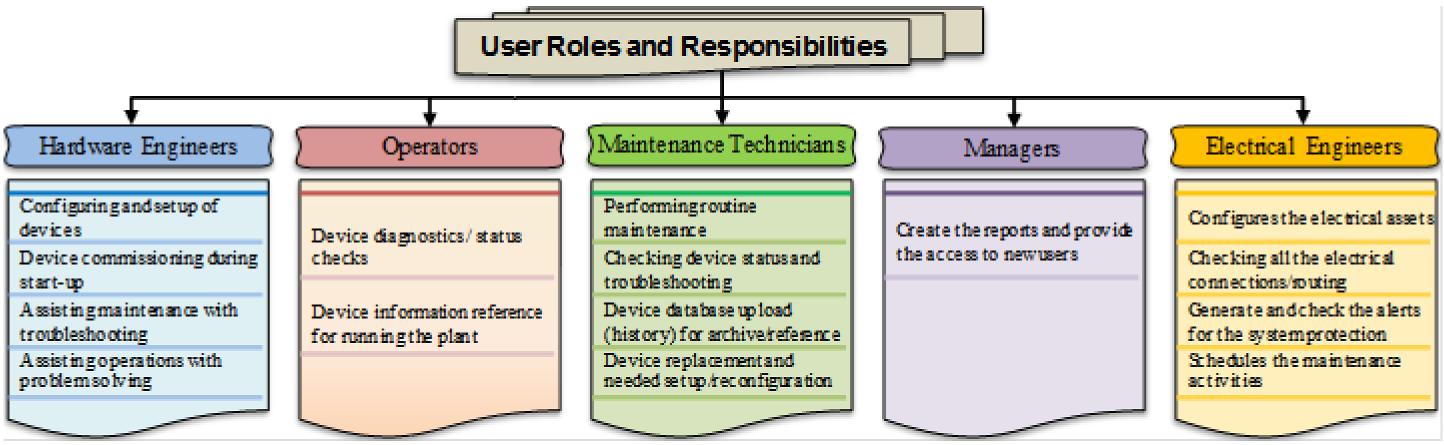


Fig. 11. *Roles and responsibilities of typical users.*

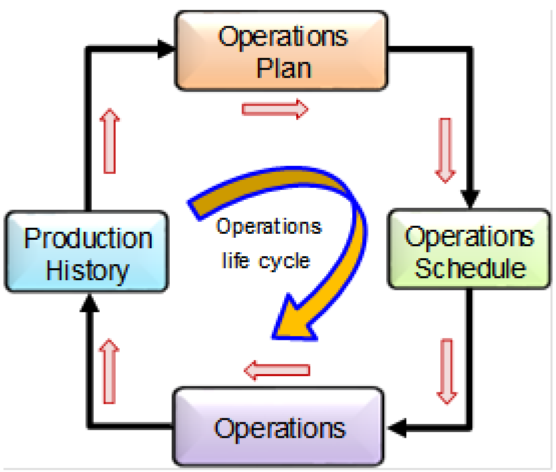


Fig. 12. *Operations life cycle of an asset.*

In the example presented in Fig.13, number of disconnector failures are compared with the number of disconnectors and the number of switching cycles. Based on this comparison, the availability of the asset in a given time duration can be analyzed. This availability metric is always compared with the threshold value 'X' (assumed as X>90%). Satisfying the threshold condition indicates the probability of the successful disconnector operation. Moreover, the measured maintenance effort is compared with the maintenance cost 'Y' (assumed as Y<70% of initial maintenance cost). If any of the limit violated, an alert signal will be activated to the AMS about the deterioration of the asset's functionality. Then the AMS will further performs the detailed analysis to identify the possible reasons for the asset performance degradation. This enables the maintenance personnel to take the necessary action such as preventive, selective, predictive maintenance actions for the assets and also replaces the completely damaged assets.

4.1.2 Risk Assessment
In the cycle of AMS operation, the identification and mitigation of the risks are the key issues. Another key concern for the electricity distribution companies is the identification of relevant risks and their assessment to reduce the effects of those risks on the business. Along with the business, these risks can also affect the plant's safety and ecological impact. There are many types of risks identified for electricity distribution companies such as risks with safety, economy, environment, company reputation, supply quality, regulatory policies and maintenance, etc. All these risks are may not relevant to each decision taking in the business, but, the consequence of mitigating one risk may cause for rising another risk. This needs to be assessed at each and every decision that is being implemented in the system. Fundamentally, there are three risk analysis categories namely, standard risk analysis, simplified risk analysis, and model-based risk analysis as described follows. The fundamental risk analysis procedures were given in [36], [37], [38], while, the derived probabilistic and active risk management methods were given in [39], [40].

- Simplified Risk Analysis: This is a qualitative approach based risk analysis method. This includes informal and/or non-technical procedures applied for risk analysis such as group discussions, brain storming sessions, one-to-one discussions, coarse risk analysis, etc.
- Standard Risk Analysis: This is a qualitative and/or quantitative approach based risk analysis method. This includes more formalized procedures. Here, recognized risk analysis procedures along with risk metrics are used for the analysis. This analysis is assisted by HAZOP (hazards and operability) metrics.

- Model Risk Analysis: This is a quantitative approach based risk analysis method. This includes formal methods fault tree analysis, event tree analysis, to calculate the risk.

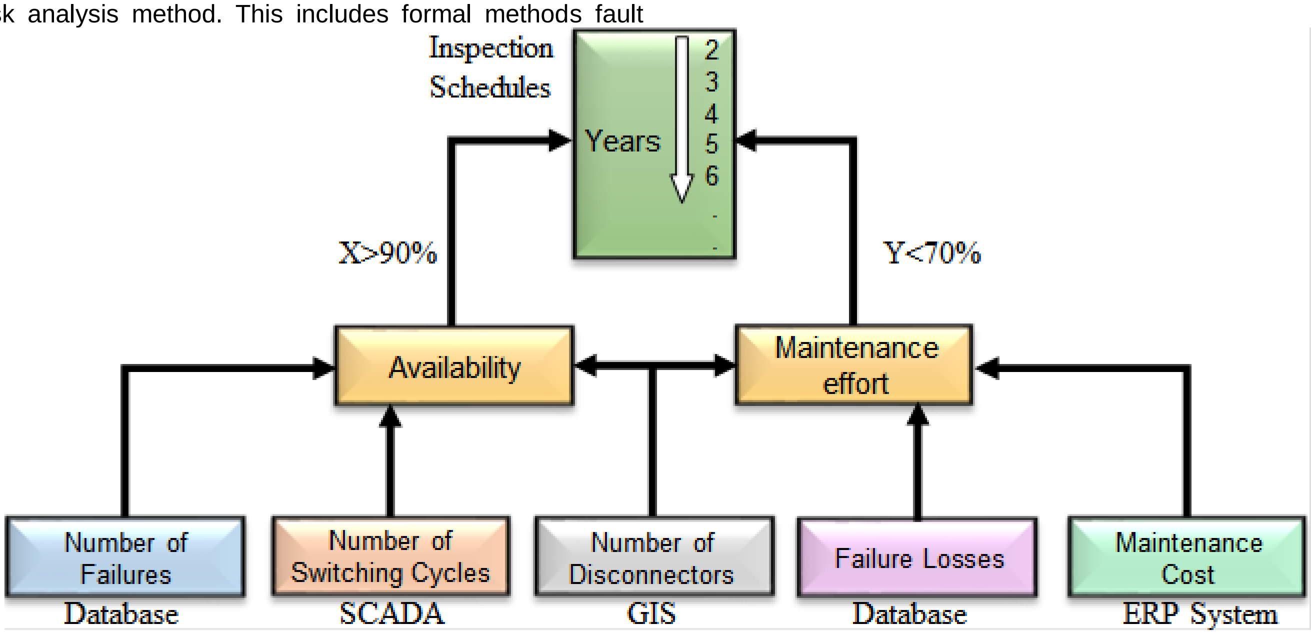


***Fig. 13**. Statistical fault analysis strategy.*

***TABLE 2** STEPS TO ACHIEVE OPTIMAL MAINTENANCE STRATEGY FOR ECONOMIZER APPLICATION*

- *Step-1: The analysis starts with the consideration of AMS decision that decides the optimal maintenance strategy.*
- *Step-2: Defining the objectives and associated constraints for the economizer maintenance. At initial stage, these are derived from the objectives and constraints identification process or these are assumed as already been defined by the industry's strategic plan.*
- *Step-3: Since economizers are dynamic and complex systems, it is intended to analyze and forecast its health conditions. This helps in delivering accurate decisions from the AMS.*
- *Step-4: Defining the potential maintenance strategies. This is performed by some experts in the domain, based on their expertise and experience. The possible strategies include preventive maintenance, reactive/corrective maintenance, predictive maintenance, tubing system renewals, etc.*
- *Step-5: Pick the best strategy and based on this, verify the AMS decision parameters. In order to achieve this, initially a qualitative analysis is performed and later on a combined maintenance strategy is executed. The economizer's tubing channels are renewed within scheduled durations. Between renewals, the economizer is maintained based on preventive and reactive maintenance strategies. In this case, the renewal duration is considered as a decision variable and is optimized.*
- *Step-6: Here, the renewal duration is optimized to reduce the total maintenance cost of the economizer that include renewal costs, repairing costs, production losses due to downtime, etc.*
- *Step-7: Validate the AMS decision using risk assessment and sensitivity study. If the decision is satisfactory, the decision control loop is closed. Otherwise, the aforementioned step-1 to step-6 is repeated in a loop.*

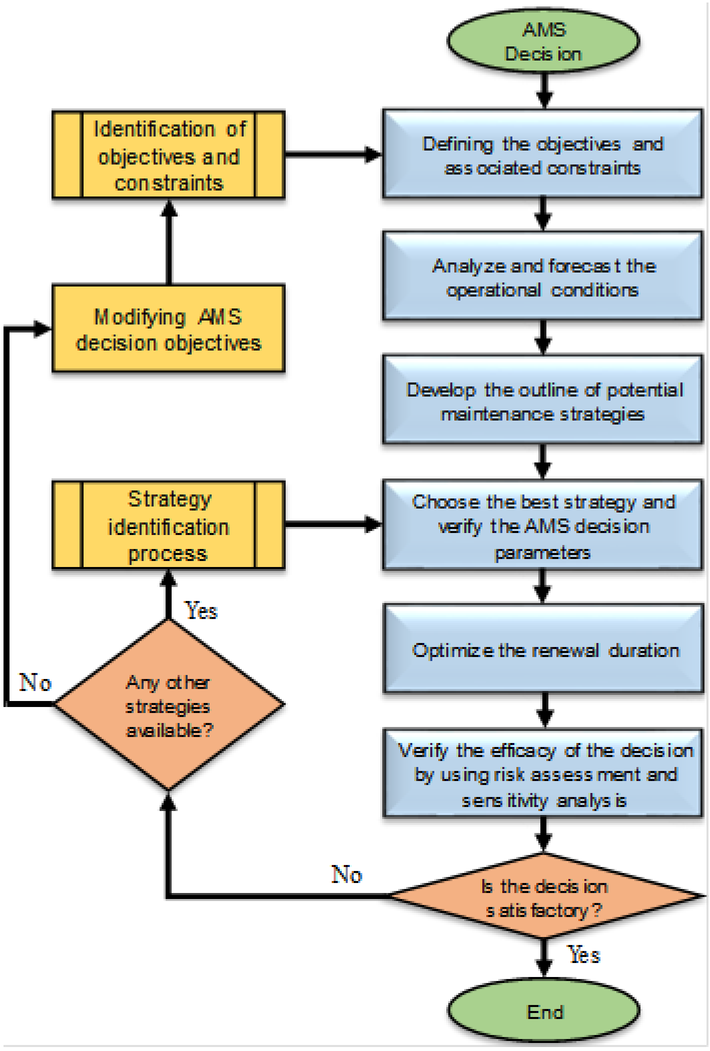


***Fig. 14**. AMS maintenance cycle for power plant economizer.*

4.2 A Sample Practical Case Study

In order to understand the AMS functionality in an asset's life cycle, this section presents a practical case of AMS strategy design for the power plant's economizer. The economizer is a key constituent for the effective operation of thermal power plants. It contains water-filled tubes that extract heat from the exhaust gases. The failure of this system usually happens by erosion may shut down the entire generator unit. Hence, the objective is to achieve the optimal maintenance strategy for the economizer [41]. Various steps involved in achieving this objective are shown in Fig. 14. The flow is carried out as mentioned in Table.2.

5 SUMMARY

The importance of asset management systems and its architecture for a smart distribution system was explained in this paper. The key drivers for AMS deployment, its goals, and responsibilities of the each AMS element were explained. A practical case study of power plant's economizer is also presented to understand the AMS operational procedure in the asset's life cycle. Further, the role based operations and various important aspects of technology advancements that are to be considered by AMS are briefly drafted. This suggests that the design of proper AMS is required for effective demand side management in power distribution systems. The technology advancements in communication and interoperability standards for AMS design, collectively reduces the burden of these critical buildings on distribution systems by effective demand side management philosophies.

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