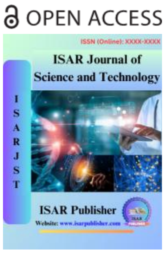

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A Review on Machine Learning Techniques in Networked Microgrids Applications

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Abstract: Application of machine learning techniques in power systems has a wide scope in research work due to their benefits in classification and regression characteristics in load balancing, fault tolerance, task processing time, and statistical nature of renewable energy resources. We have analyzed the characteristics of networked microgrids in context of their connectivity with main grid. In this paper, machine learning techniques are discussed which are applicable to distribution control, energy trading, optimization and power restoration in case of networked microgrid schemes. Paper focuses on recent progress of machine learning techniques in several aspects of networked microgrids such as control and optimization process. We have used machine learning techniques for networked microgrids applications and their review. The main problem and challenge are to achieve renewable energy resources benefits and space for high number of microgrids penetration to design a comprehensive networked microgrids management system. This comprehensive networked microgrids management system is the robust decision center by using intelligent machine learning techniques. Machine learning techniques mapped the human learning process of improving accuracy of solution over time with data and algorithms. Machine learning algorithms used the data sets, training the computers for output values within the required limits. With the support of machine learning techniques, the existing information and experience lead to take right decision for controlling and management of networked microgrids. In addition, this review paper demonstrates the development of machine learning techniques based on distributed and centralized control framework for networked microgrids.

Keywords: Load Balancing, Networked Microgrids, Machine Learning, Data Science, Distributed and Centralized Control.

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I. INTRODUCTION

Networked microgrids is an emerging concept as an efficient and effective way to integrate distributed energy resources (DERs) in the main power grid. Networked microgrids can be disconnected from the main power grid and can operate autonomously making the grid more resilient and vanishing grid disturbances and maintaining the power quality. Networked microgrids can enhance the main grid power supply reliability. These microgrids are considered as coupling microgrids having connections in clusters near electrical proximity to support energy management coordination and interactive exchange and support of energy within and outside. We can use a decentralized approach for steady state operation of networked microgrids.

The main challenges and problems existing in networked microgrids must be addressed before making them as an optimal operating system [1].

- The first challenge is understanding the dynamics of networked microgrids which consist of security indicators computing i.e., stability margin and region for networked microgrids (25). This problem arises from uncertainties, fast ramp rates, non-synchronization and low inertia. So, the challenging problem is to determine the microgrid stability assessment and enhancement to improve the networked microgrids optimization of operation and its control.

- Other challenge is interconnection and disconnection of large number of microgrids in networked microgrids which is responsible for inducing the sudden loss large number of microgrids introducing the main grid disturbance and increasing the blackout risk for both distribution and transmission networks. This challenge can be referred to as a fault tolerance problem.
- Third challenge complexity in communication infrastructure. Time delays, congestion, and failures can produce significant affects in the operation and function of networked microgrids' communication networks. Cyberattacks are considered the most important issue in the case of networked microgrids stability control and management of fault. The problem can be titled as designing of an innovative communication architecture for controlling, responding and mitigating emergencies, threats in order to completely support these scalable networked microgrids.

These issues and problems are solved by using several techniques in previous literature in order to get stable, and reliable energy from microgrids.

The benefits of renewable energy sources and high penetration of microgrids in power systems emerge new technologies in order to provide the comprehensive management system of microgrids. Networked microgrids are one of those technologies which need a robust decision for management system, and we can use machine learning techniques for this purpose which are considered as artificial intelligence techniques. Machine learning encompasses the learning process by using and deploying data and algorithms, then results and solutions are improved over time iteratively. Machine learning algorithms train the data set in such a way that outputs or results fall in predetermined range[2].

Microgrids management system can be controlled and managed by using machine learning techniques for detection of all information pattern and prediction of behavior of heterogeneous nature of networked microgrids. Machine learning has several models including supervised learning, unsupervised learning and reinforcement learning which are applicable in microgrid applications based on stakeholders' requirements as shown in figure 1. Python based scikit learn, MATLAB ML toolbox and R package cart are different language programming making the machine learning more useful in optimizing, predicting and training the issues in networked microgrids [3].

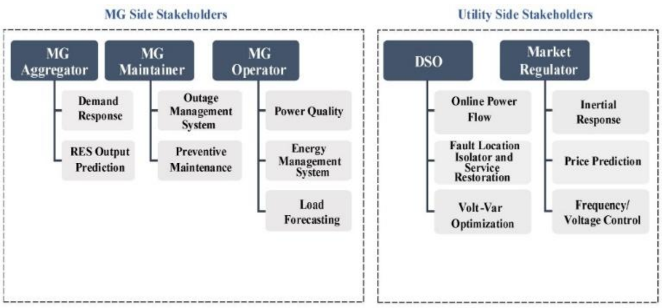

Figure 1 – Shows stakeholders based microgrid application requirements

In this paper, Section I describes the introduction of machine learning techniques in networked microgrids applications. Section II gives the characteristics of networked microgrids for getting the maximum benefits from their operations to the end users and distribution companies. In Section III, recent applications of machine learning techniques in networked microgrids are discussed. Section IV consists of results and their discussion. Section V is about conclusions and future works.

II. CHARACTERISTICS OF NETWOKRED MICROGRIDS

Networked microgrids have different characteristics as compared to microgrids. They are more reliable and stable in context of consistent power provisions. There are several characteristics of networked microgrids as follows [4]:

A. Interconnection Architecture

Currently, networked microgrids are the research focus and emerging grid designing features which can support the main grid with number of benefits like reliability, resilient nature, economic optimization, fault tolerant and local distribution networks recovery. In this context, we have several interconnection types and methods of networked microgrids with the main grid. These methods can generate many fundamental problems and challenges which can deal with advanced tools. For this purpose, we can apply single objective or multiple objective functions to analyze all possible variations in the system. We can break down the potential microgrids into two networked microgrids architecture [5]. For interconnection architecture of networked microgrids, we have three types of networked microgrids,

1- Serial microgrids on a single feeder

2- Parallel microgrids on a single feeder

3- Interconnected microgrids with multiple feeders

For the operation of each type of networked microgrids, we need configurations which have unique sets of requirements for communications and controls [6].

A.1. Serial Microgrids on a Single Feeder

Basically, serial microgrids on a single feeder configuration contains two or more microgrids which are interconnected having only one interface to be connected to distribution network of power system. Networked microgrids configuration has only a single direct connection to the distribution network. If we have two microgrids A and B in networked microgrids, we have following two options:

1. If both microgrids A and B are grid connected with a single direct connection with distribution feeder, each microgrid has the capability of controlling and optimizing respective microgrid operation with connected with distribution management system.
2. If both microgrids A and B are islanded, each microgrid has the ability of controlling and optimizing respective microgrid by utilizing internal information and resources.
3. In the case of microgrid A as grid connected and microgrid B is islanded, microgrid A is controlled and optimized based on the distribution management system while microgrid B is controlled and optimized based on the internal information and resources.
4. In the case of microgrid A is islanded, and microgrid B is grid connected, microgrid A is controlled and optimized based on the internal information and resources while microgrid B is controlled and optimized based on distribution management system.

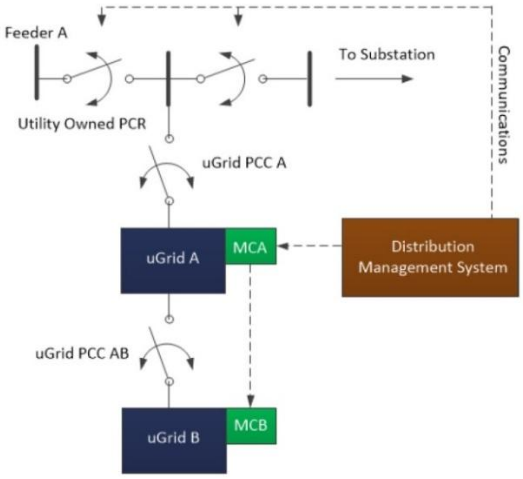

Figure 2 – Shows serial microgrids on a single feeder

A.2. Parallel Microgrids on a Single Feeder

Another networked microgrids configuration is parallel microgrids considered as single feeder configuration having their connections separately on a single feeder. The communication protocol is master slave architecture with respect to the possible interconnection tie. If we have two microgrids A and B, both microgrids interconnections to distribution management systems can have following options:

1. Microgrids A and B are individually grid-connected with distribution feeder and each microgrid has the ability of controlling and optimizing of relevant microgrid supported by the information from distribution management system.
2. Microgrids A and B are in islanded mode. Then each microgrid is controlled and optimized with respect to available internal information and resources.
3. If microgrid A is grid connected and microgrid B is in islanded mode, microgrid A is controlled and optimized by using information from distribution management system while microgrid B is controlled and optimized based on information and resources.
4. Similarly, if microgrid A is in islanded mode and microgrid B is grid connected, then microgrid A is controlled and optimized by using information and resources, while microgrid B has an option of operation based on information from distribution management systems.

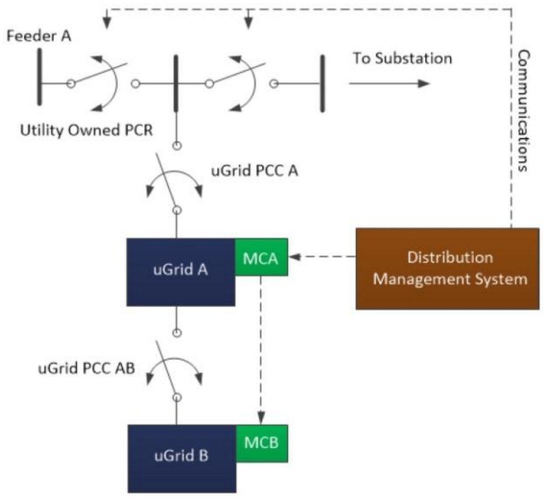

Figure 3 – Shows Parallel microgrids on a single feeder

A.3. Interconnected Microgrids with Multiple Feeders

When two or more microgrids in networked microgrids are connected to multiple feeders' configuration separately with some possible interconnection is called multiple feeders interconnection. The architecture of communication is known as master-slave architecture. Microgrids interconnections to distribution management system can have the following options:

1. Microgrids A and B are individually grid-connected with distribution feeder and each microgrid has the ability of controlling and optimizing of relevant microgrid supported by the information from distribution management system.
2. Microgrids A and B are in islanded mode. Then each microgrid is controlled and optimized with respect to available internal information and resources.
3. If microgrid A is grid connected and microgrid B is in islanded mode, microgrid A is controlled and optimized by using information from distribution management system while microgrid B is controlled and optimized based on information and resources.
4. Similarly, if microgrid A is in islanded mode and microgrid B is grid connected, then microgrid A is controlled and optimized by using information and resources, while microgrid B has an option of operation based on information from distribution management systems.

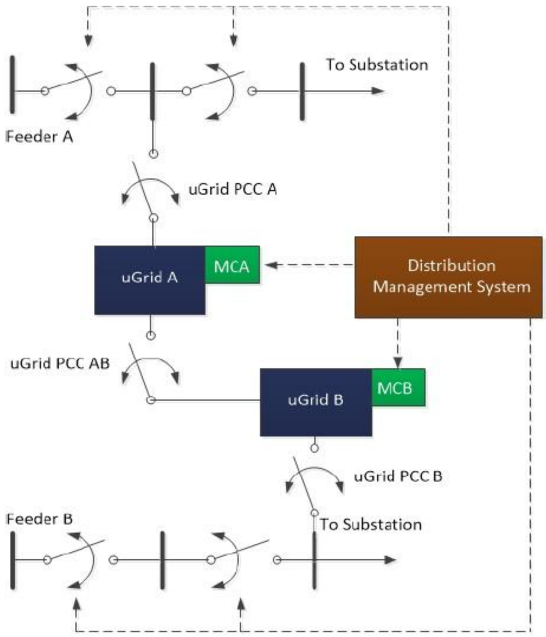

Figure 4 – Shows Interconnected microgrids with multiple feeders

B. Communications

We can use existing numerous communication methods and protocols for networked microgrids to be connected to smart grid. Direct master slave communication or publish-subscribe communication are preferred in such conditions. In the case of networked microgrids connected to smart grid, we can establish communication network making distribution management system, microgrid master controlling and devices to make intercommunication. The most important communication in networked microgrids is micro-grid to micro-grid communication provides stability and reliable energy. Microgrid to microgrid communication and coordination can be carried out with the following two methods.

B.1. Direct Master-Slave Communication

In the case of direct master-slave communication process, master device is initiating a request for a slave to provide the information or adjustment as requested. The slave is responsible for providing the correct information and adjusting based on its configuration. For networked microgrids operation, the registers read and write the data in second time interval. Networked microgrids controller acts as a communication director and handles all communication tasks as a master. In the case of islanding and resynchronization process of a microgrid in networked microgrids, there is a need for fast communication in microgrid controller, islanding switch and energy generation source controller. At point of common coupling, state change status is notified by microgrid controller to generation source controller. In master slave communication and its configuration, a complex task is needed for this device-to-device communication.

In order to establish communication between the microgrids of a networked microgrids and distribution management system, the distribution management system is considered as a master coordinator instructing the slave microgrid controller. For this purpose, it is needed the information about the adjacent microgrids polled for consistent information sharing in microgrids.

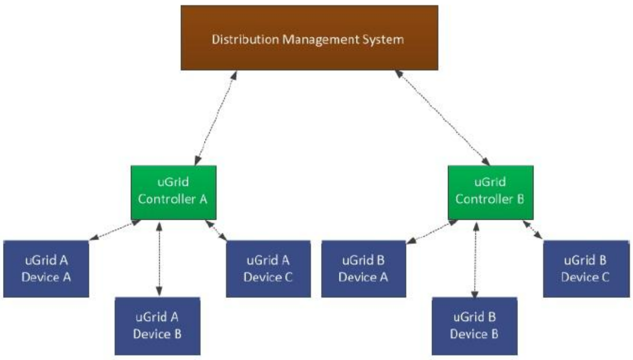

Figure 5 – Master-slave communications

B.2. Publish/Subscribe Communication

In the case of publish-subscribe communication, devices (publishers) broadcast information and subscribers read the broadcasted data. Subscription to any set of information can be achieved by any device, so islanding and resynchronization can be achieved without any master slave interfacing. For effective communication, priority-based requests must be dealt with first, ensuring a complete communication channel between the point of common coupling and source controller.

In order to communicate between microgrid of a networked microgrids and distribution management system, the distribution management system is considered as a master coordinator instructing the slave microgrid controller but the microgrid-to-microgrid communication is publish-subscribe architecture. For this purpose, it is needed the information about the adjacent microgrids polled for consistent information sharing in microgrids.

In this way, we can reduce the risk of performance of serial microgrids connected to a single feeder when new devices are integrated with other higher microgrids in order to subscribe to the information required.

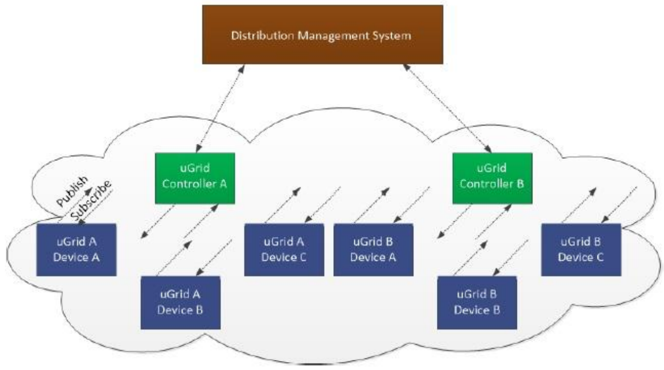

Figure 6 – Shows Publish/subscribe communications

C. Controls

We can categorize the control architecture of networked microgrids into hierarchical control and distributed control. Another form of control architecture is hybrid control architecture showing several controls of microgrids of networked microgrids.

C.1. Hierarchical Control Architecture

Distributed management system has the ability to support the coordination between microgrids of networked microgrids in case of hierarchical control architecture. By considering this architecture, we can use power electronics systems to control the device directly with voltage-frequency (V/f), active-reactive powers (P/Q) and power-voltage (P/V) in the form of primary control and secondary control of operation of networked microgrids. The distributed management system has direct control and final level of support and coordination in the form of tertiary control.

- In the case of grid connected mode of operation of networked microgrids, all microgrids are directly connected to distribution feeders or with other grid connected microgrids like serial and parallel connectivity. All the microgrids establish communication between them and get real time measurements and controls each microgrid according to that information. In this case of communication, operation of each microgrid has to perform some internal optimization of resources in the form of following options:
  - Individual microgrid price or cost signals
  - Microgrids complete targets and requirements for optimization
  - The microgrid controller works as a surrogate of microgrid and having the control for dispatch of each resource connected to the microgrid.
- In case of islanding mode of operation, each microgrid of networked microgrids must have V/f source with off grid function and a separate microgrid controller. The microgrid controller has the capability of performing automatically microgrid islanded mode function at point of common coupling of microgrid.
- For economic and reliability benefits, microgrids of networked microgrids should resynchronize to main grid via grid connected feeder. In case of unavailability of grid connected feeder, the microgrids of networked microgrids should merge and resynchronize themselves for better

operation performance. Resynchronization processes have two options:

- o Normal Operation – Resynchronization with grid connected feeder.
- o Islanded Operation – Resynchronization with islanded microgrid from networked microgrids. This is more challenging and complex than normal operation resynchronization. In case of no direct PCC available between microgrids of networked microgrids, the distribution management system can perform and identify more routes with available feeders even in case of restoration of a main distribution grid.
- o In such type of resynchronization, challenges and risks are given below:
- ✓ Microgrids of networked microgrids must have the capability to merge to make the reserve and inertia to support the connected microgrids.
- ✓ Microgrids of networked microgrids must have a dynamic nature for resources with interconnected route of microgrids. In the case of islanded microgrids, microgrids must have plug and play capacity to change the boundaries of microgrids.

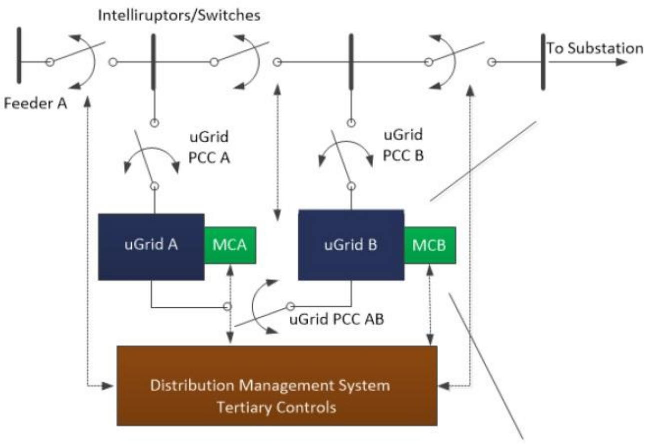

Figure 7a – Shows Hierarchical control architecture

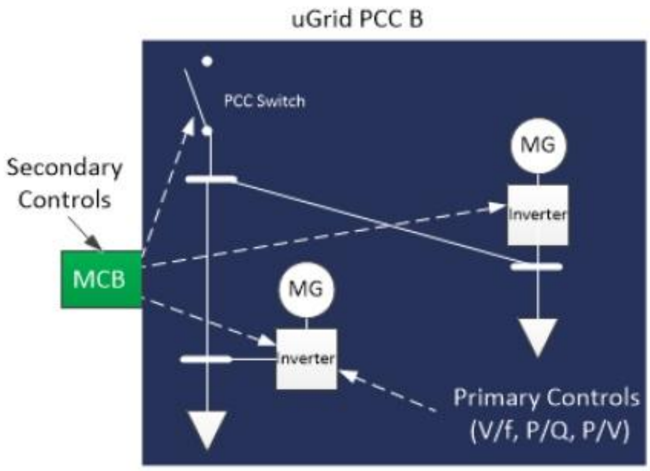

Figure 7b – Shows Hierarchical control architecture

C.2. Distributed Control Architecture

The controller of microgrids operation finds the mode of operation whether it is grid connected or islanded mode in order to optimize the microgrid operation and resources. The distributed control architecture of networked microgrids is shown in the figure.

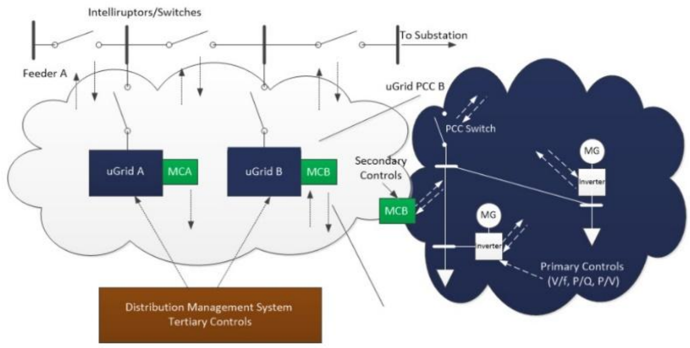

Figure 7c – Shows distributed control with publish/subscribe communications

- In the case of grid connected mode of operation of networked microgrids, all microgrids are directly connected to distribution feeders or with other grid connected microgrids like serial and parallel connectivity. All the microgrids establish communication between them and get real time measurements and controls each microgrid according to that information. In this case of communication, operation of each microgrid has to perform some internal optimization of resources until the Nash equilibrium is reached.
- In case of islanding mode of operation, each microgrid of networked microgrids must have V/f source with off grid function and a separate microgrid controller. The microgrid controller has the capability of performing automatically microgrid islanded mode function at point of common coupling of microgrid as per corresponding incentives requested.
- For economic and reliability benefits, microgrids of networked microgrids should resynchronize to main grid via grid connected feeder. In case of unavailability of grid connected feeder, the microgrids of networked microgrids should merge and resynchronize themselves for better operation performance. Resynchronization processes have two options [7]:
    - o **Normal Operation** – Resynchronization with grid connected feeder.
    - o **Islanded Operation** – Resynchronization with islanded microgrid from networked microgrids. This is more challenging and complex than normal operation resynchronization. In case of no direct PCC available between microgrids of networked microgrids, the distribution management system can perform and identify more routes with available feeders even in case of restoration of a main distribution grid [8].
    - o In such type of resynchronization, challenges and risks are given below:
    - ✓ Microgrids of networked microgrids must have the capability to merge to make the reserve and inertia to support the connected microgrids.

- ✓ Micrograds of networked microgrids must have a dynamic nature for resources with interconnected route of microgrids. In the case of islanded microgrids, microgrids must have plug and play capacity to change the boundaries of microgrids.

D. Benefits

D.1. Benefits to Distribution Systems

The resilience in networked microgrids is the key well known benefit and we can see other values while integrating networked microgrids to the distribution systems. Each microgrid of networked microgrids can be optimized itself and can handle number of objective functions of networked microgrids. The networked microgrids integrated with distribution management system can support distribution grid, having support from other microgrids as well. There are following benefits of networked microgrids to distribution management system [9]:

- Uncertainties management improvement
- Enhancement of economic benefits and efficiency
- Power quality improvement
- Reliability and resilience improvement

D.2. Benefits to Microgrids

As we have already mentioned that in networked microgrids, one microgrid has a benefit from another microgrid. The benefited microgrid has its connection with distribution system and with other microgrids at point of common coupling. Individual microgrids of networked microgrids interact with each other, and markets to optimize the operations. The microgrids benefits in several ways in networked microgrids connected with distribution system [10]:

- Each microgrid is supported with V/f support from distribution system
- Improvement in operational efficiency and reduction in operational cost.
- Critical loads are facilitated with high reliability.
- Energy and ancillary service markets are supported by maximum benefit.

III. RECENT APPLICATIONS OF MACHINE LEARNING TECHNIQUES IN NETWORKED MICROGRIDS

The usage of machine learning techniques is considered as an up-and-coming technology in applications of power engineering field. Machine learning techniques can be applied to a wide range of applications including power systems restoration, market simulations, diagnostics, condition monitoring, automation and network control of power systems. Machine learning techniques have their algorithms according to their usage to any application [11]. Any entity like microgrid has its presence by the incorporation of following features [12].

- o **Autonomy** – microgrids of networked microgrids have the ability for their individual and combined operation without any intervention of human and have some specific optimization and control over its decisions and actions.
- o **Reactivity** – microgrids of networked microgrids have the ability in order to face the changes occurring in system environment and response to handle these changes accordingly.
- o **Pro-activeness** – microgrids of networked microgrids do not limit their reaction to input, but each microgrid has the ability to take the initial step to gain goal-oriented outcomes.
- o **Social ability** – microgrids of networked microgrids have the ability to coordinate and interact with humans and other microgrids, and power system through specified feeders by using pre-determined communication through a program. The information exchange between networked microgrids and individual microgrid has some specific protocols.

There are several concepts, methodologies, and technical problems while applying machine learning techniques in applications of power systems. The power system analysis in literature review reveals that most of research work was focused on distributed microgrid controls [13]. The minor fields are electricity trading, restoration and optimization.

A. Distribution Control

The literature on distributed control depicts the current research trend for networked microgrids. There are several architectures and frameworks which are more effective in controlling the microgrids of networked microgrids.

The distributed control algorithms are considered as an accurate technique for networked microgrids due to their more robustness and reliability for distribution networks. The distributed microgrid management system can be designed using distributed dynamic population games due to their availability to handle the microgrids requirements [14]. For this purpose, distributed replicator dynamics algorithms have these three major contributions in handling the management system of microgrids.

- Applications of distributed replicator dynamics for dispatch distributed generator using communication topology in testing for a microgrid system.
- We can consider microgrids power losses in distributed replicator dynamics.
- Usage of a combination of two heuristic optimization algorithms to estimate the robust loss coefficients of distributed network with different demand patterns.

Microgrids operations based on distributed control algorithms can be used to integrate economic dispatch problem with the help of frequency control. For this purpose, we can consider complete network topology with more realistic approach including the network losses [15].

B. Energy Trading

The distribution companies are performing the tasks of scheduling issues in networked microgrids with the help of scheduling tools. These companies are responsible for the smooth and stable operation of networked microgrids [16].

In order to keep the power system stable and reliable, microgrids in networked microgrids have individual and combined operational applications as follows:

- Energy generation cost is affected for each microgrid in networked microgrids.

- The distributed network operator cost for transferring energy within other networked microgrids.
- Each microgrid in networked microgrids has its own power demand to be fulfilled.

Under such conditions, we can determine an optimal solution of microgrids operation satisfying both supply and demand along with minimizing the operational cost of the power system. At first step, the each networked microgrid is computing locally the amount of energy generation and demand, then minimizing the cost according to the current energy rates. At second step, the networked microgrids need to exchange the energy between themselves according to the bids of supply and demand

The issues of scheduling operation in networked microgrids are resolved by the operators to schedule each task with the use of scheduling tools. For this purpose, we need to search more optimal solutions methods which can result with more research pathways for the scientists.

The optimization of EVs in SMG with uncertain scenarios has not been fully explored, thus this study proposes a new methodology that involves uncertainty decisions in battery swapping stations. In the proposed method, a decision matrix is formulated to schedule EVs BSS. Furthermore, the stochastic visit is based on the K-means clustering approach. Once the visit schedule to EV BSS has been generated, idle spaces appear in the probabilistic scenarios within a decision matrix. This means that the idle spaces are generated when the charge of a battery must be mandatory.

As a result, optimization is only allowed for free spaces, that is, charging, discharging, or no action. In addition, other elements of the SMG are included in the model, such as DG, PV generation, ESS, loads with DR, and day-ahead markets. Finally, the best schedule of charging, discharging, and swapping for EVs batteries in BSS, and the transfer of power in the market are identified satisfactorily. The generation, loads with DR, and ESS are stochastic, however, the patterns are recognized of the main generators, peak hours in loads with DR (at midday), and ESS participation [17].

C. Optimization

The optimization of networked microgrids operation is highly uncertain process due to uncertain parameters. Microgrids are considered as small power systems having generation, storage and loads. The power demand uncertainties and renewable energy resources uncertainties are addressed while optimizing microgrid operation and design [18]. We can apply any type below optimization technique based on the requirements.

1- Deterministic Optimization
2- Stochastic Optimization
3- Robust Optimization
4- Distributed Robust Optimization

Distributed robust optimization technique has more potential to handle the uncertainties of variable power generation from uncertain energy resources [19].

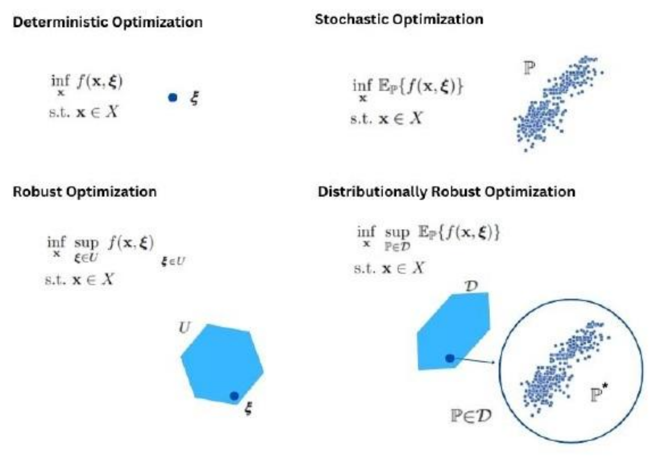

Figure 8 – Shows uncertain optimization model approaches

In figure 8, there are four optimization techniques are shown with their cost function and boundaries [19].

- **Deterministic Optimization** – This approach considers complete certainties about uncertain parameters during the optimization process.
- **Stochastic Optimization** – This approach adapts probability density functions having the uncertainties with parameters configuration range.
- **Robust Optimization** – This approach deals with uncertainties in the models using parameter values sets rather than explicit probability distributions. This ensures about the performance of uncertainty set in call cases.
- **Distributed Robust Optimization** – This approach deals with ambiguity set having an infinite list of probability distributions. It focused on the robust results

D. Power Restoration

Power restoration and fault tolerance are important in context of consistent power supply by grid friendly networked microgrids. For this purpose, multifunctional active fault management is necessary to support the networked microgrids operations. The increase in DC link voltage or inverter's output current can be the issue due to not meeting the safety thresholds. It is more feasible to get the optimal solution for active fault management of a microgrid in networked microgrids to reach at a tradeoff for multiple objectives [20].

In networked microgrids, a microgrid stakeholders must consider the online security and privacy due to neighboring microgrids or distribution operators having access to its data. It is quite good for sharing the relevant and needed information with networked community and utility company through a small amount of interfacing. We need to protect the customer privacy while designing a distributed active fault management system. For this purpose, we can use an optimization technique distributed and synchronous surrogate Lagrangian relaxation (DA-SLR). It can provide an efficient and privacy protection active fault management for networked microgrids. Basically, the power restoration process is very critical in context of the number of networked microgrids.

Networked microgrids are designed, developed and deployed extensively in previous few years providing the supporting and beneficial supplements to main grid. But industrial and academic researchers are still in research about their more benefits in order to get improved each microgrid performance in networked microgrids as per the smart grid requirements. Recently, artificial intelligence (AI) techniques are considered the best in case of data sets obtained from the micrograds and doing prediction about each microgrid in networked microgrids [21].

IV. RESULTS

In this paper, we have used four network topologies of networked microgrids, i.e., Full configuration, Ring configuration, Line configuration and Start configuration.

The simulation results are shown below in the tabular form along with interpretation of the results. These results are based on two algorithms; genetic algorithm and neural network algorithm and their results are interpreted and compared with each other as well.

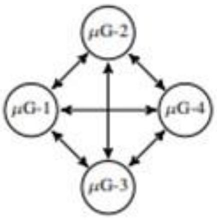

Figure 9 – Shows Full Configuration Topology of Networked Microgrids

First, we have considered full configuration topology of networked microgrids and genetic algorithm is applied in order to get the energy generation, energy cost, energy transmission. The full configuration of four microgrids in a networked microgrids is shown in the figure 9. We have got a value of total energy for a microgrid which is interconnected with networked microgrids. There are four microgrids considered in a networked microgrids. The total energy cost of all four microgrids is 2385.977863 (2385.977863) USD per hour as shown in table 6.1A.

TABLE 6.1A – Genetic Algorithm Results for Networked Microgrids Full Configuration

E_gen	E_c	Generation	Transmission	Total
9.82671	11	674.004	5.0698	679.074
9.82671	11	674.004	5.0698	679.074
9.82671	11	674.004	5.06981	679.074
4.51988	1	348.757	0	348.757

Total Energy Cost: 2385.977863 (2385.977863) USD per hour

When we consider the contingency generation or configurations, one of the microgrids is now off grid or islanded mode. The energy generation of this microgrids is fully supported by the other three microgrids with homogeneous or heterogeneous energy distribution among all three microgrids.

E_Gen Contingency	11.0000	11.0000	11.0000

TABLE 6.1B – Neural Network Algorithm Results for Networked Microgrids Line Configuration

E_gen	E_c	Generation	Transmission	Total
9.82679	11	674.01	5.07039	679.08
9.82656	11	673.994	5.07039	679.064
9.82656	11	673.994	5.0704	679.064
4.52008	1	348.769	0	348.769

Total Energy Cost: 2385.977868 (2385.977700) USD per hour

E_Gen Contingency	11.0000	11.0000	11.0000

Second, we have considered line configuration topology of networked microgrids and genetic algorithm is applied in order to get the energy generation, energy cost, energy transmission. The line configuration of four microgrids in a networked microgrids is shown in the figure 10.

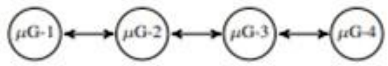

Figure 10 – Shows Line Configuration Topology of Networked Microgrids

We have got a value of total energy for a microgrid which is interconnected with networked microgrids. There are four microgrids considered in a networked microgrids. The total energy cost of all four microgrids is 2385.977868 (2385.977700) USD per hour as shown in table 6.2A.

TABLE 6.2A – Genetic Algorithm Results for Networked Microgrids Line Configuration

E_gen	E_c	Generation	Transmission	Total
9.97597	11	686.774	3.86193	690.636
9.95046	11	684.179	15.8349	700.014
9.8925	11	678.954	37.2669	716.22
4.18106	1	328.624	0	328.624

Total Energy Cost: 2395.864618 (2385.864618) USD per hour

When we consider the contingency generation or configurations, one of the microgrids is now off grid or islanded mode. The energy generation of this microgrids is fully supported by the other three microgrids with homogeneous or heterogeneous energy distribution among all three microgrids.

E_Gen Contingency	12.0884	10.4558	10.4558

TABLE 6.2B – Neural Network Algorithm Results for Networked Microgrids Line Configuration

E_gen	E_c	Generation	Transmission	Total
9.97596	11	686.773	3.86197	690.635
9.95049	11	684.182	15.8345	700.017
9.89254	11	678.956	37.2654	716.222
4.181	1	328.62	0	328.62

Total Energy Cost: 2395.864618 (2385.864618) USD per hour

E_Gen Contingency	10.4515	12.0970	10.4515

Third, we have considered ring configuration topology of networked microgrids and genetic algorithm is applied in order to get the energy generation, energy cost, energy transmission. The line configuration of four microgrids in a networked microgrids is shown in the figure 10.

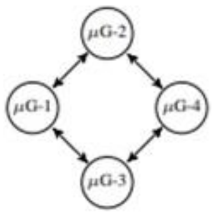

Figure 11 – Shows Ring Configuration Topology of Networked Microgrids

We have got a value of total energy for a microgrid which is interconnected with networked microgrids. There are four microgrids considered in a networked microgrids. The total energy cost of all four microgrids is 2395.864618 (2385.864618) USD per hour as shown in table 6.3A.

TABLE 6.3A –Genetic Algorithm Results for Networked Microgrids Ring Configuration

E_gen	E_c	Generation	Transmission	Total
9.84599	11	675.357	10.9135	686.27
9.86512	11	676.777	2.37163	679.148
9.84599	11	675.356	10.9136	686.27
4.4429	1	344.176	0	244.176

Total Energy Cost: 2395.864618 (2385.864618) USD per hour

When we consider the contingency generation or configurations, one of the microgrids is now off grid or islanded mode. The energy generation of this microgrids is fully supported by the other three microgrids with homogeneous or heterogeneous energy distribution among all three microgrids.

E_Gen Contingency	12.0884	10.4558	10.4558

TABLE 6.3B – Neural Network Algorithm Results for Networked Microgrids Ring Configuration

E_gen	E_c	Generation	Transmission	Total
9.84599	11	675.356	10.9136	686.27
9.86512	11	676.777	2.37163	679.148
9.84599	11	675.356	10.9136	686.27
4.44291	1	344.176	0	344.176

Total Energy Cost: 2395.864618 (2385.864618) USD per hour

E_Gen Contingency	10.4515	12.0970	10.4515

Third, we have considered star configuration topology of networked microgrids and genetic algorithm is applied in order to get the energy generation, energy cost, energy transmission. The line configuration of four microgrids in a networked microgrids is shown in the figure 12.

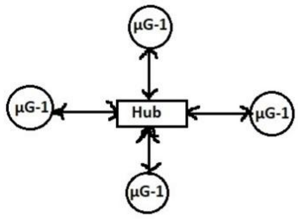

Figure 12 – Shows Star Configuration Topology of Networked Microgrids

We have got a value of total energy for a microgrid which is interconnected with networked microgrids. There are four microgrids considered in a networked microgrids. The total energy cost of all four microgrids is 2423.250826 (2423.250826) USD per hour as shown in table 6.4A.

TABLE 6.4A – Genetic Algorithm Results for Networked Microgrids Star Configuration

E_gen	E_c	Generation	Transmission	Total
9.89492	11	679.154	38.9772	718.131
9.92592	11	681.858	4.24867	686.106
9.92592	11	681.858	4.24867	686.106
4.25324	1	332.907	0	348.907

Total Energy Cost: 2423.250826 (2423.250826) USD per hour.

When we consider the contingency generation or configurations, one of the microgrids is now off grid or islanded mode. The energy generation of this microgrids is fully supported by the other three microgrids with homogeneous or heterogeneous energy distribution among all three microgrids.

E_Gen Contingency	12.0884	10.4558	10.4558

TABLE 6.4B – Neural Network Algorithm Results for Networked Microgrids Star Configuration

E_gen	E_c	Generation	Transmission	Total
9.89492	11	679.154	38.9771	718.131
9.92592	11	681.858	4.24865	686.107
9.92592	11	681.858	4.24865	686.107
4.25324	1	332.906	0	348.906

Total Energy Cost: 2423.250826 (2423.2508260) USD per hour

E_Gen Contingency	12.0884	10.4558	10.4558

V. CONCLUSION

The usage of networked microgrids system can improve the local generation and loads balancing making the power system more efficient, reliable, flexible, resilient and secure in case of system failure. Microgrids of networked microgrids are considered as an active system which is controlled by an advanced control architectures for their successful implementation. Machine learning techniques provides such an advanced control system for networked microgrids.

In this paper, we have used machine learning techniques for networked microgrids applications and their review. The main problem and challenge are to achieve renewable energy resources benefits and space for high number of microgrids penetration to design a comprehensive networked microgrids management system. This comprehensive networked microgrids management system can be the robust decision center by using intelligent machine learning techniques. Machine learning techniques map the human learning process of improving accuracy of solution over time with data and algorithms. These machine learning algorithms use the data sets, training the computers for output values within the required limits. With the support of machine learning techniques, the existing information and experience can lead to take right decision for controlling and management of networked microgrids. Machine learning techniques have the property to predict the pattern of heterogeneous computer devices.

For future works, we will deploy the machine learning algorithms in depth on networked microgrids for getting the optimal solutions even in case of multi-objective optimization problem. As each microgrid in networked microgrids have different operational behavior for the local energy demand and main grid. In future, we can use diversified machine learning techniques in networked microgrids for their reliable and stable operations.

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