Review of Power System Distribution Network Architecture

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***Abstract* –Distribution network is one of the main part of power systems as it is connected directly to the load center. The concept of integrating renewable and distributed energy sources in distributed level is a great concern for the power system engineer nowadays. Further research by power companies and engineers is ongoing to apply better techniques to improve power quality and stability of power system in distribution network. This paper presents a review of fundamental distributed network architecture including radial, ring and meshed distributed network looking at the concept of distributed network architecture, types, operation; controlling, management, growth model, advantages and disadvantages of existing distributed networks.**

***Index Terms*— Architecture, Distribution Network, Radial, Ring, Mesh**

I. INTRODUCTION

The key of successful power delivery to the load center is to design and implement a reliable and stable distribution network. Power provision to individual customer's premises can be enhanced through a proper and efficient electrical power distribution system [1], [2]. Distribution network are vulnerable by natural disaster, such as earthquake and cyclone. As each system is designed under natural disaster rated units, the damages sustain can affect the restoration of power network prolongs based on the design, control and management of that particular network. Typically a distribution network consists of substations, primary feeder, transformer, and distributor and service mains [3]. Electricity is generated in a sine wave that varies meaning that the power strength for a single phase fluctuates between weaker and stronger moments.

Recently, renewable energy sources are widely being used to meet the energy demand. A variety of development related to renewable energy sources and integration of such technologies in distribution networks make the network vulnerable. The degree of vulnerability depends upon the control and architecture of networks, while management plays an important role to sustain the network during normal operation.

Energy generation in the distribution levels provide benefits for both the user and the electricity provider as generation in distribution network can reduce the transmission losses, as well as costs for power generation [4]–[5]. To provide good power quality and reliability to the customers, we require new technologies in electric utilities. In many countries generation from the nonconventional sources is becoming an attractive solution because these will produce energy with less environmental impacts [6] – [8].

The most commonly used distributed network architectures will be presented which includes radial network, ring network and mesh network architecture. A review of the network architecture Benefits and drawbacks of each network structure, operation, controls, management, growth model, advantages and disadvantages of existing distributed networks will be discussed with the applications.

II. EXISTING DISTRIBUTED NETWORK ARCHITECTURE

A. Radial Network Structure

Radial network is the most commonly used system for power distribution grids [9]-[11]. The radial grid is topology tree shape, where close loops does not exist. Since there are no closed loops in radial network power can be delivered from one bus to another bus without tracking down the original bus. However, there will be a need to find the original bus while turning backwards. This kind of topology is the simplest and cheapest topology for an electrical grid but, with this topology, if a line is disconnected for some reason, all the lines downstream will also lose power.

Radial network has a structure which begins from the root node where the generation is connected. Lateral line follows the root node or main node in radial network. This line begins from the main feeder and connecting loads. Sub-lateral line begins from the lateral line. Finally the minor lines begin from the sub-lateral line. Distributed networks with radial network architectures can be analyzed somewhat as an extension of conventional power grid distribution system since it is one of the most commonly used approaches in power distribution system [12]-[26].

1) Application of Radial Network

The general configuration of the radial structure consists of generators only at starting point connected through the distribution transformer to the load center. The nodes are numbered in ascending order. Every adjacent node is connected by branches which are number uniquely. A sample radial distribution network is shown in the Fig.1 [27]. Radial network includes four important parts: master controller, control system, correspondence system, and the distribution line. Master controller is central controller with the activities of systems parameters identification, investigation control and client interfacing.

Stage of control system usually aims to allow multi-layer control that uses an interchange system to communicate data [28].

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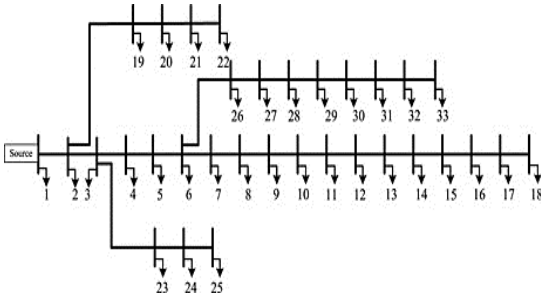

Fig.1: 33-node radial distribution network [27]

This proving ground is a remarkably adaptable system empowering the creation and trial approval of new topologies, fittings, controls, correspondence, and security. Deterministic and stochastic parts have incorporated together in this system. The limited idleness of distributed network helps to intensify sensitivities to stochastic segments [29]. Distribution lines are used for interconnecting source, loads, and energy space units in the system.

2) Advantages of Radial Network Architecture

Radial network system has a relatively simple circuit protection scheme to coordinate and design. With radial network it is quite simple to determine the system component rating requirements [30]. Another benefit while working with radial network is that voltage compensation technique such as reactive power compensators can be easily implemented. Although, there will be different voltages at each equipment/load caused by unequal conductor length, careful selection of conductor size can minimize the differences which will eliminate some of the electrical noise that may be induced on the power sensitive equipment caused by heavy equipment on the line [31]. Radial network is known as the simplest network since it is only fed at one end. The initial cost of this network is low and is very useful if generation is at low voltage. This type of network is preferred when the station is located at the center of the load as it brings the simplicity to analyze and operate the system [32].

3) *Disadvantages of Radial Network Architecture*

Radial network seems to have very limited growing flexibility when it is observed from the planning side. This is because the load addition or new generation integration would necessitate installation of new cables or other components except if the initially installed cables and other components were oversized. Hence, this will add on to extra costs.

With radial network, the end of distributor near to the substation gets heavily loaded. When the load on the distributor changes, the consumer at the distant end of the distributor faces serious voltage fluctuations. In radial network, consumers are dependent on a single feeder and distributor. Any fault in the system will cause interruption in power supply to all the consumers connected to the distributor [33]. Power availability as seen by each load may be lower than the observed with another power

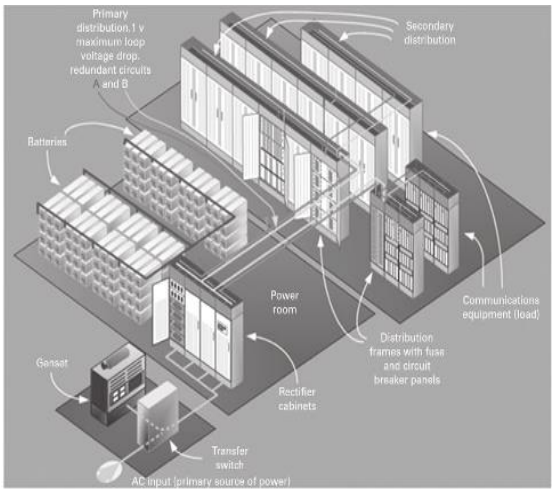

Fig. 2: Radial duplex power distribution architecture [34]

distribution configuration. Such lower availability of power is not only caused by the potential faults in the single point of failure, but also by the fact that maintenance operation of this network is more complex.

In order to address the power path availability limitations in radial network, an alternative was implemented in radial networks that have redundant circuits [14]. This means that at least two circuits are run simultaneously to each other from the sources to the given load. Telecommunication power plants are one of the most commonly used examples of the system with a redundant radial power distribution architecture where two DC circuits are feeding each load as shown in Fig. 2.

A cleaver design and planning of radial distribution system can achieve a fair degree of reliability even without much addition of cost. This feeder system is constructed as a network and operates radially, In Y-connected radial systems, the neutral conductor is connected through all open switch points forming a network connecting feeder and substations [32].

B. Ring/Loop Network Architecture

Ring distribution network follows a loop structure that loops the service from a source through a collection of loads and back to the source. In other words, all the nodes in the ring network are connected to each other in such a way that they make a close loop structure making runs through or around an area serving one or more distribution transformers or load centre and returns to the same substation [35]. There is being a “null point” somewhere on the loop where no power passes. This layout is basically dynamic radial system with open point (null point) shifting as loads change. A loop must be able to meet all power and voltage drop requirements when fed from only one end, not both [32]. Fig. 3 shows the one-line diagram of ring power distribution architecture [36]. In a ring network the utility can provide power in any direction of the ring. Due to this, fault can be isolated without disturbing service to many of the loads on the ring [37]. Ring network structure is highly attractive for

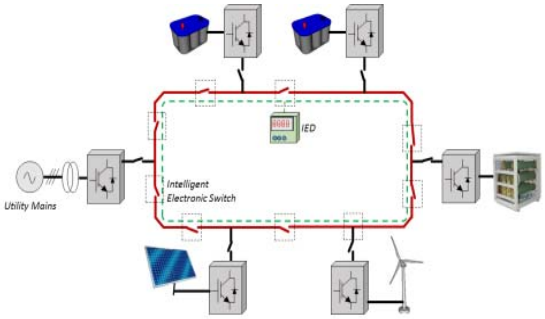

Fig. 3. One-line diagram of ring power distribution architecture [36]

high performance of distributed network due to fault isolation and the ability to flexibly locate sources with respect to loads. A distribution network with numerous connecting rings is known as a multi ring structure. In a multi ring structure, a wide range of power transfer paths may be available. This leaves significant flexibility in the event of needed maintenance or a fault on part of the system.

However, path multiplicity complicates automatic relaying or protection of a multi-ring system, as it may be difficult to quickly detect and determine the location of a fault and the correct actions to take to minimize customer interruption [38], [39]. The task of isolating faults becomes more involved with a multi-ring structure when compared to other simpler configurations [40]. More than one decision could be implemented to isolate a fault, and an optimal decision may vary with operating conditions.

1) Application of Ring Network

Ring network is commonly used in residential areas where electrical current flows in more than one direction. This offers better voltage stability and lower power losses, but makes protection against faults more difficult. Ring architecture with enhanced fault tolerant capacity can also be used with renewable energy parts and EV charging stations [41].

2) Advantages of Ring Network

Ring network is known to be most organized network since it forms a closed loop by joining nodes to each other. Due to this, several zones of protection within the ring network can be implemented. The protections can be implemented on both the positive and negative ring bus. This network structure has a better performance rate compared to radial network even if the load in the network increases giving high reliability. The performance is not affected by the additional devices to the network. In case one feeder is under fault or maintenance, the ring distributor is still energized by other feeders connected to it whilst saving in cabling/copper compared to parallel feeders. [42]. This depicts that source to the customers is not disrupted even when a feeder is inoperable. Different section in the ring system also isolates at different appropriate points to isolate sections in case any fault occurs.

Furthermore, according to previous research, a protection scheme of distributed network was proposed with ring network structure [43]. This protection was

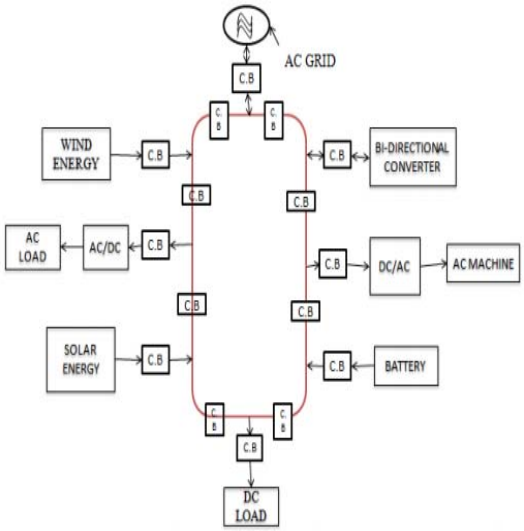

Fig. 4. Block diagram of DC ring bus distributed network [43]

achieved through the use of a ring configuration for the main DC bus, creating several zones of protection within the ring bus. Once a fault is detected in the network, a controller is used to open the zone breakers. This ensures that all breakers are opened and the fault zone is de-energized. Fig. 4 below illustrates that the ring bus will split into zones and each zone is monitored by a segment controller.

3) Disadvantages of Ring Network

A major disadvantage of this structure is that the network is highly dependent on the cables that connect other components to the network. In terms of complexity, a loop feeder system is only slightly more complicated than a radial system and has a major drawback of catering the capacity and cost of the loop system [32].

C. Mesh Micro-grid architecture

The electrical grid can also be organized in mesh architecture apart from radial and ring structures. Mesh structure normally used with high or medium voltage while radial used with low level voltage [44]. Hence distribution systems enable to offset the three phases and the moment of peak power output is equally disseminated between the three phases, countenancing a more consistent peak power output.

A mesh network structure follows the radial structure but includes redundant lines in addition to the main lines. These are organized as backups for the purpose of rerouting power in the event of failures to a main line [45]. Fig. 5 represents the mesh distributed network configuration.

In comparison to ring and radial configurations, mesh grid has the most complicated configuration since it includes many alternative connections between nodes. This significantly makes the operation and protection of the distributed network challenging [46]. Mesh grid is less ideal pertaining to its complexity as it is the most often

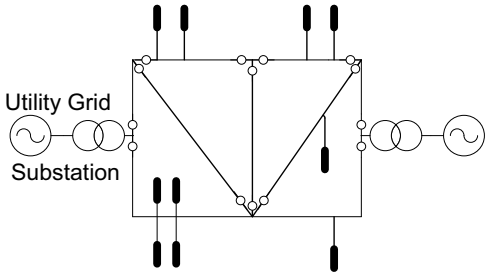

Fig. 5. Mesh distributed network configuration [45]

architecture rather than ring configurations [25]. Perhaps this is because mesh distributed networks utilize the configuration of the existing instead of installing a new network.

1) Application of Mesh Distributed network

The revolution in the generation, transmission and distribution of electricity is expected to be achieved with smart grid network solutions. Hence smart grid can complement electric grid with renewable energy resources and enabling cleaner environment. For efficient transmission and avoidance of loss of power generated, it deems essential to have power systems that are advantageous in power distributions.

Mesh micro-grid structure is efficient for short-distance transmissions and very well incorporates an existing network structure. That is, it can effectively be upgraded from a radial to a mesh network structure. The power transmission in mesh architecture can be carried to an aggregation point, often a sub-station that allows for reliability and a control over the fluctuating power generation [46]. The peak power is generated to various units and houses hopping around the transformers. Hence, sufficient power is generated and transformed according to the house needs of the end consumer. Fig. 6 shows the distributed generation using mesh configuration.

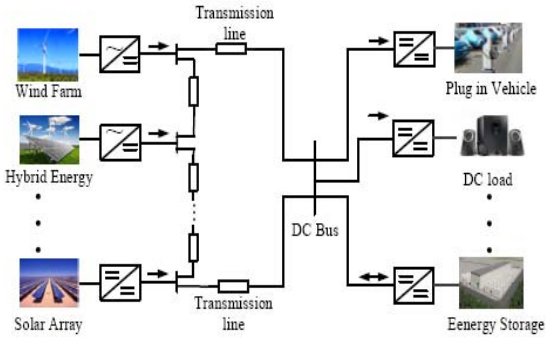

Fig. 6. Distributed generation using Mesh configuration [46]

Power distribution at 380V provides advantages of lower equipment costs, enhancement of distribution capabilities and improvements in sustainability due to reduced copper use.

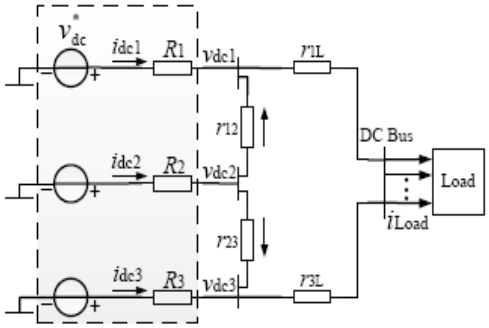

Fig. 7. Simplified model of DC distributed network using Mesh Configuration [47]

Mesh configurations can be efficiently utilized for distribution characteristics of renewable energy resources whereby the interface converters are connected to each other. By using Thevenin equivalent circuits, the simplified models of a DC distributed network are shown in Fig. 6 and a simplification in Fig. 7. The reference of the DC output voltage is selected as 380 V, since this level is globally accepted for standardized components with the best balance of economics and safety [47].

2) Advantages of Mesh Network

Using the traditional droop control method, in a distributed network, accurate load power sharing accuracy can be obtained when the converter DC output power is set to be inversely proportional to the corresponding droop coefficient. Power sharing error can also be eliminated if the droop coefficient and line impedance satisfy the relationship. However, this supposition is only suitable for an ideal system and hence in a practical system there is some error. This is the limitation of the traditional droop control method in the mesh configuration of DC distributed networks [48]. The simplest network structures to protect are radial systems while meshed distribution networks have a higher short circuit power. The advantage of meshed networks is relatively balanced voltage profile and high reliability through redundancy [49].

3) Disadvantages of Mesh Network

Transmission using Mesh architecture utilizes a nonlinear method that suffers from limitation of only focus on lossless distributed networks with purely inductive distribution lines. The results may not be applicable for distributed networks with heterogeneous and mixed R/X ratio lines, which is common in low voltage distributed networks. Reactive power sharing is often not guaranteed as careful analysis can only be done on droop control [50]. Communication delay in a mesh configuration is a very sensitive parameter which can impact largely the stability of the system. For instance, as shown in Fig. 8, if the communication delay is set to a large value, poles III, IV and VI move towards the imaginary axis, the system becomes unstable.

TABLE I
COMPARISON TABLE FOR RADIAL, RING AND MESH NETWORKS

Network	Sources	Stability	Reliability	Capital Cost	Maintenance	Voltage Level	Protection Required	Renewable Penetration
Radial	Single	Low	Low	Low	High	Low	Medium	Problematic
Ring	Multiple	High	Medium	High	Low	Low	high	Accepted
Mesh	Multiple	High	High	Low	High	Medium or High	Higher	Moderate

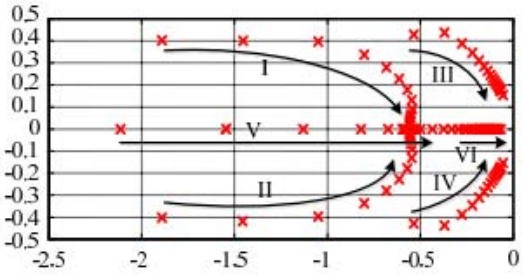

Fig. 8. Closed-loop dominant poles for varying communication delay using Mesh configuration [49]

III. DISTRIBUTION GENERATION PENETRATION INTO DISTRIBUTION NETWORK

Distribution companies have limited control on installation of Distribution Generation (DG) units. Many studies have been conducted to find loss variations in distribution networks in the presence of DG units. Both technical and economic benefits can be achieved by employing DG in existing distribution networks [51] and the Disadvantage [52] associated with them are listed below in addition to Benefits.

A. Technical Benefits:

- Line losses can be reduced
- Improves voltage profile
- Pollutants emission can be reduced
- Energy efficiency can be improved
- System security and reliability can be achieved
- Power quality can be improved
- T&D congestion can be relieved

B. Economic benefits:

- Some DG technologies provide less O&M costs
- Productivity can be enhanced
- Health care costs are less because of the improved environment
- Fuel cost is also very less because of the increased overall efficiency
- Reserve requirements and associated costs are also very less
- Because of the peak saving on load curve the operating cost is very less
- Security for critical loads has improved

C. Disadvantages:

- Connecting DG in Distribution system causes to flow reserve power flow which results in malfunction of protection circuits
- Stability issues
- Increased fault current
- Asynchronous DG sources which use inverter for interconnection will inject Harmonics into the system

IV. RELIABILITY ON THE FUTURE TREND

Future distribution network topology is likely to change from being radial to ring in order to optimize the integration capacity of Energy Generations (EGs). Ring operation mode of distribution network increases the reliability of electric power supplies and it eases the issues of voltage control of EGs [53]. Delivering the electrical power to the customers is the aim of electrical distribution system. In this way the reliability of such a system is a major issue. The customers demand higher reliability in the new competitive environment of electrical system. Also the consequences of losing one part of electrical system are inconvenience of customers, economic losses or a threat to health and safety [54], [55]. Therefore every effort to improve the reliability is appreciated.

V. COMPARISON OF NETWORKS

Many factors needs to be considered looking at the different scopes of the networks while comparing the best suitable network structure between the radial, ring and mesh architecture network as shown in Table I. Considering factors such as location of DG's, voltage range, grid structure considering the transmission target (underground or overhead), climate and environment, principles of operation (directional, over current), types of generators (synchronous, asynchronous, converters), load classification, characterization and load schedules, different failure condition are few of them [56], [57].

VI. CONCLUSION

This paper has presented a review of existing distributed network architectures. This includes radial distributed network structure, ring/loop distributed network architecture and mesh distributed network architecture. Each of the mentioned distributed network architectures is defined with benefits and drawbacks are discussed together with its application. Distribution networks have usually a radial or loop design, while transmission networks have only mesh design. Therefore, the power flow in distribution networks usually is one-directional and no or little redundancy exists. The interconnection is further impacted through aspects of the network topology. There are a number of active distributed network projects around the world involved with testing and evaluation of these advanced operating concepts for electrical distribution systems hence, further research on better control and management techniques should be considered which are intrinsically potential for the future energy systems to achieve reliability, efficiency and quality power supply.

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