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Challenges with renewable energy sources and storage in practical distribution systems

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ABSTRACT

The intuition of the power distribution system is to supply good quality of power to the customers with cost-effectively and environment friendly. Renewable energy resources (RES) are integrated in the distribution system to meet out the variable load demand with the decarbonizing effect. With the inclusion of RES, the operation of Distribution Network (DN) has become more complex. This paper describes the state of art in various load flow methods used to analyze the parameters in DN. This paper emphasizes upon the various challenges of DN with the integration of RES. It reviews the various pricing methodologies for the delivered power in DN elaborately. The importance of Demand Side Management (DSM) and energy storage in DN are explored in this paper. The analysis of nodal voltages in the DN with Solar PV, Storage, PHEV and Diesel sources is demonstrated on IEEE four node test feeder.

1. Introduction

Throughout the world, the demand for reliable power is increasing. After the restructuring of the power market, many power companies are actively engaged in power trading. The Distribution power flow and network pricing has become more important which has lead to new power flow methods and innovative network pricing models. The intuition of this paper is to review the characteristics of various distribution load flow methods, pricing, Demand Side Management and the impact on renewable integration in the practical distribution system. The electrical power network has been developed accordingly to the need of the latest technological trend and has been restructured into a vertical market [1]. Researchers are contributing more in the conversion of this conventional power market into a smart network. Due to the emerging renewable energy resources, the Distribution Network (DN) has become a meshed network from radial network. This has introduced many Distribution Generators (DG) in the network and made the network more complex [2]. Study of Distribution power flow has become a challenging task due to its complexity [3]. Tracing the distribution power flow is complicated, pricing the Distribution power flow is also more complicated [4]. Addition of Renewable Energy Resources (RES) in the DN created a path for Smart Grid and Micro Grid in the 21*st* century [5]. Due to the irregular power output of RES voltage profile control, System stability and reliability are important areas which has to be concentrated. In order to improve the system reliability effective measures are taken like Advanced metering infrastructure (AMI) which is used to improve the two way communication between consumers and companies and makes the consumers actively participate in the distribution side, thus increasing the Demand Side management (DSM) [6].

The generated power is transmitted through an interconnected power system network. This electrical network has several branches and nodes. The branches represents the transmission lines and the nodes represents the buses. The power transmitted after the substation to the consumers through the feeders is called as the Distribution Network (DN). Previously no generators were present in the DN but after the introduction of RES, more DG's are included in the DN which has made the DN into an active network. Thus power is injected in the network through RES and the market design has become smart market design (SMD) [7]. The grid has been emerged into a smart grid and presently with more generators added in the load side the grid is now called as micro grid. The micro grid has changed the concept of central dispatch into a decentralized dispatch, thus islanding the network from the main network. Further to reduce the CO_2 emissions and scarcity of fossil fuels more electricity appliances have emerged [8]. In many countries the production of electrical vehicles (EV) have increased and usage have also increased. Thus for charging the EV the distribution network is used, which makes the DN with more challenges like voltage stability and system reliability etc., [9]. The DN is one of the complex network due to its design with more number of feeders supplying

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power. If there is any major fault occurs the fault should be identified and the system should be restored as soon as possible. To identify the fault in the DN fast screening algorithm is used to avoid critical failures [10].

This paper discusses the various distribution power flow methods adopted and gives the merits of the various methods. The second part discusses the different Distribution pricing methodologies adopted to price the power and gives an introduction about smart reference networks. It also describes the best network pricing method in all aspects. The third part emphasizes the different steps taken by the companies and consumers with active participation and the importance of DSM. The last part gives the details about Distribution Generation, optimal sizing and location of DG's along with the integration of RES in the DN. It also explores the introduction about the energy storage impact over the present micro grid and the challenges related to protection of micro grid. This review will give a clear picture on the evolution of Active Distribution Network from its conventional network and will help the researchers to have an idea about the recent developments in the DN.

2. Distribution power flow

The power generated should be transmitted to the consumers in an effective way such that the network is stable, reliable and economical [11]. In the fast growing environment, the demand for electrical power is increasing day by day. In order to meet out the demand more alternative energy sources are added to the DN. Many renewable energy technologies have emerged and are integrated with the DN. The integration of RES faces many challenges, as it needs large back up for conventional power and energy storage [12]. Fig. 1 gives the broad classification of the different Distribution power flow methods. These methods were used to perform the load flow in the Distribution Network. Each method has its own merits and demerits which are explained in this section.

Load flow in the DN has become more complex with the inclusion of more RES and the radial networks have been converted into meshed network [13]. The nodal distribution algorithm was used to trace the real and reactive power flow in which the transmission losses were included [14]. The conventional Newton Raphson method is not suitable, for distribution power flow method so a new efficient power flow method was introduced which had a fast convergence control and was suitable for polynomial load applications [15]. Further to reduce the time of convergence and to solve the power flow directly a new algorithm was proposed which uses only the bus-branch data for calculation, here time consuming (Lower – Upper) LU decomposition and substitution in Jacobian matrix is not needed. This method was

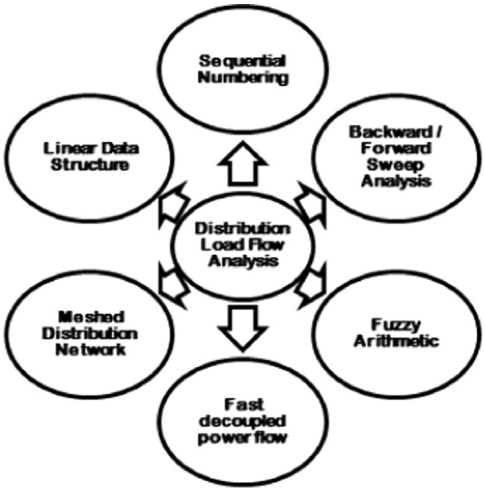

Fig. 1. Classification of Distribution Power Flow methods.

suitable for large distribution network [16]. More simple and powerful algorithm was introduced which used the data from the graphical representation of power drawn and this also converged with less iterations [17].

In the power flow calculations, matrix singularity problem arises to avoid this a unified transformer model was introduced. This technique was used to model the diverse distribution transformer into forward /backward sweep load flow algorithm [18]. To make the load flow common for both transmission and distribution a new software was introduced. This Distribution Systems power flow analysis package (DSPFAP) uses different sweep based algorithm which can also locate the DG's [19]. In all the above methods the required data for load flow analysis is more and the numbering scheme is sequential. To avoid this a new accurate load flow method was proposed which needs only the starting node of the feeder each of lateral and sub lateral. This method used less computer memory and had fast convergence [20]. The load flow studies discussed so far concentrated only on meshed networks and radial networks were not addressed. A multi port compensation technique was introduced for calculating the current injections at nodal point and current flow in each loop is calculated for different load models [21].

The evolution of smart grid made more DG's inclusion in the distributed network which had a greater impact in the voltage profile, active and reactive power flows and line losses [22]. To have steady state operations, planning and analysis MATPOWER was introduced. This is an effective tool for power system research and education [23]. After the evolution of smart grid, distribution management system was introduced. A new framework was formulated by name three phase optimal power flow (TOPF). This algorithm accommodates even micro generator outputs, storage systems and appliances [24]. New path matrix concept was introduced to study the DN with multiple transformers, by studying the structure of distribution system an incident matrix between nodal voltages and current injections were established for obtaining direct solution [25]. With the latest advancements in the distribution side and challenges faced in the bidirectional power flow the distribution network has many more uncertainties. To reduce the time of calculation a cost selling push-rebel algorithm was introduced on optimal power flow tracing [26]. The distribution system has ungrounded system where the conventional power flow analysis cant be implemented hence a hybrid model was proposed in which the distribution system is bifurcated into main line and set of sub systems for easily solving the power flow [27]. With the emerging field of intelligent controllers a new power flow algorithm using fuzzy arithmetic and fuzzy logic principle was introduced to solve the load flow problem. This technique eliminates flat voltage at nodes and sequential numbering [28]. Due to the irregular generation of DG's the micro grid experience unbalanced load in all the three phases. To overcome these limitations semi definite programming (SDP) relaxation techniques was introduced. This method arrives the global optimal solution accommodating thermal and quality of power constraints [29]. In three phase power flow, singularity problem in transformer connections occurs, this can be overcome by a phase component, isolating the zero sequence component thereby creating an improved transformer model [30]. The conventional load representation as P-Q becomes less accurate and a new load model with voltage dependent algorithm was proposed. Using this technique the load flow problem was formulated which is a simple distribution load flow and reduces the execution speed and achieves global optima. This method can be applied for both radial and meshed loop analysis [31]. Further to reduce the time and space complexity, a new load flow studies were introduced based on linear data structure. Here the data preparation time has been reduced and the efficiency of load flow has been increased [32].

In the latest DN the micro grids are islanded and needs to be analyzed under different operating modes. This can be done by using Newton trust region method [33]. The optimal power flow when many energy storage devices are included in the distribution network has