Distributed generation system planning based on renewable energy source

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***Abstract*— Distributed generation systems are needed in order to use existing energy resources efficiently and to meet energy needs. Although the interconnection of distributed generation systems with renewable sources offers many advantages, technical difficulties may arise from the inappropriate integration of distributed generation. Therefore, optimal planning of distributed generation is very important for the distributed grid to provide the expected power. Optimizing production systems is used to increase efficiency, provide flexibility in electrical systems, reduce costs and reduce power fluctuations. Meta-heuristic algorithms are more suitable for multi-purpose applications. In this study, the renewable energy source and energy storage system in the distributed generation system are also mentioned. Some of the optimization methods used for optimal planning of the distributed system are also included.**

Keywords—distributed generation, renewable resources, meta-heuristic algorithm, energy storage system

I. Introduction

The depletion of fossil fuel resources such as natural gas and coal, which have a large share in meeting the energy demand in the world, the increase in environmental awareness due to climate change and the reduction in the use of existing systems have led power systems engineers to seek alternative technologies such as smart grids. Smart Grid is an advanced two-way power flow power system that can be self-healing, adaptive, flexible and sustainable with foresight for the prediction of uncertain situations [1]. The transition from existing networks to smart networks is not instantaneous, but certain stages should be passed. Basically, in order to create a more reliable, flexible and economical smart grid, at least a certain part of the consumed energy should be provided from renewable energy sources. Expanding the use of distributed generation based on renewable energy sources within the network is an important issue [2].

Distributed generation (DG) systems are developing rapidly. Therefore, changes are made on the planning. According to the International Energy Agency, distributed generation is defined as a source of electricity that is directly connected to distribution networks to support the distribution grid and support local customers. Distributed generation is divided into renewable technology, non-renewable technology and storage technologies. With the easy integration of distributed generation systems, which are the basis of smart grid applications, with renewable energy sources, consumers can become productive consumers. A distributed generation system comprise with small scale generation units straight attached to distribution grids with a bidirectional power flow varying from KWs to MWs. It is a discontinuous system since renewable energy sources vary in their production amounts according to weather conditions. The use of energy storage systems is important in terms of environmental effects in order to ensure the continuity of renewable energy sources. It provides benefits such as network boosting, reducing power loss, reliability, voltage stability, and power quality. It also contributes to maximizing its economic benefits and reducing the total cost with energy storage systems. Optimal planning is required to provide cost reduction and other benefits of energy storage. Faulty position and dimension of DGs can cause peak power losses, voltage imbalance and poor quality in power distribution networks [3]. By finding the optimum size and ideal location of the DGs, system losses will be reduced and the demand for field establishment of transmission and distribution will decrease. Financial benefits include electricity charges and fuel efficiency. Its ecological advantages are the reduction of pollution and greenhouse gas effects [4]. If we look at the literature studies;

Ref. [5], optimal distributed generation planning methods in distribution networks and the modeling technique for uncertainty factors such as generation of intermittent renewable DCs, generation interruptions and increase in electricity demand are discussed. Ref. [6], reviewed recent advances in optimization methods for the placement and sizing of renewable DGs. Ref. [7], A comparative analysis of mathematical modeling methods of optimization techniques for DG planning has been made and optimization techniques have been examined. Ref. [8] reviewed recommendations for energy storage system (ESS) selection, smart ESS charging and discharging, ESS sizing, placement and operation, and power quality issues. Ref. [9], they applied the optimal layout of energy storage systems to a mixed integer linear program on a 13-bus system. As a result of the study, they stated that the energy storage system reduced the operating and installation costs. Ref. [10] using the MATLAB interface MISOCP, the optimum determination of the location and energy capacity of the energy storage systems in a 33 busbar system was made. Ref. [11] used mathematical algorithms to maximize the capacity by placing at certain points for the restructuring of the networks and observed an improvement as a result.

This article focuses on the distributed generation system. Dimensioning in the distributed generation system will contribute to the reduction of the voltage distortion of the system, the increase of the power quality and the reduction of the cost. For this reason, information about optimization methods in sizing and distributed production planning has been given and their contributions have been mentioned.

II. DISTRIBUTED GENERATION (DG)

The concept of distributed generation is a term used to distinguish it from traditional centralized production. The distribution network becomes an active distribution network by integrating it into distributed generation. Distributed generation power plants are generally planned with powers less than 50 MW. The output voltage of power supplies and distributed alternators is dependent on distribution systems from 230/415 V to 154 kV. The reason for the use of distributed generation is thought to be environmentally friendly, low-cost energy production with low environmental damage. Distributed generation provides a good use case for adjusting the use of heat lost in industrial, domestic or commercial applications. DGs have low capacity due to their low energy density and dependence on the geographical conditions of the region [12]. DG can benefit consumers and utilities, especially in distribution systems where there is no transmission system or centralized generation cannot be implemented [13,27,32].

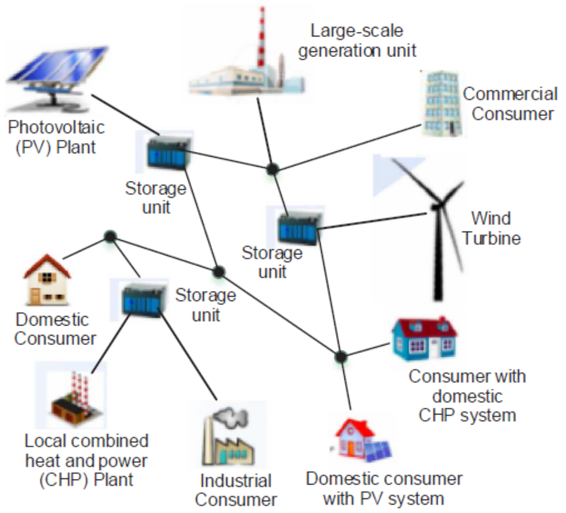

Fig. 1. Distribution System [3]

DGs technology can be classified into three types: renewable technology, non-renewable technology (traditional) and storage technology. Renewable technology includes wind, solar (photovoltaic (PV) and thermal), biomass, geothermal, tidal and hydro-power (small and micro). Non-renewable technology consists of micro turbine, gas turbine, reciprocating engines and combustion turbine. Storage technology consists of batteries, supercapacitor, flywheels, compressed air energy storage (CAES) and pumped storage [5].

A. *Renewable Technologies*

A large part of the world meets its electricity needs from fossil fuels. It has been observed that this situation harms the environment and causes global warming. Later, interest in environmentally friendly renewable energy sources has increased in order to make the world more livable. Sustainability refers mainly to the economic, social and environmental performance of systems. It is generally accepted that renewable energy sources have a better sustainability than conventional energy systems. If we list the renewable energy sources; solar energy, wind energy, geothermal energy, bioenergy, hydropower and ocean energy. Advantages of renewable energy sources; It can be listed as less damaging to the environment, advantageous for the user and reducing the country's dependence on foreign sources. The disadvantages are the high cost and convenient geographical location. Due to the discontinuous nature of renewable energy sources, storage methods are used to ensure their continuity.

1) Photovoltaic solar system

Solar radiation can be directly converted into electricity via solar cells (photovoltaic (PV)). Solar cells perform this conversion process using semiconductor elements [14]. The most basic unit of this system, the solar cell, is connected in series and parallel to ensure that the panel is at the desired power .

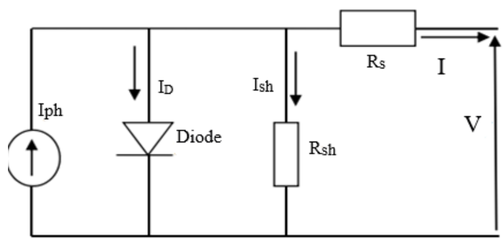

Fig. 2. Photovoltaic cell circuit diagram

A single diode PV circuit diagram is used in the solar model. V output will be the pump voltage. The relationship between the outputs current (I) and voltage (V) of the PV panel for a single unit is expressed as follows [15].

$$I = I_{Ph} - I_0\left(e^{\frac{V+IR_s}{aV_T}} - 1\right) - \frac{V + IR_s}{R_{sh}} \tag{1}$$

I_{Ph}, I_0 , R_s , R_{sh} and V_T were performed under standard test conditions of 1 kW/m2 air mass and 25°C. These parameters are used in analytical and numerical solutions.

2) Wind energy system

Wind turbines generate electricity by powering an electric generator with wind power. The wind passes over the blades, creating lift and applying a turning force. Rotating blades rotate a shaft inside the nacelle connected to the Generator. In this way, a power is supplied to the generator [16,30]. Output power (P_W) is given by following expression

$$P_W = \frac{1}{2}\rho_w A v^3 C_p \tag{2}$$

Where ρ_w denseness of air in (kg/m^3) , A is swept area of rotor blades, C_p is power coefficient.

The power coefficient can be expressed by following equation;

$$C_p = \frac{1}{2}(\delta - 0.022\beta^2 - 5.6)e^{-0.17\delta} \tag{3}$$

Where β is slope angle of blades in degree,δ is tip speed ratio of turbine .

B. Storage Technologies

Energy storage is a essential technology that uses stored electrical energy when there is high load requirement. Smart energy storage systems are used to provide continuous, flexible and quality power. The development of energy storage technologies is of great importance in solving power quality problems such as voltage drops and interruptions, both at the system and equipment level. However, energy storage; It also has benefits such as increasing system efficiency, enabling the integration of renewable energy sources, increasing grid stability and reliability [5]. Energy storage systems are an effective system in the development of new technologies, changing consumer habits and changing the distribution system. It can also provide increases in system performance such as reliability, responsiveness and load capacity. The contribution of energy storage systems to smart grids is explicated as frequency control and meeting high power demands [17]. Storage and conversion of energy is provided by batteries, compressed air, flywheels, thermal power, super capacitors, superconductors and fuel cells. Energy storage technologies are divided into three as mechanical, electrochemical and electromagnetic.

Pumped storage systems, compressed air energy storage and flywheels are a mechanical energy storage technique. Storage with batteries and hydrogen energy is an electrochemical energy storage technology. It defines the group that includes electromagnetic energy storage technologies, supercapacitors and superconducting magnetic energy storage systems. [18]. The energy storage system must be prepared for the form of application in from low power to large power and the type of generation that can be permanent, renewable. Among the energy storage systems, the methods that can be used in large-scale systems that have large capacity and can provide energy for a long time are pumped hydro storage and compressed air energy storage. The most efficient and economical method in large powerful systems is the pumped hydro storage system.

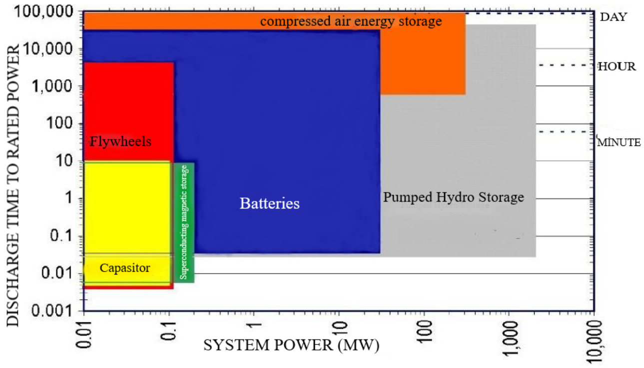

Fig. 3. Energy Storage Systems

Figure 3 shows the discharge times of different energy storage systems at nominal power and their storage capacities in minutes, hours and days based on system power. As can be seen, pumped hydro energy storage systems from these systems provide storage at the level of MW and on a large scale. Since renewable energy sources cannot provide a continuous energy due to seasonal differences, long-term storage should be required. For an effective storage system, it should be able to respond to demand fluctuations in environmental factors such as changing loads and weather conditions. It should be able to provide uninterrupted energy and its efficiency should be increased. Energy storage systems are often used in large-scale systems such as power generation, distribution and transmission systems, renewable energy, and industrial and commercial facilities. [8].

III. The Challenges of Distributed Generation

Challenges in today's DG installations will be separated into four types: commercial, technical, environmental and regulatory. Overcoming these challenges will contribute to maximizing the use of DGs. In Fig. 4 the classification of difficulties is given in more detail.

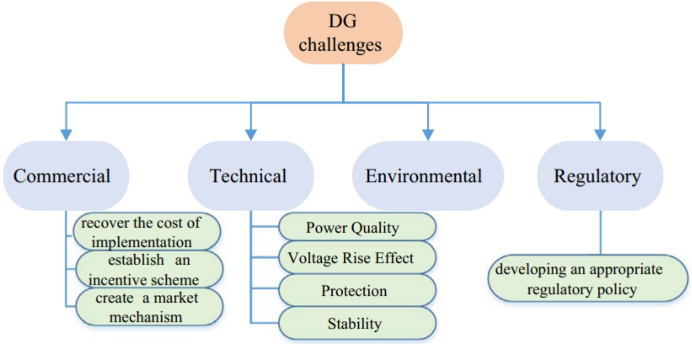

Fig. 4. Distrubition Generation, DG Challenges [5]

A. Technical challenges

1) Power quality

Power quality; It explains the harmonic distortion and transient voltage instabilities of the mains voltage. DGs can lower or raise the distribution network depending on the conditions that adjust the quality of the power factor, current and voltage received by the consumers. [5,26]. Criteria determining power quality; voltage waveform, effective value, frequency and phase angle balance in phase voltages for three-phase systems.

2) Voltage spike effect

Voltage spikes occur when connecting DGs in the network. This is a distribution network dependent factor that can limit DG capacity. Voltage spikes and power supply instability are exploited to control the optimum power flow, active and reactive power fluctuations under constraints [4]. Heavy loads, incorrectly sized power supplies, or poorly modulated transformers will cause voltage spikes. Distributed production has adverse effects such as data loss, vibration of lighting elements, downtime or damage to sensitive equipment. [19].

3) Stability

In the design of the distribution network and transmission network, the impact on reliability under the influence of different conditions and the stability effect when working with different DGs for network security should be taken into account. There are two fields to think about evaluating renewable GM plans: transient stability and long-term dynamic stability and voltage sag [5]. The fact that the distributed generation units depend on renewable energy sources have a uncertain and variable generation structure, have low inertia constants, and tend to leave the system and switch to island mode according to the fault situation cause problems in the stability of the power system [2].

B. Environmental challenge

Increasing the use of DG does not always depend on environmental impact. This is market dependent on different DG technologies. For example, the environmental impact of DG technologies that consume fossil fuels such as fuel cells and micro turbines is more effective than renewable energy technologies (such as solar, wind, hydroelectric).

IV. Optimal planning of distributed generation

Optimum planning of distribution networks is a method that helps provide the maximum potential corrections of DGs at low cost to power generational feeder loads. Optimal DG planning is based on technical constraints and optimization of economic objectives. Equipment capacity, voltage drop, network reliability indices are examined under technical constraints. Optimal planning includes optimization of economic objectives, minimization of investment and operating costs, minimization of imported energy from transmission, reduction of energy loss and reliability costs. [5]. Its basis is the resolution of a set of DG decision variables for optimal planning of distributed generation compact. For example, to increase or decrease an objective function, the size, location, and type determination must be done correctly [3]. In an energy storage system, an optimal planning is made to ensure appropriate arangement, enhancement of power quality, reduction of peak load demand, reduction of cost, integration with renewable energy source and increase system efficiency. It can help ensure power flow in distribution systems and cut down power loss for optimum operation of an energy storage system [8,25]. A brief description of the optimization methods is included in this section. These methods are traditional techniques and metaheuristic algorithms. Due to the enhanced penetration of DGs in the distribution network, DG location and sizing is becoming progressively significant in distribution network planning. There are various optimization methods used in planning optimum size and positioning to solve discrete DG problems. Briefly, these methods can be divided into two main groups:

1. Conventional methods are also divided classical or non-heuristic methods. Linear programming (LP), nonlinear programming (NLP), mixed integer nonlinear programming (MINLP), dynamic programming (DP), optimal power flow-based Approach (OPFA), direct approach (DA), sequential optimization (OO), analytical approach (AA) and continuous power flow (CPF).

2. Smart search-based methods are also classified heuristics. Evolutionary algorithms (EAs), tabu search (TS), particle swarm optimization (PSO), ant colony system algorithm (ACSA), bat algorithm (BA), cuckoo search algorithm (CSA)

A. Conventional methods

Traditional techniques for optimal planning of distributed generation in power distribution networks are discussed in detail below:

1) Analytical techniques

Analytical techniques are used to execute a mathematical evaluation of the power distribution system and to formulate an objective function. Analytical techniques are generally easy to execute and supply the opportunity for a DG planning solving. Analytical method is applied to minimize power losses in distribution network and to decide DG size and location. Analytical equations are used to decide the size, location and power factor, while multi-objective index-based analytical methods are used to reduce active and reactive power losses and voltage deviations [3].

Analytical techniques are a set of equations capable of theoretical analysis of the power distribution network using mathematical expressions. These equations are used to describe an objective function that can reach minimum or maximum values depending on a decision variable and constraint space. For example, according to the full lost formula, the losses in a distribution network are calculated as given in Equation (4) to find the total active power. When a DG with active/reactive power generation is related to the i bus, the active/reactive power emerge on the i bus will modify as given in (5) and (6). (4) is used to derive (7), which is used to find the optimal DG size in the busbar. Finally, this analysis is done to determine the optimal positions and capacities of DG units. [3].

$$\begin{cases} P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j - P_iQ_j)] \\ \alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j), \beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin(\delta_i - \delta_j) \end{cases} \quad (4)$$

$$P_i = P_{DGi} - P_{Di} \quad (5)$$

$$Q_i = Q_{DGi} - Q_{Di} \quad (6)$$

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}\left((P_{DGi} - P_{Di})P_j + (Q_{DGi} - Q_{Di})Q_j\right) + \beta_{ij}((Q_{DGi} - Q_{Di})P_j - (P_{DGi} - P_{Di})Q_j)] \quad (7)$$

P_L is active power, P_i and P_j active power components, V_i and V_j voltage components, Qi and Qj reactive power components. (5) and (6) are used to minimize power losses Analytical approaches are used to decide the optimum location of DGs in radial distribution systems to reduce power losses. They are not iterative algorithms because there is no matching problem in analytical approaches and can get very fast results as a result.

1) Mixed-integer non-linear programming

Mixed integer linear programming (MILP) methods determine the linearization of the power flow technic and constant and distinct conclusion changeables. It can be advised for minimizing annual investment costs and optimal planning of DGs in radial apportioning networks. Linear statements have been used to model various load levels and short-circuit current limits. Linear programming (LP) techniques are thinking about appropriate for handling complex problems, but an error output may be produced due to the linearization process.

Ref. [20], the integration of a linear battery aging and degradation model into a micro grid sizing formulation into a multi-energy micro grid sizing model utilizing mixed integer linear programming is observed. As a result of the study, they stated that thinking about battery degeneration in optimum micro grid sizing problems affects the detected storage value. Ref. [21], A new predictive contemplate and transmission optimization algorithm based on Mixed Integer Linear Programming (MILP) is mentioned. The new method has beeen applied to both the annual performance estimation and design of microgrids and compared with a heuristic methodology. The study has been carried out to increase the economic competitiveness of micro grids and to provide the best operating performance with the lowest total cost. It can be used to improve computational efficiency during the sizing phase.

2) Probability techniques

Probabilistic techniques are followed to deal with unsure location. Ref. [22] a probabilistic approach is presented to determine the most cost-effective position and dimension of DG units. As a result of the study, they concluded that it minimized the downtime cost and increased its reliability. Probabilistic techniques frequently need the handiness of large amounts of operational data along with peak data processing [3].

B. Metaheuristic algorithms

The metaheuristic algorithm is loop establish, which surveys and falls prospect solving by connecting deversified construct to arrest for a sub-heuristic. These algorithms are effective in seeing some objective functions. However, the adjustment of the optimization parameters depends entirely on the adjustment of the optimization parameters in terms of optimality and productivity. Some of the meta-heuristic algorithms are mentioned below.

1) Genetic algorithms

Genetic algorithm (GA) is a search algorithm by genetic simulation and natural selection, such as crossover, variation, and inheritance. It can be used to resolve the optimal arangement of renewable DGs, taking into explain generation uncertainties to minimize power losses and economic costs. GA is acceptable for resolution complex multi-objective planning problems. However, GA has disadvantages such as feasible early overlap of the solving and computational incompetence due to the colculation of the objective act [3,32]. Ref. [23], genetic algorithm was used for optimal placement and sizing of DG units. A multi-objective optimization model is used to control energy savings, voltage variation and line loss. As a result of the study, they observed that it improved the optimal placement and sizing. Ref. [24] the optimal location and sizing of the distributed generation has been made by genetic algorithm to minimize active power losses and voltage variations on a 33-bus radial distribution system.

2) Particle swarm optimization

In 1995, Eberhart and Kennedy first suggested Particle Swarm Optimization (PSO). The main focus of their research was social behavior inspired by a flock of birds or fish [4,28]. Distinct variants of the PSO algorithm have been used to different areas of electrical system problems. Particle swarm optimization (PSO), a PSO-based planning method is suggested in which optimum arrangement and sizing of DG units as well as allocation static compensator are decided to decrease power losses and enhanced the voltage profile in radial distribution networks. For optimal planning of DGs to minimize power losses in distribution networks, PSO can correct solving quality and necessitate fewer loops associate to GA [3,31]. The PSO is formatted with a particular population size and particle numbers. Initial power appropriate, demand, PV power and grid energy cost will be used so as to find the solving of the first iteration [29]. Studies on the PSO algorithm have been done on settling the optimal dimensions of the distributed generation, cutting down the total operating cost, improving the voltage profile, minimizing the losses, reducing the total harmonic distortion (THD) and maximum power quality.

3) Ant colony optimization

In the 1990s Dorigo et al advised Ant Colony Optimization (ACO) as a new technique for resolution optimization problems [4]. It was created by being inspire by the food-finding movement of ants. Ant colony optimization (ACO) analyzes by imitating the social behavior of insects. An ACO method can be utilized to optimally assignation of a hybrid system depend on photovoltaic, wind turbine, battery, and hydrogen technologies, with the objectives of minimizing system cost and maximizing system reliability, enhancing voltage, balancing the load, and cutting down power losses. [3]. Ant colony algorithm is used for determining the optimal size and location of DGs, solving capacity allocation problems in distribution systems, minimum power loss and restructuring problems.

V. CONCLUSION

In order to ensure system security and meet the energy require in a healthy way, studies on the planning and sizing of distributed generation are increased.

In this article, research studies carried out in the field of DG sizing are reviewed in terms of the benefits of its application and integration. Studies have shown that multi-purpose functions can give better results.

With optimal integration and planning of distributed generation in distribution networks, several benefits can be achieved, such as better power quality, supply safety, voltage stability, cost reduction, improved power quality, minimizing power losses, maximizing distributed generation units, reliability and loss savings. It has been examined that it would be better to use systems based on mathematical algorithms in distributed production optimizations. In order to enhance the efficiency of renewable energy sources , studies can be carried out on energy storage systems .

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