A review of various power flow management and control techniques in Distributed Generation

Sujit Suman Acharya, Asst. Prof. Abhishek Shrivastava
RadhaRaman engineering college, Bhopal, India

ABSTRACT

Distributed generation across the world is becoming more and more popular because of its clear advantages of providing efficient power source with added reliability. But there are many techno-commercial challenges that are also needed to be addressed to make DG especially based on renewable energy sources a popular option. With advancements in power electronics many solutions have been proposed and are successfully working. This paper aims to provide a review of use and development of various power flow management and control techniques that can be used in a DG system. Different popular DG generation sources are discussed, brief literature review is provided and finally basic characteristics of a traditional distributed generation system are presented.

Keywords: *Distributed generation, Fuel Cell, Solar PV, wind turbines, Micro turbines, Microgrids.*

I : INTRODUCTION

Power Generation particularly in India is still centralized. Which means power is generated by many large generators or power stations which feed this power to a high voltage transmission grid. Grid transfers this power to long distances which is finally reaches its end users through distribution transformers. Indian power sector and power distribution utilities are going through a reformation process to cope up with the regulatory change for reduction in AT & C Loss, improvement in Power Quality, Reliability of Power Supply, Improvement in Customer Satisfaction and rationalization of electricity tariff. [1]

History of Distributed generation started from the start of 20th century i.e. post 1900, when in UK there was no national transmission system. In the year 1919, total 570 electricity utilities were operating 439 generating stations. In the absence of transmission system, generators were directly connected to local distribution networks [2].

Distributed Generation (DG) can be defined as the integrated use of small generation units directly connected to a distribution system or inside the facilities of a customer. DGs have potential to be used in areas like increasing power quality, to reduce investment in transmission lines, reduces AT & C Loss, reducing CO2 emission, increasing environmental protection and reducing high energy prices at retail level.[3]

In general, any power productions which are connected within distributed system and are close to the point of use are referred as Dispersed or distributed generation. DG are usually connected to MV (medium voltage) or LV (Low voltage) grids. As they are integrated within distribution system, hence they are not planned centrally. Any application which have small generators (typically less than 30 MW) distributed at different locations in a power systems and which powers the electrical consumers can be included in distributed generation.

These days distributed generation mainly includes Solar-cell, wind power, fuel cell (FC) plants, micro turbine engines and storage devices as local energy sources [4]. These sources are more popular due to many advantages like lesser power losses, improvements in voltage level and these sources can be connected in radial power line with low losses [5-6]. It is expected that Distributed generations based on Solar photovoltaic modules, wind turbines (WTs) and other renewable energy sources (eg. Biogas) will play a key role in future electricity supply. These technologies are herein collectively called as distributed energy resources (DERs) [7].

DERs have many advantages. They can reduce carbon emissions to great extent, thereby helping nations to meet their greenhouse emissions reduction targets. Further power quality and reliability is greatly increased because not generation is closer to consumption. They can also increase energy efficiency through combined heat and power equipments. Other advantages include reduced line losses and grid expansion deferral.[7]

The rest of the paper is organized as follows: Section II briefly discusses various Distributed Energy resources technologies. Section III provides literature review of various research papers relevant for power flow management and control techniques in a distributed generation. Section IV discusses most popular techniques used in a traditional DG. Section V concludes the paper.

II : Distributed energy resources technologies [3]

Distributed energy resources (DER) refers to electric power generation resources that are directly connected to medium voltage (MV) or low voltage (LV) distribution systems, rather than to the bulk power transmission systems. DER not only

includes generation units but also storage units. Examples of generation units include photovoltaic's cells, fuel cells, micro-turbines, etc. While examples of storage technologies include batteries, flywheels, superconducting magnetic energy storage, etc. A brief discussion of each of these technologies is discussed below:

Fuel cells (FCs)

Fuel cells convert chemical energy directly into electrical energy and heat. The overall chemical reaction in fuel cells is shown below :

$H2 + (1/2)\ O2 = H2O$

Based on material of electrolyte used, there are broadly five types of Fuel cells. They include proton exchange membrane fuel cell (PEMFC), alkaline fuel cell (AFC), phosphoric acid fuel cell (PAFC), solid oxide fuel cell (SOFC), and molten carbonate fuel cell (MCFC). This technology has many advantages like high efficiency, can work at partial load with no reduction in efficiency, very less carbon emissions and less noisy due to non moving parts. Conversion efficiency is as high as 40% considering only electric output. If generated heat is also converted to electricity or other energy source, reported efficiency is as high as 85%.

Gas turbines (GT)

A Gas turbine which is sometime referred as combustion turbine is a rotary engine that extracts energy from a flow of combustion gas. It includes a combustor where air is mixed with fuel and is ignited. Fuel combustion increases the temperature, velocity and volume of the gas flow. This is directed through a nozzle over the turbine's blades, spinning the turbine and powering the compressor.

Micro-turbines (MT).

Micro-turbines have an advantage that they can start quickly, that's why they are becoming popular for distributed power and combined heat and power applications. They are most ideal for hybrid electric vehicles. Micro-turbines differ from gas turbines in a way that micro-turbines generally range from 30 to 400 KW while gas turbines range from 500KW to more than 300 MW. Typical efficiencies of micro turbines lies in between 33% to 37% but can reach up to 80% in a combined heat and power (CHP) application.

Photovoltaic systems (PVs)

PV solar panels consist of discrete multiple cells, connected together either in series or parallel, that convert light radiation into electricity. PV technology could be stand-alone or connected to the grid. PV cells have much larger footprint compared to any other energy resource because output power of PV cell is directly proportional to surface area. Efficiency of PV cells range between 10-24%. Though this technology has lower efficiency and much higher footprint, this is one the most popular energy resource because of being clean and green energy source.

The current output of a PV cell depends both on radiation and temperature. Hence to draw maximum output from a PV cell a maximum power point tracking stage is required. PV cells can be connected to a grid using DC DC boost converter and voltage inverters as shown below :

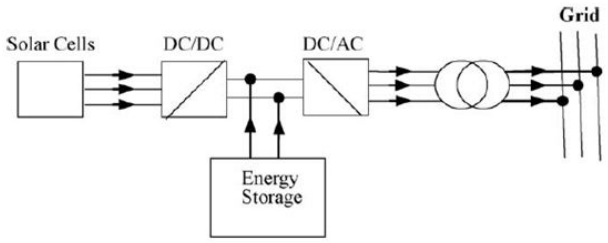

Fig-1 : PV based DG system with energy storage

Wind energy conversion system (WECS)

Windmills or wind turbines convert the kinetic energy of the air winds or streams to electric power. The size of the wind turbine has increased rapidly during the last two decades with the largest units now being about 4 MW. Present trend is that wind turbines are mostly installed in off shore in larger parks that are connected to high voltage level transmission systems. Among all renewable sources, wind energy is considered to be most competitive.

Geothermal

Geothermal energy is the heat from the earth. This energy source is most widely used with more than 6000MW installed generation capacity in 21 countries across the globe. The advantage of this energy source includes environment friendliness, lower cost of land and installation compared to oil, gas, coal, or nuclear power plant, low running cost as there is no purchasing, transportation, and cleaning of fuel is required. However disadvantages include non-availability of geothermal hot spots in the land of interest and suddenly stoppage of steam production.

Biomass

Biomass is considered one of the most important energy sources among the renewable energies in near future. Biomass is organic material made from plants and animals. It is a renewable energy source because more trees and crops can always be grown, and waste from them would always exist. According to the US International Energy Agency, 11% of the world's energy, both heat and power, is currently derived from biomass, with the poorest nations deriving 90% of their energy from it. Some examples of biomass fuels are wood, crops, manure, and other garbage.

III : Literature review of power flow management and control techniques

This sections summaries various literature documents relevant to our work. They are discussed as below:

[2] This paper investigates economic, regulatory and various commercial issues faced by the development of microgrids. The results of investigation have been presented. Microgrid primarily solves the problem of integrating small or medium powered renewable sources and providing reliable electricity supply. Ability to operate in islanding mode and using active management approach make micro generators ideal to provide reliable power supply. Hence technically feasible solutions are required to make this concept safe to operate. Also such solutions must be commercially viable, cost effective as well as must support existing electricity regulations. This paper also presents potential economic benefits and environmental benefits arising from the applications of microgrid technology.

[6] This paper discusses the working of a distributed generation system in much detail. A distributed generation system includes a DC DC boost converter before it is fed to voltage source inverter for transmission through grid. To provide a highly stable supply different control techniques have been discussed both for DC DC converter and Voltage source inverter with different kinds of loads connected locally. The power flow between the grid and the DG is controlled by applying a power/voltage method that regulates the amplitude and the displacement of the grid voltage synthesized by the DG. And to synchronize the DG frequency with that of grid a phase-locked loop algorithm is used. Finally both simulations model and a working prototype have been created and experimental results are presented.

[7] Compared to our traditional power systems, microgrids have clear economic and environmental benefits. Hence microgrids undoubtedly are our future power systems. However development of microgrid concepts and technologies has various economic, commercial and technical challenges to address. As a result extensive R&D activities are in progress across the world especially in Europe, USA, Japan and Canada. The aim of these researches is to provide efficient solutions and to demonstrate its working prototypes. Formation of international symposiums to form close cooperation and open exchange of information has helped a lot in the advancement of relevant research.

[8] This paper has proposed Optimal Real-Time Power Flow (ORPF) problem to integrate renewable power generation and energy storage. The aim is to minimize the energy storage cost as well as power generation from fossil fuels. To solve the problem a novel decentralized algorithm has been presented using tie-set graph theory. Tie-set graph theory significantly reduces the complexity of the ORPF problem by dividing a power network into a set of independent loops referred to as "tie-sets." Simulation results suggest that reliable operation of batteries is possible with optimal power productions and flow controls based on
the system of tie-sets. Hence the proposed method is cost effective and can be proved as a sustainable grid management strategy that compensated for fluctuations in load and renewable generation in a complex large-scale future power grid.

[9] This paper focuses on power flow management and control techniques to improve power flow quality. It has discussed a DC DC converter and DC-AC voltage inverter to be interfaced with grid. Low power factor and high harmonic content is inherent in such systems. This work proposes the harmonic mitigating pulse width modulation (PWM) technique to improve power quality and thereby reducing harmonics. The DC-AC converter provides the bi-direetional power flow between point of common coupling (PCC) and local load. DC DC boost converter make sure that DC bus voltage is maintains at constant level. The simulation study is performed in MATLAB/ SIMULINK and results are discussed.

[10] Photovoltaic (PV) generation is a cost-effective method for renewable power generation source and has minimum environmental impact. As a result it is a most widely used distributed energy resources (DER) in distributed generation systems or microgrids. In this work a DC voltage source model of polycrystalline PV Array has been developed in MATLAB/SIMULINK. Simulations results have been studied under various load conditions and different weather conditions. Further simulation model has been used to develop a load shedding scheme for a standalone PV system.

[11] Inverters find wide applications in power systems domain with the main function of providing AC power and minimizing THD (total harmonic distortion). This work analyses the performance of a single phase H-Bridge inverter based on unipolar switching controlled sinusoidal pulse width modulation (SPWM) with load voltage regulation. Different PWM switching techniques have been investigated to minimize THD. MATLAB/SIMULINK Model was created and performance of H-bridge inverter was evaluated with and without filter. It was found that without filter THD was 13.75% while with filter it was 0.02% only. Hence author recommends the use of H-bridge inverter with filter for the applications requiring constant output voltage with minimum THD such as UPS, PV power generation systems, etc.

IV: Distributed generation characteristics: Traditional approach.

On the basis of literature review we can briefly discuss the basic configuration of distributed generation, its characteristics

in traditional or most discussed approach. There two main aims of any DG system. First aim is to provide power to high voltage grid and secondly serve the local loads. There are various challenges to fulfil these aims. Stability and power quality are most serious concerns raised by most of the authors in the literature review.

So to provide better control on generated AC output power, a dc-dc converter is employed to equalize the dc link voltage before it can be inverted and fed to the grid. It also helps to deliver reliable power even during fast transients as required by local loads. Whereas a dc-ac converter is used to guarantee power quality both to the local loads and the grid. [6]. A general diagram of power stages used in a typical DG is shown below :

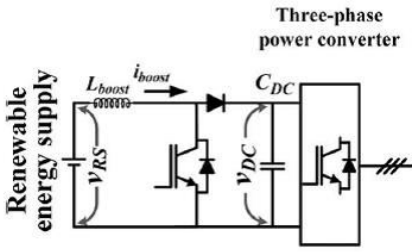

Fig-2 : General diagram of power stages in a DG

A. DC-DC Converter

As discussed before dc-dc converter is used between a power source and DC source inverter. This converter serves two purposes. One it helps to draw maximum power from power source. For example in case of photovoltaic cells it is essential to operate it at Maximum power point to capture maximum possible power from the source. Failing to do we may not be able to draw maximum power from a photovoltaic cell. Hence a tracking algorithm to run solar cells at MPPT (Maximum power point tracking) is discussed in [10]. Secondly, natural power sources are not ideal Voltage power sources. It means that such sources may not provide infinite current and may not provide instantaneous reaction to fast transients in the load. Poor reaction to such transients will lead to power disturbances in feeder side which is not desirable. Hence DC-DC converter increases the reaction response of natural power source because they store some energy either in capacitor or inductors used in its circuit. This stored energy supports the original power sources during transients and sudden power demand and thus minimizes disturbances in the feeder current. To keep the converters operating in a stable mode, proportional-integral (PI) controllers were most commonly used as a control technique. [6] [10]

B. Voltage source inverter

As discussed before DC-AC inverter does the main task of converting DC energy into AC energy which is preferred source both for distribution as well as consumption. [6] [10] have proposed a two level inverter topology as shown in fig-3.

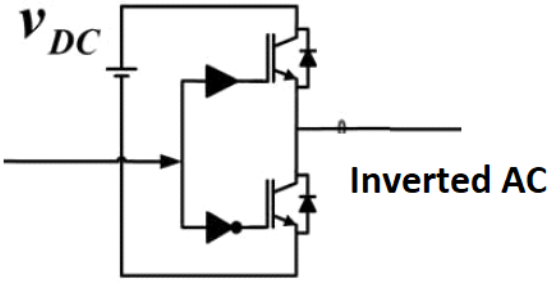

Fig - 3 : Half bridge inverter topology

V: Conclusion

Compared to our traditional power systems, distributed generations have clear economic and environmental benefits. Hence DGs are promising candidate for our future power systems. However development of microgrid concepts and technologies has various economic, commercial and technical challenges to address. This paper provides a detailed discussion of various DG sources both renewable and non renewable, focussing more on renewable sources. Brief discussion of various referenced literature is also provided which broadly talks about advantages, challenges, power flow management issues and different control techniques used in a traditional DG system. They also provide different solutions to all these issues. Lastly characteristics of most widely used techniques in traditional distributed generations are also discussed.

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