Reducing Voltage and Frequency Fluctuations in Power Systems using Smart Power Electronics Technologies: A Review

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***Abstract*— The power quality on grids is an important issue that has been studied for years by manufacturers and researchers. The power quality determines the efficiency and stability of a grid, and it effects the costs. Energy quality is mostly affected and deteriorated by the load. Loads with non-linear voltage-current characteristics draw non-sinusoidal currents from the network. Changes in the amplitude of the voltage, interruptions, voltage pulses, flicker, direct component of the voltage, divergence of the waveform from the sinusoidal, frequency changes, three phase imbalances are reasons of the poor-quality energy. The uncertain changes in resources cause voltage and frequency fluctuation. Due to fluctuation problems, power quality and non-stable output voltage problems occur. In this study, the suggested solutions to voltage and frequency fluctuations are examined and discussed and some smart power electronics technologies are presented to overcome these problems.**

Keywords—power quality, voltage fluctuation, frequency fluctuation, smart grid, power electronics technologies

I. INTRODUCTION

Power quality in electrical energy is an important subject that has been studied for years by manufacturers and researchers. In the last 30 years, the number of studies in this field is very large. The fact that these studies are up to date is due to the new generation load equipment, the need for high efficiency, the increase in end users' knowledge about power quality and the increase in the variety of loads connected to the grid. Quality electrical energy is the protection of the nominal values such as amplitude and frequency of the voltage at any point in the network and the voltage waveform being in sinusoidal form. Energy quality is mostly affected and deteriorated by the load. Loads with non-linear voltage-current characteristics draw non-sinusoidal currents from the network, and these currents create non-sinusoidal voltage drops in the network and distorting the waveform of the voltage at the supply point. Changes in the amplitude of the voltage, interruptions, voltage pulses, flicker, direct component of the voltage, divergence of the waveform from the sinusoidal, frequency changes, three phase imbalances are reasons of the poor-quality energy. In particular, the number of studies on voltage and frequency fluctuations is too great to be underestimated. In a study about voltage fluctuation, there are six algorithms were presented and short-term flickers were obtained as a result of using the measured parameters from the power grid with an algorithm that allows to occur of the voltage variations to occur [1]. Another important issue is to locate the source of voltage fluctuations and to determine its type in the power grid. A related research about this subject was presented to determine the location of voltage fluctuation sources. For this purpose, disturbance loads were located to obtain both symmetric and asymmetric voltage fluctuations in a radial power grid [2-3]. There are some optimization techniques are being used for voltage stability in grids and in a review paper, performances of golden section search, particle swarm, multi-objective artificial bee colony, self-correction etc. optimization algorithms were compared in distributed generation and photovoltaic systems [4]. In another study, the performance of phasor measurement units for a prepared hardware setup (distribution grid) was presented under unexpected voltage fluctuations such as light flickers. Also, the effects of these problems were determined and analyzed experimentally [5]. Many types of renewable energy and traditional energy sources are connected to the power grids, i.e., fuel cell, photovoltaic cell and wind turbine. The outputs of fuel cell and photovoltaic cell are DC and power electronic interfaces are needed to connected them to grid. Also, wind turbine which has AC output can be connected to grid directly or through power electronic interfaces. Traditional generation technology is called as central generation, and as a result of connecting multiple renewable energy sources to the grid, this structure calls as dispersed generation. A simple dispersed generation structure is shown in Fig.1 [6].

The power quality shows the efficiency and stability of a grid and it effects the costs. The output voltages of solar and wind turbines are generally not stable due to changes of resources (wind speed, solar irradiance change). These uncertain changes in resources cause voltage and frequency fluctuation. Due to fluctuation problems, power quality and non-stable output voltage problems occur. In this study, the suggested solutions to voltage and frequency fluctuations are examined and discussed and some smart power electronics technologies are presented to overcome these problems.

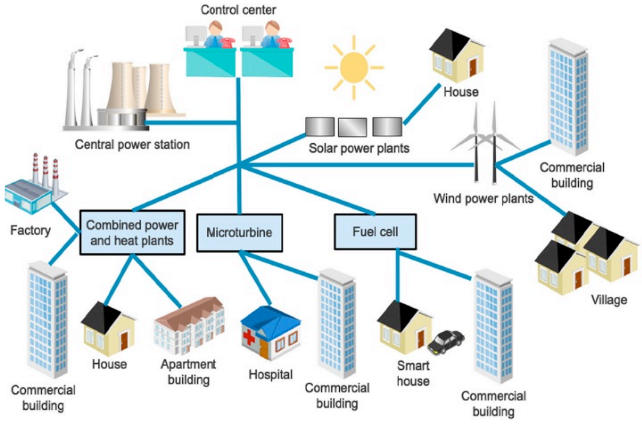

Figure 1. A simple dispersed generation structure

II. Power Quality Issues

Researchers have been working on voltage and current irregularities called power quality problems for many years. There are many types of power quality problems occur on power grids. The most common problems are listed as below;

- Voltage fluctuations (undervoltage, overvoltage, sag, swells)
- Frequency fluctuation
- Noise problem
- Harmonic distortion problem
- Long and short (term) interruptions (outage)

Not only to generate the voltage but also transmit this voltage in healthy ways with the grid is an important issue. Instantaneous rise and fall, long-term rise and fall, noise problems, harmonic problems and interruptions in the voltage reduce power quality. The power quality problems and solution systematic are shown in Fig.2.

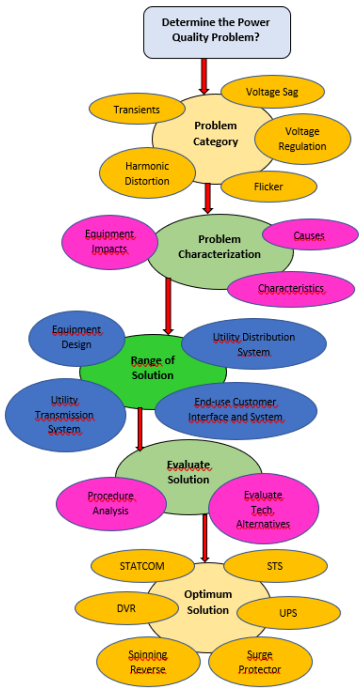

Figure 2. To obtain the optimum solution for power quality problem [48]

A. Voltage Fluctuations

The voltage fluctuation problems such as swell and sag problem are occurred when the rms value of voltage exceeds nominal value between 10%-90% and below nominal value between 10%-90%, respectively. Flicker is another problem about random changes in rms voltage between 90%-110%. Spikes is a traditional very fast and high increases in voltage. Voltage drops and rises (below-above) more than 10% of the nominal voltage for a minute [7]. There are too many studies have been performed about voltage and power fluctuation by the researchers. For voltage fluctuations, a smart grid monitoring equipment was developed to improve the power quality [8]. Load changes, unexpected conditions, distributions, unbalanced voltage generation from renewable energy sources are some reasons for fluctuations on grids. Especially, it is not easy to obtain balanced-stable power generation with wind turbines and photovoltaic panels as a result of source condition changes [9-12]. At the last decades, too many active control algorithms such as vector control [13], sliding mode control [14], second order negative sequence resonant control [15], robust control [16], smoothing control [17] for DFIG based wind systems. Also, using variable frequency transformer is not alternative solution for power fluctuations on wind systems [18] and simplified pitch angle and frequency control method is another solution, too [19]. The same voltage fluctuation problems can be occurred on grid connected photovoltaic systems. The solutions of the problems begin with analysis and some studies have investigated and analyzed power quality problems on grid connected photovoltaic systems [20-22]. For the traditional systems, another analysis study was performed to UPQC system for grid voltage fluctuations and unbalanced loads [23]. The renewable energy systems especially photovoltaic systems include inverters and converters circuits. In two researches, an optimized transformerless inverter system for grid connected photovoltaic and adaptive voltage control for two level photovoltaic inverter system were suggested as alternative solutions [24-25].

B. Frequency Fluctuations

There are many different sources and load types can be used on power grids. Also, multiple disturbances can be occurred and cause frequency fluctuations on power grids. The heavy-tailed, asymmetric, Levy and Gaussian are some of the distributions can be seen on grids [26-27]. The important point for eliminating the effects of distributions is to hold frequency in a narrow band [28]. First step to ensure a stable power grid, it is a necessity to monitor and model of the power grid frequency. The main approach is to record power grid frequency with high resolution. Second step is to identify of frequency fluctuations on power grids [29-31]. There are some studies have been presented about to correct of the short term and large frequency changes on power grids [32-33]. For micro grids, electrolyzer system and fuzzy PI controller, using storage devices, using electric springs are some solution methods for frequency fluctuations [34-38]. Also, SMES strategy and adaptive artificial neural network-controlled energy capacitor system are appeared as remedy for wind turbine systems frequency fluctuations [39-40].

III. Suggested Smart Power Electronics Technologies

Voltage and frequency fluctuation problems of a power grid can be mitigated using smart power electronics technologies since the smart inverters are capable of delivering voltage and frequency-controlled outputs. One of the power electronics technologies suggested to overcome these problems is a piecewise linear-elliptic (PLE) droop control technique to develop the dynamic behavior of islanded microgrids that are generally vulnerable to voltage and frequency fluctuations, which occur, when a high- and a low-inertia power generation are connected to the microgrid. In addition, renewable energy sources can also cause sudden power mismatches, and thus, voltage and frequency fluctuations due to their intermittent nature [41]. In another study, the power electronics technology has been addressed as the key actor in the power system in order to enable the maximum power output and instantaneous control of voltage and current [42]. Optimized operation and management of smart grid have been achieved by using high-voltage high-power semiconductor technologies. Thus, smart grid transmission power system can be developed by establishing a reliable and flexible alternating current transmission (FACT) power system as well as high-voltage direct current (HVDC) power transmission systems. So that, an opportunity is offered to improve the controllability, stability, and power transfer capability of the AC smart grid system by using a flexible alternating current transmission system. Multilevel converter topologies have been proposed for these purposes [43]. Other study to mitigate the voltage and frequency fluctuations is to regulate the raw energy from storage system and transferring it to the smart grid by using power electronics technology [44]. The use of power electronics systems in power engineering in order to convert classical grid to smart grid by using information and communication techniques have also been studied in reference [45]. As the recent technologies direct the researchers to study digitization, automation and information, the power electronics technologies play key role to improve the operational safety and operational efficiency of the smart grid by suppressing the fluctuations of voltage and frequency [46]. For power fluctuations, communication enhanced dynamic demand control algorithm was presented as a solution for power fluctuations on grids [47]. Using custom power devices such as D-STATCOM, UPQC, UPS, TVSS, DVR are some methods to mitigate for power quality problems [48].

IV. Conclusion

The possible causes of voltage fluctuation are intermittent operation of loads, sudden changes on source, non-stable renewable energy sources, etc. Generally preferred solutions for voltage fluctuation are reconfigure distortion, relocate sensitive loads, power conditioner, UPS, and other classic technics. Some of the frequency fluctuation problems are generally occur due to load-demand changes, unbalanced conditions, and long-distance transmission of photovoltaic plants. Many solutions have been suggested to eliminate of frequency fluctuations such as primary, secondary, tertiary and time control methods, smart power electronics technics, ineffectively governed standby generators, etc. Especially, collecting long-time data of systems, using smart power electronics technologies (i.e. smart inverters, multilevel converter topologies) and find algorithmic solutions for all possible scenarios can be preferred to overcome of fluctuation problems.

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