Phase Balancing in Smart Grids

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Abstract – With the increase of technology and trying to make the world "smart" the problem of phase imbalance in a three-phase distribution system becomes challenging. This is due to the increasing penetration of renewable energy resources and plug-in electric vehicles into the smart grid [2]. This paper will talk about Phase Balancing in the Smart Grid. First, this paper will give a general introduction about Smart Grids and Phase Balancing. This will be followed by different techniques about how phase balancing is being done, along with some new interesting theories about how phase balancing can be done in the future. Later results, conclusion, and what the future holds will be presented in this paper.

Index Terms – Smart Grid, Phase Balancing, Plug-in Electric Vehicle, Microgrid, Customer Load Profile, Low Voltage Distribution Grid, Renewable Energy Generators

I. Introduction

a. Smart Grid

As discussed in [1] "the smart grid is seen as a fundamentally transformative, global imperative for helping the plant deal with its energy and environmental challenges". As discussed in [1], a Smart Grid (is defined) to be an "end-to-end cyber-enabled electric power system, from fuel source to generation, transmission, distribution, and end use, that will: 1) enable integration of intermittent renewable energy sources and help decarbonize power systems, 2) allow reliable and secure two-way power and information flows, 3) enable energy efficiency, effective demand management, and customer choice, 4) provide self-healing from power disturbance events, and 5) operate resiliently against physical and cyber-attacks".

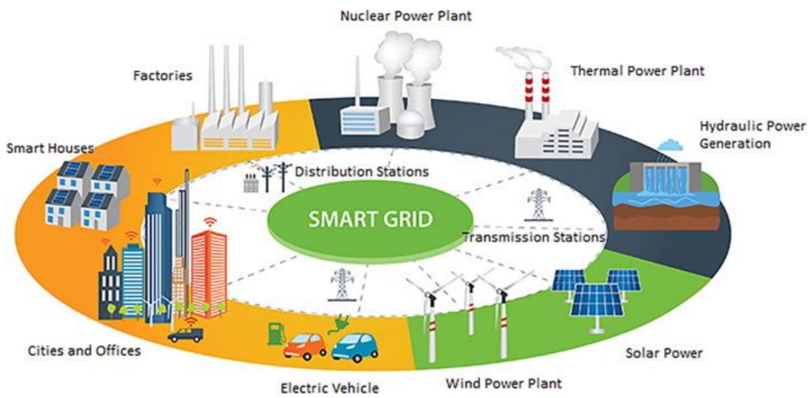


Fig 1. Visual Representation of the Smart Grid in today's society.

From the visual above it can be seen that the power grid is one of the biggest, most complex, and fruitful systems, but one drawback is that it is becoming old, antiquated, and challenging because it is very expensive to update the current power system. The smart grid is in turn trying to "exploit opportunities in where system operators have control based cyber-infrastructure" to have more efficiency, better overall performance, lower costs, and to make the earth a greener place [1].

b. Phase Balancing

Phase imbalance is one of the most important factors when it comes to power quality. Due to the large number of unequal single-phase loads, three phase distribution systems are inherently unbalanced. Load imbalance among different phases can bring disadvantageous impacts on the power equipment and therefore the system [2]. In research paper [2] it explains how under "unbalanced conditions, currents in some phases as well as in the neutral line will increase, thus incurring more energy losses and heating efforts. This can even lead to the tripping of the distribution feeders which over loads protection circuits. Phase imbalance also has several over consequences such: it can reduce the available capacity of feeders and transformers investments costs, deteriorate the power quality and lifetime of induction motors." Another consequence is that it will generate non-characteristic harmonics from electronic devices [2].

II. Techniques

a. Previous Techniques

In recent times there has been an increase to the penetration of distributed renewable generators around the world. Since the power of these distributed renewable generators is intermittent and uncertain, the phase imbalance is getting severe. Just like in all comparative techniques, electric utility needs to look at past techniques in order to improve, make and prove new techniques. Customary technique is to reassign loads to different phases [2]. There are also different techniques where it was a manual re-phasing, but this technique is very costly. Phase imbalance is a two-part imbalance, which are systematic imbalance and random imbalance. Re-phasing techniques can only help reduce systematic imbalance, but not the random imbalances [2]. This is one of the key reasons new theories need to be evaluated.

b. New Techniques

i. Game Theoretic Approach to Phase balancing by PEV in the Smart Grid

This new technique is a plug-in electric vehicle-based phase balancing scheme. In [2] the authors propose a PEV based game which is a plethora of formulas that help the phase balance problem. The authors of this article believe that with phase balance remuneration will give an incentive to PEV owners to help distribution system operators to help reduce phase imbalance autonomously. The theory behind this idea is to utilize the power generation and consumption of demand side response to balance loads. This can be done because Photovoltaic inverters and plug in electric vehicles chargers are made to transfer power from highly loaded phases to a less loaded phase, which means by strategizing charging and discharging of these energy storages can hopefully solve the phase imbalance problem. This theory was tested by a simulation that had different schemes.

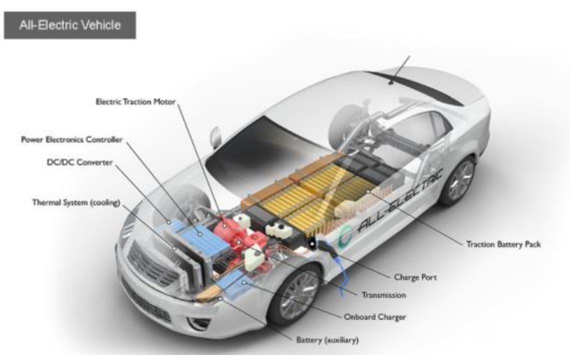


Fig. 2 Plug-In Electric Vehicle Diagram

ii. Phase Balancing and Reactive Power Support Services for Microgrids

Another way that phase imbalance can be solved in the future is with microgrids. Alternating current microgrids can be considered as a candidate for ancillary services since they are more flexible to coordinate their distributed generation sources and loads [3]. Some examples of ancillary services that the microgrid can provide are: reactive power support, voltage control, frequency control, and what is most important in this paper Phase Balancing. In [3] the authors talk about how most of the loads in low voltage distribution systems and micro grids are single phase connected, meaning that phase imbalance is intense where micro grids are connected with a point of common coupling. The intense imbalance of the phases can cause lessening of the power quality and can affect the capacity of the lines. There are a couple of solutions that have been proposed such as using shunt active power filters with dedicated hardware that switches single phase PVs to different phases in line with loading conditions. Another way to solve phase imbalance is to use grid tied inverter from photovoltaics or an energy storage solution. This theory was tested by simulations. What is needed is an advanced grid inverter that is not out yet to help with phase balancing and other ancillary services.

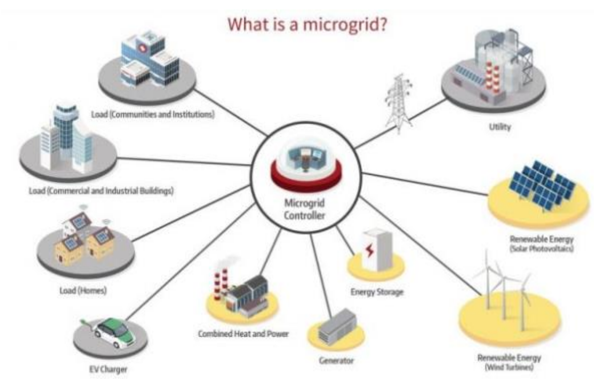
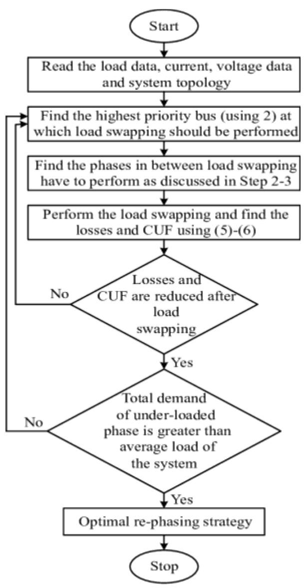


Fig. 3 Microgrid Overview

iii. An Analytical Approach for Phase Balancing Considering Customer Load Profile

In [4], the authors discuss a novel of way of doing phase balancing by using nodal phase balancing. The method discussed is done by swapping the load between over loaded and under loaded phases. The authors and researchers in [4], created a novel priority vector which proposes which to find the buses at which nodal load swapping should be executed. This theory was done by using a case study in where the results are shown in the figure below.



Cases	IEEE 34-bus system	
	Before phase balancing	After phase balancing
Power loss (kW)	686.5	623.1
CUF of primary feeder (%)	42.8	19.6
Load balancing index	0.0452	0.0388
Minimim voltage (pu)	0.93	0.94
Number of phase swapping	-	2
Computational time (seconds)	-	1
IEEE 123-bus system		
Power loss (kW)	1815.2	1745.2
CUF of primary feeder (%)	25.66	17.67
Load balancing index	0.4394	0.4215
Minimim voltage (pu)	0.89	0.91
Number of phase swapping	-	3
Computational time (seconds)	-	2

Fig. 4 and 5 Showing the process done by the algorithm and the results of the simulation

iv. Control Scheme for Phase Balancing of Low Voltage Distribution Grids

In [5], the authors propose a solution in which they utilize the advanced capabilities of the grid tied inverters of photovoltaics and storage systems to increase the utilization of distribution lines and to compensate the asymmetric loading conditions of the substation. This solution is made possible by using the existing ICT infrastructure. This theory was simulation based on a transient model from MATLAB/Simulink. The theory works as a low-cost solution to eliminate asymmetrical loading.

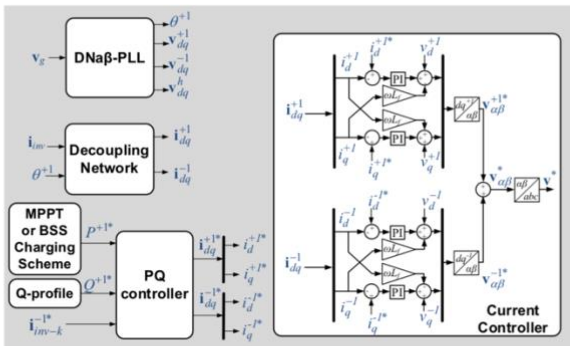


Fig. 6 Demonstrating top level of theory and different components that help with phase balancing

III. Results

All the theories discussed above are about helping phase balancing in the smart grid which are useful. All of the sources used in this paper are simulation based. What can be concluded is that with the phase balanced in the smart grid other parameters of the power was increased such as the power quality, CUF, and VUF. With the current trend of shying away from regular cars and moving into plug-in electric vehicles it can be helpful in the near future with phase balancing. The other theories such as using a microgrid seem to prove useful. The other two theories are also great for alternatives in the future: customer load profile and control scheme. All these theories prove to be useful but, they all still need more research and more knowledge is needed before they can be implemented in real life and on a large scale.

IV. Conclusion

Although these theories prove to be useful there is one thing that is holding them back from being used ubiquitously. The limiting factor is money. All these ideas are very new so besides more research being done, the implantation cost will be great as well. One of the many hurdles will be the initial investment that will be quite great. After getting more funding for research the equipment and software will also be needed before these theories can be used. One of the pieces of equipment that may prove to be useful are the solid-state transformers which allows the integration for energy storages and has ancillary services [6].

V. Future Work

The future work that should be done on these theories is first more research. With more research being done utilities and consumers of this product will have more knowledge about the consequences of using this product. By consequences this means how will this theory work in coordination with the smart grid and how will this work in cooperation with renewable power sources. After the research has been done then implementation will be needed to take these theories to the next step. After this is done there will need to be real world testing and refining. When all of this is done then the phase balance problem in the smart grid can be mitigated with the possibility of even being somewhat eliminated.

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