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Analyzing the Effect of Using Facts Devices "STATCOM and SVC" in a Network Including DG Resources in terms of Power Quality "Voltage Sag and Voltage Unbalance"

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Abstract

Voltage unbalance and Voltage Sag is one of the main important reasons of energy loss in power networks and impose considerable economic loss on the electrical industry. On the other hand, considering the growing trend of using DGs, FACTS devices can be employed to decrease the voltage unbalance and improve the power quality. Power distribution firms are very concerned about power quality due to the increased awareness of users and growth of sensitive loads in power system. Decreasing the effective or maximum value of the voltage between 0.1-0.9 per unit at the main frequency for 0.5 cycle to 1 minute is defined as the Voltage Sag which is one of the power quality issues, introducing large loads like furnaces, driving large induction motors or line to ground fault (SLG) and moving load from one power source to another are the main factors which lead to Voltage Sag in a power system. Equipments like DVRs and parallel FACTS devices protect the system's loads against the Voltage Sag and voltage unbalance. Now, In this article we consider two types of FACTS devices and study their effects on improving power quality parameters "Voltage Sag and Voltage unbalance" in a typical network including DGs.

Keywords: Voltage Sag, Voltage unbalance, microgrid, FACTS devices, Power quality

1.Introduction:

Generating electric power is one the bases of economic power of a country, thus increasing electricity generation and added value has attracted attentions in the last decades. By achieving advanced technologies, employing clean energies and systems including DGs in providing the human's required energy had a significant growth.

Solar energy using photovoltaic system is turned into electrical energy directly and without using mediated processes. Producing solar cells and modules had a significant growth in recent years. Moreover, there has been an increasing interest for installing solar cells in recent years, the most

important characteristic of photovoltaic cells is that their output power which is given to the network is not controlled because they are naturally random and depend on many different factors.
Using photovoltaic systems may cause problems like voltage unbalance. There have always been other problems in distribution network, the existing problems in distribution networks in terms of power quality can be studied from two viewpoints: network and the user. From the network's viewpoint, user create disturbances in the network and phenomena like flicker and the unbalanced load which draws balanced current from the network and non-linear loads which draw harmonic current from the network. These disturbances have negative impacts on other users and the network's equipments. On the other hand, users know that some of the disturbances are created by the network which causes voltage unbalance, voltage harmonic disturbances, breaks and frequency deviation. By investigating the previous researches, (N.Fardad et al.,2015) has studied Voltage Sag in a network including wind resources and in the presence of errors and unbalance, in (FaridRezvani et al.,2015) the presence of photovoltaic systems in a distribution network and using DVR in improving power quality has been studied. In (Suresh Kamble and ChandrashekharThorat, 2014) the effects of Voltage Sag in a distribution network are studied. In (K. SatyanarayanaRaju and AvalaRamulu,2015) Voltage Sag is compensated and improved by using DVR. In (KeinHuat Chua, et al.,2012) voltage unbalance in radial distribution networks and in the presence of renewable energy resources including photovoltaic cells has been studied. (FarhadShahnia, et al.,2012) has investigated the effect of photovoltaic cells in distribution networks and power quality issue. In (Kojovic,2002) effects of network with DGs in voltage adjustment have been studied. In this article, FACTS devices including SVC and STATCOM, effect of photovoltaic cells in the studied network and employing them in networks with DGs and the effects of such equipments in Voltage Sag and voltage unbalance is studied.

2.Theoretical basis of research:

2.1 General Concepts and Performance Principles of Parallel FACTS Devices

In order to solve the problems of transmission lines including unloading, loading, voltage collapse, voltage instability, power and angle fluctuation and transient instabilities, voltage, active power and reactive power should be controlled instantly, the first devices which were proposed for solving these problems were parallel compensators (inductors and capacitors), series compensators and phase shifters. But since the above equipments cannot control instantly and operate in steps, devices are required to perform the related controls separately or simultaneously. Such devices are called FACTS. FACTS devices have different types and are categorized into series, parallel or a combination of both in terms of functionality. The most important functionality of such devices include: 1- increasing the power transmission capacity 2- improving the dynamic stability and permanent state 3- improving the attenuation of fluctuations 4- improving the voltage stability. In this article, parallel FACTS devices like SVC and STATCOM which are able to absorb and generate reactive power are studied in terms of reducing the dynamic voltage and voltage unbalance.

2.2 SVC

SVC is one the FACTS controllers based on thyristor switches, these controllers use conventional thyristors (thyristors which are not able to switch off automatically), thus they operate like controlled and switched capacitors and reactors and transformers with tap changers but their response is faster and their control circuits are more complex. Basically, SVC is used to control voltage. SVC is an equipment which creates a parallel variable impedance to exchange the required compensation current with the network. Therefore, the proper compensation depends on the voltage of the point in which the SVC is installed. SVC is usually used to adjust the voltage of the transmission system in the considered terminal. SVC not only adjusts voltage but also improves the transient and dynamic stability (AhadKazemi et al., 2004) & (Yong-Hua Song et al., 1999). An example of the most common SVCs which includes TCR+TSC which is shown in Figure (1).

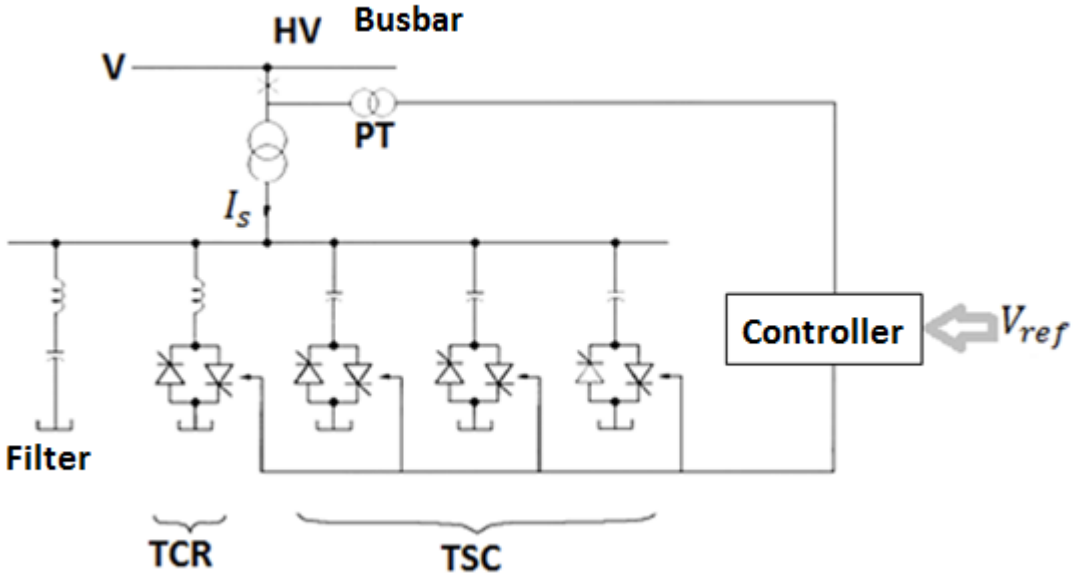


Figure (1): SVC including TCR+TSC

2.1.1 SVC Model

Based on the model proposed by Special Stability Controls work groups in IEEE, SVC can be represented as a PV busbar in the place of compensator and with maximum and minimum reactive power (related to the SVC compensator) and as a PQ busbar in the high voltage busbar where Xst shows the gradient of the V-I characteristic (Narain G. Hingorani et al., 2000).

Figure (2) shows the V-I characteristic of the SVC. The following describes Figure (3).

A: maximum voltage with each TSC being on

B: capacitor design point

C: minimum voltage of continuous operation

D: Inductor design point

E: Maximum voltage with each TSC being on

F: overload condition

2.2 STATCOM and SVS

One of the FACTS controllers which uses Synchronous Voltage Sources (SVS) are the STATCOMs. Therefore, first we need to introduce the SVS briefly:

2.2.1 SVS

SVS is a sinusoidal periodic voltage which has fixed control inputs, its output impedance is zero, and therefore it does not create a resonant circuit. SVS is able to exchange reactive power bilaterally between its dc and ac terminals. Therefore, dc terminals of two or more SVSs can be coupled to each other. By combining SVSs, active and reactive powers of separate lines can be controlled and balanced. Unlike compensators with controlled parallel admittance (SVCs), SVS compensates independent of network's parameters like fault current and phase angle (AhadKazemi et al., 2004) & (Narain G. Hingorani et al., 2000). Therefore if there are any disturbances in the network, it performs its tasks without any pause.

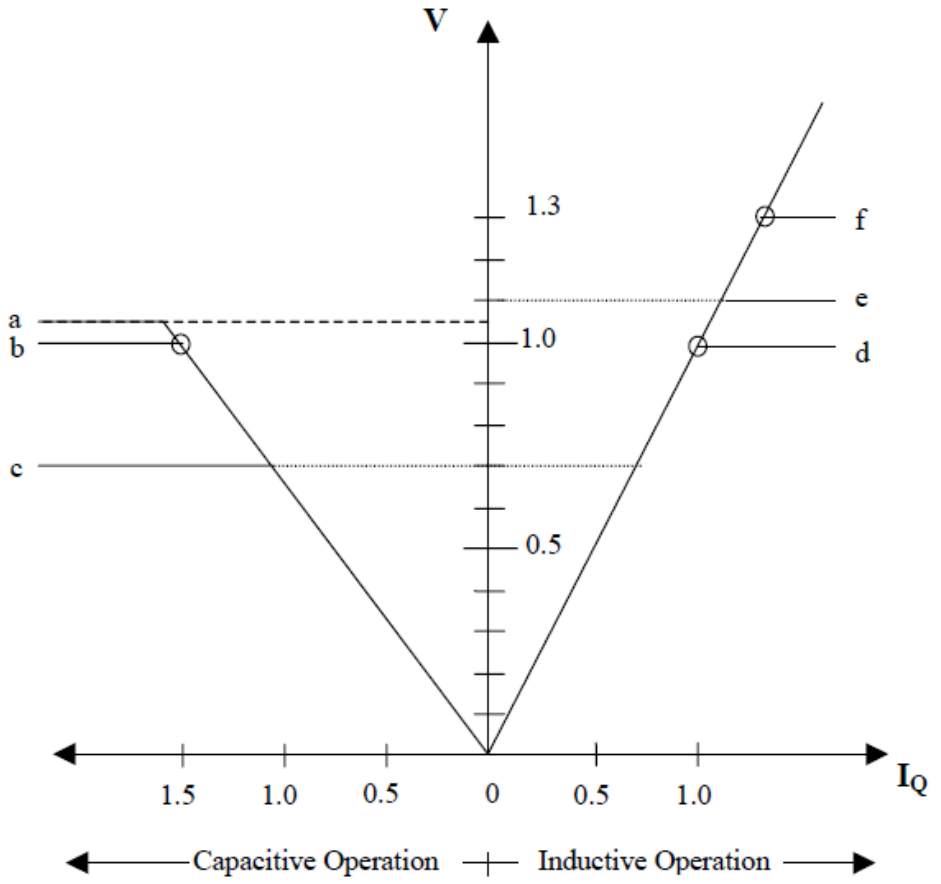


Figure (2)- V_I characteristic of a static compensator

2.2.2 STATCOM

This equipment is installed in parallel like SVC and controls the transmission voltage by compensating, if SVS is only used for compensating the reactive power, a small DC energy source is replace, then the exchanged power between the AC and DC systems is reactive, thus the converter keeps the charged capacitor at the required voltage level. The converter absorbs a little reactive power from the AC system and consumes it to provide its internal losses and keeps the capacitor at the required voltage level, this is done by postponing the phase's angle and the output voltage of the converter, Figure (3) shows the structure of a STATCOM using SVS. In STATCOM, the output current can be controlled independent of the AC system's voltage (AhadKazemi et al., 2004) & (Yong-Hua Song et al., 1999) & (Narain G. Hingorani et al., 2000).

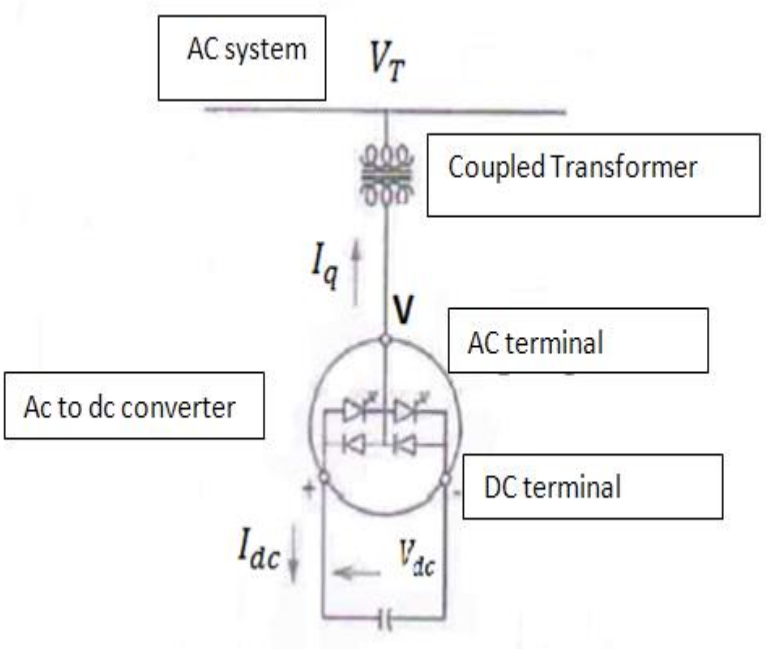


Figure (3)- Structure of a STATCOM using SVS

3. Research Background:

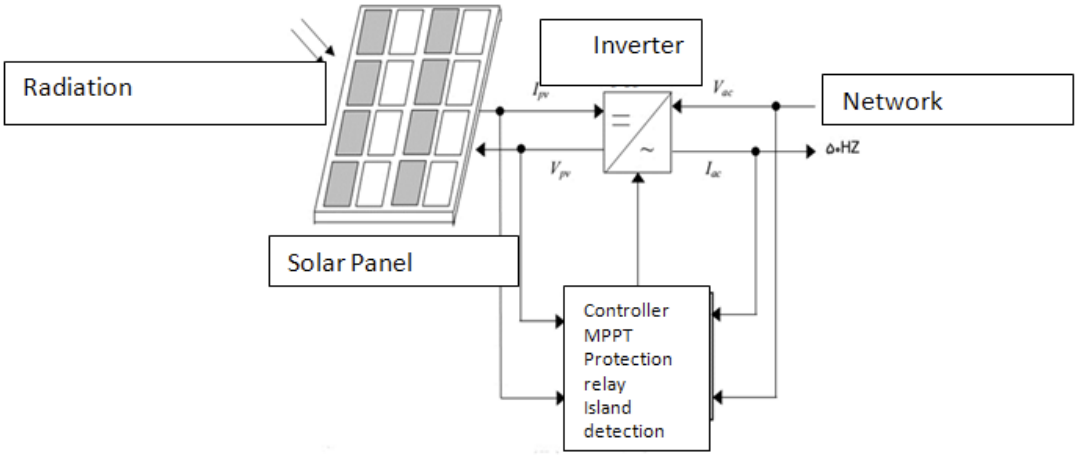
The Studied Network Including DGs and Studying the Power Quality in terms of voltage sag and Voltage Unbalance

3.1 Introduction:

A photovoltaic system in a DG microgrid, converts the Sun's light into alternating current (AC). The main purpose of this system is to reduce the generation of electrical energy by thermal plants.

Figure (4) is a conceptual diagram of a photovoltaic system connected to a network. The output DC current of the solar panels is called Ipv which is converted to AC current by the inverter and then it is injected to the network.

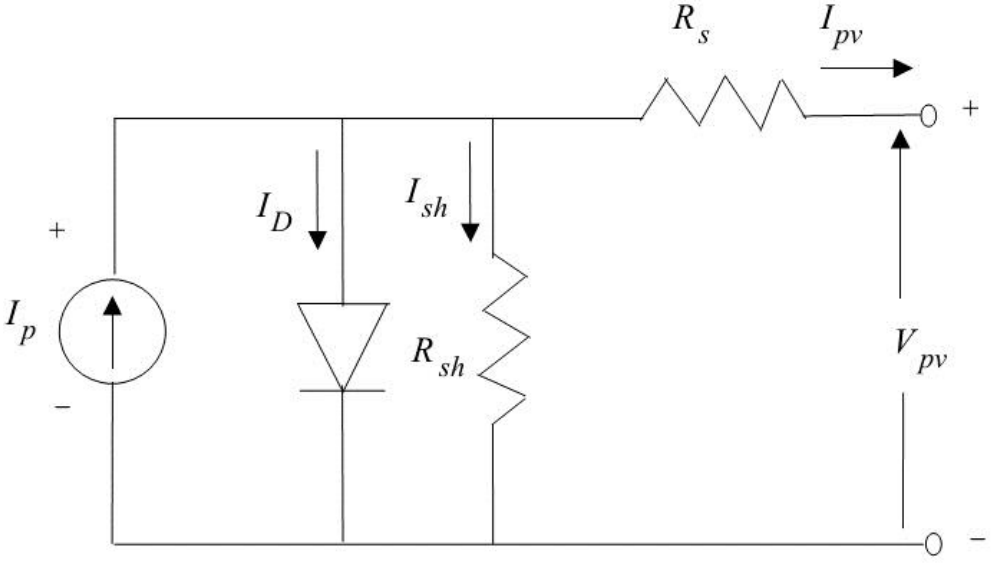
The inverter's controller performs all main controlling and protecting functions including maximum power point tracking (MPPT), protection relays and detecting the operation associated with island state (Jun Liu; et al.,2015).



Figure(4)- Basic Solar Plant in a Microgrid

3.2. Properties of Solar Cells

The equivalent circuit of Figure (5) shows a solar cell which is described by Equation (1).



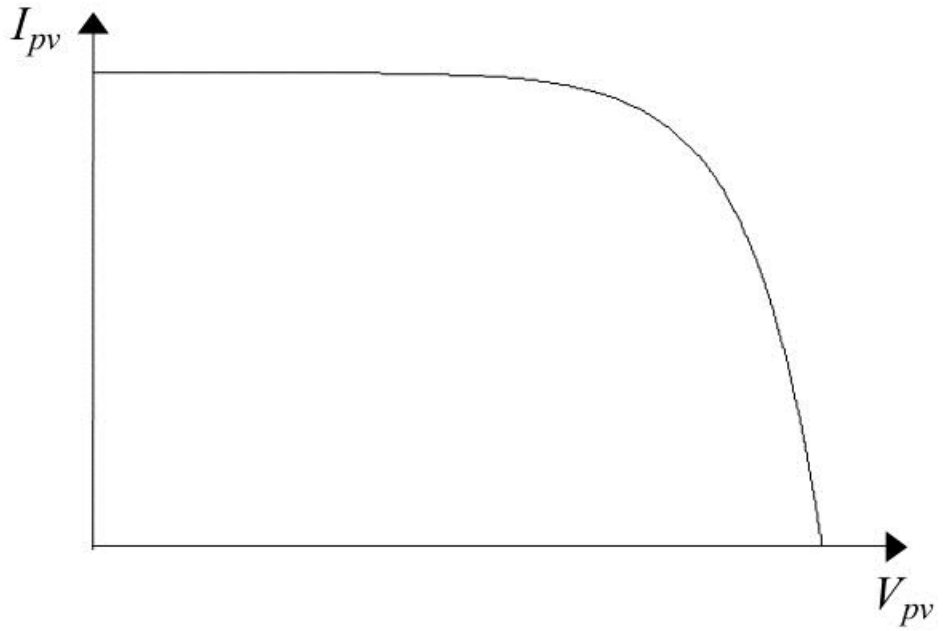
Figure(5)- Equivalent Circuit of a Solar Cell

$$I_{pv} = I_p - I_D - I_{sh} \Longrightarrow$$
$$= I_p - I_0\left[e^{\frac{q(V_{Pv}+R_sI_{Pv})}{NKT}} - 1\right] - \frac{V_{Pv}+R_sI_{Pv}}{R_{sh}} \quad (1)$$

Where:

R_s: series resistance	q: electron's charge	I_0: saturation current	I_P: photon's current
R_{sh}: parallel resistance	K: Boltzman constant	I_{sh}: parallel current	V_{Pv}: voltage of the solar cell's terminal
T: temperature	N: ideality coefficient	I_D: diode's current	

Figure (6) shows Ipv versus Vpv of a solar cell. A panel includes a number of solar cells which are connected to each other and create one unit suitable nominal power. Characteristics of a photovoltaic panel can be specified by multiplying each cell's voltage to the number of series cells and multiplying their currents to the number of parallel cells.



Figure(6)-Characteristic of a Solar Cell

3.2.3 Maximum Power Point

Under radiation and constant temperature of a solar cell, the operating point of a solar panel is demonstrated by the intersection of Ipv-Vpv and the load's characteristic as shown in Figure (7). Load's characteristic is shown with a direct line whose slope is "1⁄R=I_load⁄V_load" . the operating point of the system moves along the Ipv-Vpv of the solar panel such that the operating point moves from A to B while increasing the load's resistance from 0 to infinity. Point C is the maximum power point (Jun Liu; et al.,2015). In this point the area of the Ipv-Vpv characteristic is equal to the maximum output power of the system.

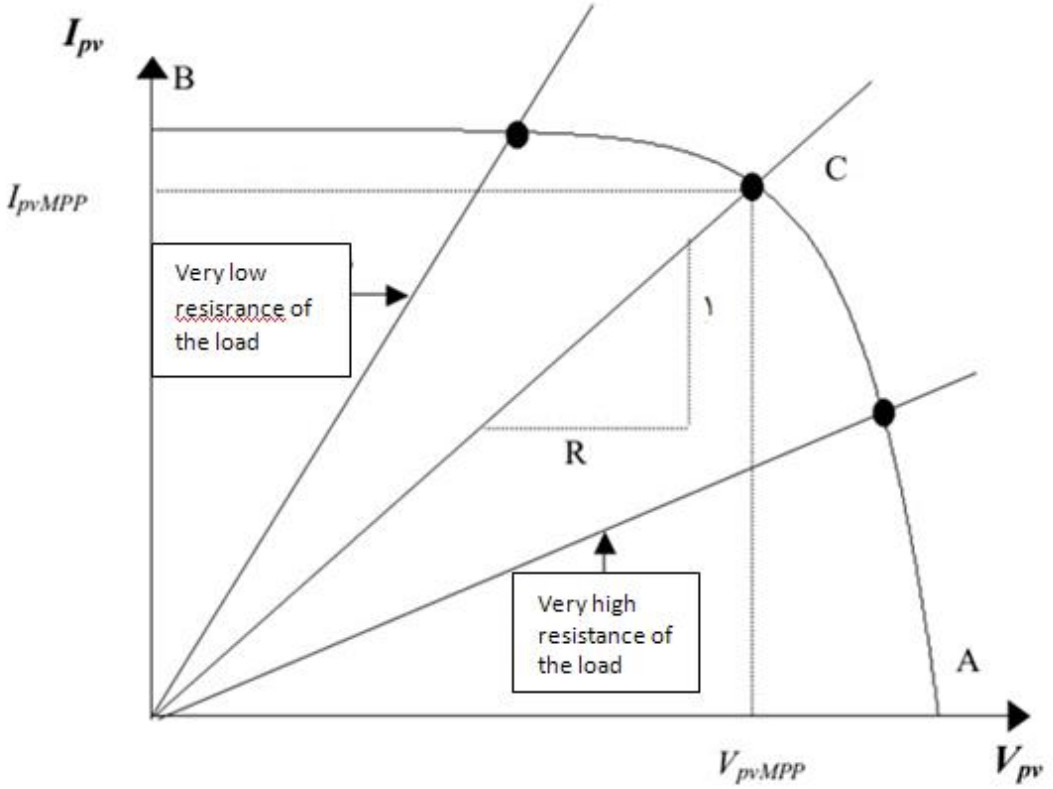


Figure (7)- Intersection of Ipv-Vpv characteristic and load's characteristic

3.3 Inverter

One of the essential sections of a photovoltaic system connected to the network is to employ equipments for converting the DC output of the output panel to AC power to provide synchronization with the network. Inverters do this. Two types of inverters are used for photovoltaic system which includes thyristor based line commutated inverter and voltage controlled inverter.

Many of the available photovoltaic systems use TLCI inverters which is shown in Figure (8), such inverters have advantages like lower cost, being used for higher powers and matching with technology. If this type of inverter is connected directly to the solar panel, the current drawn from the panel is controlled by changing the triggering angle of the thyristors. This type of inverter is usually used in photovoltaic systems which are connected to the network. Figure (9) also shows the algorithm used for computing the PV's output power (Jun Liu; et al.,2015).

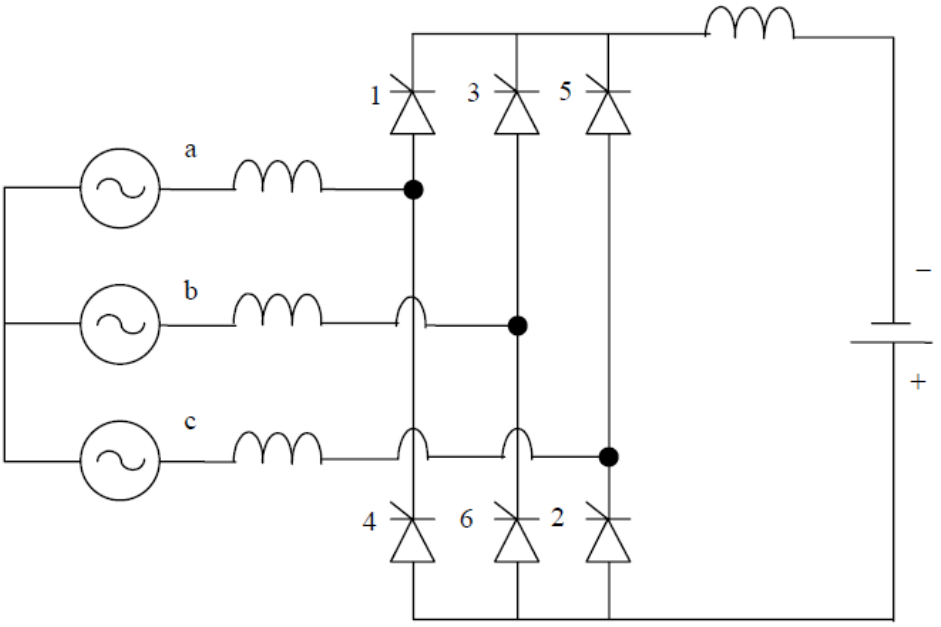


Figure (8)- TLCI Inverter

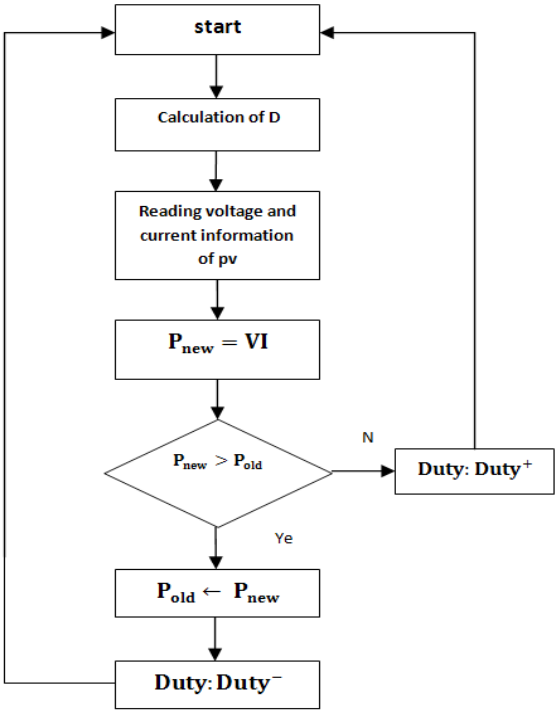


Figure (9)- The Algorithm used for Computing the PV's Output Power

3.4 Power Quality Issues

A microgid includes a set of DGs, energy storage system and loads which can be exploited while connected to the network or in Island state. Microgrid has many advantages for the user and the electricity generation firms. A microgrid can provide electricity and heat simultaneously, increase reliability, decrease the greenhouse gases emission, improve power quality and decrease the consumption costs. For the Electrical companies, employing microgrids decreases consumer demand, thus the development facilities if transmission lines are decreased and would also remove the peaks which in turn would decrease the network's losses (AlirezaJalilian, et al.,2005) & (Wesley Angelino de Souza et al.,20015) & (Thomas Ackermann ,goran Anderson,2005) & (Juan A. Martinez and Jacinto Martin-Arnedo,2010). According to the formal standars, a microgrid has the following properties:

1- lack of focused planning in the microgrid 2- decentralized distribution of energy in the microgrid 3- connecting the microgrid to the distribution network

DGs are mainly connected to the network through the 4 following methods:

1- connection to the network without parallel operation in outage of the main network,

2- parallel operation with the network and lacking injection of extra power to the main network, in this case, network and DG feed the network simultaneously.

3- parallel operation along with injecting extra power to the main network when user's load decreases.

4- no connection between the global network and the users who are fed through DG.

Voltage unbalance and Voltage Sag are the common problems in networks with DG, voltage unbalance is the result of increase in losses, warming of electrical motors and saturation of magnetic cores and Voltage Sag is the result of line to ground fault (Thomas Ackermann ,goran Anderson,2005).

3.5. Power quality and Microgrid

When several DGs are used in the network and they are connected to the feeder, all the changes in the voltage magnitude should be considered. Investigating the voltage stability of the point where DGs are connected to the feeders is one of the main parameters of these networks. Thus some standards have been formulated for changes of voltage in medium voltage and low voltage networks which have DGs. According to the Standards of the European countries this amount should not exceed 2-3% in medium voltage networks such that changes of low voltage network do not exceed 10% (Chen CS, et al., 2011) & (D. Manasa, et al, 2014) . When the power generated by DGs is maximum and the power consumed by the network's loads is minimum, changes in voltage is are maximum and whenever the power generated by DGs is minimum and the power consumed by the network's loads in maximum changes in voltage would be minimum. Fast changes in voltage in the connection point of the DGs to the network might be the result of switching and connection and disconnection of the source or sudden changes of the output power (Jun Liu; et al.,2015) (Wesley Angelino de Souza et al.,2015). The main factors which cause voltage unbalance in the DGs which are connected to the distribution networks include:

- Asymmetric distribution of single phase users among feeder's phases
- Inequality of fixed consumption among single phase users (fixed consumption like refrigerator and freezer)
- Unpredictable consumption of single phase users (washing machine, cooler, vacuum cleaner)

Voltage Sag is mainly caused by faults resulting from the increase of consumption demands or transient states like driving a large motor (temporary reduction of voltage) (L. Wang, D. Truong, 2013) & (Jin-Seok Kim et al., 2016) & (M.ArunBhaskar, et al.,2010) .

Other reasons for Voltage Sag include:
- Powering large transformers
- Single phase faults
- Phase to phase faults

4.Research methodology:

Analysis and Simulation of the Effect of Using FACTS devices on improvement of Power Quality Parameters "Voltage Sag and Voltage Unbalance"

In this section we present the simulation of the DGs which were performed in MATLAB and SIMULINK and the results for improving the power quality parameters. The network is comprised of sources, transmission lines and load. This network is radial and comprises balanced 3-phase sources, transmission lines with resistance and inductance. Figure (10) shows the single- line diagram of this distribution network.

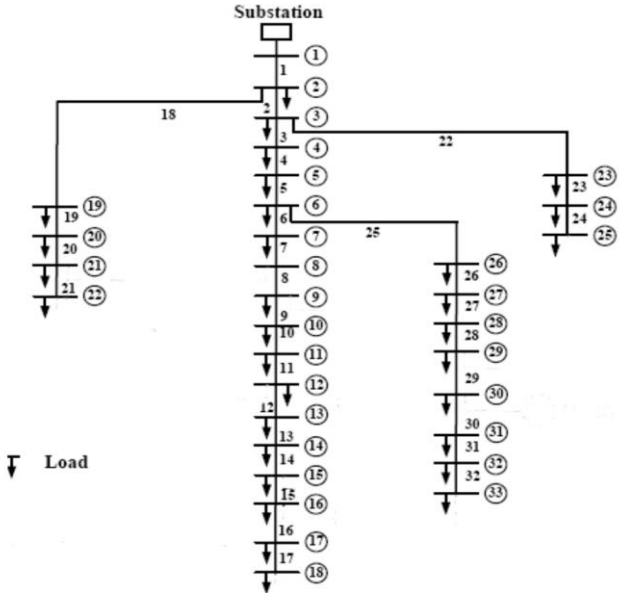


Figure (10)- single line diagram of the radial distribution network including 33 IEEE busbars (FaridRezvani et al.,2015)

4.1 Simulated Block of the Photovoltaic Panel

This block includes two input quantities, one is temperature in Centigrade and the other is the amount of radiation in Watts per square meter. Figure (11) shows the simulated block of the photovoltaic panel in SIMULINK:

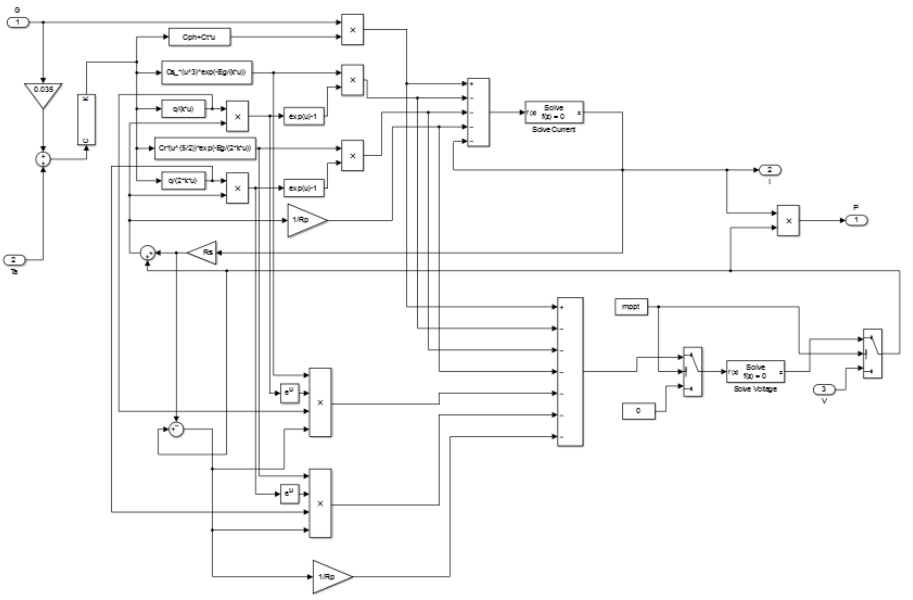


Figure (11)- Simulated Block of the Photovoltaic Panel

4.2 Simulated Block of the STATCOM

One of the equipments employed in the studied network is the STATCOM which is used to adjust voltage, balance voltage and preventing the Voltage Sag, Figure (12) shows the simulated block of the STATCOM in SIMULINK:

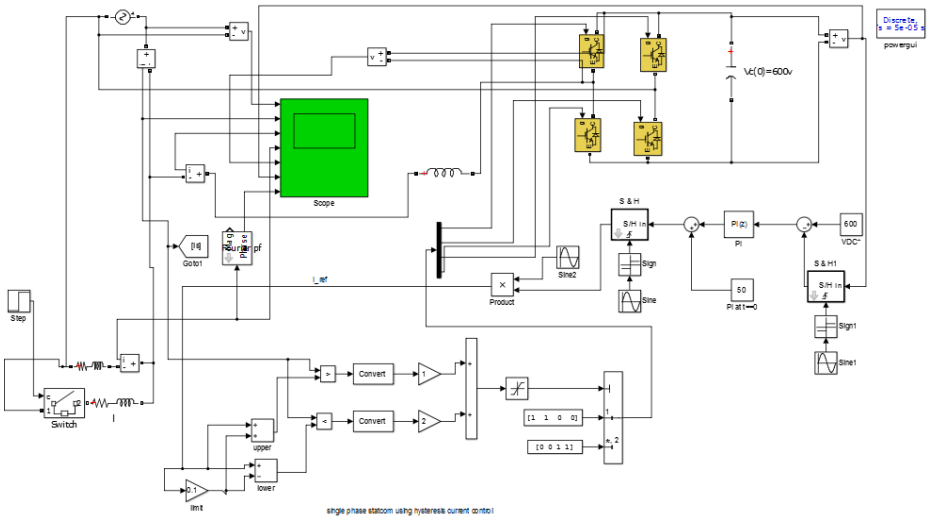


Figure (12)- Simulated Block of the STATCOM

4.3 Simulation Results for Improving the voltage Unbalance and Voltage Sag with SVC

By placing the FACTS devices including SVC I parallel, voltage unbalance is controlled to an acceptable extent and the voltage reaches a certain extent, when voltage is unbalanced, photovoltaic generator will trip. Figure (13) shows the diagrams related to radiation, active power and voltage. Figures (14) and (15) show the unbalanced voltage waveform and the balanced voltage respectively, Figure (16) also shows the robustness against Voltage Sag in the presence of the mentioned equipments after simulation.

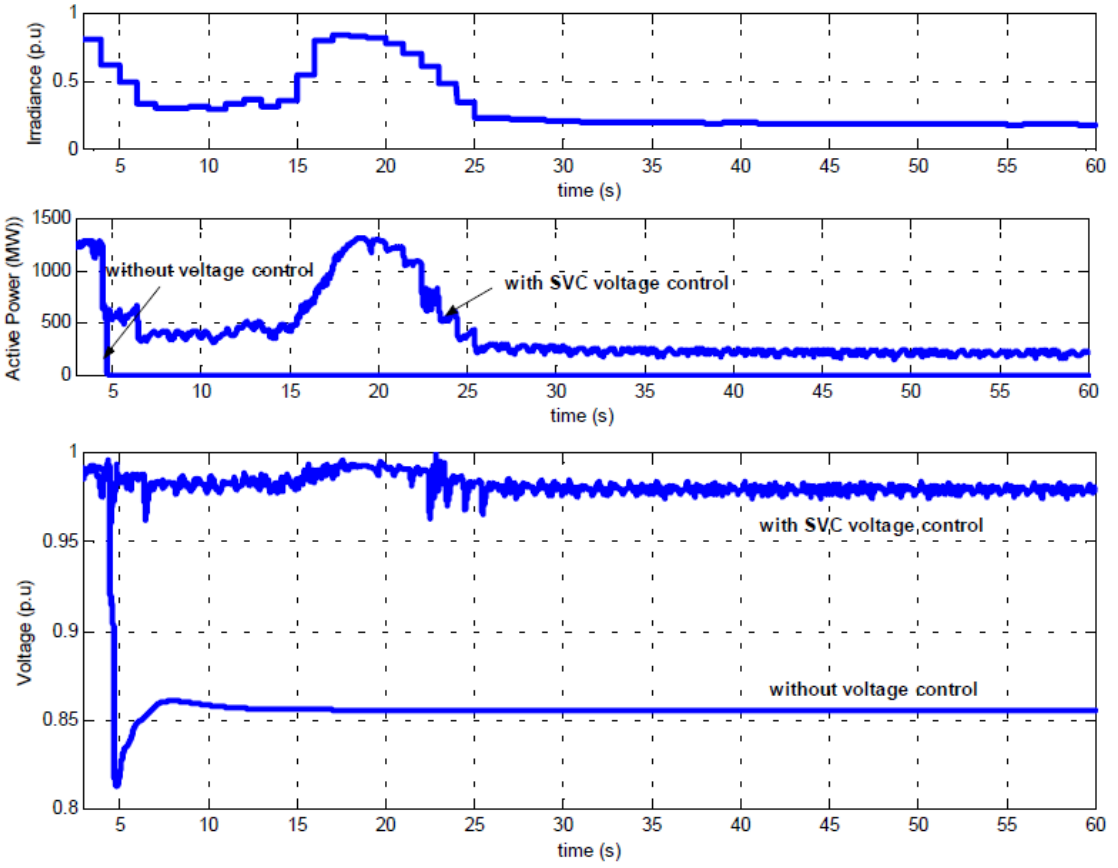


Figure (13)- Simulation Results for Balancing the Voltage with SVC

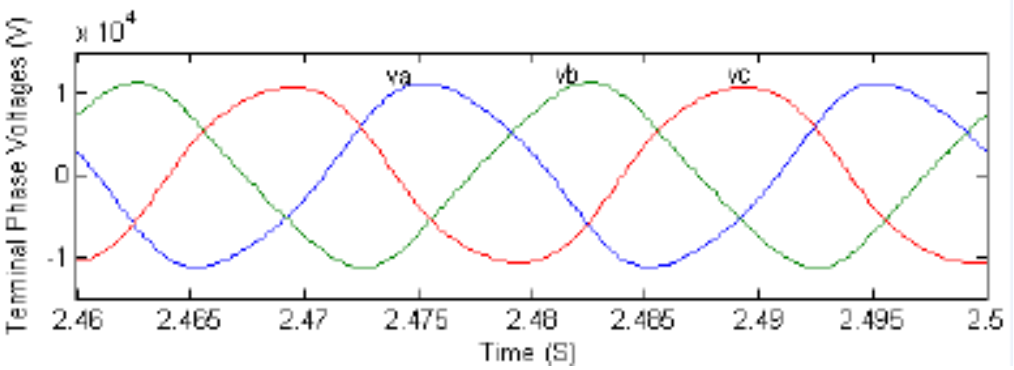


Figure (14)- Unbalanced Feeder Voltage of each Phase

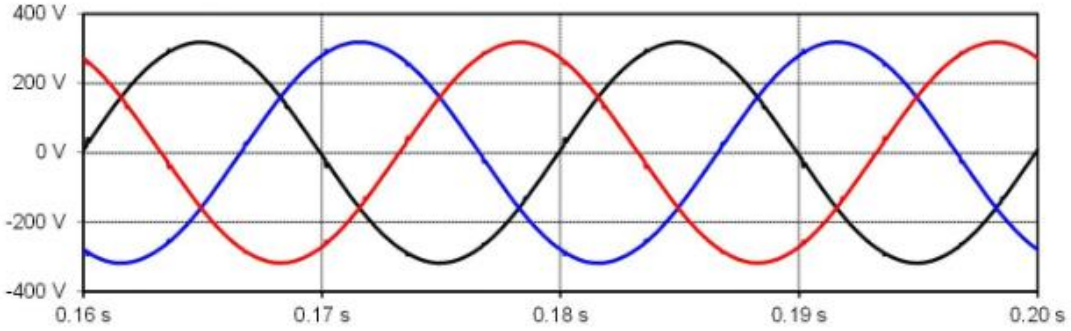


Figure (15)- Balanced Feeder Voltage

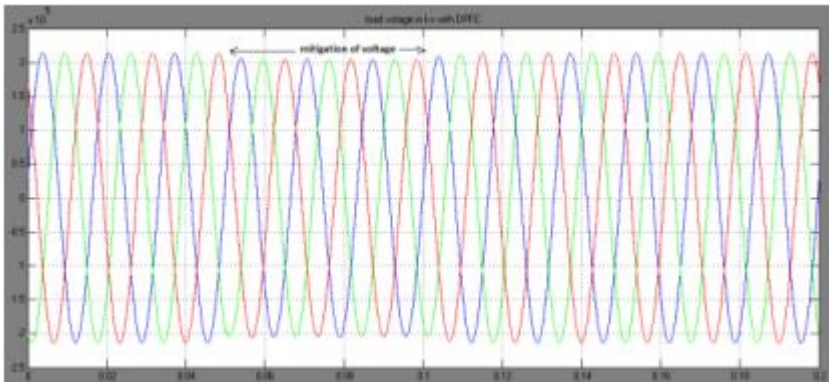


Figure (16)- Improving Voltage Sag

5. Conclusion:

With the development of DGs and employing them in power networks, problems concerning the power quality including voltage unbalance, Voltage Sag and etc will arise. One of the proper approached for decreasing these effects is to use FACTS devices especially parallel FACTS devices. In this article, effect of two types of such devices "STATCOM and SVC" in unbalancing the voltage and Voltage Sag is studied. This article simulates the distribution system while using DGs including photovoltaic and analyzes the effect of using such devices and photovoltaic cells on decreasing the unbalanced voltage. As a conclusion for photovoltaic cells it can be said that when a photovoltaic cell goes away from the intended load, effect of decreasing voltage unbalance also decreases and the closer the photovoltaic system to the intended load, the unbalance compensation would be more.

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