International Journal for Innovative
Engineering and Management Research
A Peer Revieved Open Access International Journal
www.ijiemr.org

Title: **A NOVEL APPROACH FOR CONTROL OF SINGLE-STAGE PHOTOVOLTAIC INVERTERS THROUGH UNBALANCED VOLTAGE CONDITIONS**

Volume 07, Issue 12, Pages: 178–185.

Paper Authors

BHUKYA NEELIMA RANI , MD.FIROZ ALI

Nimra College of Engineering & Technology, A.P., India.

International Journal for Innovative Engineering and Management Research
PEER REVIEWED OPEN ACCESS INTERNATIONAL JOURNAL
www.ijiemr.org

A NOVEL APPROACH FOR CONTROL OF SINGLE-STAGE PHOTOVOLTAIC INVERTERS THROUGH UNBALANCED VOLTAGE CONDITIONS

BHUKYA NEELIMA RANI [1], **MD.FIROZ ALI**[2]
[1]Student, M.Tech (POWER SYSTEMS), Nimra College of Engineering & Technology, A.P., India.
[2]Associate Professor and Head,Dept. of Electrical & Electronics Engineering ,Nimra College of Engineering & Technology, A.P., India.
alekhay-neeluneelima67@gmail.com

Abstract—This paper presents a novel system with improving the Integration of distributed generation (DG) such as photovoltaics (PV) represents a challenge for the traditional operation of distribution power systems. As the installed power of DGs grows, grid codes are being modified to involve DGs in the provision of ancillary services. This includes the ability to ride-through large disturbances. In this paper, the behavior of a single-stage PV system under unbalanced voltage conditions is studied, and a fault ride-through control scheme is proposed which is able to support the grid through the injection of reactive power. Furthermore, adjustable power quality is enabled as a tradeoff between power ripple and current harmonics. The control scheme makes use of a current controller based on the space vector Fourier transform concept. No rotational transformation is required, and zero steady-state error is ensured when tracking distorted current references. The controller was tested in detailed MATLAB computer simulations, and implemented in a real grid-connected PV system to demonstrate its performance under unbalanced voltage conditions.

KEY INDEX: distributed generation (DG),Photovoltaics (PV),Unbalanced Voltage Conditions.

I. INTRODUCTION

distributed generators (DGs), are primed to play a central role in future distribution systems. If properly integrated, DGs present two main advantages. First, they increase the efficiency of the system by avoiding transmitting power over long distances. Second, emissions are reduced since most DGs are based on renewable like wind and solar. Their integration into distribution systems is thus one of the main challenges the power industry will be facing in the coming years. Up to now, interconnection standards for DGs have been mostly defensive, focusing on safe operation [1]. For instance, IEEE-1547 states DGs should disconnect as quickly as possible under abnormal conditions [2].However, the recognition that their aggregated behavior may have an impact on the bulk power system is paving the path for new transmission-type regulations. As the installed power of DGs grows, grid codes are being modified to consider provision of ancillary services such as: controlled active power output, steady-state voltage regulation, and fault ride-through (FRT) capabilities [3]. The latter may require DGs not only to remain connected in the event of a fault, but also to support the grid through the injection of reactive power. In the German MV grid code introduced in 2008 [4], this requirement is already included under the rubric of “dynamic grid support.” Photovoltaic (PV) power generation represents a key technology for realizing the DG concept. As the cost of PV panel production continues to decrease, it is expected that solar power generation will be competitive with other forms of renewable energy, and hence massively deployed [5]. PV systems are connected to the ac grid via a power electronic interface. This interface may include a boost dc/dc converter, and an inverter.

The two-level voltage-source inverter (VSI) is widely adopted as the configuration of choice by most major PV system manufacturers [6], [7]. When the boost converter is eliminated by connecting an appropriate number of PV panels in series, the resulting architecture is referred to as single-stage topology. This architecture is more efficient and economical than its two-stage counterpart under homogeneous irradiance conditions [8], [9], and is the subject of this paper. this paper proposes a novel FRT control scheme for PV inverters able to perform “dynamic grid support” through the injection of reactive power under unbalanced grid faults. The control scheme enables adjustable power quality as a tradeoff between power ripple and current harmonics, and therefore can be adapted to comply with different operational standards. The inverter is operated under current control mode, and the controller is implemented in the α–β stationary frame based on the SVFT concept. No rotational transformation is required, and zero steady-state error is ensured for the positive sequence harmonic components selected to be controlled.

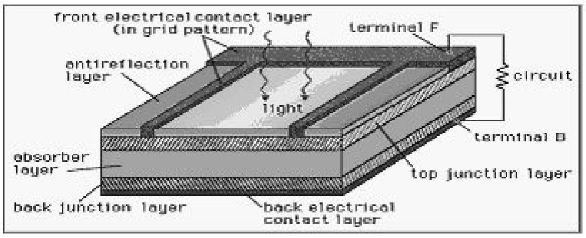
II. DC- AC CONVERTER (INVERTER):

An inverter is an electrical device that converts direct current (DC) to alternating current (AC); the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits.Solid-state inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high-voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries.There are two main types of inverter. The output of a modified sine wave inverter is similar to a square wave output except that the output goes to zero volts for a time before switching positive or negative. It is simple and low cost (~$0.10USD/Watt) and is compatible with most electronic devices, except for sensitive or specialized equipment, for example certain laser printers. A pure sine wave inverter produces a nearly perfect sine wave output (<3% total harmonic distortion) that is essentially the same as utility-supplied grid power. Thus it is compatible with all AC electronic devices. This is the type used in grid-tie inverters. Its design is more complex, and costs 5 or 10 times more per unit power (~$0.50 to $1.00USD/Watt).[1] The electrical inverter is a high-power electronic oscillator. It is so named because early mechanical AC to DC converters was made to work in reverse, and thus was "inverted", to convert DC to AC. The inverter performs the opposite function of a rectifier.

III. OVERVIEW OF PHOTOVOLTAICS

The conversion of solar radiation occurs by the photovoltaic effect which was first observed by Becquerel. It is quite generally defined as the emergence of an electric voltage between two electrodes attached to a solid or liquid system upon shining light onto this system. Energy conversion devices which are used to convert sunlight to electricity by the use of the photo-voltaic effect are called solar cells. Single converter cell is called a solar cell or more generally photovoltaic cell and combination of such cells designed to increase the electric power output is called a solar module or solar array and hence the name ‘Photovoltaic Arrays’. Solar cells can be arranged into large groupings called arrays. These arrays, composed of many thousands of individual cells, can function as central electric power stations, converting sunlight into electrical energy for distribution to industrial, commercial and residential users. Solar cells in much smaller configurations are commonly referred to as solar cell panels or simply panels. Practically, all photovoltaic devices incorporate a P-N junction in a semiconductor across which the photo voltage is developed. The solar panels consist mainly of semiconductor material, with Silicon being most commonly used.

3.3.2 Basics of Solar Cells



The overwhelming majority of solar cells are fabricated from silicon with increasing efficiency and lowering cost as the materials range from amorphous (non-crystalline) to polycrystalline to crystalline (single crystal) silicon forms. Unlike batteries or fuel cells, solar cells do not utilize chemical reactions or require fuel to produce electric power and unlike electric generators, they do not have any moving parts.Light enters the device through an optical coating, or antireflection layer that minimizes the loss of light by reflection; it effectively traps the light falling on the solar cell by promoting its transmission to the energy-conversion layers below. The antireflection layer is typically an oxide of silicon, tantalum or titanium that is formed on the cell surface by spin coating or a vacuum deposition technique. The three energy-conversion layers below the antireflection layer are the top junction layer, the absorber layer, which constitutes the core of the device, and the back junction layer. Two additional electrical contact layers are needed to carry the electric current out to an external load and back into the cell, thus completing an electric circuit. The electrical contact layer on the face of the cell where light enters is generally present in some grid pattern and is composed of a good conductor such as a metal. Since metal blocks light, the grid lines are as thin and widely spaced as is possible without impairing collection of the current produced by the cell. The back electrical contact layer has no such diametrically opposed restrictions. It needs to simply function as an electrical contact and thus cover the entire back surface of the cell structure. Because the back layer also must be a very good electrical conductor, it is always made of metal. Since most of the energy in sunlight and artificial light is in the visible range of electromagnetic radiation, a solar cell absorber should be efficient in absorbing radiation at those wavelengths. Materials that strongly absorb visible radiation belong to a class of substances known as semiconductors. Semiconductors in thicknesses of about one-hundredth of a centimeter or less can absorb all incidents visible light; since the junction-forming and contact layers are much thinner, the thickness of a solar cell is essentially that of the absorber. Examples of semiconductor materials employed in solar cells include Silicon, Gallium Arsenide, Indium Phosphide and Copper Indium Selenide.When light falls on a solar cell, electrons in the absorber layer are excited from a lower-energy “ground state,” in which they are bound to specific atoms in the solid, to a higher “excited state” in which they can move through the solid. In the absence of the junction-forming layers, these “free” electrons are in random motion and so there can be no oriented direct current. The addition of junction-forming layers, however, induces a built-in electric field that produces the photovoltaic effect. In effect, the electric field gives a collective motion to the electrons that flow past the electrical contact layers into an external circuit where they can do useful work.There are several approaches to manufacturing solar cells, including the kind of semiconductor used and the crystal structure employed, with each different factor affecting the efficiency and cost of the cell. Other external factors such as the ambient weather conditions like temperature, illumination, shading, etc., also affect the solar panel’s output. The aim is to design a system that will extract the most possible power regardless of ambient weather conditions or solar cell efficiency.

3.3.3 Solar Cell Characteristics

The current-to-voltage characteristic, power-to-voltage characteristics of a solar cell are non-linear, which make it difficult to determine the maximum power point. It is straightforward to determine the maximum power point on a linear curve as maximum power is transferred at the midpoint of the current-voltage characteristic. A typical V-I characteristic of solar cell is shown in Fig 3.2.

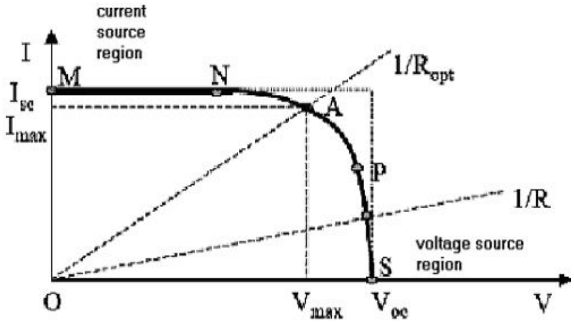


Fig 3.2 Solar Cell Characteristics

For a solar cell, the non-linear relationship means the maximum power point has to be determined by calculating the product of the voltage and output current. In order to extract maximum power from the solar cell, the solar cell must always be operated at or very close to where the product of the voltage and output current is the highest. This point is referred to as the maximum power point (MPP) and it is located around the ‘bend’ or ‘knee’ of the I-V characteristic. The operating characteristic of a solar cell consists of two regions: the current source region and the voltage source region. In the current source region, the internal impedance of the solar cell is high and this region is located on the left side of the current-voltage curve. The voltage source region, where the internal impedance is low, is located on the right side of the current-voltage curve. As can be observed from the characteristic curve, in the current source region, the output current remains almost constant as the terminal voltage changes and in the voltage source region, the terminal voltage varies only minimally over a wide range of output current.According to the maximum power transfer theory, the power delivered to the load is maximum when the source internal impedance matches the load impedance. For the system to operate at or close to the MPP of the solar panel, the impedance seen from the input of the MPPT needs to match the internal impedance of the solar panel. Since the impedance seen by the MPPT is a function of voltage (V = I * R), the main function of the MPPT is to adjust the solar panel output voltage to a value at which the panel supplies the maximum energy to the load. However, maintaining the operating point at the maximum power point can be quite challenging as constantly changing ambient conditions such as irradiance and temperature will vary the maximum power operating point. Hence, there is a need to constantly track the power curve and keep the solar panel operating voltage at the point where the most power can be extracted.Irradiance is a characteristic related to the amount of Sun energy reaching the ground, and under ideal conditions it is measured as 1000 W/m^2 at the equator. The sun energy on the earth is highest around the equator when the sun is directly overhead. Some important magnitudes related to irradiance include the spectral irradiance, irradiance and radiation. Spectral irradiance is the power received by a unit surface area at a particular wavelength, while irradiance is the integral of the spectral irradiance extended to all wavelengths of interest. Radiation is the time integral of the irradiance extended over a given period of time.In designing PV systems, the main concern is the radiation received from the sun at a particular location at a given inclination angle and orientation and for long periods of time. Since solar radiation is the energy resource of the solar panel, the output of the panel is significantly affected by changing irradiance. The I-V and P-V characteristics of a solar cell including the effects of irradiance are shown in Fig 2.4.

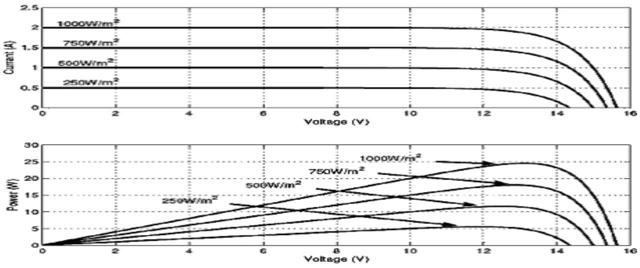


Fig 3.3: The I-V and P-V characteristics of a solar cell including the effects of irradiance

The irradiance at any location is strongly dependent on the orientation and inclination angles of the solar panel. Orientation is usually measured relative to the south in northern latitudes while it is measured relative to the north in southern latitudes. On the other hand, the inclination angle is measured relative to the horizontal. Using these two parameters, the irradiation at any location can be determined. The irradiance information for many sites worldwide is widely available.As it can be observed from Fig 3.3, the output power is directly proportional to the irradiance. As such, a smaller irradiance will result in reduced power output from the solar panel. However, it is also observed that only the output current is affected by the irradiance. This makes sense, since by the principle of operation of the solar cell the generated current is proportional to the flux of photons. When the irradiance or light intensity is low, the flux of photon is less than when the sun is bright and the light intensity is high, thus more current is generated as the light intensity increases. The change in voltage is minimal with varying irradiance and for most practical applications, the change is considered negligible.Although irradiance is an important factor in determining the I-V characteristic of a solar panel, it is not the only factor. Temperature also plays an important role in predicting the I-V characteristic, and the effects of both factors have to be considered when designing a PV system. Whereas the irradiance mainly affects the output current, the temperature mainly affects the terminal voltage. A plot of I-V and P-V characteristic with varying temperature is shown in Fig 3.4.It is observed from Fig 3.4 that the terminal voltage increases with decreasing temperature. One of the reasons the solar panel operates more efficiently with decreasing temperature is due to the electron and hole mobility of the semiconductor material. As temperature increases, the electron and hole mobility in the semiconductor material decreases significantly. The electron mobility for Silicon at 25° C is about 1700cm2/volt-sec and will decrease to about a fourth of this value as temperature increases to 225° C and likewise the hole mobility decreases from about 600cm2/volt-sec at 25°C to 200cm2/volt-sec as temperature increases to 225°C. While the higher reference temperatures are not realistic operating conditions for a solar panel, it does show that electron and hole mobility decrease with increasing temperature.

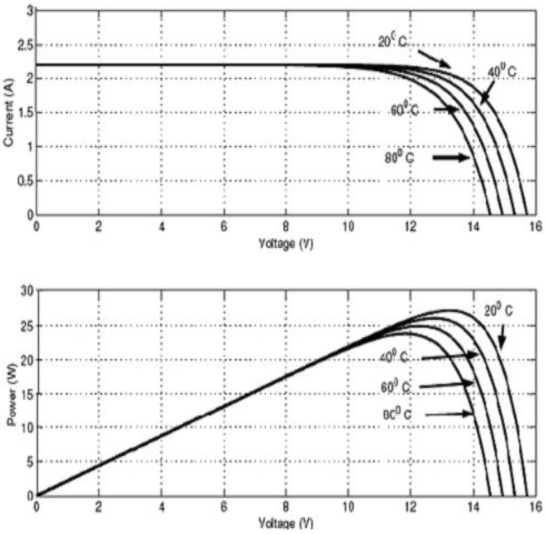


Fig 3.4.: I-V and P-V characteristic with varying temperature

The band gap energy of semiconductor materials also varies with temperature. An increase in temperature will cause the band gap energy of the material to increase. With higher band gap energy, the electrons in the valence band will require more energy from the photons to move to the conduction band. This means that a lot more photons will not have sufficient energy to be absorbed by the electrons in the valence band resulting in fewer electrons making it to the conduction band and a less efficient solar cell.It should be noted here that irradiance and temperature represent only two of the most significant external factors that affect the efficiency of a solar cell. Inclination, location and time of the year are also factors that affect the efficiency of solar cells. Additional parameters of a solar cell can be discussed by an illustration of the maximum power point as shown in Fig 3.5.

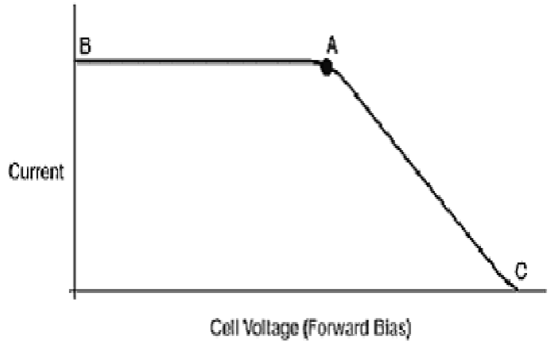


Fig 3.5: illustration of the maximum power point.

The cell's short circuit current intersects the Y-axis at point B and the open circuit voltage intersects the X-axis at point C. To achieve maximum energy transfer, systems powered by solar cells should be designed to transfer energy to the load at point A on the I-V curve. No energy should be delivered at points B and C, and most of the energy should be delivered as the operating point approaches point A. In a solar panel array, it is even more important that load impedance and source impedance are well matched. Once the cells are matched by their I-V characteristics, they can be grouped into individual arrays and each array is then made to operate at its maximum energy transfer point. Majority of solar cells have high capacitance associated with their forward biased p-n junctions because the charged carriers are much closer together. The unwanted capacitance increases as the size of the solar cell and junction area increases. The I-V curve of the solar cell can be determined by taking fast I-V measurements, which is done by applying a constant voltage and measuring the resulting current for the device being tested. However the high capacitance makes it difficult to get fast I-V measurements.The shape of the I-V curve of the solar cell is governed by the cell's high Thevenin's equivalent impedance. The short circuit current is determined by the incident light intensity and it is inversely proportional to the applied voltage. The total circuit voltage and incident light determine the external circuit current.

3.3.4 Solar Cell Modelling

To properly model a solar cell, it is important to understand how solar cells operate. Solar cells are primarily made of semiconductor material that when exposed to light induces a process of photon reflection and absorption, generation of free carriers and lastly charge separation, which creates an electric field. The semiconductor properties determine how effectively this process occurs. Some of the most important properties include the absorption coefficient, the reflectance of the semiconductor surface, drift-diffusion parameters and surface recombination velocities. For practical power applications, the voltage produced by one solar cell is usually not sufficient to power most equipment. An array of 20 to 80 solar cells connected in series to form a "Solar Module" is usually necessary to provide the required voltage. Solar cell manufacturers provide some key parameters of a solar module in their Data Sheet. The output power is given in Wp (Watt peak), which means the module is rated at Standard Test Conditions (STC). The STC are illumination levels of 1000 W/m2 (bright sunshine), a spectrum equivalent to Air Mass 1.5 and 25°C module temperature at the test. The manufacturer's data sheet also provides the short circuit current, the current produced when the output voltage is zero and the open circuit voltage, the voltage across the output terminals when there is no current flowing in the cell.The simplified equivalent circuit of a solar cell consists of a diode and a current source which are switched in parallel. The current source generates the photo current I_{Ph}, which is directly proportional to the solar irradiance G. The p-n transition area of the solar cell is equivalent to a diode.

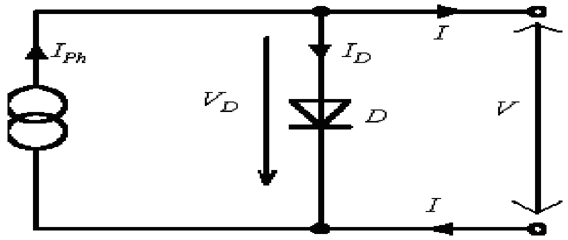


Fig.3.6: Equivalent circuit of a solar cell

The *V-I* equation of the simplified equivalent circuit could be derived from Kirchhoff's current law

$$I = I_{Ph} - I_D = I_{Ph} - I_S \cdot (\exp(\frac{V}{m \cdot V_T}) - 1)$$

…(2.1)

Where

I_{Ph} --- Photo current

I_D --- Diode current

I_S --- Diode reverse saturation current

m --- Diode ideal factor

$V_T = (k*T)/q$ is Thermal voltage (25.7 mV at 25°C)

k = Boltzmann Constant=1.3824*e-23

T = AbsoluteTemperature

q = charge of an electron=1.60*e-19 couloumbs

V = output voltage of the solar cell

I = output current through the solar cells

SIMULATION RESULTS

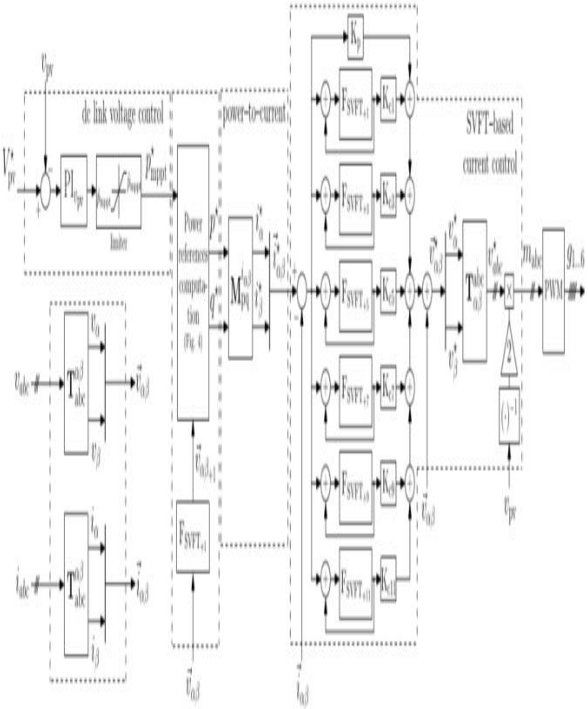


Fig. Schematic of the FRT control including a dc link voltage control

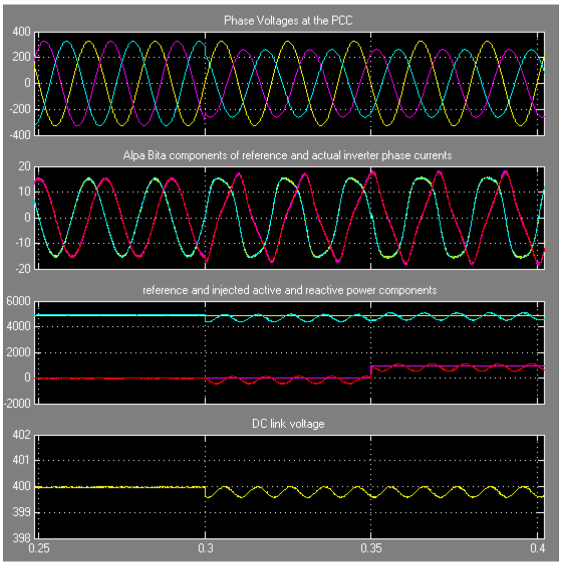


Fig. Simulation results showing the performance u=0.5

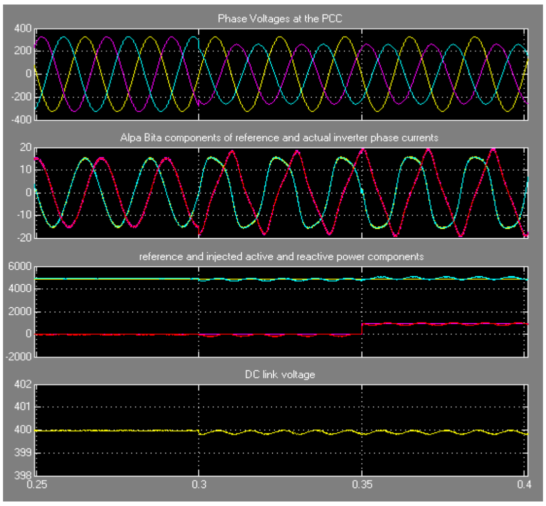


Fig. Simulation results showing the performance u=0

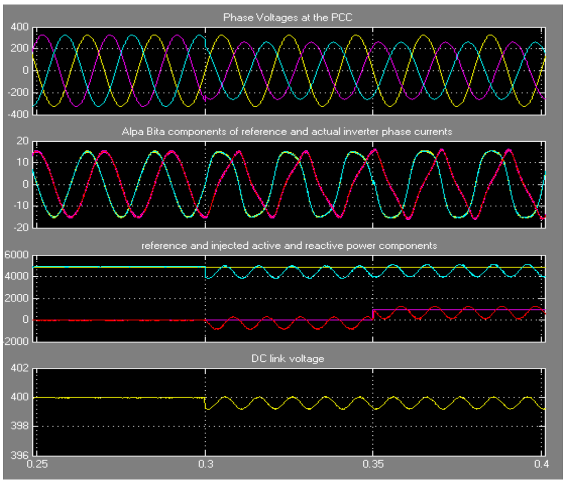


Fig. Simulation results showing the performance u=1

CONCLUSION

In this paper, the behavior of a single-stage PV system under unbalanced grid faults was studied, and a control strategy proposed able to perform “dynamic grid support” through the injection of reactive power. The described approach for the computation of current references enables adjustable power quality as a tradeoff between power ripple and current harmonics. Furthermore, a current controller was implemented in the α–β stationary frame based on the SVFT concept. No rotational transformation is required, and zero steady-state error is ensured for the positive sequence harmonic components selected to be controlled. Simulation results demonstrated the performance of the controller, and its ability to reduce oscillations in the injected power.

REFERENCES

[1] C. Schauder, “Impact of FERC 661–A and IEEE 1547 on photovoltaic inverter design,” in *Proc. IEEE Power Energy Soc. Gen. Meet.*, Jul. 2011, pp. 1–6.

[2] *IEEE Application Guide, IEEE Standard for Interconnecting Distributed Resources With Electric Power Systems*, IEEE Standard 1547.2-2008, Apr.2009.

[3] Y. Yang, P. Enjeti, F. Blaabjerg, and H. Wang, “Suggested grid code modifications to ensure wide–scale adoption of photovoltaic energy in distributed power generation systems,” in *Proc. IEEE Ind. Appl. Soc. Annu.Meet.*, Oct. 2013, pp. 1–8.

[4] BDEW. (2008). BDEW technical guideline. Generating plants connected to the medium-voltage network [Online]. Available: http://www.bdew.de/

[5] T. Stetz, F. Marten, and M. Braun, “Improved low voltage grid–integration of photovoltaic systems in germany,” *IEEE Trans. Sustainable Energy*, vol. 4, no. 2, pp. 534–542, Apr. 2013.

[6] A. Yazdani, A. R. Di Fazio, H. Ghoddami, M. Russo, M. Kazerani, J. Jatskevich, K. Strunz, S. Leva, and J. A. Martinez, “Modeling guidelines and a benchmark for power system simulation studies of three–phase single–stage photovoltaic systems,” *IEEE Trans. Power Del.*, vol. 26, no. 2, pp. 1247–1264, Apr. 2011.

[7] E. Figueres, G. Garcera, J. Sandia, F. Gonzalez–Espin, and J. C. Rubio, “Sensitivity study of the dynamics of three–phase photovoltaic inverters with an LCL grid filter,” *IEEE Trans. Ind. Electron.*, vol. 56, no. 3, pp. 706–717, Mar. 2009.

[8] R. Kadri, J. P. Gaubert, and G. Champenois, “An improved maximum power point tracking for photovoltaic grid–connected inverter based on voltage–oriented control,” *IEEE Tran. Ind. Electron.*, vol. 58, no. 1, pp. 66–75, Jan. 2011.

[9] W. Xiao, F. F. Edwin, G. Spagnuolo, and J. Jatskevich, “Efficient approaches for modeling and simulating photovoltaic power systems,” *IEEEJ. Photovoltaics*, vol. 3, no. 1, pp. 500–508, Jan. 2013.

[10] P. Rodriguez, A. Timbus, R. Teodorescu, M. Liserre, and F. Blaabjerg, “Flexible active power control of distributed power generation systems during grid faults,” *IEEE Trans. Ind. Electron.*, vol. 54, no. 5, pp. 2583–2592, Oct. 2007.

[11] I. Etxeberria–Otadui, U. Viscarret, M. Caballero, A. Rufer, and S. Bacha, “New optimized PWM VSC control structures and strategies under unbalanced voltage transients,” *IEEE Trans. Ind. Electron.*, vol. 54, no. 5, pp. 2902–2914, Oct. 2007.

[12] M. S. El Moursi, W. Xiao, and J. L. Kirtley, “Fault ride through capability for grid interfacing large scale PV power plants,” *IET Generation,Transmiss. Distrib.*, vol. 7, no. 9, pp. 1027–1036, Sep. 2013.