Voltage Unbalance Compensation for Distributed Generation Systems under Grid Fault

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Abstract: Distributed Generation (DG) - defined as small-scale electricity generation at or near the end user - is becoming more prevalent in recent years with an increasing penetration of renewable generation emerging in utility distribution grids. Flexible operation of these DG units is a major objective for such grids. In the operational control framework, DG units should be considered as a part of the system, so that system reliability can be enhanced by ancillary service provided by DG systems. As conventional electrical networks were not built to accommodate large DG penetration levels, several new challenges have emerged. An important issue that appears in low voltage (LV) feeders is over-voltage and under-voltage, which can limit the level of DG penetration that can be tolerated and this also, affects the LV protection systems. On the other hand, control of DG units enables a wide range of new support functions such as real/reactive power control under unbalanced voltage conditions, which can help to mitigate these unbalanced network voltages. Finally, the third research objective is to investigate inverter power control methods which can contribute to voltage quality, in particular during unbalanced voltage conditions. A detailed theoretical analysis is developed for the output power control of DG inverters under such conditions, incorporating factors which can contribute to mitigation of abnormal voltage conditions such as real and reactive power oscillatory terms, and differing grid impedance characteristics ranging from resistive to inductive. The results are used to identify the most effective control approach which achieves better voltage quality at the point of common coupling. Furthermore, fault ride through capabilities can be added to the DG inverter functionality to support the grid voltage during such symmetrical/asymmetrical faults, which consequently allow increased penetration of Distributed Energy Resources (DER). The design, modeling and simulation of the smart inverter system is performed in MATLAB/SIMULINK software environment

***IndexTerms* - Distributed Energy Resources (DER), Distributed Generation (DG), Grid-connected inverter, Reactive power control, Voltage sag, Grid fault.**

I. Introduction

The complete system is composed of the power source (PS), the inverter, and the grid is shown in Fig. 1. Interconnection between the PS and the inverter is operated by a dc-link capacitor.

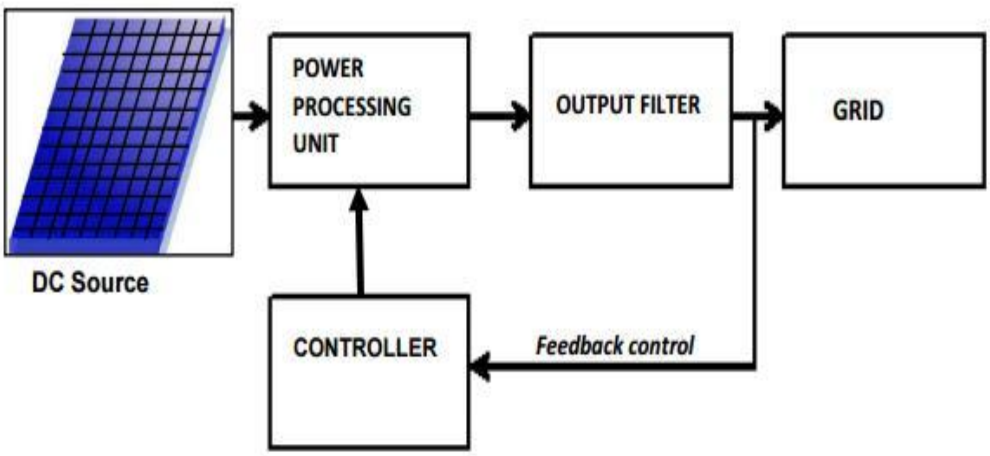

Figure 1. The impact of high level of PV penetration on feeder voltage profile under low load condition.

1.1 PV Array Model

The representation of a PV panel which captures the sunlight through the PV cells is shown in Fig 2.2 below. The PV cells comprises of silicon p and silicon n layers. The atoms of the silicon and the internal field between the positive and negative charges are ionized by the light with precise wave length inside the photovoltaic device. There is a better interaction between the atoms when there is a high irradiance resulting into a high production of potential difference . Disturbances such as solar irradiation is a factor in which the output voltage of the solar cell relies on during the course of its operation which is also a function of the photocurrent. The solar cells' output current is represented in equation for a PV array which comprises of Ns modules in series connection and Np parallel connected modules. Equation and represents the voltage and current of the PV array respectively. The power output of the PV array is given in equation which is the product of output current in and output voltage in of PV

$$I_c = I_{ph} - I_o = I_{ph} - I_{sat}\left[e^{\frac{q}{AKT_c}(V+IR_s)} - 1\right]$$

$$V_{pv} = N_s \times [V_{ref} - \beta(T - T_{ref}) - R_s(T - T_{ref})]$$

$$I_{pv} = N_p \times \left[I_{ref} + \alpha\left(\frac{G}{100}\right)(T - T_{ref}) + \left(\frac{G}{100} - 1\right)I_{sc}\right]$$

$$P_{pv} = I_{pv} \times V_{pv}$$

Where, Ic = Output current of the solar panel Iph = Light generated current in a solar cell Io = Reverse saturation current of diode G = Irradiance α = Current temperature coefficient K = Boltzman constant q = Electron charge Tc = Cell temperature in kelvin β = Voltage temperature coefficient A = Ideality factor Np = Number of modules connected in parallel Ns = Number of modules connected in series T = Stack temperature Ppv = Output power of the PV array Ipv = Output current of the PV array Vpv = Output voltage of the PV array

1.2 Maximum Power Point Tracking

The V-I characteristic of photovoltaic cells is non-linear which depends on solar intensity and cell temperature. It is challenging to control the output of the PV cells due to its non-linear characteristics so that the maximum power that is available will be fed to the grid. The process of maximizing the power output of the PV array is identified as maximum power point tracking (MPPT). However, Maximum Power Point Tracking is one of the most essential things that must be considered while working with PV panels. further explained MPPT as a means of finding a method to extract the maximum power obtainable from the PV panel. This subject is very crucial when dealing with solar energy. The knowledge of MPPT originated from maximum power transfer which means that the maximum power is transferred from the source to the load when the internal resistance of the source is the same with the resistance of the load. The transfer of maximum power will not be possible if the load resistance is fixed. Hence, the DC to DC converter will be used as a variable load while changing the duty cycle in order to reach the maximum power point. It is worth nothing to note that MPPT is carried out by the DC to AC inverter for a single stage inverter.

1.3 EMI Problems

EMI (electromagnetic interference) problems are caused by sudden fluctuations in voltage (dv/dt) or current (di/dt) levels in a waveform. Most fast switching power semiconductor devices found in GCIs generate high dv/dt and di/dt in their waveforms. The radiated high-frequency wave generated from a conductor having a high dv/dt wave which works like an antenna, may combine with a sensitive signal circuit and appear as noise known as radiated EMI. This noise signal may be carried by a dependent coupling capacitor through the ground wire (conducted EMI). A high di/dt current wave may also produce conducted EMI by combining through a dependent common inductance. The problems related to EMI include interference in the communication line and faults in sensitive signal electronic circuits. EMI problems can be resolved through adequate shielding, noise filtering, careful equipment layout, and grounding. Several standards relating to EMC (electromagnetic compatibility) have been defined to control EMI problems

1.4 Non-Controlled Grid Connected Inverter

The modelling of the inverter is implemented through its nominal input impedance in parallel with a current perturbation during this operating state, which signifies the current needed by the inverter to introduce sinusoidal power to the grid. Hence, the power conversion structure can be modeled as a single system comprising of the PV panel, the DC to DC converter, and the inverter as a whole system.

Standard gridconnected inverters need DC-link voltages higher than the usual PV voltages; therefore, a boost DC to DC converter was implemented. Boost converters are nonminimum phase systems in voltage mode, hence, the inductor current control must also be implemented instead of voltage control. The inductor current iL and the state variables chosen are the input and output capacitors voltages VCi and VCo for the system. In addition, the sources of perturbation are the PV panel short-circuit current ISC that models the changes in irradiance, the perturbation of the load current IO and the variable used is the duty cycle of the inverter d ($0 \leq d \leq 1$)

The main purpose of control strategy of 3-Φ grid connected inverter is to control the active and reactive power flow independently. Control variable id is used for active power control and iq is used for reactive power control. A control strategy is developed by using equation

For the transient study and to design a control strategy for controlling the active and reactive power independently transformation of three phase system (abc) to synchronous rotating reference frame is preferred.

Lets consider the system after the application of Parks transformation [1] , Vd is d-axis voltage, Vq is q-axis voltage, Id is d-axis current, Iq is q-axis current, P is active power, Q is reactive power, S is apparent power.

As d-axis and q-axis are of 90 deg phase difference with each other the voltage and current can be expressed as depicted in equation (1.1) and (1.2),

$V_{dq}= V_d+jV_q$ (1.1)

$I_{dq}= I_d+jI_q$ (1.2)

It is well known the apparent power

S= Idq* Vdq (1.3)

$S= (V_dI_d+V_qI_q)+j(V_qI_d-V_dI_q)$ (1.4)

According to PCC voltage orientation frame Vd is assumed as the maximum value of grid voltage and Vq=0. By substituting this condition in equation (1.4) active power and reactive power are derived as follows

$P= V_dI_d$

& $Q= -V_dI_q$

The negative sign in the reactive power signifies that it can flow in either direction i.e from inverter to grid and vice versa. For the control algorithm the d-axis reference current is generated from equation (1.5) and also it can be generated from the dc-link voltage error and the q-axis reference current is generated from equation (1.6). So in other words control of d-axis current (I_d) is done for active power control and that of q-axis (I_q) for reactive power control.

II. Literature Review.

Several works are going on solar photovoltaic systems. Some of these are discussed below:

Prakasit Sritakaew, Anawach Sangswang, and Krissanapong Kirtikara [1] presented a paper about On the Reliability Improvement of Distribution Systems Using PV Grid-Connected Systems. The purpose of their paper was to examine issues related to the distribution system reliability improvement using photovoltaic (PV) grid-connected systems. The output characteristics of a PV system were experimentally measured. The measured data were used to investigate the effects of PV system installation to improve the distribution system's reliability. The system constraints such as, recovered real power, and loading reduction of the tie line/switch after the installation of PV grid-connected systems are concentrated. Simulation results show that with the action of a tie switch, system losses and loading level of the tie switch can be reduced with proper installation location.

Allen M. Barnett [2] presented a paper about solar electrical power for a better tomorrow. The promise of solar electricity based on the photovoltaic (PV) effect is well known. Why don"t we see these systems all over the world? Consumers in the United States are well-known for their attraction to new technology. Why aren"t PV systems appearing on roof-tops in the U.S.? 29 The answer may be that grid-connected roof top systems are Too difficult to acquire, Too difficult to integrate with the grid, Too difficult to measure the energy and Too expensive .It is essential that we make PV systems user friendly, while reducing the component and system costs. Our elegant technology must be reduced to practical systems that can be used by the average person - everywhere.

R. Ramkumar & J. E. Bigger [3] presented a paper of photovoltaic systems including a discussion of major U.S. and international activities. After a brief review of system types and output characteristics, various system configurations were discussed and a classification based on photovoltaic (PV) system rating was provided. Modeling, design, and economic Considerations were briefly discussed. The worldwide status of PV system technology was discussed with a view to making an assessment of the future. The assessment presented includes some specific areas for further research and development. Although no major technical barriers are evident the entry of PV, as the level of penetration increases, several key issues identified in this paper will need further consideration. Photovoltaic is still evolving and has not reached its full potential. It is likely to grow for decades to come; however, the rate of growth may depend on several exogenous factors such as cost of conventional energy sources and the people desire to improve the global environment.

G. Ofualagba [4] in his paper first explained the reasons for the mounting interest in photovoltaic technology and has provided a quick synopsis of the operation of these technology and their applications and markets. Photovoltaic technology have received increasing attention over the last decade as one response to the challenges of global warming, 30 appropriate. The technology of the various components of a photovoltaic system is discussed and the overall system design considered. Typical applications of photovoltaic systems are described.

Souvik Ganguli & Sunanda Sinha [5] presented a paper about Estimation of Grid Quality Solar Photovoltaic Power Generation Potential and its Cost Analysis in Some Districts of West Bengal. The objective of their work was to estimate the potential of grid quality solar photovoltaic power in some districts of West Bengal (Birbhum, Burdwan, Hooghly, Howrah and Kolkata), study the solar radiation level and potential of the above mentioned districts and finally develop a system corresponding to the potential. Equipment specifications were provided based on the system developed and finally cost analysis was also carried out.

Brig.M.R.Narayaoan, D.V.Gupta, R.C.Gupta & R.S.Gupta [6] presented a paper about Design, Development and Installation of 100 kW utility grid connected solar PV plants for rural application- an Indian experience. This paper briefly describes tile features of the two power plants, the developmental approach adopted based on "Building Block Philosophy" With 25 KW System as the basic unit with the attendant advantages. It includes the indigenous design and development effort made for grid connected operation and most importantly the special design features incorporated to ensure a very high degree of safety and protection so necessary in the rural areas with predominantly non-literate users. Tile paper is concluded with some important lessons learnt from both the technical and logistics point of view for guiding installation of similar such plants in the remote rural areas in India and other developing countries in the future.

Wang Jianqiang & Li Jingxin [7] researched two grid connected photovoltaic power systems. One is 10kW located in Beijing, the other is 100kW located in north of Shan"xi province of China. Inverter and its different operation of modes for both the photovoltaic power system were discussed. For 10kW Photovoltaic power system, the single phase transformers less grid connecting inverters are applied to this system. The inverters have two-stage structure, DCDC and DC-AC, but they often operates only with last DC-AC stage according to the panel string output voltage. For 100kW photovoltaic power system, 3 phase transformer less gridconnecting inverters are used. But they concluded that although all the inverters in two systems have two stage structures, only single stage were designed to work during most of time. Because 31 the system efficiency can be increased availably. So large photovoltaic power system should adopt series-wound panels for high operating voltage and less loss. The research shows the correlation. The output power quality of one inverter of 10kW systems was analyzed, too.

B. Marion,J. Adelstein,K. Boyle and fellows [8] presented a paper about performance parameters for Grid-Connected PV systems. Three performance parameters may be used to define the performance of grid-connected PV systems: final PV system yield Yf , reference yield Yr , and performance ratio PR. The Yf and PR are determined using the nameplate d.c. power rating. The Yf is the primary measure of performance and is expressed in units of kWh/kW. It provides a relative measure of the energy produced and permits comparisons of PV systems of different size, design, or technology. If comparisons are made for different time periods or locations, it should be recognized that year-to-year variations in the solar resource will influence Yf . The PR factors out solar resource variations by dividing Yf by the solar radiation resource, Yr . This provides a dimensionless quantity that indicates the overall effect of losses and may be used to identify when operational problems occur or to evaluate long-term changes in performance. As part of an operational and maintenance program, the PR may be used to identify the existence of performance issues.

Chang Ying-Pin & Shen Chung-Huang [9] presented a paper about Effects of the Solar Module Installing Angles on the Output Power. In their paper they discussed that the output power increment of photovoltaic cells is mainly based on two factors. One is decreasing the cell modular temperature and the other is increasing the cells received solar illumination intensity. The former can be simply achieved by maintaining a proper radiating space between the modules and the ground. The later is more complicated. One needs to consider the installation of cell modules and then the maximum power output which can be derived. This paper was theoretically calculated the solar orbit and position at any time and any location. With the estimation of their model on the variation of solar illumination intensity, they can derive the output power of the solar modular cell at any tilt angle and orientation. The simulated results could be utilized in large scale photovoltaic power generation systems when considering placement for optimal installation. It also provides a useful evaluation for the output power of photovoltaic cells mounted on roofs and out walls of buildings.

Grid interconnection of photovoltaic (PV) power generation system has the advantage of more effective utilization of generated power. However, the technical requirements from both the utility power system grid side and the PV system side need to be satisfied to ensure the safety of the PV installer and the reliability of the utility grid. Clarifying the technical requirements for grid interconnection and solving the problems are therefore very important issues for widespread application of PV systems. Grid interconnection of PV systems is accomplished through the inverter, which convert DC power generated from PV modules to AC power used for ordinary power supply for electrical equipments. Inverter system is therefore very important for grid connected PV systems. Inverter technology is very important to have reliable and safety grid interconnection operation of PV system. It is also required to generate high quality power to AC utility system with reasonable cost. To meet with these requirements, up to date technologies of power electronics are applied for PV inverters. By means of high frequency switching of semiconductor devices with PWM (Pulse Width Modulation) technologies, high efficiency conversion with high power factor and low harmonic distortion power can be generated. Reduction of inverter system cost is to be accomplished..

III. Simukation

The simulation was carried out based on system parameters given in in MATLAB/Simulink environment. In this part output voltage and current waveforms of inverter have been shown. The Simulation output voltage across PV Array it has two variable temperature and irradiation vary increase power.

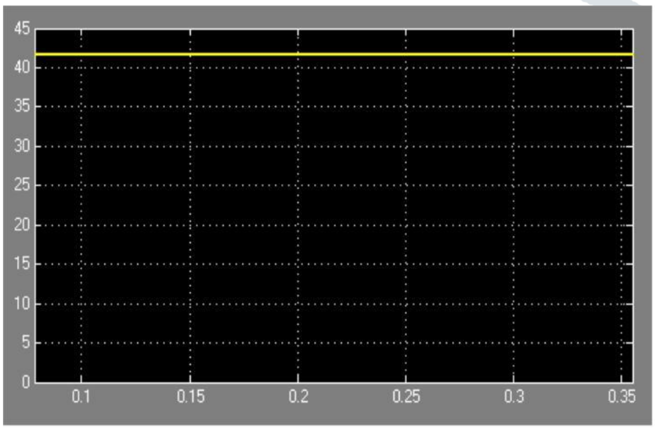

Figure 2. PV Array Output

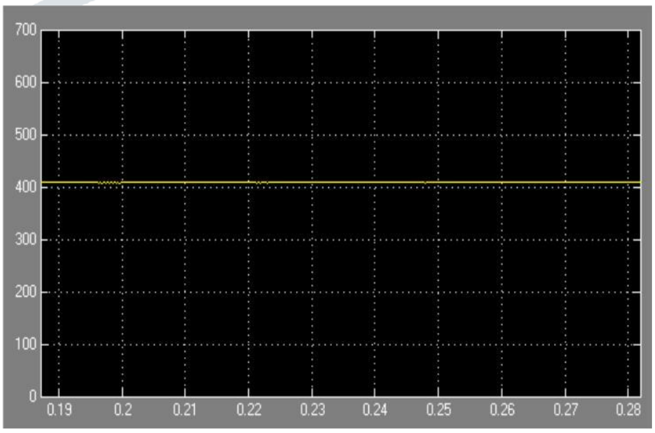

Figure 3. PV Boost Output

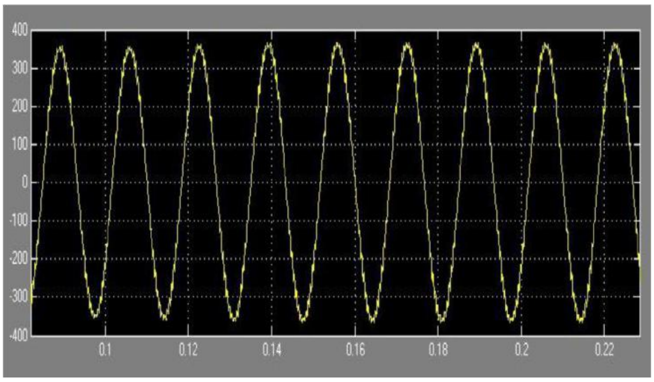

Figure 3. Inverter output voltage between phase A & B

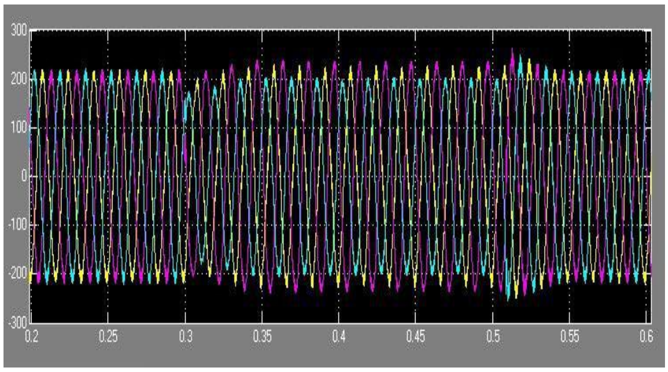

Figure 4. Grid Voltage

The figure no.4 boost the voltage using maximum power point tracking (MPPT)after that this voltage is applied to inverter, the voltage of inverter is fluctuating , to get pure sine wave and remove harmonic the voltage is pass through filter. after that we applied to grid. And apply fault to analysis what the effect of fault in circuit.

IV. Conclusion

The paper presented a simulation tool for PV grid-connected generation systems suitable for large scale systems studies for both steady state and transient analysis. The tool developed is characterized by modularity which allows combining the various blocks in a very user-friendly and flexible way to create simulation models for different system configurations. An important application of these tools is to check how the voltage at the various nodes of a feeder varies during a studied period due to the variations of PV generation and load demand. As an example application of the models developed, the paper presented a study to show the voltage rise in a LV distribution feeder at the PCC with grid-connected PV units.

Further, the use of the presented models, appropriately developed and extended, allows to study by numerical simulation the problem of assessing the amount of power that distributed generation can inject into distribution feeders in compliance with limitations imposed by voltage and thermal constraints

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