CONTROL OF PHOTOVOLTAIC POWER GENERATION SYSTEM DURING UNBALANCED GRID VOLTAGE SAG CONDITIONS

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ABSTRACT

This paper presents a robust control strategy for renewable power generation system during voltage sag condition. The renewable power sources like photovoltaic, fuel cell and wind turbine are connected to grid using power electronic converters include DC-DC converter and grid connected voltage source converter. To control the power from renewable power source and stabilize the dc–link power during voltage sag, control strategy has been designed for DC-DC converter. Moreover, a robust current control strategy of voltage source converter for both positive and negative symmetrical components is presented. The hybrid system is studied under unbalanced voltage sag condition. Simulation and experimental results are given to show the response of system under voltage sag and illustrate the performance including active power control and voltage sag ride-through capability of the proposed control strategy.

INTRODUCTION

Nowadays the power system is in a process of undergoing from regulated market to the deregulated one, centralized to more localized systems that are situated nearer to the load centers. The reasons behind are; increased concern for environment, utilization of renewable energy technologies, flexibility of operation, lower initial investment costs, lower time of project completion, electricity market liberalization, developments in Distributed Generation (DG) technology, constraints on the construction of new transmission lines and increased customer concern for highly reliable electricity etc[1]. Many of the renewable power generation systems like wind turbine, photovoltaic and fuel cell are connected to the grid via power electronic converters to improve the system integrity, reliability and efficiency [2-4]. With the increasing power capacity of DG systems, it is important to design control strategy to keep the safe operation of these system during voltage and load disturbances. The grid-connected power electronic converters are highly sensitive to voltage disturbances. This makes it necessary to reduce the effects of voltage disturbances on their operations [5]. A voltage sag is a drop in voltage with duration between one half-cycle and one minute [6], which is, in most cases, caused by a short-circuit fault. The operation of DG units under voltage sag has not received much attention in the past. Moreover, many grid operators demand the immediate shutdown of DG in case of grid disturbances as a prerequisite for grid connection. As the power generated by DG units increases, this behavior stresses the utility grid and could cause power unbalance; which may turn into instability. So, the interaction between DG units and the grid during the voltage sag is very important and it must be considered when designing the proper control strategy. In this paper a control strategy has been proposed for renewable power generation system during voltage sag conditions. First, description of renewable power generation system include power electronic converters are presented. Then control structure of the hybrid power generation system is investigated. Simulation and experimental results prove the effectiveness of the proposed control strategy.

DESCRIPTION OF PHOTOVOLTAIC POWER GENERATION SYSTEM

To investigate the interaction between grid and photovoltaic power generation system during voltage sag, it is necessary to consider a set of power electronic devices to connect renewable power source to main grid. The structure of proposed system that considered in this paper is shown in Fig.1. As shown, it consists photovoltaic power source, DC to DC power converter, grid connected converter and transformer and output filter [7-8].

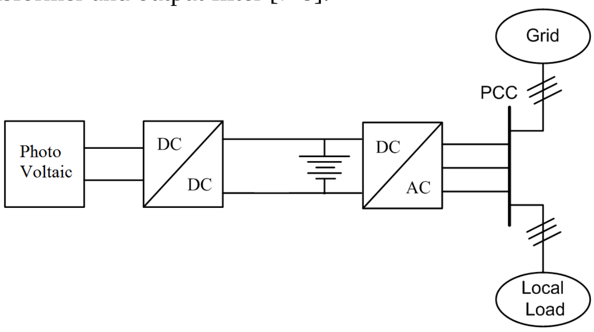

Fig. 1 Topology of Photovoltaic Power System

POWER CONTROL DURING VOLTAGE DISTURBANCE

One important problem that must be considered during voltage sag is the control of distributed generation power. In fact, during voltage sag conditions, the power flow control strategy must be design to stabilize the dc link power and regulate the dc link voltage consequently. Under voltage sag, a decrease in voltage amplitude occurs at the converter terminal. To keep the power supplied to the grid constant, the current should increase. It will be limited by the current controller however, to avoid overloading of the converter. This will thus limit the power that the DG unit can supply to the grid during a sag, resulting the dc-link voltage will increase. To avoid a too high dc-link voltage, the power balance between inverter power and DG power must be satisfied. The following differential equation for dc link is given:

$$C_{dc} v_{dc} \frac{dv_{dc}}{dt} = P_{DG} - P_{grid} \qquad (1)$$

Where:

P_{DG} is the power of renewable source,

P_{grid} is the grid power

According to the equation (1), in order to regulate the dc link voltage it is necessary to keep the power balance in dc link. But the amount of power that should be produced to balance the power in dc link is very important and it depends on the dc link energy. The dc link energy measurement is carried out by means of the following calculation:

$$E_{dc}(k) = (\frac{1}{2}) C_{dc} V_{dc}^2(k) \qquad (2)$$

In this paper, a power flow control structure has been developed for hybrid power sources during voltage sag. It is based on self tuning fuzzy control strategy that determines the renewable generation power according to the following inputs:

$$\begin{aligned} e(k) &= E_{dc-ref}(k) - E_{dc}(k) \\ \Delta e(k) &= e(k) - e(k-1) \end{aligned} \qquad (3)$$

Where $E_{dc\text{-}ref}$ is the reference dc link energy which calculated by reference dc link voltage. The detail of the self tuning fuzzy controller has been given in [9]. The block diagram of the fuzzy PI controller is shown in Fig.2.

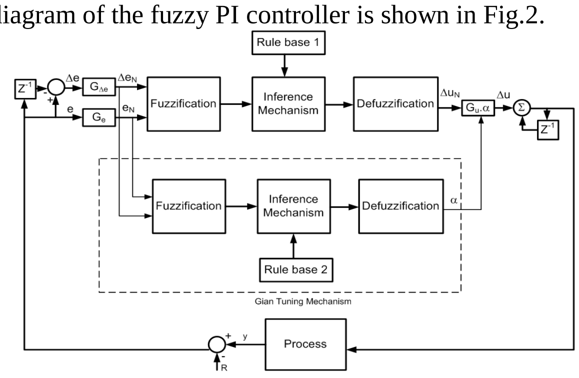

Fig.2. The block diagram of the self-tuning fuzzy PI controller

By using the scaling factors (SFs) G_e, $G_{\Delta e}$, the quantities e and Δe are converted to normalized e_N and Δe_N. These normalized quantities e_N and Δe_N are crisp in nature and therefore need to be first converted to their corresponding fuzzy variables. After fuzzification, the fuzzified inputs are given to the fuzzy inference mechanism which, depending on the given fuzzy rile base, gives the normalized incremental change in control output (Δu_N). The output Δu_N is converted into actual incremental change in control output (Δu) by using the scaling factor G_u. For the implementation the fuzzy inference engine, the “min” operator for connecting multiple antecedents in a rule, the “min” implication operator, and the “max” aggregation operator have been used. Actually, the output Δu_N from the inference mechanism is fuzzy in nature, hence, to determine the crisp output, the defuzzification stage is applied. The centroid defuzzification scheme has been used here for obtaining the output Δu. Finally, the actual value of the controller output (u) is computed by:

$$u(k) = u(k-1) + \Delta u(k) \qquad (4)$$

The relationships between the SFs and the input and output variables of the self-tuning FLC are as follow:

$$\begin{aligned} e_N &= G_e . e \\ \Delta e_N &= G_{\Delta e} . \Delta e \\ \Delta u &= (\alpha . G_u) . \Delta u_N \end{aligned} \qquad (5)$$

In this scheme, the FLC is tuned on-line (while the controller is in operation) by dynamically adjusting its output scale factor by a gain updating factor (α). The value of α is determined from a rule base defined on e and Δe and derived from the knowledge of control engineering.

SIMULATION AND EXPERIMENTAL RESULTS

In order to show the effectiveness of proposed control strategy, the simulation and experimental results for the system shown in Fig.3, using the specifications of a low power laboratory system are presented. The test bench is presented in Fig.9. The parameters of the system are shown in Table 1. The control system has been implemented using a PC embedded DSP (dSPACE), with a sampling time Ts=100µs. Hence, the switching frequency (fs) is set to 10kHz. The system with the proposed control strategy has been tested under a 60% voltage sag type C (unbalanced). Voltage sag has been generated at the laboratory by switching one grid phase from its rated voltage to a smaller voltage by a three phase autotransformer, using fast switches. The control strategy that has been described in section 2, has been examined in case of unbalanced voltage sags. A voltage sag, resulting from two-phase fault (sag type C), is applied at the grid side. The voltage sag starts at 4.5 sec for duration of 0.1 sec with voltage drop of 60%.

Fig.3 Test bench for grid connection of Renewable power source

TABLE 1: Parameters of the photovoltaic power generation system

Boost DC-DC Converter Parameters	
Rated voltage (V)	100V/300 [V]
Rated power	250 [W]
Nominal duty cycle	0.66
L	415×10-6 [H]
C	$1500\times10\text{-}^{6}$ [F]
DC/AC Converter Parameters	
Nominal AC Voltage	100 [V]
Nominal Power	200 [W]
Maximum current of grid	3[A]
Nominal DC voltage	300 [V]
DC-link capacitance	3300 [μF]
R_s	23 [mΩ]
L_s	0.5 [mH]
f_s	50 [Hz]
DC Power Source Parameters	
Nominal DC voltage	100[V]
Nominal DC current	2[A]
Internal Resistance	0.01[Ω]
Minimum Active Power	100[W]
Maximum Active Power	250[W]

The grid voltage during voltage sag type C has been shown in Fig.4 (a). The grid currents during voltage sag type C increase (Fig.4 (b)). In this case, the grid currents are limited by current controllers to avoid overloading of the converter. Also after voltage sag, the current controllers adapt fast according to the new current references to shape the grid currents. In Fig.4 (c), the average and instantaneous active power during normal and voltage sag conditions have been illustrated. As shown during voltage sag the injected active power to the grid is decreased and there is a small oscillation in active power. These oscillations are according to the proposed current control strategy that considered in this paper. It makes that the oscillating active power that demands by the filter to be delivered from the grid and no oscillating active power flows between the dc link and the filter. But the average active power is zero. The DC-link voltage is shown in Figs.4 (d). During the voltage sag, there is an increasing on dc link voltage but it is not much more than 10% of nominal value. In these conditions, to stabilize the dc-link power, the fuzzy controller manages the power from the DC power source, resulting the reference power of the renewable power source changes for decreasing the input power to dc bus during voltage disturbances. For the validation of proposed control strategy, the experimental results also have been presented in Fig.5.

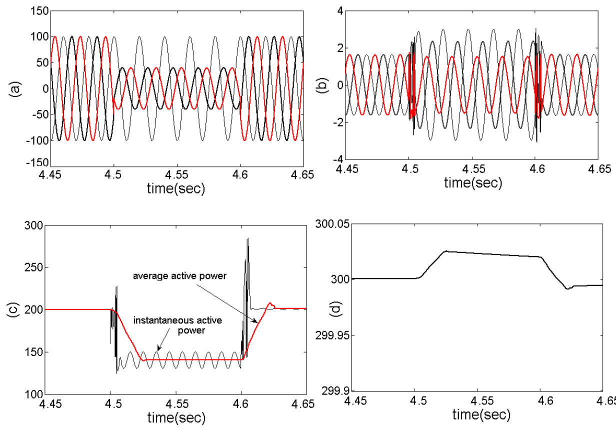

Fig.4. simulation results during voltage sag type C: grid voltage (a), grid currents (b), average and instantaneous active power (c), average and instantaneous reactive power (d), dc link voltage

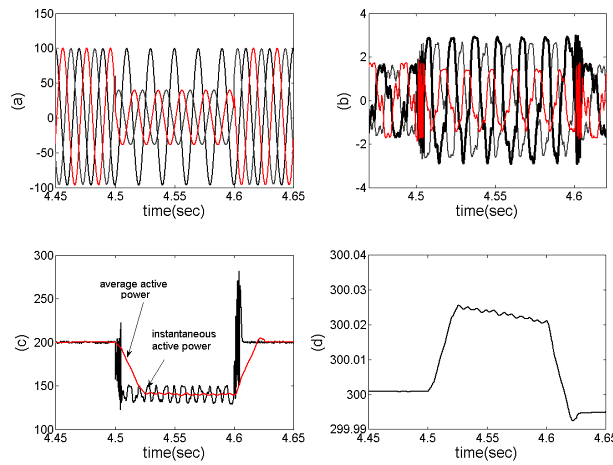

Fig.5. experimental results during balance voltage sag: grid voltage (a), grid currents (b), average and instantaneous active power (c) and dc link voltage (d)

According to the Figs. 4-5 (b) (c), there is a transient condition in grid currents and instantaneous active power at the beginning and the end of the voltage sag. The main reason for these transient conditions is related to the delayed signal cancellation method (DSC). Another reason could be related to the fast control response of sliding mode current control strategy. In this case, control variables will exceed switching strategy limits, leading to the over modulation region and transient conditions. Despite of these inaccuracies due to DSC and switching strategy limits that can be observed in the currents and power performance, the simulation and experimental results obtained seem to be acceptable and good agreement is found between simulation and experimental results. The main difference between simulation and experimental results is found on grid current harmonic content. These harmonics could be reduced by designing a proper filter. The operation of renewable power generation system under voltage sag condition is very important problem. The amount of active power that could be delivered form this system to grid is related to some parameters like voltage sag magnitude, dc-link power, dc-link voltage and current control strategy. The dc-link power is very important during voltage sag. In some power sources i.e. fuel cell and photovoltaic system, there are limitations to respond very fast to the change in power during voltage sag. In this case, the need for implementation of energy storage like supercapacitor and battery is vital [8].

CONCLUSION

This paper presents the control strategy of renewable power generation system under unbalanced voltage sag conditions. For this purpose, power electronic converters model and a simple model for renewable power source are presented and then by designing control strategy for each component, the power control problem of the proposed system is studied under unbalanced voltage sag. To control of the dc link power and regulate of dc link voltage, self tuning fuzzy controller is presented to determine the necessary power according to the amount of energy in dc link. Moreover, robust current control strategy has been developed to control of positive and negative sequence of dq-components. Simulation and experimental results show that the proposed control strategy is able to tolerate under various voltage sags and keep the system performances like active power control and stability of dc-link.

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