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Voltage Sag and Support in Power Control on Distributed Generation Inverters

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ABSTRACT

During voltage sags, continuous power delivery from distributed generation systems to the grid is desirable for the purpose of grid support. Ancillary services for distributed generation (DG) systems become a challenging issue to integrate renewable-energy sources into the grid. Voltage control is one of these ancillary services which can ride through and support the voltage under grid faults. In order to facilitate the control of distributed generation systems adapted to the expected change of grid requirements, flexible voltage support control scheme is proposed for inverter based distributed generation, aiming at regulating voltage limits and reactive power injection to remain connected and supports the grid under fault. In three-phase balanced voltage sags, the inverter should inject reactive power in order to raise the voltage in all phases. In one- or two-phase faults, the main concern of the DG inverter is to equalize voltages by reducing the negative symmetric sequence and clear the phase jump. Thus, over and under voltage can be avoided, and the proposed control scheme prevents disconnection while achieving the desired voltage support service which can be analyzed and simulated by using Matlab/Simulink environment. The main contribution of this work is the introduction of a control algorithm for reference current generation that provides flexible voltage support under grid faults.

KEYWORDS: *Distributed Generation Inverters Reactive power control, voltage sag, voltage support*

I. Introduction

The recent trends in small scale power generation using the with the increased concerns on environment and cost of energy, the power industry is experiencing fundamental changes with more renewable energy sources (RESs) or micro sources such as photovoltaic cells, small wind turbines, and micro turbines being integrated into the power grid in the form of distributed generation (DG). These RES-based DG systems are normally interfaced to the grid through power electronics and energy storage systems[1] One of the most critical sections of the control system for a distributed generation (DG) unit's interconnection to the utility grid lies within the grid-connected converter's control and protection system; specifically the islanding detection algorithms. Through this controller subsection, the system is able to determine whether or not it is safe to remain connected to the grid. These islanding detection algorithms, which are integrated into the control system, are mainly present to prevent the undesirable feeding of loads during fault conditions and disconnections from the grid, whether or not the disconnection as intentional[2] This is required by standards since the creation of such "power islands" is forbidden. Thus, in effect, standards require DG control systems to sense islanding events and disconnect themselves from the grid. This brings into question the method of how to implement such a detection scheme.[Islanding Detection Using a Coordinate Transformation Based Phase-Locked Loop] Islanding is a condition in which a microgrid or a portion of the power grid, which contains both load and distributed generation (DG), is isolated from the remainder of the utility system and continues to operate Some distinctions of islanding are: non-intentional islanding occurs if after the fault it is not possible to disconnect the DG; non-intentional islands must then be detected and eliminated as fast as possible; intentional islanding refers to the formation of islands of predetermined or variable extension; these islands have to be supplied from suitable sources able to guarantee acceptable voltage support and frequency, controllability and quality of the supply, and may play a significant role in assisting the service restoration process microgrids, seen as particular types of intentional islands, basically operated in autonomous mode, not connected to the supply system; the whole microgrid can be seen from the distribution system as a single load nd has to be designed to satisfy the local reliability requirements , in addition to other technical characteristics concerning frequency, voltage control and quality of supply.[2].

II. Related Work

This paper focuses on current-mode three phase inverters to smartly support the grid voltage under fault. Inverter behavior is commanded by the controller unit, which, according to [11] and [12] ful fil the following requirements:
1) Active power control
2) Reactive power control
3) Voltage ride through
4) Reactive current injection
5) High power quality

In normal grid conditions, DG inverters must regulate both active and reactive powers injected into the grid. When the grid is in fault, voltage support control can mitigate voltage sag effects by injecting additional reactive current to ride through the perturbation and support the grid voltage. High quality of the injected currents is obtained when no harmonic distortion is present in the grid currents even during grid faults.

A. Three-Phase DG Inverter

Fig. 1 shows the typical configuration of a three phase DG inverter. The complete system is composed of the power source (PS), the inverter, and the grid. Interconnection between the PS and the inverter is operated by a dc-link capacitor. The control of the dc-link voltage Vdc balances the power flow in the system. The inverter consists of a three-leg voltagesource pulse width-modulation inverter with an LCL filter to reduce high-frequency harmonics [13]. To avoid filter resonance, a passive damping resistor is included in series with the capacitor [14]. Finally, the DG inverter is connected to the grid at the point of common coupling (PCC). Grid impedance is mainly.

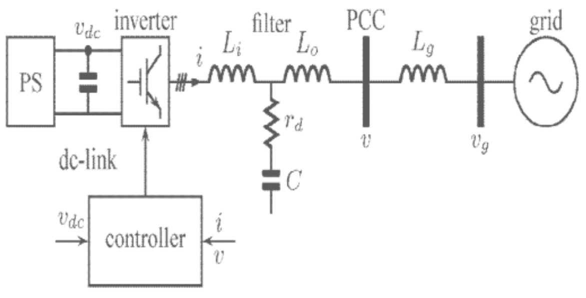

Fig.1. Grid-connected three-phase DG inverter.

Inductive, so the inductance Lg is used to model the connection between the three-phase DG inverter and the grid. Grid voltage vg can be affected by the fault produced somewhere in the transmission system.

B. Voltage Sag Characterization

Voltage sag is an abnormal condition in the grid voltages, characterized by a short-time reduction in one or various phases. The causes of voltage sags are mainly phase to ground short circuit, phase-tophase (to ground) short circuit, and the start-up of large motors. The most widely accepted classification of voltage sags is presented in [10]. Voltage sags can be characterized by the module, frequency and initial angle of each phase or by the positive, negative, and zero symmetric sequences

$Va = Va+ +Va-+Va0$

$Vb = Vb+ +Vb-+Vb0$

$Vc = Vc+ +Vc-+Vc0$

Where the super indexes (+, −, and 0) indicate the positive, negative, and zero symmetric sequences, respectively. In three wire systems, zero sequence voltage v0 and current i0 are not present. Instead of using a natural frame for characterizing the grid voltage, the Clarke transformation is applied to express measured voltages in the stationary reference frame (SRF)

C. Grid Code Requirements

TSO requirements in grid codes state that power generators should remain connected even in faulted grid conditions in order to feed the grid and support the grid voltage. Different TSOs provide different voltage profiles as limits for disconnection , depending on sag depth and duration.
During a short interval (typically, less than 0.150 s),the inverter must remain connected even in very deep sag conditions [0.2 per unit (p.u.)]. In moderate voltage sags (below 0.8 p.u.), the inverter must remain connected for a longer time (2 s). Another issue in voltage support requirements is the reactive/ active power ratio. In deep voltage sags, only the reactive power must be injected to the grid. However, in less deep voltage sags, both active and reactive powers must be transferred to keep feeding the grid.

D. Control of Three-Phase DG Inverter under Fault

The behaviour of the current-mode three phase inverter is determined by the injected current at the PCC. By injecting reactive power into the grid, the rms voltage at the PCC can be increased to support the grid voltage under fault. Then, a proper reference current generator is required when the grid is under fault in order to counteract the voltage sag effects on the system. In Fig. 2, a block diagram of the controller for DG inverters under grid fault is shown. The inputs of the controller are the measured phase voltages v at the PCC, the currents i flowing through Li inductor, and the dc-link voltage Vdc. Voltage v and current i am transformed into SRF values. Voltages vα and Vβ are then decomposed into symmetric components using a sequence extractor. The symmetric sequence extractor is a key aspect to characterize the grid voltage. Many sequence extractors can be found in the literature to extract voltage sag information at run time. The dc-link voltage regulator is in Charge of the active power reference P∗ that keeps power balance.

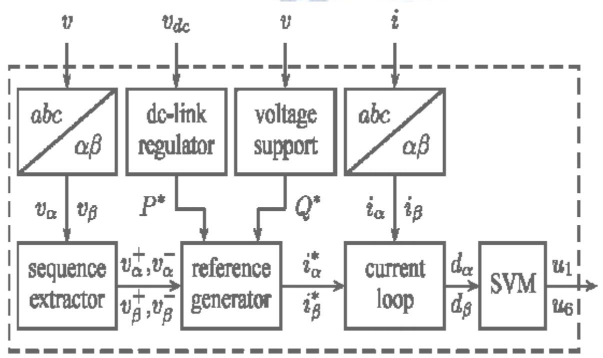

Fig 2. Control diagram of three-phase DG inverter under grid fault.

The voltage support block needs first to detect the voltage sag. This can be done by computing the voltage rms in each phase. When one or several rms values drop below a predefined threshold, the voltage support control is activated. The voltage support block decides which strategy should be implemented according to grid codes and system limitations. This part provides the reactive power reference Q∗; for the sake of simplicity, in this study, this reference is computed offline, and no closed loop is implemented. All this information passes through the reference generator to build reference currents i∗ α and i∗ β. The reference current generator is the kernel of the control algorithm because it can flexibly support the grid voltage. At the end of the current control loop, duty cycles dα and dβ are processed by the space vector pulse width modulator to commute the switches u1, u2, . . . , u6.

III. Implementation

From conventional to proposed control:

A. Controller Design

Under grid connected operation DG should be should be synchronized with the grid. In this mode each DG inverter works for the system by the measured voltage and desired power levels. For unity power factor operation, it is essential that the grid current reference signal is in phases with the grid voltage. Current controller design using Flexible Voltage Support Controller is shown in fig.3

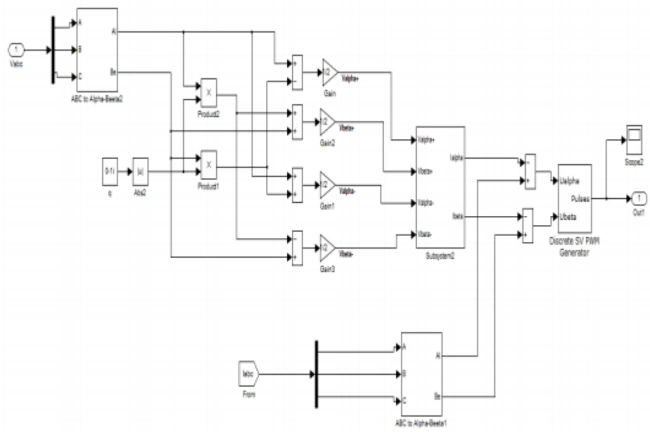

Fig 3 Controller Design

B. Point of Common Coupling

The PCC is a point in the electrical system where multiple customers or multiple electrical loads may be connected. According to IEEE-519, this should be a point which is accessible to both the utility and the customer for direct measurement. Although in many cases the PCC is considered at the metering point, service entrance or facility transformer, IEEE-519 states that “within an industrial plant, the PCC is the point between the non-linear load and other loads.” PCC at service entrance, metering point or facility transformer it will generally be easier to meet harmonic distortion limits when the PCC is considered at the metering point, facility transformer or service entrance.

In most cases, the current flowing at this point represents a combination of pure fundamental current flowing to linear loads and both fundamental and distorted current flowing to non-linear loads. The distortion current will often be a smaller percentage of the total (combined) fundamental current at this point. PCC within the plant and between the non-linear and linear loads Considering the PCC at the equipment will often meet the IEEE-limits both at this point and also at a PCC near the service entrance. The IEEE-519 limit at this point, which is essentially at the input to the non-linear loads, is often 12%, 15% or even 20% THD-I. The ratio of short circuit current to load current is typically much larger at this PCC, which typically has less total load, than at the metering point, where the entire plant load is connected. Usually, if the THD limit is met at each non-linear load within the plant, the TDD limits at the service entrance will also be met. Even though the THD limits are typically lower for the PCC considered near the utility metering point, the overall THD at this PCC may be considerably lower if there are additional linear loads in the plant that share the power source.

C. Filter

The rectifier circuitry takes the initial ac sine wave from the transformer or other source and converts it to pulsating dc. A full-wave rectifier will produce the waveform shown to the right, while a halfwave rectifier will pass only every other half-cycle to its output. This may be good enough for a basic battery charger, although some types of rechargeable batteries still won't like it. In any case, it is nowhere near good enough for most electronic circuitry. We need a way to smooth out the pulsations and provide a much "cleaner" dc power source for the load circuit.

To accomplish this, we need to use a circuit called a filter. In general terms, a filter is any circuit that will remove some parts of a signal or power source, while allowing other parts to continue on without significant hindrance. In a power supply, the filter must remove or drastically reduce the ac variations while still making the desired dc available to the load circuitry. Filter circuits aren't generally very complex, but there are several variations. Any given filter may involve capacitors, inductors, and/or resistors in some combination.

Each such combination has both advantages and disadvantages, and its own range of practical application. If we place a capacitor at the output of the full-wave rectifier as shown to the left, the capacitor will charge to the peak voltage each halfcycle, and then will discharge more slowly through the load while the rectified voltage drops back to zero before beginning the next half-cycle. Thus, the capacitor helps to fill in the gaps between the peaks, as shown in red in the first figure to the right. Although we have used straight lines for simplicity, the decay is actually the normal exponential decay of any capacitor discharging through a load resistor.

IV. EXPERIMENTAL WORK

A. Over All Simulation Diagram with Symmetrical Fault:

The modeling of the system with flexible voltage support control is designed in simulink. The gain parameters of flexible voltage support controller obtained by proper tuning. Flexible voltage support control works as a regulator of the voltage and current during transition from grid connected to Symmetrical Fault. α and β for flexible voltage support control is chosen proper tuning. The Overall Simulation Diagram with Flexible Voltage Support controller Fig 3.

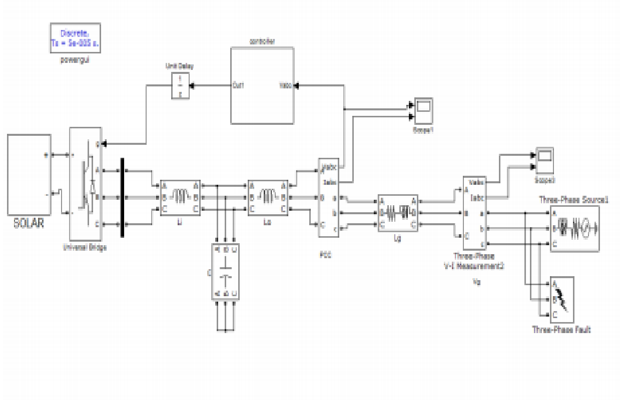

Fig.4 Simulation Diagram with Symmetrical Fault.

B. Over all Simulation Diagram with Unsymmetrical Fault

The modeling of the system with flexible voltage support control is designed in simulink. The gain parameters of flexible voltage support controller obtained by proper tuning. Flexible voltage support control works as a regulator of the voltage and current during transition from grid connected to Unsymmetrical Fault. α and β for flexible voltage support control is chosen proper tuning. The overall Simulation Diagram with Flexible Voltage Support controller fig4.

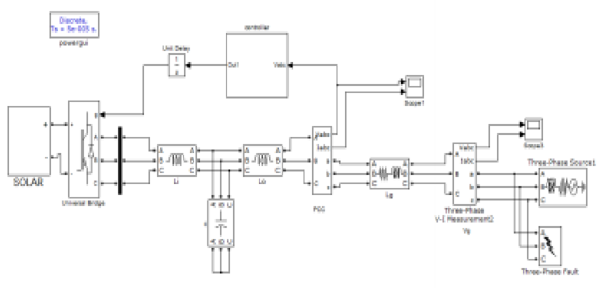

Fig.4 Simulation Diagram with Unsymmetrical Fault

C. Grid Voltage and current for symmetrical fault

The grid voltage and current waveforms without fault is shown Fig.6. The grid voltage is 565V and current value is 25A.

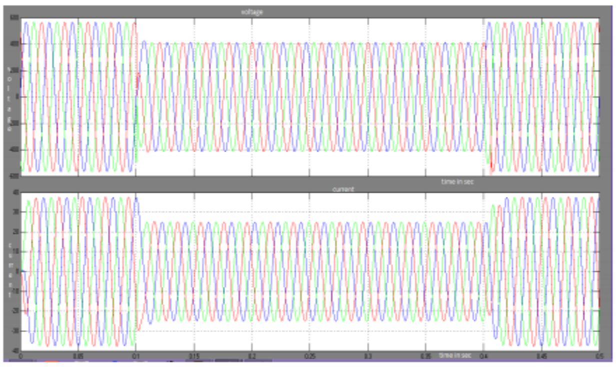

Fig.5 Grid Voltage and Current for symmetrical Fault.

The Fig.5 shows the voltage and current value of grid and interconnection of solar power plant and three phase conventional source. In the Figure 5 normal condition the voltage and current values are calculated by using voltage current measurement. In normal condition with any disturbances grid voltage value 400V and current value is 38A in grid.

D. Grid Voltage and current for Unsymmetrical fault

Duration of fault 0.1 to 0.4 msec

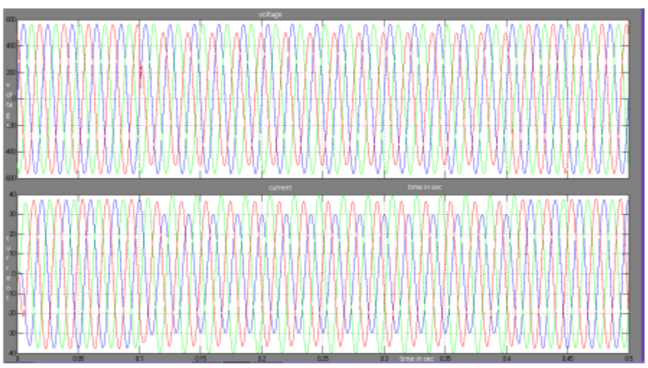

Fig.6 Grid Voltage and Current for symmetrical Fault.

The grid voltage and current waveforms without fault is shown Fig. 6. The grid voltage is 560V and current value is 40A.The Fig.6 shows the voltage and current value of grid and interconnection of solar power plant and three phase conventional source. In the Fig 6, Unsymmetrical condition the voltage and current values are calculated by using voltage current measurement. Here R&Y phases are fault condition. The grid voltage value in RY&B phases -565V per phase and grid current value in B phase 40A in R&Y phases 38A. So reduces the fault current values with in limit using reactive power injection in normal condition.

V. Conclusion

This paper has proposed the method for flexible voltage support control of distributed generation inverters operating under grid fault. The obtained results indicate that the conventional control strategy is not effective in the low voltage grid, where the network impedance is mainly resistive. The voltage support strategy can be modified by means of a control parameter according to the type of voltage sag. When the sag is very deep, k + should be near to zero; when the sag is less deep, a balance between these two extreme policies should be obtained. On the other hand, the proposed method can flexibly support the grid voltage with the positive sequence voltage recovery and negative sequence voltage reduction and also it clears the phase jump which is a powerful tool for voltage support under grid fault.

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