Management of Renewable Energy Sources Under Grid Fault Conditions

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***Abstract*—This master thesis deals with the control of a grid converter during a grid fault. After research of the state of the art of the grid control techniques during faults, five interesting control techniques were selected, analyzed and then experimentally tested on a 15 kVA prototype.**

I. Introduction

The great spread of distributed energy sources, such as solar or wind, has faced grid-interfacing converters with challenges regarding operation during grid faults. These challenges require the control algorithms not only to manage the power flow to the grid and to accurately control the grid-side currents, but also to ensure a stable and ripple free DC-side current and voltage. In this thesis, five inverter control techniques during faults are presented. The goals of these techniques are improving the DC-link voltage quality and to cancel power ripple oscillations caused by the cross effect of the direct and inverse voltage sequence rising from the fault occurrence. For each technique, a current limit technique to avoid inverter protection triggering during fault occurrence has been developed.

II. Inverter Control Scheme

The considered conversion system is shown in Fig.1 and it consists of low voltage grid, an LCL filter and the voltage source inverter. A bidirectional DC/DC converter interfaces the DC side to a load or a generator.

The control consists of four blocks: the sequence extractor to track the positive and negative voltage sequences, the reference generator, the current control to generate the voltage reference and the modulator to impulse the inverter legs, as shown in Fig.2.

The variables sent to the sequence extractor, are the grid voltages, V_{conc}. For the current control loop, a PR (Proportional Resonant) regulator was chosen. The reason behind this choice is that in this application, it is necessary to track current references both in positive and negative sequence. A traditional PI regulator in the rotating dq reference frame synchronous with the grid voltage would not suffice, as it would only track the positive sequence (DC values in dq) but not the negative one (AC at double grid frequency in dq).

The input of the reference generator are the voltage sequences, $v_{\alpha\beta}^{+}$ and $v_{\alpha\beta}^{-}$, the power references, P_{ref}^{*} and Q_{ref}^{*}. The input to the PR regulator are the reference currents, $i_{\alpha\beta}^{*}$, and the output are the voltage references, V_{abc}, for the modulator to impulse the inverter leg.

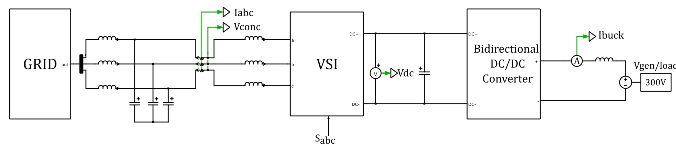

Fig. 1. System setup scheme.

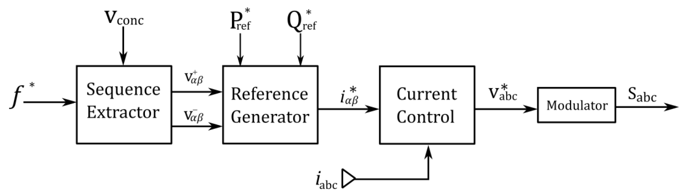

Fig. 2. Control Scheme.

Every developed technique works through injecting positive and negative currents sequences, with the goal to cancel the power ripple. The currents depend on the direct and inverse voltage sequences. For this reason, the first step was to implement the sequence extractor to track the positive and negative voltage sequence.

The control technique must be chosen according to the application. In general, the goals are cancelling AC power oscillations, limiting DC-link voltage oscillations and source current oscillations. In this study, the control techniques reported are five:

- IARC (Instantaneous Active Reactive Control)
- BPSC (Balanced Positive Negative Control)
- PNSC (Positive Negative Sequence Control)
- AARC (Average Active Reactive Control)
- FPNSC (Flexible Positive Negative Sequence Control)

Each of the techniques has its own peculiarities.

A. IARC (Instantaneous Active Reactive Control)

This technique performs constant instantaneous active and reactive power, as shown in Fig.4, improving so the DC-side voltage and source current quality. The flaw is that the grid side currents feature bad THD because of higher harmonic in the grid currents, as show in Fig.3.

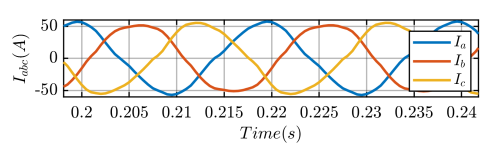

Fig. 3. Grid side currents with IARC technique.

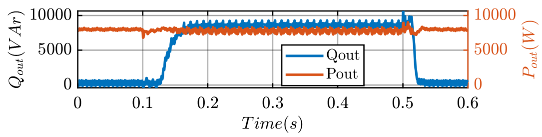

Fig. 4. Active and reactive power with IARC technique.

B. BPSC (Balanced Positive Sequence Control)

The peculiarities of this technique it is that is possible to inject a set of sinusoidal and balanced currents, as shown in Fig.5 and Fig.7, but the output power will feature oscillations at 100Hz, according to the cross effect of positive and negative voltages sequence, as shown in Fig.6.

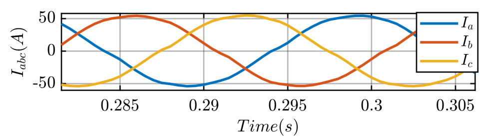

Fig. 5. Grid side currents with BPSC technique.

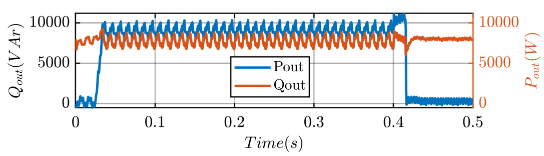

Fig. 6. Active and reactive power with BPSC technique.

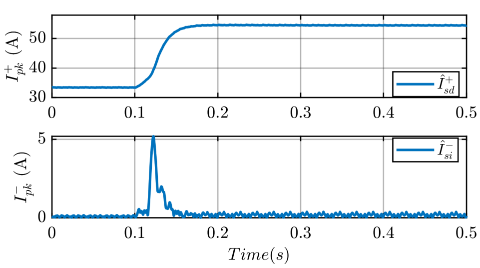

Fig. 7. Positive and negative current sequences with BPSC technique.

C. PNSC (Positive Negative Sequence Control) and AARC (Average Active Reactive Control)

The peculiarities of this technique is that both direct and inverse currents sequence are injected, as shown in Fig.10. PNSC performs constant active power when the reactive power reference is set to zero, as shown in Fig.8. The technique is similar to the AARC with the difference that the power reference must be set to zero for not performing oscillations.

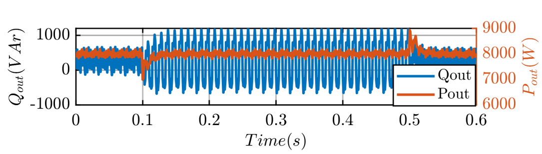

Fig. 8. Active and reactive power with PNSC technique.

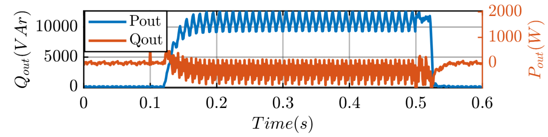

Fig. 9. Active and reactive power with AARC technique.

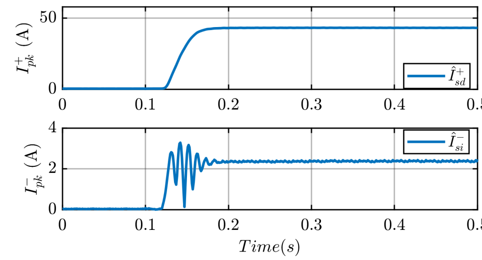

Fig. 10. Positive and negative current sequences with PNSC and AARC technique.

D. FPNSC (Flexible Positive Negative Sequence Control)

This technique is the more flexible. By setting two parameters, k_1 and k_2, it is possible to choose the amount of negative and positive current sequence to inject. So it is possible to obtain the same result of the BPSC if to minimize the ac current THD is the goal or cancelling active power oscillation if the DC-side current and DC-link voltage quality is the goal.

III. Summary and Conclusion

Each of the technique's peculiarities are reported in the table below (Y for yes, N for not). The FPNSC is not reported in the table because its performance change with k_1 and k_2.

	Settings		Current Sequence?		Goal		
	Q	P	+	−	Constant Active Power	Disadvantages	Advantages
IARC	$Q^*>0$	$P^*>0$	Y	N	Y	Harmonics in phase currents	Constant Powers P,Q
BPSC	$Q^*>0$	$P^*>0$	Y	N	N	Power oscillations	Balanced Sinusoidal Currents
PNSC	$Q^*=0$	$P^*>0$	Y	Y	Y	No Reactive injection	Constant Active Power
AARC	$Q^*>0$	$P^*=0$	Y	Y	Y	Null Active Power	No DC-side oscillations

The right techniques to use depends on the goals. Each technique performs advantages and disadvantages. In general, if the goal is to improve DC-side current and voltage DC-link, techniques whose perform constant active power are the best. If the goal is the THD minimization, the best techniques are the ones which inject a set of balanced sinusoidal currents (e.g. BPSC). If the grid codes impose to inject a certain amount of reactive power during a fault, the best technique is the IARC. The personal contributions to this work are summarized as:

- Research and analysis of the control techniques.
- Development of four current limitation algorithms.
- PLECS simulations and validation.
- Preparation of the test bench and experimental validation.