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A Review on Adaptive Active Damper for Improving the Stability of Grid-Connected Inverters

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Abstract: *When a grid-connected inverter is connected to a weak grid, the system may be instable. An adaptive active damper can be connected to the point of common coupling (PCC), which can automatically regulate a virtual resistor to the critical value to stabilize the system. Furthermore, A harmonic current reference compensation technique is used to regulate the simulation of virtual resistor in wide frequency range. This paper showcases the use of the harmonic current reference compensation technique for the stationary* $\alpha-\beta$ *frame, synchronous* $d-q$ *frame and decoupled synchronous* $d-q$ *frame controlled three phase adaptive active damper. With the help of this method the adaptive active damper directly controls the reactive and active power and also improves the stability of the grid connected inverters under weak grid.*

Keywords: *Active damper; grid-connected inverter; active and reactive power control; hybrid frame, pi controller and fuzzy logic controller.*

1. Introduction

As the breach of distributed power generation systems sets out high, the power grid displays more like a weak grid which attributes a large set of grid impedance values. Even though the inverters are designed to be stable during stiff grid, but they often become unstable when connected to the weak grid via point of common coupling. Conventionally, an impedance-based stability criterion is used to evaluate the stability of the system. This makes use of consideration of two points where one is under stiff grid condition, the grid connected inverter is stable and the second being the ratio between grid impedance and output impedance of the inverter satisfies the Nyquist criterion.

In order to improve the stability of the grid either the control parameters must be optimized or the control algorithm of the grid connected inverter must be modified in such a way that the output impedance becomes positive. These methods make the system robust and stable against the variations in the grid impedances but at the same time there is need of change in the internal configuration of the grid connected inverters, power circuit and control algorithms, which are usually modularly designed [1].

In an alternative method, an external damping resistor is connected in parallel at the point of common coupling so as to damp out the resonances between the grid and grid connected inverters. This resistor when updated with power electronic converters so as to eliminate the addition power loss in the system is termed as active damper.

Usually, different types of filtered grid connected inverters are used in conjugation with the active dampers. These filtrations may be of L type, LC type, LCL type etc. where L type is the basic form of filtering used. In order to reduce the active damper's voltage rating, a capacitor is used in series with the filter. It also maintains the fundamental component of the voltage at point of common coupling. The use of LCL filtered grid connected inverter along with active damper showcases better attenuation of the harmonics present in the switching frequency, small construction size and feasible as compared to others [2].

The active damper showcases similar operating principle as that of resistive active power filter, by simulating a virtual

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resistor during harmonic frequencies and thereby controls the output current

$$G_{\mathrm{LPF}}(s) = \frac{1}{s/(2\pi f_{\mathrm{LPF}})+1}$$

harmonic components in such a way that it is proportional to the point of common couplin2g voltage harmonics. Also the active damper acts as a grid connected inverter by injecting currents into the grid. The power rating of the active damper is kept lower as compared to the grid connected inverters in the system so as to achieve a wide control band width and to obtain high switching frequencies.

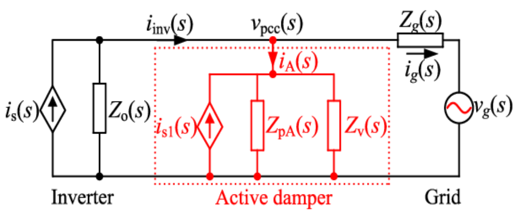

Fig.1 Active Damper System Connection

2. Adaptive Tuning Method of the Virtual Resistor

In practical applications, the information of the grid connected inverter and the grid impedance may be inaccessible, thus the desired damping resistor cannot be directly calculated with . Although the stability of the system can be guaranteed by synthesizing an extremely small resistor, it will lead to a large current flow in the active damper and increase the power loss. Note that when a system is destabilized, the resonance between the grid-connected inverter and the grid will dramatically amplify the harmonic components in the PCC voltage. Therefore, it is possible to adaptively regulate the virtual resistor Rv according to the harmonic content of the PCC voltage. If the harmonic content is within an acceptable range, it indicates that the system is stable and Rv could be increased, whereas if the harmonic content rapidly increases, it indicates that the present Rv is not small enough to stabilize the system, and Rv should be decreased until the system become stable again. The implementation of the adaptive tuning method is shown in the dashed block in Fig. 2. By squaring vpcch and sending the result to a low-pass filter GLPF(s) to eliminate the ripples, its mean-square value 2 Vpcch can be obtained, where Vpcch is the RMS value of vpcch.
GLPF(s) can simply be a first order low-pass filter, expressed as where fLPF is the corner frequency of the filter. To achieve a balance between the ripple suppression and the dynamic response, fLPF can be set at the fundamental frequency. Then, 2 Vpcch is compared with a preset harmonic limitation 2 Vlim , and the error signal is sent to the resistor regulator GRA(s), which can be implemented with a proportional integral (PI) compensator, expressed as
where KpR and KiR are the proportional and integral coefficients, respectively. The output of GRA(s) is taken as the reciprocal of the virtual resistor, i.e., 1/Rv. A saturation block is added to the output of GRA(s) to ensure 1/Rv to be nonnegative, and avoid a too large 1/Rv causing the harmonic port current to exceed the capacity of the active damper. With the adaptive tuning method above, if the grid connection system is stable, 1/Rv will be fixed to zero since Vpcch is always lower than Vlim, which means the virtual resistor is not needed. Once the system becomes unstable, 1/Rv will automatically increase to damp out the resonance. Because the PI compensator can guarantee zero static error, the system will be kept in a critically stable statewhere Vpcch = Vlim, and correspondingly, 1/Rv will be regulated to the critical value to stabilize the system. If 1/Rv is regulated smaller, it will be insufficient to stabilize the system; if 1/Rv is regulated larger, although the resonance can be better damped, the port current of the active damper could still be increased due to the remaining harmonic components in the PCC voltage. Thus, it is reasonable to consider that an optimized value of 1/Rv is obtained with the adaptive tuning method. Also note that the PM of the system is close to zero at steady state, but during a dynamic process such as step changes in the inverter current reference or the grid voltage, 1/Rv will adaptively increase as transient oscillation appears in the PCC voltage. As a result, the PM of the system will be temporarily increased, making the oscillation converge in a short time. Therefore, the system will still have good dynamic performance. Since the virtual resistor is tuned according to the harmonic content of the PCC voltage, its dynamic response is related to the configuration of the entire grid-connection system, including the grid-connected inverter and the grid impedance. However, the active damper is intended to serve as a standard stabilizer which can apply to various situations, so it is not reasonable to design the adaptive tuning control parameters based on the modeling of a specific system. Instead, this paper gives some general design guidelines which are listed as follows. 1) Harmonic limitation Vlim: By adaptively tuning the virtual resistor, the active damper can effectively damp the resonance caused by system instability, but it is difficult to further suppress the harmonic components in the PCC voltage introduced by the grid background harmonics.

2) Proportional coefficient KpR: When the system becomes unstable, 1/Rv, the output of the resistor regulator GRA(s), is supposed to rise to a sufficiently large value in a short time to damp the harmonic resonance, and the fast dynamic response is mainly contributed by the proportional term of GRA(s). Thus, the proportional coefficient KpR can be designed as

$$K_{pR} = \frac{1/R_{v\_p}}{V_{pcch\_p}^{2} - V_{lim}^{2}}$$

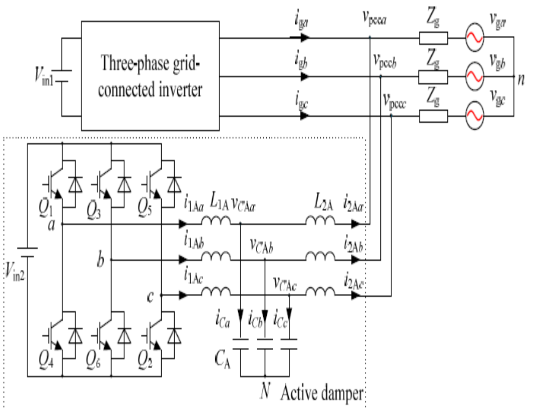

Fig. 2 Circuit Diagram of Three phase grid connected inverter with adaptive active damper

3. Methodology

This dissertation mainly deals with the adaptive active damping which is a process of adding an external resistor in parallel at the point of common contact so as to damp out the resonance between the grid and the grid connected inverters. In modern electronics this resistor is been replaced with power electronic converters and is termed as active damper and the process is termed as active damping. Figure 2 shows the proposed model of the dissertation that shows the inclusion of active damper in a grid connected inverter under weak grid. Here the active damper is implemented with the help of an LCL filtered grid connected inverter. The working of adaptive active damper is similar to that of resistive active power filter that simulates a virtual resistor with harmonic frequencies in such a way that the output current harmonic components are proportional to point of common contact harmonic voltage. There are various operational principle used by the active damper that is discussed below briefly:

3.1 Active damper under hybrid frame

The hybrid frame uses the combination of the harmonic current reference and filter capacitor current feedback from the stationary α-β frame and the direct control of active and reactive power of the synchronous d-q frame.
In short, the adaptive active damper automatically simulates a virtual resistor so as to damp the resonance at the point of common coupling and improves stability of gird connected inverters under weak grid. Also, it can also be taken as a LCL type grid connected inverter that injects current into the grid.

3.2. Fuzzy Logic Controller

Fuzzy Logic Controller: In order to implement control algorithm of a shunt active filter the DC side capacitor voltage must be sensed and compared with reference value. The error and change in error are two inputs for fuzzy processing. In fuzzy controller the control action is determined by sets of linguistic rules. The advantage is it does not require mathematical model and works with imprecise inputs.

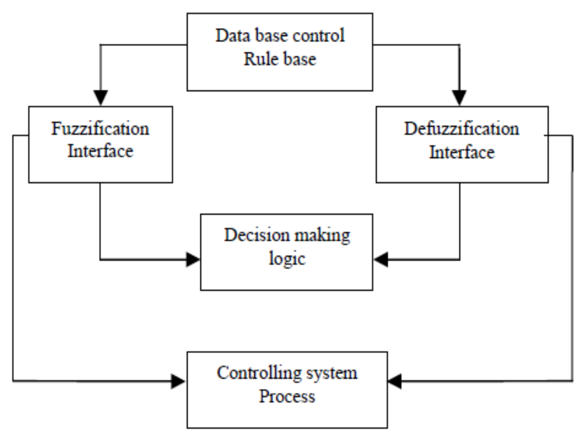

Fig.3 Fuzzy Inference System

3.3 Design of Control Rules

The fuzzy control rule design involves defining the rules that relate the input variables to the output model properties. Since fuzzy logic controller is independent of system model, the design is majorly based on the intuitive feeling and experience of the process. The rules are expressed in English like language with syntax such as If {error *e* is A and change of error *Δe* is B} then {control output is C}. For better control performance finer fuzzy petitioned subspaces (NL, NM, NS, ZE, PS, PM, PB) are used.

3.4 Advantages of Fuzzy Control

The advantages of fuzzy control over the adaptive control can be summed as follows:

- It relates output to input, without much understanding all the variables, permitting the design of system to be more accurate and stable than the conventional control system.
- the linguistic, not numerical; variables make the process similar to that of human thinking processThe fuzzy controller uses two input membership variables; error E and change in error dE. The fuzzy function has only one output. The function considered is 'mamdani' function with seven membership functions in each variable.

4. Conclusion

In order to ensure the stability of a grid-connection system under weak grid, an active damper can be connected to the PCC, which emulates a resistor to damp the resonance between the grid-connected inverter and the grid. An adaptive tuning method of the virtual resistor based on the detection of the PCC voltage is proposed, which does not rely on the information of the grid-connected inverter or the grid. Besides, the equivalent circuit of the active damper is derived, showing that its total port impedance is composed of the original port impedance and the virtual impedance. when the grid system is connected with different controller based active damper circuits, the harmonics will be less in case of FIS controller as compared to PI controller.

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