SOLAR PHOTOVOLTAIC (PV) BASED SERIES LC FILTER GRID TIED SYSTEM TO SUPPRESS HARMONICS-A MATLAB APPROACH

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ABSTRACT- A series-LC-filter active damper is proposed to reduce the harmonics in the system. The series LC-filter has active damper which helps in suppressing the low order harmonics (3rd, 5th, 7th etc.) and also demonstrates in increasing the stability of the system. The filter has an extra capacitor connected in series for withstanding most of the system voltage. The damping converter is realized with a low voltage and a smaller filter inductor, for simulation. The proposed damper is similar to the series-LC-Active Power Filter. However, their control requirements and challenges encountered are different with the active damper concentrating on the higher-frequency resonances damping, rather than the low-frequency harmonics compensation targeted by the APF. On the other hand, the capacitive filter characteristic in the low-frequency range challenges the stability of grid current controller for the damper. A fourth-order resonant controller is also used to minimize switching losses. For realizing this, renewable energy source (solar energy) is considered, which hitherto, was done by conventional energy sources, on Mat lab platform. Stability of the proposed active damper has been analyzed over a wide frequency range with appropriate controllers recommended for each requirement for grid disturbance rejection. The results were compared analytically and were observed to be higher than simulated result which may be due to the selection of the parameters values.

Index Terms- Active damper, PV module, resonances, stabilization, series LC-filter, converters, disturbance rejection.

I. INTRODUCTION

Distributed power generation systems based on renewable energy sources are attracting the market and research interest as a feasible choice in a sustainable development environment. In this context, grid-connected photovoltaic (PV) plants are becoming a common technology to generate energy and its penetration level is gradually increasing. These plants consist of sets of PV generators and power electronic inverters connected in parallel to the distribution network through a distribution transformer.

The inverters installed in PV plants are generally voltage source converters with an output filter. LCL filters are preferred to L filters because their switching harmonic attenuation with smaller reactive elements is more effective. Thus, the cost and the weight of the inverters are reduced. However, due to the need to damp the resonances, the filter and the current control design are more complex. Active damping is preferred to passive damping in order to improve the efficiency of the conversion. Either the inverter side current, or the grid side current, of the LCL filter can be controlled. Each alternative has its own advantages and drawbacks. Depending on the controlled current, specific active damping techniques have been proposed. Exceeding the harmonic injection limits may require the inverters to disconnect from the grid. Thus, the LCL filters are implemented to prevent the grid from being polluted with switching harmonics, whereas plenty of control algorithms, including repetitive controllers, integrators in multiple rotating frames, and resonant integrator , have been proposed in order to mitigate the low-order current harmonics.
In this paper, PI controllers are considered, and the damping technique based on a lead-lag element applied to the feedback of the capacitor voltage proposed in is chosen, but the same methodology can also be applied to other control algorithms or active damping techniques leading to the same equivalent inverter model.

First, a digital control emulator that maintains the s-domain analysis with good reliability is presented. Second, the modeling and control of a single grid-connected inverter are described. Third, the modeling and control of the N-paralleled grid-connected inverters of a PV plant are analyzed. Fourth, the theoretical study is validated through simulation. Fifth, experimental waveforms of inverters with resonant behavior in a PV plant of are shown. In addition, these experimental waveforms are reproduced in simulations making use of the equivalent inverter. Next, some control design guidelines and practical uses are suggested. Finally, conclusion is discussed.

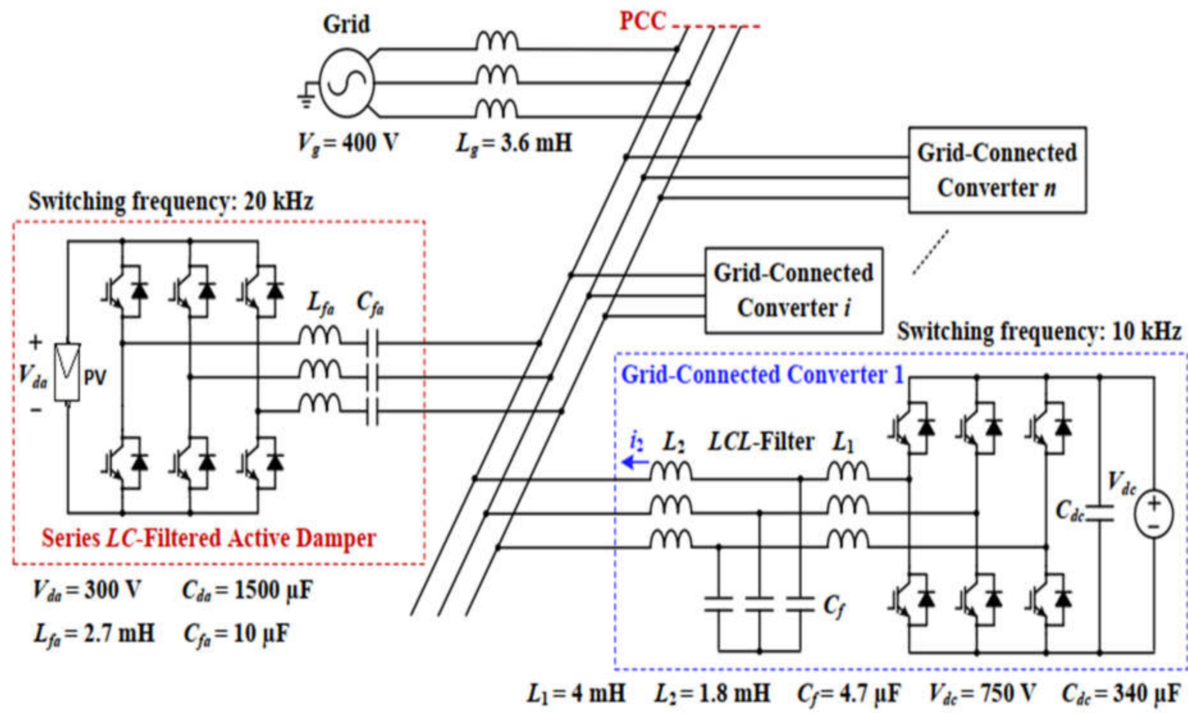


Fig.1. An Example Power System Showing the Series-LC-Filtered Active Damper and Multiple Paralleled LCL-Filtered Grid Converters.

II. OPERATIONAL PRINCIPLE

Fig. 1 demonstrates a precedent power system with the proposed series-LC-damper added to the PCC, together with other LCL filtered grid converters. Like in for a series-LC-APF, the additional filter capacitor C_{fa} is utilized for withstanding the majority of the PCC voltage, permitting a lower evaluated converter and a littler filter inductor L_{fa} to be utilized, thus. In any case, as an APF, the topology is mainly intended for alleviating prevailing low frequency harmonics, whose bandwidth and other control requests are along these lines less stringent. The LC-filter reverberation frequency of the APF is additionally generally tuned near the low frequency harmonics, which is unique in relation to an active damper. Filter reverberation frequency framed by C_{fa} and L_{fa} of the active damper ought to in certainty be marginally lower than the small system reverberation frequency[1]. A quick trade off will at that point be the harder dismissal of the normal fifth and seventh grid voltage harmonics. The transcendently capacitive filter trademark at those frequencies challenges the utilization of common harmonic current controllers. It is in this way nontrivial to plan the damper control conspire, whose general portrayal is given in Fig. 2 for acknowledging three capabilities to be depicted straightaway.

A.DC-LINK VOLTAGE REGULATION

DC-link voltage regulation of the damper includes both the DC Voltage Control and AC Current Control blocks appeared in Fig. 2. Their motivation is to keep voltage Vda over the dc-link capacitor C_{da} constant. Nitty gritty diagram of the DC Voltage Control is given in Fig. 3(a), where a relative fundamental (PI) controller has been incorporated for authorizing zero dc voltage mistakes in the steady state. The PI controller output is an active current direction i_{Lq}* that the damper draws for repaying losses. Reactive current order i_{Ld}* is incorporated as well, yet is set to zero[1] Filter reverberation identifies with C_{fa} and L_{fa} of the active damper just, while system reverberation since the damping converter is commonly not ready to create a sizable reactive power.

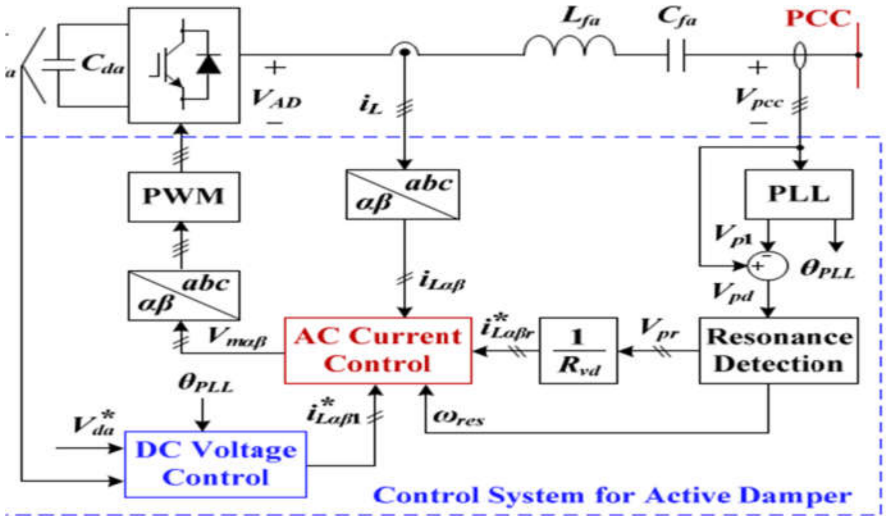
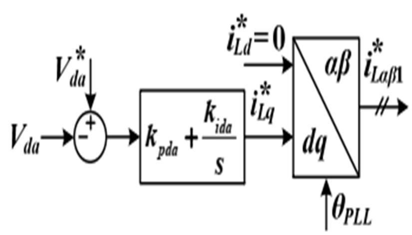
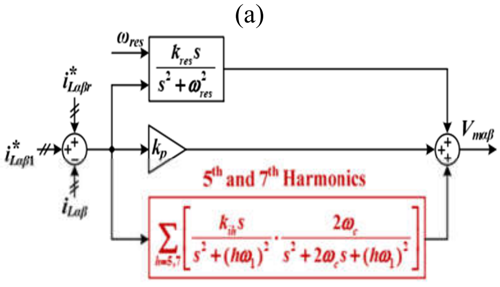


Fig.2. Overall Control of the Active Damper.

Reactive power generation is rather ruled by filter capacitor C_{fa}, whose voltage is higher while conveying a similar series current. The active and reactive current directions can next be conveyed to the stationary αβ outline by playing out the vital "dq-to-αβ" change. A Phase-Locked-Loop (PLL) is required, as appeared in Fig. 2, for creating the phase point PLL synchronized to the PCC voltage. Current through it and the damping converter in series will thus be around symmetrical to the PCC voltage. As such, if the PCC voltage is adjusted along the d-pivot in the synchronous casing, the damper active current order must be adjusted along the symmetrical q-hub. This is the reason the active and reactive current directions in Fig. 3(a) have been recorded with subscripts q and d, separately, rather than the turn around.



(a)



(b)

Fig.3. Illustration of the (a) DC Voltage Control and (b) AC Current Control blocks of the active damper.

This related concern can be disclosed by alluding to Fig. 4 (a), where the presumption made for performing "dq-to-αβ" change has been delineated pictorially. It plainly demonstrates that with the voltage crosswise over capacitor C_{fa} accepted in phase with the PCC voltage, the subsequent total of voltages crosswise over C_{fa}, L_{fa} and the damping converter does not prompt the PCC voltage. It is consequently not feasible practically speaking, but rather only an estimation made for disentangling investigation. The almost certain phasor diagram is appeared in Fig. 4(b), where it tends to be seen that the genuine active current flowing through the series filter and damping converter can't be actually along the q-pivot. It is in this way unrealistic for the real active current to follow its order prior put along the q-pivot. Basic routine with regards to including a controller for authorizing zero steady-state current tracking blunder should along these lines not be connected to abstain from destabilizing the system. Consequently, just a relative gain kp is utilized with the air conditioner current controller for the dc-link voltage regulation, as appeared in Fig. 3 (b). Other than the relative current controller, the AC Current Control block additionally contains a second-arrange resounding controller for system adjustment and a fourth-arrange thunderous controller proposed for grid aggravation dismissal. They are clarified in the accompanying.

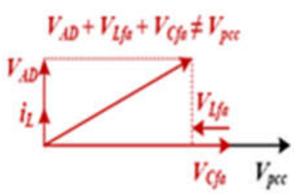
B.RESONANCE DETECTION AND DAMPING

This second function of the active damper is acknowledged by the Resonance Detection and AC Current Control blocks appeared in Fig. 5 and Fig. 3(b). A Frequency-Locked Loop (FLL) based on a Pre-filtered Adaptive Notch Filter (P-ANF) is utilized to distinguish the reverberation component from the PCC voltage. The essential principle basic this location conspire is the Least Mean Square (LMS) adjustment calculation. Uniquely in contrast to the Second-Order Generalized Integrator (SOGI)-based FLL utilized for grid synchronization, the GI with a 6th request Taylor series guess is connected to the ANF for an increasingly exact estimation of the high-frequency reverberation component.

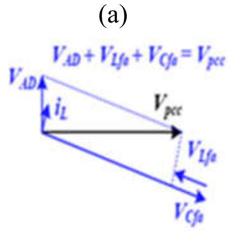
To additionally evacuate the low-frequency unsettling influences, two ANFs are cascaded to shape a pre-filtered structure. The reverberation component of the PCC voltage is then partitioned by a picked virtual opposition R_{vd} for the damping reason, as appeared in Fig. 2. Along these lines, the active damper carries on like an opposition, which adaptively reshapes the grid impedance at the reverberation frequency so as to balance out the system.

C.GRID DISTURBANCE REJECTION

Usually for the grid voltage to be exasperates by the fifth and seventh harmonics, found lower than most system resonances. Dismissal of these grid voltage harmonics isn't trifling for the proposed active damper, inferable from its prevalently capacitive filter trademark at those frequencies. Common synchronous indispensable and stationary thunderous controllers will thusly not work. Rather, a fourth-arrange thunderous controller is proposed and appeared in Fig. 3(b), where ω_1 is the fundamental frequency, ω_c is the cutoff frequency, and k_{ih} is the controller gain. The motivation behind this controller is to re-shape the overwhelmingly capacitive "control plant", which in the most pessimistic scenario, can be spoken to by a proportionate capacitance C_{eq}. For showing the expected re-forming, the forward transfer function of grid unsettling influence dismissal way is composed as:



(a)



(b)

Fig.4. (a) Assumed and (b) actual phasor orientations of the active damper.

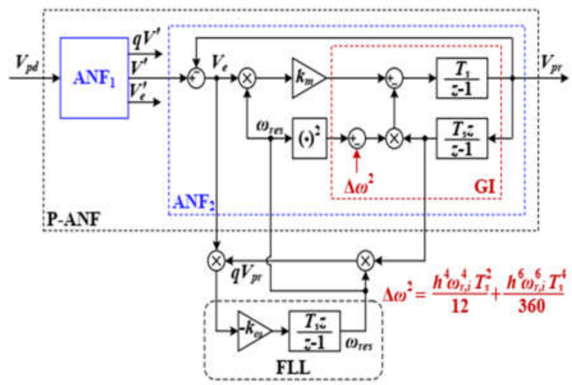


Fig.5. Block diagram of Resonance Detection of the active damper.

$$G_R(s).G_{re-p}(s) =$$

$$\sum_{k=5,7}\left\{\frac{k_{ih}s}{s^2+(hw_1)^2}\cdot\frac{2\omega_c}{s^2+2\omega_c s+(h\omega_1)^2}C_{eq}\right\}\mathrm{s}.C_{eq}$$

$$=\sum_{h=5,7}\left\{\left[\frac{k_{ih}s}{s^2+(h\omega_1)^2}\right]\cdot\left[\frac{2\omega_c s}{s^2+2\omega_c s+(h\omega_1)^2}C_{eq}\right]\right\}(1)$$

Where GR(s) is the typical resounding controllers put at the fifth and seventh harmonic frequencies, and $G_{re\text{-}P(S)}$ is the re-molded "plant". The re-formed "plant" turns into a band-pass filter with a typical gain of C_{eq} set at the fifth and seventh harmonic frequencies. As such, the re-formed plant acts like a resistor at those thought about frequencies, henceforth permitting $G_{R(s)}$ to play out the important control without being troubled by strength and dynamic concerns.

III. SIMULATION RESULTS

For confirmation, the three-phase exploratory system appeared in Fig. 1 has been assembled, yet with just a single LCL-filtered grid converter. Table I records the controller parameters utilized for the active damper. The control plan of the grid converter and current controller parameters are appeared in Fig. 6. Security of Fig. 6, with its grid current i2 managed by a Proportional Resonant (PR) controller in the stationary αβ-outline, is anyway extraordinarily impacted by time defers acquired from its computerized execution and variety of the grid impedance. Fig. 7 demonstrates the deliberate grid current i2 of the LCL-filtered grid converter without and with the active damper.

The grid inductance is exchanged between 3.6 mH and 7.2 mH, which results in two distinctive reverberation frequencies at 1.3 kHz (26th harmonic) and 1.25 kHz (25th harmonic), individually, as appeared in Fig. 7 (an) and (b). Fig. 7 (c) demonstrates the deliberate outcome in the wake of empowering the active damper, where obviously the system is balanced out by the active damper in the two cases. Fig. 8 next demonstrates the deliberate dc-link voltage and output current of the active damper. At the moment of empowering the active damper, the dc-link voltage quickly tumbles from its pre-charged esteem (through enemy of parallel diodes of the damping converter) to the controlled estimation of 300 V.

Contrasted and the dc voltage of 750 V required by the grid converter, dc-link voltage of the damper is unmistakably diminished by the additional series filter capacitor. This decrease can additionally be expanded by utilizing higher appraised filter capacitor relying upon prerequisites. Fig. 9 demonstrates the air conditioner current flowing through the damper without and with utilizing the grid unsettling influence dismissal control depicted in Subsection II (C). Without the grid unsettling influence control, the nearness of seventh grid voltage harmonic impacts the damper control, bringing about seventh harmonic current seen from Fig. 9 (a). This harmonic current is immediately expelled in Fig. 9 (b) by the fourth-arrange full controller created in this letter.

TABLE I Controller Parameters of Active Damper

Symbol	Meaning	Value
T_{s_AD}	Sampling period of active damper	50 μs
k_{pda}	Proportional gain of dc-link voltage controller	0.5
k_{ida}	Integral gain of dc-link voltage controller	0.01
R_{vd}	Virtual damping resistance	0.2 Ω
k_p	Proportional current controller	15
k_{rez}	Resonance damping controller	600
k_{ih}	Proposed resonant controller gain	$4*10^5$
ω_c	Proposed resonant controller cut-off frequency	250 rad/s

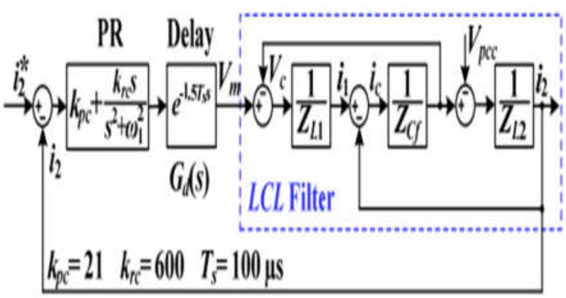


Fig.6. Grid current control loop for the LCL-filtered grid converter.

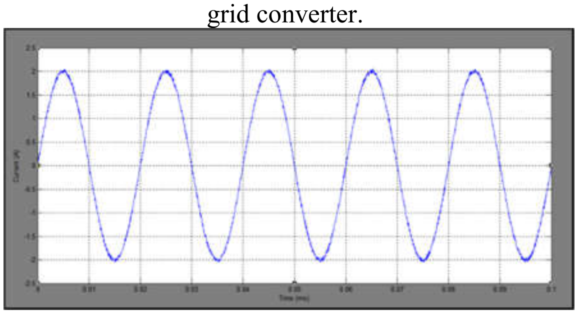


Fig.7. Measured grid current i_2 of the LCL-filtered grid converter and its harmonic spectrum with active damper.

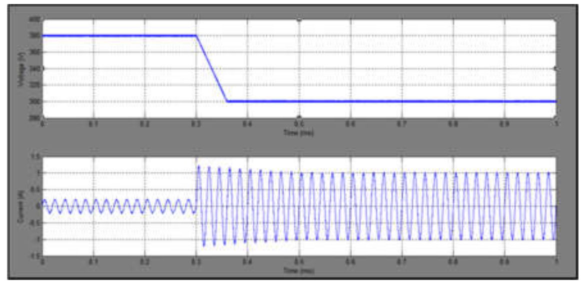
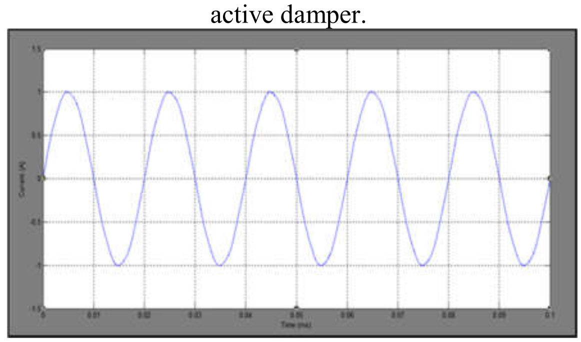
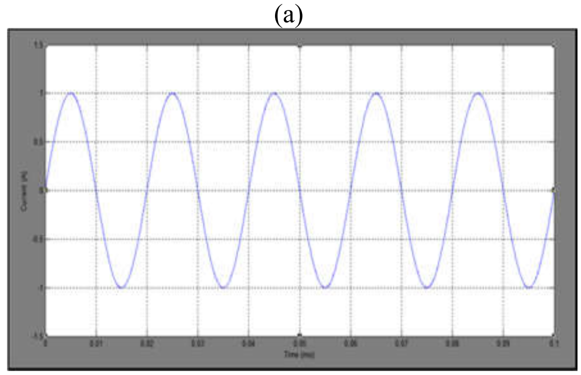


Fig.8. Measured dc-link voltage and ac current of the active damper.



(a)



(b)

Fig.9. Measured output current of the active damper and its spectrum. (a) Without grid disturbance rejection. (b) With grid disturbance rejection.

IV. CONCLUSIONS

A Solar (PV) based series-LC-filtered active damper for stabilizing AC power-electronics-based power systems to suppress the harmonics in system. The effectiveness of an Active power filter had been demonstrated by simulating on MATLAB platform. The Performance of the damper has been verified in experiment with the series filtered capacitor demonstrated to withstand most of the system voltage. The damping converter can then be rated low in voltage, allowing for a faster switching operation. Stability of the proposed active damper has been analyzed over a wide frequency range with appropriate controllers recommended for each requirement for grid disturbance rejection. The above results were compared analytically and were observed to be higher than simulated result which may be due to the selection of the parameters values.

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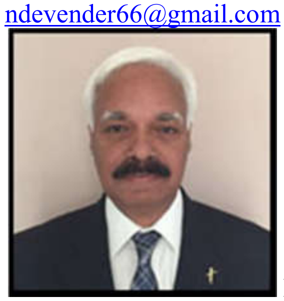

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