CONTROL OF GRID CONVERTERS IN MICROGRID USING SERIES AC CAPACITOR

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ABSTRACT

This paper presents control of grid connected inverter using current controller with the transformerless grid-connected converters in the distribution generation of power grids. The capacitive characteristic of the resulting series LC filter restricts the use of conventional synchronous integral or stationary resonant current controllers. Thus this paper proposes a simplified resonant controller in the stationary frame, which guarantees a zero steady-state current tracking error for the grid converters with series LC filter. This method is then implemented in a three-phase experimental system for verification, where the current harmonics below the LC filter resonance frequency are effectively eliminated. The proposed is designed by using MATLAB software for analysis.

Keyword: - *Grid converter, Micro grid, SPWM, SVPWM, LC-filters*

1. INTRODUCTION

Recently the Power electronic converters have increasingly been applied for grid integration of renewable power sources [1], energy efficiency improvement of electric power loads [2], and power quality enhancement in distribution power systems [3]. A low frequency transformer with the step-down or step-up functions is usually needed for these grid-connected converters, which increases the system volume and weight. The transformerless ac/dc power converter with a series-connected ac capacitor has recently been reported in hybrid active filters and dampers [4]-[7] and in distributed generation systems [8]-[10]. Fig. 1 shows the general circuit diagrams of three-phase grid connected voltage- source converters with a series connected ac capacitor *Cg*. This coupling capacitor can also be used together with the high-order *LC*/*LCL* filters in the voltage source converters.

The series coupling capacitor is used to withstand most of the grid voltage, and thus reduces the voltage stresses of power components and the rated power of the converter [4]. Therefore it provides an alternative configuration for the transformerless grid-connected converters. However, this series capacitor also brings a number of challenges. First, the capability of power transfer, especially the output active power, is more sensitive to the size of capacitor than the normal grid converters with the coupling inductor [8].

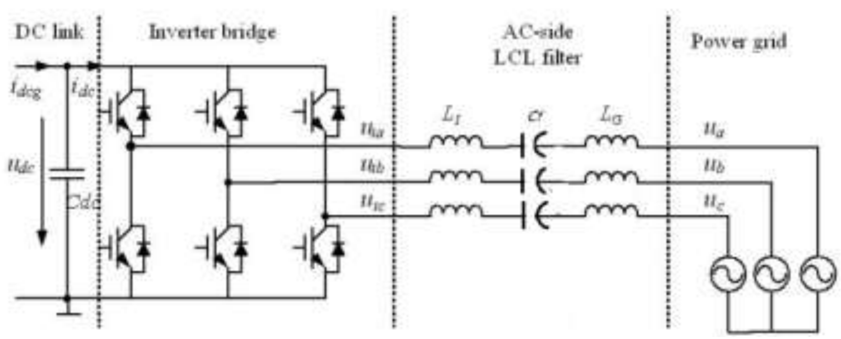

Fig-1: Grid converters coupled with a series ac capacitor *Cg* voltage source converter.

Second, there is a coupling between the dc-link voltage regulation and reactive power control, which affects the power controllability of the converter [10]. Third, the capacitive filter characteristic at those frequencies lowers than the series *LC* resonance frequency challenges the use of usual synchronous integral and stationary resonant controllers.

Those controllers are generally developed for the inductive filter "plant". It is shown that the direct use of conventional harmonic resonant controllers for the rejection of (5th and 7th) harmonic disturbances may destabilize the system.

To address these challenges, several research works have been reported. A quantitative analysis on the size of capacitor, dc-link voltage, and the transferred active power is given in [8]. Also, to mitigate the coupling between the dc-link voltage and reactive power control, the voltage in the middle of the series *LC* filter is controlled to operate the *L*-filtered converter as a voltage source. However, only a proportional current controller is employed to avoid the instability caused by the capacitive filter "plant". The resulting steady-state current tracking error has a little effect at the grid fundamental frequency, due to the use of Proportional-Integral (PI) controller for the outer dc-link and reactive power control. Yet the harmonic disturbance from the grid voltage, which may be lower than the filter resonance frequency, distorts the grid current injected by the converter. In [9], a hysteresis current control scheme is employed, where an adaptive dc-link voltage control method is developed for the hybrid active filter to provide the dynamic reactive power compensation. The wide spectrum of current harmonics is however brought by the hysteresis modulation.

This paper proposes a current control method for grid converters coupled with a series capacitor. A fourth-order resonant controller in the stationary frame is introduced for the zero steady-state current tracking error with the capacitive filter "plant". Thus, besides the control of the fundamental frequency current, the low-order harmonic currents, which may be caused by the grid harmonic voltages, the core saturation of the filter inductor, and the dead-time of the converter, can be eliminated effectively. It thus enables hybrid active filters to selectively reject or absorb harmonic currents at both the low- and high frequencies.

The effectiveness of the approach has analyzed using MATLAB design software system comprising a three-phase grid-connected voltage-source converter coupled with a series capacitor is developed. The simulation results demonstrate the performance of harmonic current compensation of the proposed controller interms of output voltage, current, THD.

2. PROPOSED SYTEM MODELLING

The operation principle of a voltage-source converter coupled with a series capacitor to the power grid is presented here. The synthesis of the proposed current control scheme for a capacitive filter "plant" is illustrated as follows.

Fig. 2 shows the overall control diagram for a three-phase grid-connected voltage-source converter with an *LC* filter and a coupling capacitor at the Point of Connection (PoC). The PoC voltage *Vpoc* is measured for the grid synchronization by using a Phase-Locked Loop (PLL) in the synchronous reference frame [1]. The grid current that flows through the coupling capacitor is controlled in the stationary $\alpha\beta$-frame. Table I lists the main electrical parameters of the system. Fig. 3 depicts the frequency response of the filter "plant" of the grid current control loop, which can be obtained based on the transfer function of the converter voltage to grid current where it clearly shows that the "plant" has a phase shift of 90° below the resonance frequency of the filter, which indicates a capacitive characteristic at the fundamental frequency and the low-order (5th and 7th) harmonic frequencies. To avoid the influence of the coupling between the dc-link voltage and reactive power compensation, the following two operating scenarios are considered in this work:

2.1 Controlled dc-link voltage with reactive current

The dc-link voltage is controlled by a PI controller, whose output is used as the reactive current command i^*_{gq}. The active current command i^*_{gp} is set to zero. In this case, the grid current cannot be controlled with Zero steady-state error at the fundamental frequency, which will be discussed next. Hence, the proposed current controller is only applied to compensate the low-order be controlled with zero steady-state error at the fundamental frequency, which will be discussed next. Hence, the proposed current controller is only applied to compensate the low-order harmonics.

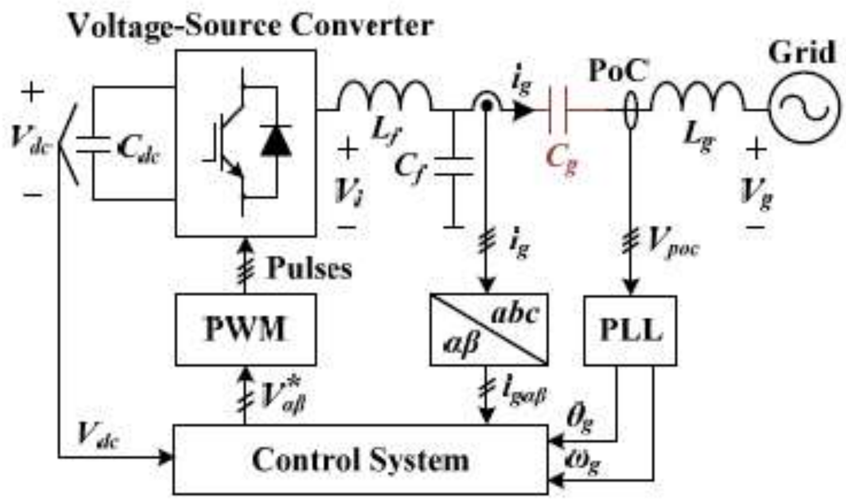

Fig-2: The proposed system architecture with series AC Capacitor

2.2 Constant dc-link voltage

The dc-link voltage is in this case kept as constant by an external dc power source. Hence, the reactive current commands i^*_{gq} is merely used for dynamic reactive power compensation. The fundamental frequency grid current can then be controlled with zero steady-state error. Fig. 3 illustrates the block diagram of the Control System in Fig. 2, including the controllers for the dc-link voltage and reactive power, as well as the proposed fourth-order resonant current controller at the fundamental and low-order harmonics frequencies. These controllers are explained in the following.

2.3 Control of DC-Link Voltage and Reactive Power

Unlike the normal grid-connected converters coupled with the inductor, the dc-link voltage control here is realized by the closed-loop output admittance $Y_{oc}(s)$ reactive current aligned to the orthogonal q-axis, rather than the active current along with the d-axis which the PoC voltage is aligned to. This is because the coupling capacitor is supposed to withstand most of the grid voltage, and the reactive current thus dominates the current injected into the grid [5]-[7]. However, it is important to note that the active current still exists to keep the dc-link voltage constant. Thus, even though the active current command is set to zero, there is still an active component in the actual grid current. Hence, the current control schemes with zero steady-state tracking error cannot be used at the fundamental frequency.

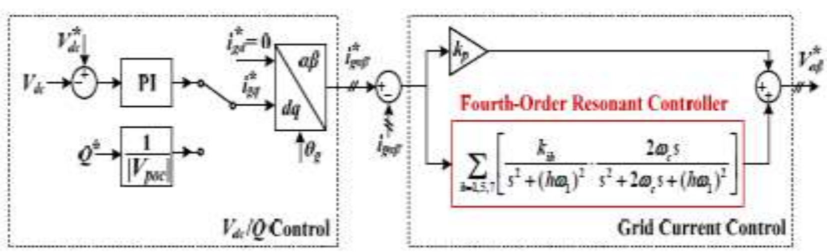

Fig-3: Control System block of the grid-connected converter

3. RESULTS AND ANALYSIS

The figures from 4 to 10 showing the simulation of the proposed system using MATLAB design software. The proposed system is operated for different operating conditions. The main focus is here made on the active and reactive power management by the proposed current loop controller when using SPWM and SVPWM converter fed to grid.

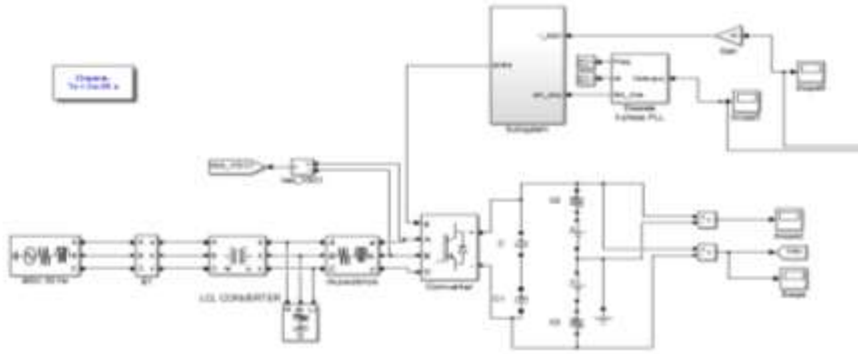

Fig-4: Simulation of proposed circuit using MATLAB

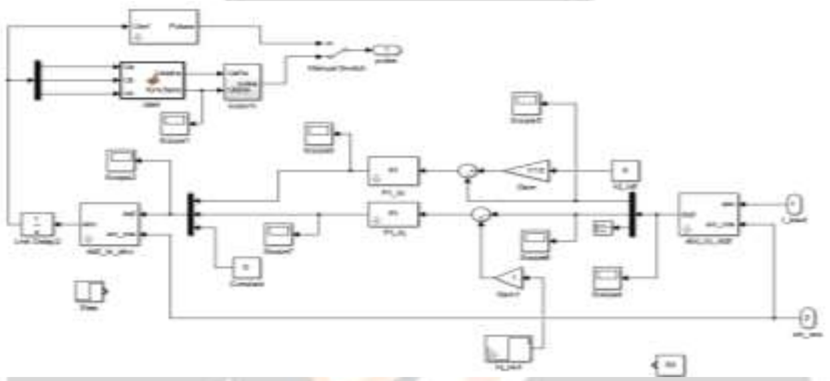

Fig-5: Design of proposed controller using MATLAB

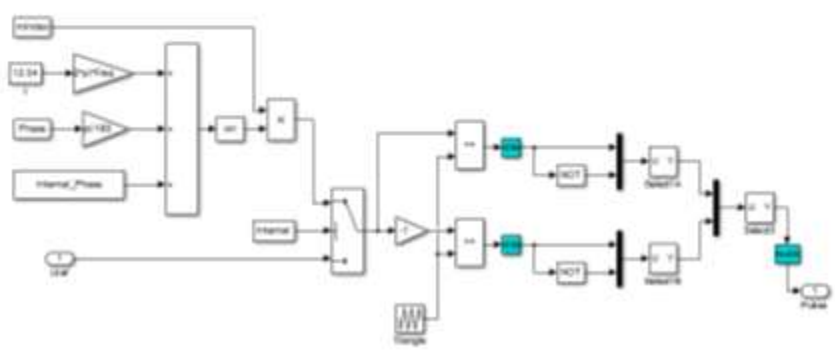

Fig-6: SPWM technique applied to proposed topology

The space vector modulation technique is more efficient pwm technique over all other pwm techniques interms of THD

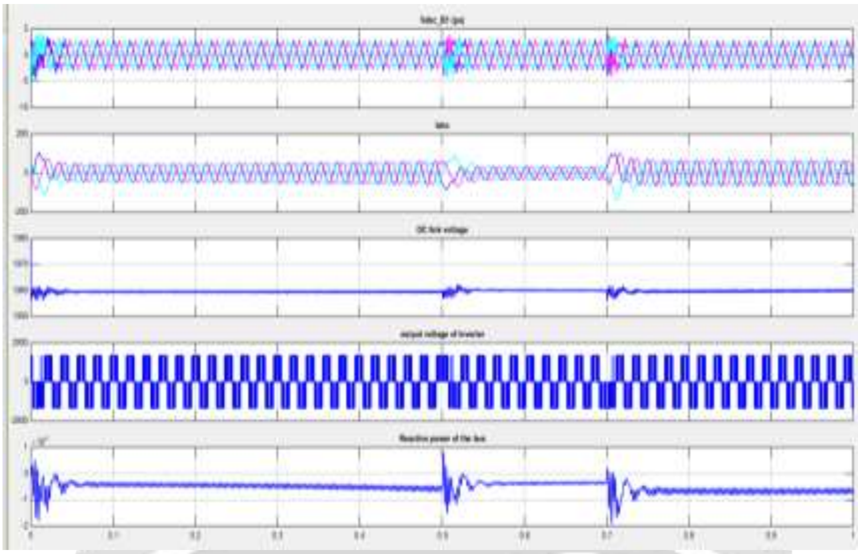

Fig-7: Overall outputs of the circuit for SPWM technique.

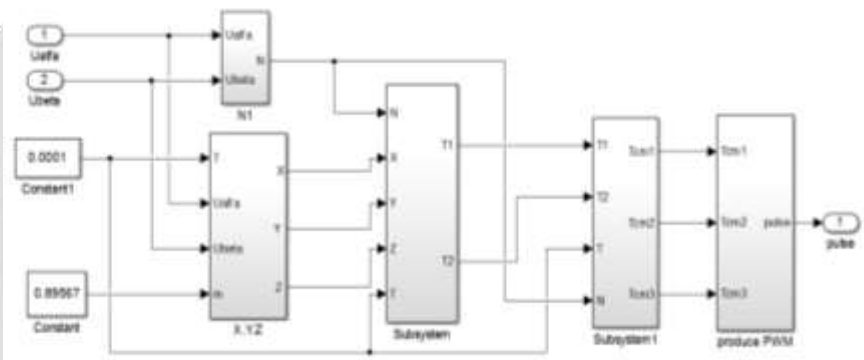

Fig-8: The proposed controller with SVPWM technique

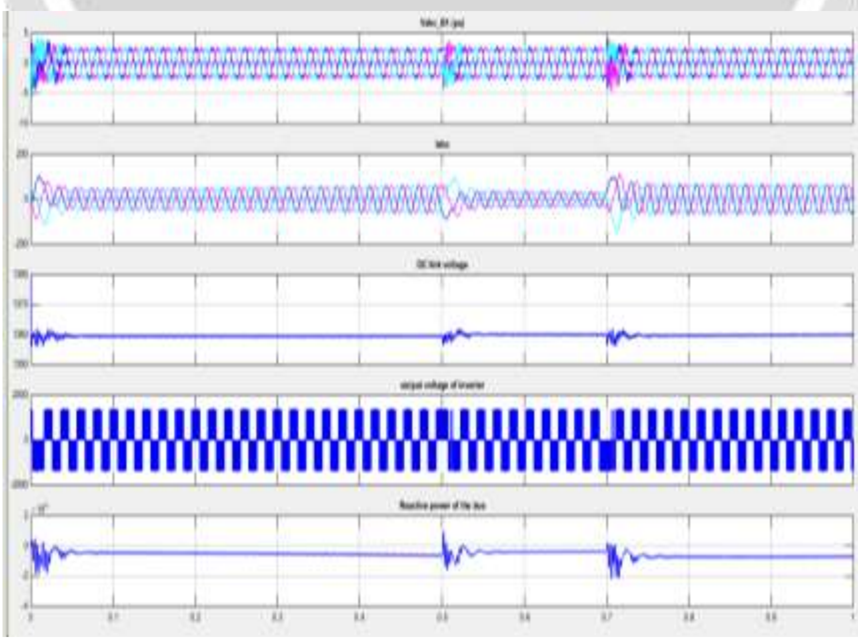

Fig-9: Overall outputs when using SVPWM to proposed controller

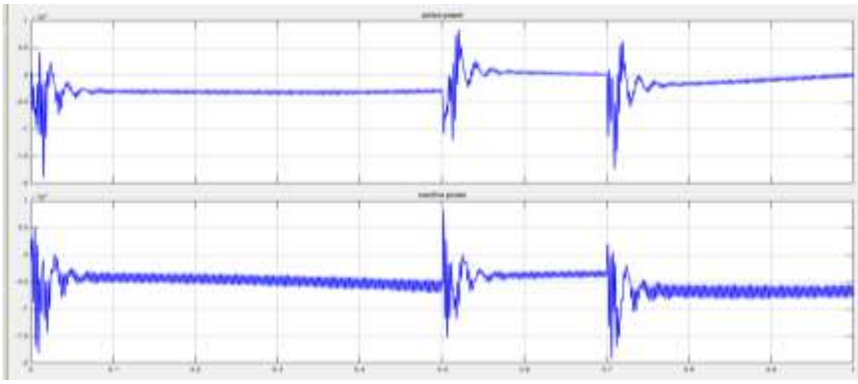

Fig-10: The Active and Reactive powers of the proposed circuit during dynamic operation

4. CONCLUSIONS

This paper has presented a new current controller for grid converters coupled with series ac capacitor. Simulations results have shown that the conventional resonant controllers cannot be applied for a capacitive “control plant”. It is then necessary to re-shape the derivative filter by using the second-order transfer function, which together with the usual resonant controller, forms the proposed fourth-order resonant controller. It has been demonstrated that the proposed controller is important for the compensation of the low-order harmonics, which are below the resonance frequency of the output filter and the coupling capacitor. Simulation results obtained from a three-phase voltage-source converter using MATLAB software for the effectiveness of the proposed control scheme.

5. REFERENCES

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