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AN ENERGY SHAPING CONTROL FOR CIRCULATING CURRENT REDUCTION OF A GRID-CONNECTED PARALLEL INTERLEAVED CONVERTER

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ABSTRACT

This paper proposes a method to regulate low frequency, parallelly interleaved, rotating currents. The inverters are paralleled with the magnetally connected inductors in this configuration. In general, the carrier interleaving is used to boost the harmonic value of the output stress. As a consequence of the two voltage source converters (VSCs) an increased circulating current (differential mode stream) flows. The reciprocal inductance of Coupled Inductors (CI) effectively reduces the high frequency components of circulating currents. However, the low frequency components can not be filtered efficiently by CI.If the circulating currents are too strong, these result in CI saturation, greater switching losses and degrade the converter's overall efficiency. This paper therefore proposes a global control strategy for a parallel grid-connected interleaved converter based on the Port Controlled Hamiltonian principle (PCH). This controller efficiently manages the active and reactive forces supplied to the grid. The controller also reduces substantially the value of the circulating low-frequency current. Converter output is simulated in relation to the regular PI control and Linear Quadratic (LQ) control.The viability of the proposed method was tested by an experimental set-up. Results obtained from the tests indicate that the efficiency of the proposed approach has been well agreed with the simulation.

1. INTRODUCTION

Several creative power converter systems have been built to handle the rising power from renewable sources. The literature suggested multi-stage converters, multi-pulse converters and matrix converters to expand the grid-connected converter power ratings [1] for these applications. A new topology for achieving high-power converters has been recently proposed. The topology is shown on the figure. 1 and is based on the simultaneously use of cupled inductors for regular two-tier inverters [2,3]. With respect to flowing currents, CI exhibits a high impedance.Therefore, the output currents of the two converters are naturally divided without a further control solution for the current balance. This topology seems particularly important because if It can increase the harmonic spectrum of output voltages using the right modulation techniques. This process normally switches to 180 psi, which provides various network benefits, including multilevel outputs and the reduction in output filter size and different mode voltage (CMV)[4,5]. However, the benefits of interconnecting carriers come at the expense of increased flow between converters. Appropriate CI selection[6] will reduce higher-frequency elements of circulating currents to an acceptable level. The filtering feature design methodologies have been proposed in Ref. [7].In addition, the efficiency of the harmonic contents for circulating current and output voltages of asymmetric interleaving angles was discussed in Ref. [8]. Discontinuous 30 ° and 60 ° clamp panels were proposed for this work. In comparison to the popular PWM with a symmetrical interlacing or center-aligned Space Vector Modulation (SVM), it has been shown that the DPWM technique improves harmonic performance[9]. In addition, theoretical work focused on rising moving currents through the (CI).In ref. [10] the authors proposed to minimize circulating voltage current and standard mode a three-tier (SVM) system. In the Ref.[11], PWM techniques for selective harmonic elimination (SHE-PWM) have been used to reduce circulation current peak values. In Ref.[12] special attention was paid to the control by a proportional resonant (PR) controller of low frequency currents. This approach defines and uses circulating currents in each stage for the PR controller as input. The output of the controller is connected to only one converter of the two parallel VSCs for modulating signals.A updated DPWM scheme to reduce flux contact and circulating currents was also suggested in Ref. [13]. Capella et al . suggested a technique to align each converter, producing leg-specific reference signals. At intervals equal to the switching time, reference signals are determined with each converter's output current[14]. The authors suggested, in comparison [15], a deadbeat control technique for reducing circulating currents. In addition, other research studied the decrease rather than the individual differential mode currents of the zero-sequence circulating current (ZSCC).ZSCC is known as the sum of the three-phase circulating streams. The ZSCC in a modular, two-tier interleaved converters was replaced by a phase-shift PWM carrier. In Ref. and on the Harmonic-Elimination Pulse Width Modulation (HEPWM) technique , two methods of reducing the (ZSCC) were proposed. Ye et al. suggested a method to further delete (ZSCC), which changes null-vector distribution via the PI-controller. To further suppress (ZSCC). Both of these strategies aim to keep the current circulating instantly within reasonable limits.In this paper , authors suggest controling energy shaping (ES) of low frequency circulating currents. In this process, the system is considered to be an electricity conversion device that fulfills the EBE. The ES Control provides (asi-)passive system stabilization with a hamiltonian structure and a desired storage feature that represents the loop system energy.

In many applications, including power converter, this control technique has been used. For instance, a three-phase front end converter was operated.A DFIG wind turbine control strategy based on ES control was outlined at Ref. It was also used to power the micro grid backward converter. The authors have provided an ES controller to feed into a magnetic energy storage device a three stage T-type converter. This article aims to create an ES controller for a conversion conversion conversion device in parallel. In other efficient applications, such as Renewables systems and Reality controllers, the converter can be integrated. With the proposed design , low-frequency circulating currents are effectively regulated along with currents injected into the grid.

EXISTING METHOD:

The inverters are paralleled with the magnetally connected inductors in this configuration. In general, the carrier interleaving is used to boost the harmonic value of the output stress. As a consequence of the two voltage source converters (VSCs) an increased circulating current (differential mode stream) flows. The reciprocal inductance of Coupled Inductors (CI) effectively reduces the high frequency components of circulating currents. However, the low frequency components can not be filtered efficiently by CI.If the circulating currents are too strong, these result in CI saturation, greater switching losses and degrade the converter's overall efficiency. To delete the (ZSCC) further, Ye et al. proposed a method for modification of traditional (SVM) null vector distribution by PI controller[19]. [19] Both of the above methods help to keep the current circulating instantaneously within reasonable limits.

DRAWBACKS OF EXISTING METHOD:

- However, carriers interleaving benefits are provided at the cost of higher circulating currents between the transformers.
- The unregulated flow currents are of fairly high interest.
- And the coupling inductors can be saturated.
- Reduces the power converter switching losses.

2. LITERATURE REVIEW

H. Liu.-Liu. L. Flax, Solar photovoltaic (PV) generation systems are suggested by Chowdhury and are radically different from traditional synchronous generators. They have no inertia and the characteristics and controls of electronic inverters are dominating their dynamic behaviour. The effect of increased penetration of solar photovoltaic energy into complex power system efficiency should be understandable. This paper explores the effect of solar PV generation on the energy system with modal analysis and time-domain simulation. Limited signal stability.The simulation results show that, depending on the place and permeation of solar PV generation, the effect can be beneficial or detrimental on small signal stability. If solar photovoltaic integration adversely affects the limited signal stability, critical synchronous generator systems may need to be held online or other steps are required to ensure that low frequency oscillations are damped sufficiently.

C. G. and Rodriguez. A. Johann Amaratunga. A mathematical model of grid-connected photovoltaic sources of energy that are suitable for the study of stability is proposed. The electronic power conditioning unit is based on simple transmission relations.It is shown by this model that there are two alternatives, one of which is unstable, for a particular power output. Dynamic orbits that help to envision any possible problem which may occur under disturbances, are posed by performing self value and self-vector analysis. Instances where a photovoltaic panel voltage collapses are simulated, in particular when working near the maximum power point.

1. 1. Juarez, and I, Rueda, C. A. Erlich is the author of this paper on the use in the study of low frequency electromechanical oscillating power system (LFEOs) of continuous wavelet transformation.A revised Morlet Motherwavelet method is proposed to use the relationship between low frequency system oscillation characteristics and the Morlet CWT system ringdown signal for modal shift detection and modal frequency and damping measurement. In order to provide accurate modal recognition estimates, several criteria are also provided for the selection of the center frequency and bandwidth parameters, the scale factor and the translation factor. Applying this to synthetic, virtual and calculated signals indicates the feasibility of the proposed method.

F. The core characteristics of the network are modified as alternative power sources are connected to the grid. It especially applies to intermittent and unreliable sources of power such as PV systems. PV power systems have become more and more cost-effective in recent years , leading to more expanding large and small PV systems. Power flow, power efficiency and system general stability may be affected by the broad incorporation of photovoltaic systems into the existing grid – and possibly negative.This paper dissects the effects of interfacing an enormous scope photovoltaic force source to the current utility network utilizing the MATLAB based Power System Analysis Toolbox (PSAT). This paper uncovers a strong technique for investigating the impacts a huge scope PV framework can have on the dependability of the force matrix and the aftereffects of this examination uncover the conceivably destructive impacts of coordinating such a framework into the current network.

B. Tamimi, C. Canizares, and K. Bhattacharya, are proposed The conduct of Solar Photo-Voltaic Generation (SPVG) in the framework is characterized by the manner in which its yield dynamic and receptive force are controlled; the responsive force can be controlled legitimately as a preset worth or in a roundabout way through controlling the voltage greatness at the purpose of basic coupling (PCC). In this way, two essential demonstrating approaches are considered in the current work: steady responsive force and consistent voltage size models, for an unending capacitor SPVG. In view of these models, investigations of the impact on the framework's voltage and point soundness of coordinating SPVG into the matrix are introduced and talked about for the IEEE 14-transport benchmark framework. The investigations are performed at the transmission framework level and from the framework administrator's viewpoint. In this way, voltage strength contemplates are done utilizing PV bends, little bother soundness considers are performed dependent on eigenvalue examinations of the linearized framework modes, and time space contemplates are completed to look at the general execution of the framework on account of possibilities. From the outcomes and studies introduced, it is demonstrated that SPVG in PV-control mode doesn't contrarily influence the strength of the framework, and it might really improve it.

3. METHODOLOGY

3.1 PI control of the grid connected converter

The parallel interlocking converter control algorithm is shown on Fig. 1. At the point in which the grid is connected, current and voltage sensors are used to calculate currents and voltages. The angle of the grid phase gr is calculated via a locked loop process. By placing the e*grd direct grid voltage part at zero, the lock is achieved. The grid angle of an error from e*grd to egrd is corrected using the PI controller. Therefore, the voltage vector of the grid is aligned with the rotating system q axis. In several works such as [5,6] this approach has already been defined. The active and reactive power expressions given in the grid are:

$$\begin{cases} P^{gr} = e_{grd} i^{d} + e_{grq} i^{q} \\ Q^{gr} = e_{grq} i^{d} - e_{grd} i^{q} \end{cases}$$

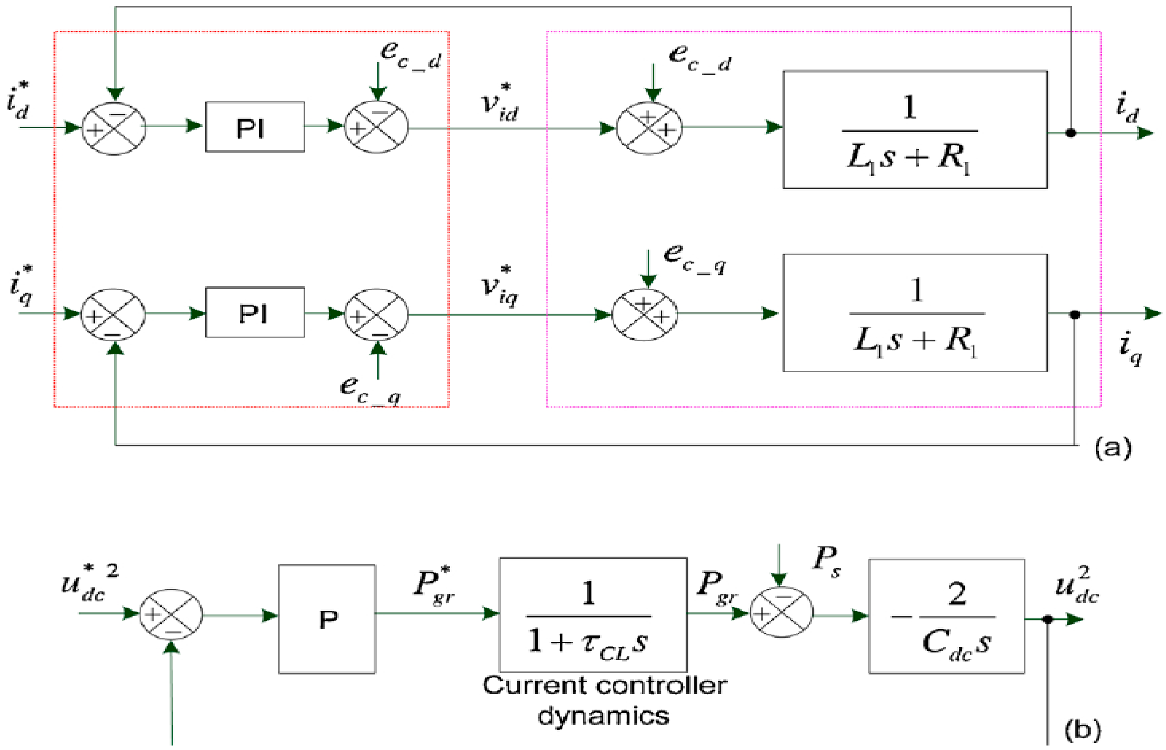


Fig. 1**.** Control loops of the converter based on PI controllers. (a) Control loopsof grid currents. (b) Control loop of the DC bus voltage.

First, using the pole compensation method the PI parameters shall be determined. The PI controller's zero is positioned above the pole of the first order. The combined time constant is then used to determine the time of the closed loop constant CL. Nevertheless, the closed loop system's (1 CL) bandwidth has to be considerably less than that of the converter transition frequency in order to avoid instability[1].

3.2. LQ control of the grid connected converter

The grid-connected inverter LQ controller is shown in Fig. 2. This controller is based on the state space representation of the Equation above method. Therefore, the device is shown as:

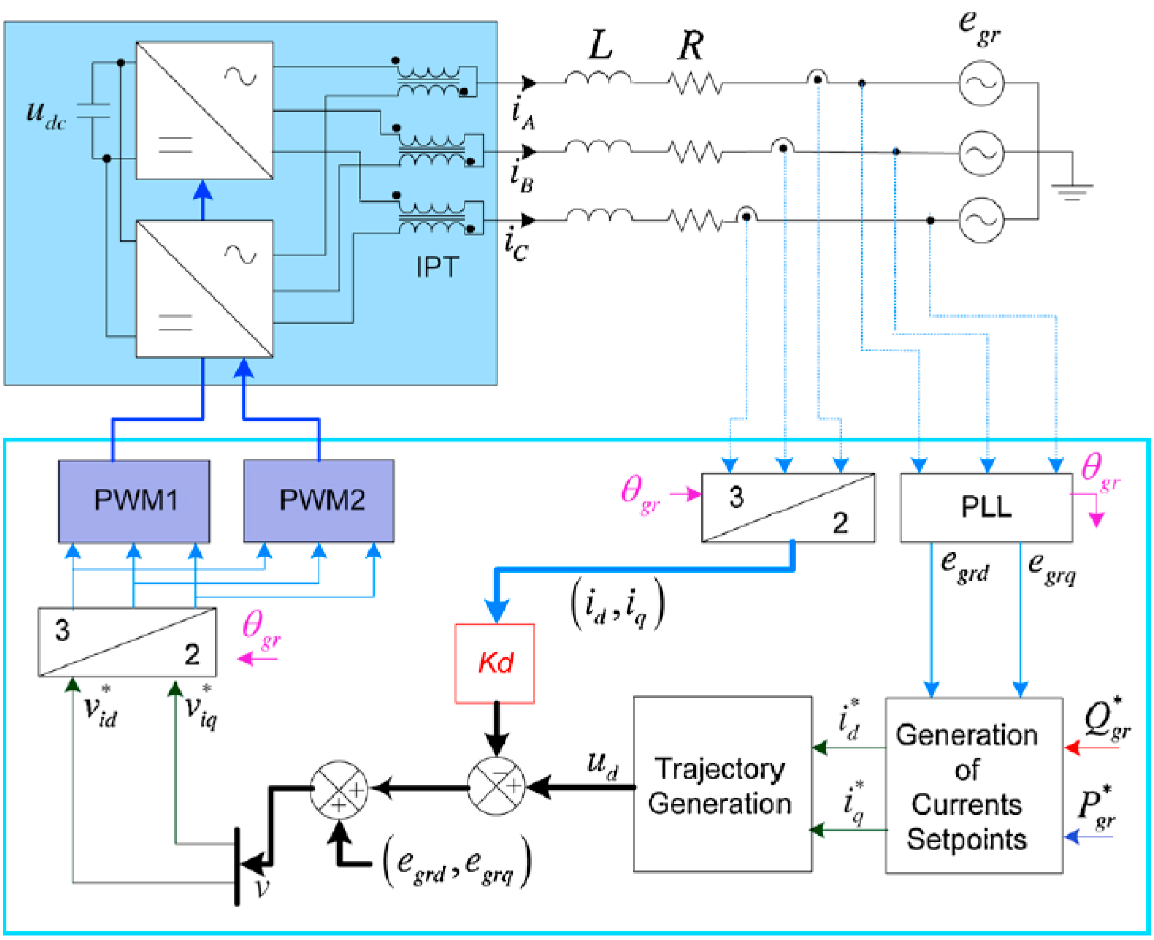


Fig. 2. Linear Quadratic control of the grid-connected converter.

LQ technology helps find an efficient trade-off between the control energy and the transient response output of a stabilizing Kd feedback matrix. The architecture of this device is explained in depth

3.3. ES control of the grid connected converter

The grid-connected converter fulfills Eq's PCH representation . Interconnection and damping matrices record the internal energy exchanges in PCH systems. And the ideal structure of these matrices must first be set. In the following equation the desired system is expressed:

$$\dot{x} = [J_d(x) - R_d(x)]\frac{\partial H_d(x)}{\partial x}$$

ES regulation ensures the stabilization of the regulated system by the desired power function Hd (x) around a non zero equilibrium point. By solving the corresponding equation, the control variables u of the device can be determined:

$$[J(x) - R(x)]\frac{\partial H(x)}{\partial x} + g(x)u = [J_d(x) - R_d(x)]\frac{\partial H_d(x)}{\partial x}$$

The output currents are preferably shared by the two converters at equilibrium point and the magnitude of circulating currents tends to be zero (icc d = icc q = 0). Under these situations, the constant status values of the switching function are the same for the two converters, determined by:

$$\begin{cases} S_{d_1}^* = S_{d_2}^* = S_{d0}^* = \dfrac{-\omega L_1 i_q^* + R_1 i_d^* + e_{grd}}{u_{dc}/2} \\ S_{q_1}^* = S_{q_2}^* = S_{q0}^* = \dfrac{-\omega L_1 i_d^* + R_1 i_q^* + e_{grq}}{u_{dc}/2} \end{cases}$$

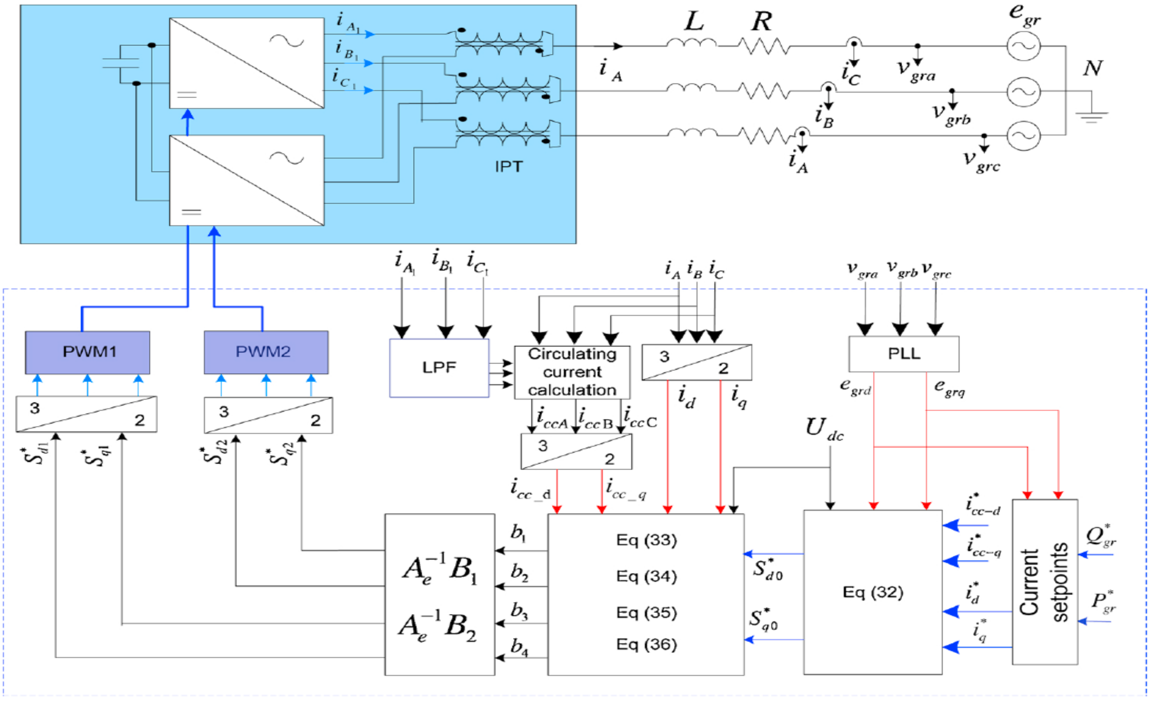
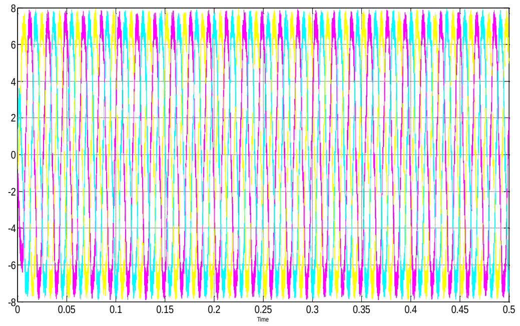


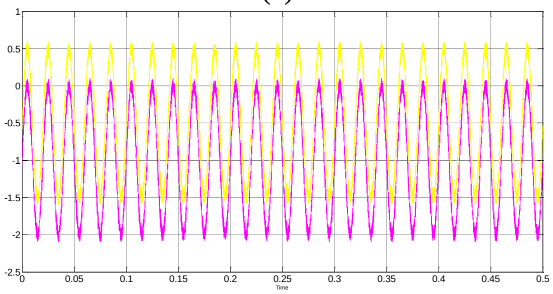
Fig. 3. Energy shaping control of the grid-connected converter.

4. SIMULATION RESULTS

Fig. 6. Converter behavior with PI control. (a) Grid currents. (b) Converters currents. (c) Differential mode currents. (d) Grid powers.



(a)



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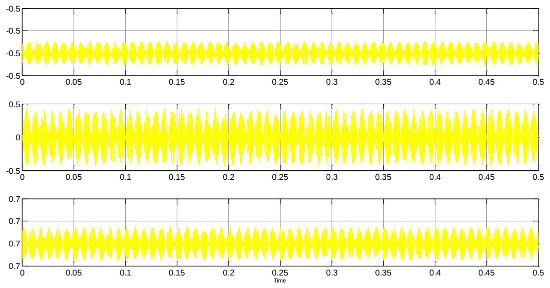

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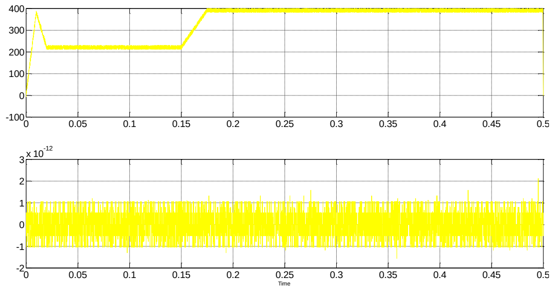
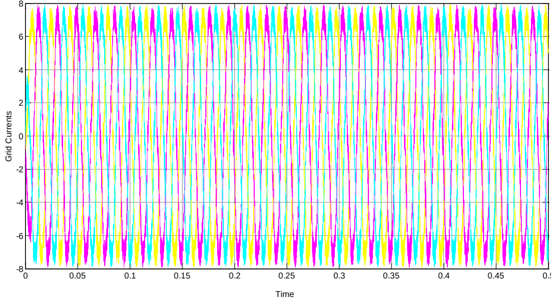


(d)

Fig. 6 presents the behavior of the system when PI control is used. Fig. 6a depicts the currents delivered to the grid and Fig. 6b depicts the converter currents delivered by phases C1 and C2. The current iC1 measured at phase C1 of the first converter is significantly higher than the current iC2 delivered by phase C2 of the second one. Hence, grid currents are not perfectly shared between the two converters due to low frequency circulating currents. The DC component of circulating current can reach 0.6 A (iccC) as shown in Fig. 6c which represents approximately 30% of the grid current magnitude. Thus, the value of the uncontrolled circulating currents is relatively high and can lead to the saturation of the coupled inductors. It also increases the switching losses in the power converters. Active and reactive powers delivered to the grid are illustrated in Fig. 6d. As it can be seen, the system remains stable during steady state or transients, that is, when the power reference is modified.

Fig. 7. Converter behavior with LQ control. (a) Grid currents. (b) Converterscurrents. (c) Differential mode currents. (d) Grid powers.



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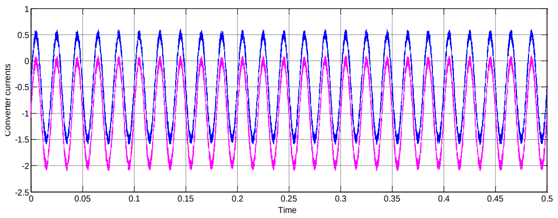

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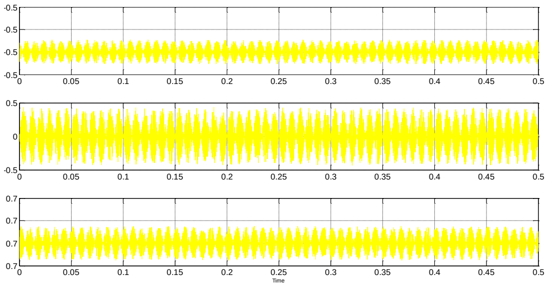

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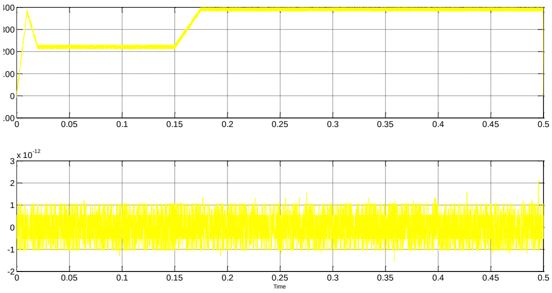
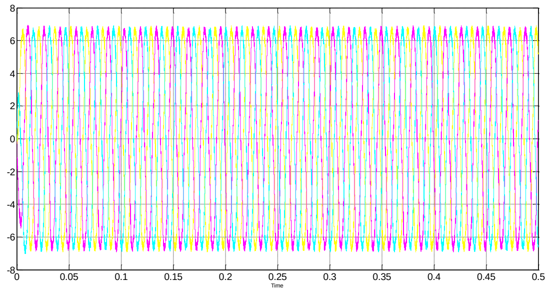


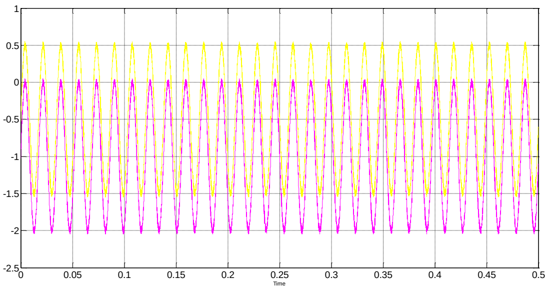
(d)

Fig. 7 presents the behavior of the grid connected converter when the linear quadratic control is used. As it can be seen, the results are close to the performances with PI control. Significant circulating currents still flow between the two converters as shown in Fig. 7c. For example, the average value of the circulating current flowing between phases C1 and C2 reaches 0.7 A. This result confirms the interest for a control strategy which synthesizes independent voltage references for each inverter in order to keep equal power sharing.

Fig. 8. System behavior with ES control. (a) Grid currents. (b) Converterscurrents. (c) Differential mode currents. (d) DC bus voltage. (e) Voltage betweenphases A and B. (f) Grid powers.



(a)



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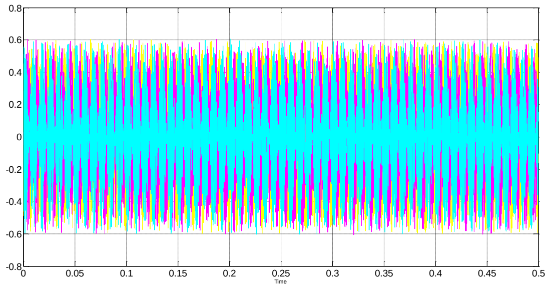

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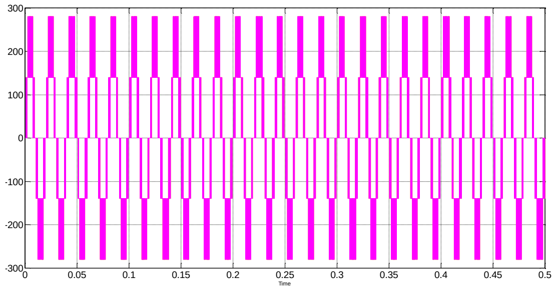

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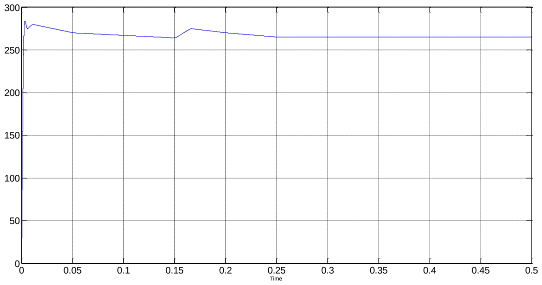

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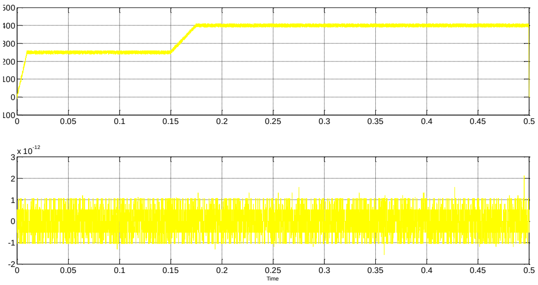

(f)

Fig. 8 presents the response of the system when ES control is used. The currents delivered to the grid are depicted on Fig. 8a and b depicts the currents delivered by phases C1 and C2 of each converter. As it can be seen, currents are equally shared between the two converters. In addition, the DC component of circulating currents is reduced to zero for the three phases and only high frequency components flow between the two converters as shown in Fig. 8c. The DC bus voltage keeps a stable value as shown in Fig. 8d due to the controller corrective action. In addition, Fig. 8f shows that active and reactive powers delivered to the grid are efficiently controlled during steady state or during the variation of the active power reference.

THD COMPARISON TABLE.

TYPE	PI CONTROL	LQ CONTROL	ES CONTROL
CONVERTER CURRENT	26.91	16.93	7.62
GRID CURRENT	27.93	19.14	13.51

CONCLUSION

The classic two-stage inverters are simultaneously connectivized through coupling inducers to increase the grid-connected converters' rated capacity. Without any special control, the operation of this system is possible to match the flow of the two converters. This causes, however, excessive flowing low-frequency currents, which increases stress on power semiconductors. A balancing technique was considered in this paper for interleaved, three-phase inverters with magnetically coupled inductors.The converter is considered as a passive system to develop this technique and was modeled with the Port Operated Hamiltonian system principle that meets the energy-shaping management requirements. Section 3 describes the technique for the control technology. In terms of circulating current decline and regulating active and reactive capacity, simulation and experimental results show the utility of the ES control strategy. Nevertheless, this algorithm includes additional sensors at the output of the original converter to calculate the iA1, iB1 and iC1 currents.The cost and sophistication of the design would be increased. That is why the proposed control permits better efficiency at the expense of a greater number of sensors and reduced energy losses.

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