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An Exhaustive Strategy and Concentrated on Power Quality Indexesefficiency for the Plan of Microgrids with Numerous Dgus

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ABSTRACT

This paper presents a comprehensive method, focused on power-quality indexes and efficiency for the design of microgrids with multiple DGUs interconnected to the ac grid through three-phase multi-Megawatt medium-voltage pulse width-modulated-voltage-source inverters (PWM-VSI). The proposed design method is based on a least square solution using the harmonic domain modeling approach to effectively consider explicitly the harmonic characteristics of the DGUs and their direct and cross-coupling interaction with the grid, loads, and the other DGUs. Extensive simulations and analyses against PSCAD are presented in order to show the outstanding performance of the proposed design approach.

***Index Terms** : Harmonic analysis, design optimization, power quality, PWM-VSI*

I.INTRODUCTION

Ideal operating conditions are increasingly difficult to sustainas valid, since harmonic generation, interaction of controlsand harmonic components, resonances, harmonic stability issues,etc, are phenomena commonly reported in systems withhigh harmonic penetration [7]. In practical networks with powerelectronic-based DGUs, this could lead to erroneous or unfavorableoperating scenarios. This gap has been recognized and addressedin the open literature, although not in a holistic

way. Forinstance, [8] deals with the power transfer capability problem ofDGUs including harmonic distortion, and considering powerqualityregulations at a specific point of the network. Referencebrings out some pitfalls of electric power-quality indexesallowed by international regulations showing that being withinthe limits is not enough in order to ensure proper performanceof the DGUs electrically close to each other. In more sophisticatedapproaches, the power quality on the distribution systemis improved by the use of harmonic compensation methods inthe control schemes of the interconnected DGUs.

In this way, one of the best practice to mitigate the adverseharmonic effects is the proper design of the passive filtersconnected to the end terminals of power electronic converters.

Several design methods or procedures, specially for the LCLfilter, have been proposed. However, most are based on a trialand error process in which their difficulty and convergence

problems considerably increase for systems with multipleDGUs based on power electronic converters, specifically from medium to high power levels.This paper proposes a comprehensive approach, based on optimizationand the extended harmonic domain (EHD) [21], forthe design of multiple grid-connected multi-Megawatt mediumvoltagePWM-VSIwith LCL filters. This is carried out by meansof a Nonlinear Least SQuares formulation (NLSQ), which calculatesthe filter parameters and the steady state control variableswhich meet certain proposed reference operating conditions and includes power-quality restrictions and efficiency. As an example,the design of two DGUs, based on three-phase PWM-VSIs,which are connected to a microgrid is presented. Two case studiesare presented to show the proposed design approach, oneconsidering that the interconnections grid is unknown and theother when is known. The obtained results show the remarkablegood performance of the proposed design approach on bothcases, along with advantages over other design methodologies,which rely on the comprehensive consideration of multiple designobjectives.

II. DESIGN OF DGUS

Three main elements could be identified in the design of aDGU. (1) The Design Objectives (DO) (power quality, operatingconditions, size limitations, cost, etc.), (2) the ExternalConditions (EC) (distributed resource, grid equivalent, weatherevents, faults, generation outages, etc.) and (3) the DesignableElements (DE) (topology, component values, control parameters,etc). In this context, a proper design can be summarized asthe selection of certain DE that ensure the fulfillment of the DOin the presence of some EC. This requires to understand in detailthe relationships and interactions among these main elements.Fig. 1 shows a very basic representation of a typical DGU andsome of the above identified main elements are shown (DO, ECand DE). From Fig. 1 the DO could be established, for example:DC bus voltage, DC voltage ripple, RMS voltage at *PCC*,active power at *PCC*, reactive power at *PCC*, THD voltage at*PCC*, current ripple at *PCC*, among others. Some of the DEare: distributed resource topology, power electronic topology,AC and DC filter topologies, control unit topology, switchingfrequency, power switches ratings, DC filter component valuesand AC filter component values, control unit gains, among others.In order to have a selection of the DE that ensures thatthe reference design objectives (DOref) are met under boundedvariation of certain EC, is then required to understand the relationshipsbetween these main elements.

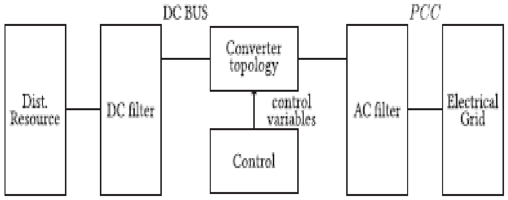

Fig. 1.Simplified layout for design.

It is clear that the relationships between the DO and the DEare far from linear and decoupled. Fig. 2 shows schematicallyan insight of the intricate relationships among the DO, DE and

EC; depicted by grey circles, blue ovals and green squares, respectively. The pointing arrows between these elements arelinks with the elements that have influence on or relation to the final value of them. Solid and dashed lines represent strong andweak interactions, respectively.

Fig. 2 shows an insight of the challenges in the designing\ of DGUs. Some of the most common practices used to tacklethem are: (1) settle many of the designable elements based on experience and a priory knowledge, especially those in respectthe topology, (2) decouple the relationships by considering onlythe most relevant designable elements for each design objective,(3) neglect some design objectives focusing only on themost important.

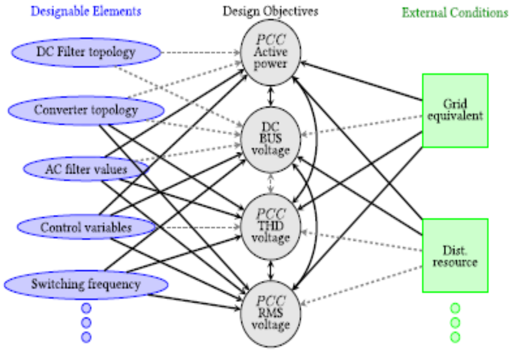

Fig. 2. Relationship between designable elements (DE), design objectives (DO) and external conditions (EC).

III.DISTRIBUTED GENERATION UNIT SUBSYSTEM MODEL

Fig. 3 shows the topology for *DGn*subsystem with $n = \{1, 2\}$. The time-domain three-phase variables are denoted by lowercase bold letters that in general represent vectorsof size (3×1) constructed with the phases *a*, *b* and *c*, i.e.,$\mathbf{i}_{n1} = [i_{n1a}, i_{n1b}, i_{n1c}]^T$; $T_n$is the $Y - \Delta$ transformer withparameters r_{tn}, $l_{tn}$and a_n referred to the primary winding;control variables $m_{na}$and $\theta_n$are the modulation indexand phase shift, respectively, of the modulating signalfrom which the PWM block generates the switching functions. For a closed-loop operation, the control variables will begenerated by a control strategy for given reference operatingconditions.

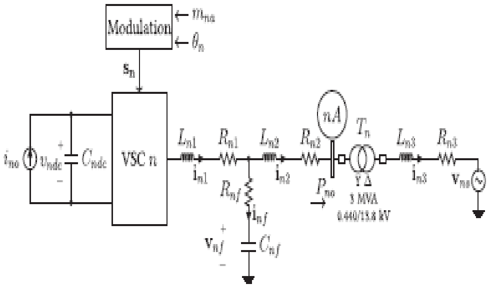

Fig. 3.Distribution generation unit of test system.

III. DESIGN ELEMENTS OF PROPOSE SYSTEM

1) Steady State Control Variables mna and θn :By consideringthe control variables as DE, the closed-loop performanceof each DGU is considered in the design. In thisway, the control references can be included as DO, allowingto consider the nominal operating conditions in thedesign.

2) Input dc Current Source ino and dc Side Capacitor Cndc :By designing these parameters, the power quality of the dcvoltage bus along with power rating related to the operatingconditions (such efficiency and transfered power) are able to beintroduced as DO.

3) LCL Filter Passive Components $Ln1$, $Ln2$, Rnf and Cnf :The LCL filter parameter are mainly related with the powerquality of ac signals. However, their design impacts not only
power-quality DO but also on the overall closed-loop performanceof the DGU. One example is to increase the dampingresistance Rfin order to reduce the resonance peak, howevera large value will affect the DGU overall efficiency. Hence,the proper design of these parameters consider power quality,operating conditions and transfer power DO.

IV. RESULTS

Multiple and diverseDO$_{\text{ref}}$ are closely met, while the grid side power-quality standardsare easily fulfilled with a very reduced converter currentripple; even in the presence of low switching frequencies andharmonic loads, with the best efficiency possible. In both designCase Studies, the performance of each DGU is seen bythe network almost as an ideal harmonic free voltage sourceand prevents any harmonic related issue in the network causedby the operation of th DGUs. For this reason, the overall performanceof the system and the obtained DE are very close in both case studies. However important differences should bepointed out.

Regarding the performance of $DG1$, an improvement ofaround 0.7% in the efficiency for comprehensive case could benoticed. Despite the relatively small improvement, notice that
there are significant differences among both DE, specially in thedamping resistance. An interpretation is that in the comprehensivedesign, the damping is obtained from the grid resistances.This allows to improve the efficiency by decreasing Rnfwhileall the other DE are adjusted to meet the other DOref .For $DG2$, the isolated design presents a difference in the outputpower $Pno$of around 30kW respect to the reference value,which results from non consideration of the interconnectiongrid. This difference is significantly improved in the comprehensivedesign. Additionally, most of the simulated design objectivesin the comprehensive design are slightly better than inthe isolated design. However a small decrease in the efficiencycan be noticed, resulting from an increased Rnfvalue. In short,comprehensive design provides an improvement in the overallperformance of $DG2$.

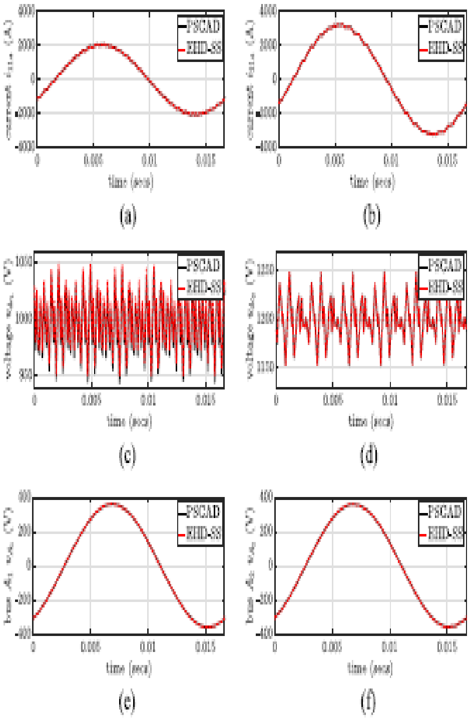

Fig. 4.Simulatedwaveforms for isolated design Case Study. (a) *DG*1 *i*11 converter current. (b) *DG*2 *i*21 converter current. (c) *DG*1 *v*1*dc* voltage. (d) *DG*2 *v*2*dc* voltage. (e) *DG*1 node 1*A* voltage. (f) *DG*2 node 2*A* voltage.

From the simulations shown in Fig. 4 it can be seen that bothwaveforms are practically overlapped. This validates the EHDmodel used to obtain the designable elements and the designapproach proposed. The achieved power-quality indexes are excellentconsidering the high power capability and low switchingfrequency considered in the design. When interconnected to themicrogrid, each DGU behaves very close to an ideal harmonicfree voltage source and their overall harmonic distortion impactover the microgrid is practically negligible. However, sinceeach DGU was designed without considering all the elementsinterconnected to them, the obtained design is decoupled andthe isolated operating conditions have to be verified when interconnected.From this point of view, a better design couldbe obtained if the complete system model is considered in theproposed design approach.

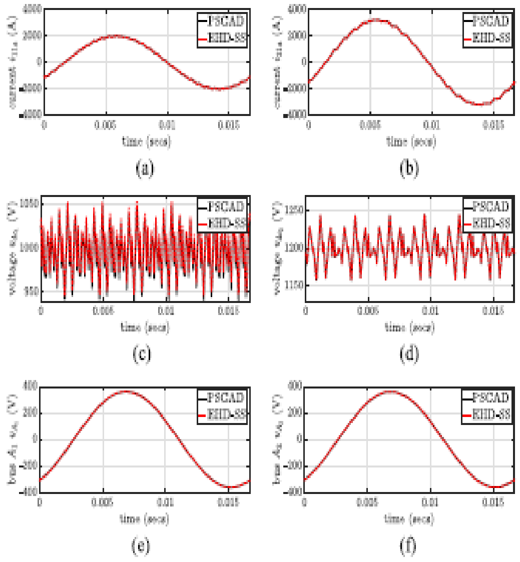

Fig.5.Simulated waveforms for comprehensive designCase Study. (a) *DG*1 *i*11 converter current. (b) *DG*2 *i*21 converter current.(c) *DG*1 *v*1*dc* voltage. (d) *DG*2 *v*2*dc* voltage. (e) *DG*1 node 1*A* voltage.(f) *DG*2 node 2*A* voltage.

V.CONCLUSION

This project has introduced a novel design methodology basedon optimization and the extended harmonic domain (EHD) forinterconnected distributed generation units (DGUs) in which

the harmonic distortion and its effects over multiple design objectivesare explicitly considered. The design results of the presentedcase studies have shown a remarkable performance whenboth, the grid parameters are available and not available, offeringan excellent power quality with the best efficiency possiblein the presence of low switching frequencies. Compared withother design methodologies, this proposal offers an advancedperformance, which rely on the comprehensive consideration ofmultiple design objectives.

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