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Augusto Matheus dos Santos Alonso

Distributed Harmonic Compensation in Single-Phase Low-Voltage Microgrids

Compensação Distribuída de Harmônicos em Microrredes Monofásicas de Baixa Tensão

Dissertation presented to the Universidade Estadual Paulista "Julio de Mesquita Filho", in partial fulfillment of the requirements for the degree of Master in Electrical Engineering.

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ATA DA DEFESA PÚBLICA DA DISSERTAÇÃO DE MESTRADO DE AUGUSTO MATHEUS DOS SANTOS ALONSO, DISCENTE DO PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA ELÉTRICA, DA FACULDADE DE ENGENHARIA - CÂMPUS DE BAURU.

Aos 27 dias do mês de fevereiro do ano de 2018, às 09:00 horas, no(a) Instituto de Ciência e Tecnologia de Sorocaba-UNESP, reuniu-se a Comissão Examinadora da Defesa Pública, composta pelos seguintes membros: Prof. Dr. FERNANDO PINHABEL MARAFAO - Orientador(a) do(a) Engenharia de Controle e Automação / Instituto de Ciência e Tecnologia/UNESP, Prof. Dr. FRANCISCO DE ASSIS DOS SANTOS NEVES do(a) Departamento de Engenharia Elétrica / Universidade Federal de Pernambuco - UFPE, Prof. Dr. JAKSON PAULO BONALDO do(a) Departamento de Engenharia Eletrônica / Universidade Tecnológica Federal do Paraná - UTFPR, sob a presidência do primeiro, a fim de proceder a arguição pública da DISSERTAÇÃO DE MESTRADO de AUGUSTO MATHEUS DOS SANTOS ALONSO, intitulada **DISTRIBUTED HARMONIC COMPENSATION IN SINGLE-PHASE LOW-VOLTAGE GRIDS**. Após a exposição, o discente foi arguido oralmente pelos membros da Comissão Examinadora, tendo recebido o conceito final: APROVADO. Nada mais havendo, foi lavrada a presente ata, que após lida e aprovada, foi assinada pelos membros da Comissão Examinadora.

Prof. Dr. FERNANDO PINHABEL MARAFAO

Prof. Dr. FRANCISCO DE ASSIS DOS SANTOS NEVES

Prof. Dr. JAKSON PAULO BONALDO

UNIVERSIDADE ESTADUAL PAULISTA
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“Ask, and it shall be given you; seek, and ye shall find;
knock, and it shall be opened unto you:
for every one that asketh receiveth;
and he that seeketh findeth;
and to him that knocketh it shall be opened.”
(“Matthew, 7:7-8”)

ABSTRACT

The employment of switching power interfaces (SPIs) in power quality related issues is becoming a reasonable alternative to pursue maximum contribution of distributed energy resources in electrical grids. Beyond their major functionality, which is active power injection, additional ancillary services are possible due to the flexibility of their operations, being capable of providing interventions in reactive power support and many other important matters. Multifunctional inverters, as they are also called, could specially play a key role on harmonic mitigation, which may become a meaningful matter in low-voltage microgrids with high density of nonlinear loads spread out. Nevertheless, to take advantage of such multifunctional use it is fundamental to conquer a mutual and coordinated operation of many SPIs dispersed over the energy networks. Therefore, this work proposes an alternative two-level hierarchical topology focused on the cooperative operation of distributed SPIs, aiming their use on multifunctional activities related to harmonic mitigation in single-phase low-voltage microgrids. A novel secondary control approach, named Current-Based Control, is proposed aiming at achieving a coordinated contribution of inverters through a current sharing scheme, attempting power quality enhancement in a point of common coupling. The scope of this dissertation ranges from the design of primary level controllers for inverters, passing through simulation examples, up to the final experimental validation.

Keywords: Cooperative Control; Distributed Compensation; Harmonics; Multifunctional Inverters.

RESUMO

O emprego de *switching power interfaces* em problemas relacionados a qualidade de energia, tem se tornado uma alternativa interessante na busca de aproveitar ao máximo a contribuição de recursos energéticos distribuídos. Além da função majoritária, que é a injeção de potência ativa, serviços auxiliares são possíveis devido à flexibilidade de operação destes dispositivos, sendo capazes de prover suporte para potência reativa e muitas outras necessidades. Inversores multifuncionais, assim como também são chamados, podem especialmente ter papéis fundamentais na redução de distorção harmônica, que pode se tornar um ponto crítico em microrredes de baixa tensão com alta densidade de cargas não lineares dispersas. Entretanto, para usufruir dos benefícios da multifuncionalidade, é fundamental que se estabeleça uma operação coordenada desses inversores distribuídos. Portanto, este trabalho propõe uma topologia hierárquica de dois níveis focada na operação cooperativa de inversores, com o intuito de empregar atividades multifuncionais relacionadas à compensação harmônica em microrredes monofásicas de baixa tensão. A recente metodologia do chamado *Current-Based Control* é proposta, visando uma contribuição coordenada de inversores através de um esquema de compartilhamento de correntes, com a tentativa de melhorar a qualidade de energia em um ponto de acoplamento comum. O escopo desta dissertação foca desde o projeto de controladores de nível primário para inversores, passando por exemplos de simulação, até uma validação experimental final.

Palavras-chaves: Controle Cooperativo; Compensação Distribuída; Harmônicos; Inversores Multifuncionais.

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List of Abbreviations and Acronyms

AC Alternating Current

APF Active Power Filter

CBC Current-Based Control

CC Central Controller

CPT Conservative Power Theory

CSI Current Source Inverter

DC Discrete Current

DER Distributed Energy Resource

DG Distributed Generator

DSO Distribution System Operator

EG Energy Gateway

FBD Fryze-Buchholz-Depenbrock

FFHC Fixed Frequency Hysteresis Controller

FFT Fast Fourier Transform

MEA Mean Absolute Error

PBC Power-Based Control

PCC Point of Common Coupling

PI Proportional-Integral

PRep Proportional-Repetitive

PRes Proportional-Resonant

PV Photovoltaic

PWM Pulse Width Modulation

SG Smart Grids

SPI Switching Power Interface

SRF Synchronous Reference Frame

SS Storage System

TDD Total Demand Distortion

THD_i Total Current Harmonic Distortion

THD_v Total Voltage Harmonic Distortion

UI Utility Interface

VFHC Variable Frequency Hysteresis Controller

VSI Voltage Source Inverter

ZOH Zero Order Holder

Contents

1 Introduction

Renewable energy, since the past decades, has been catching attention as one of the most prominent alternatives to modernize the electrical power system. Besides this undeniable relevant matter, many other related reasons of a new trend on the energy sector lie on the sustainable capability of interchanging non-renewable sources by clean ones, and also on the economical side of their deployment, which is becoming more and more attractive around the world (OBAMA, 2017). As a result of this aggregation of ideas within the context of renewable energy, energy efficiency, future decentralization of resources, economic profitability and digitalization, a powerful definition named Smart Grids (SG) has been changing the implications of electricity and how its technologies are thought (KIESLING, 2016).

Focusing on the electrical outlook, this new approach based on distributed energy resources (DERs) directly impacts on grids' dynamics, once more diversified electricity generators may now be interconnected and contribute to the overall power availability in a network. In addition, with its intrinsic assorted generation capability, the traditional electrical grid concept has been evolving towards a more flexible structure under bidirectional power flow, able to account for smarter power management and countless other operations that may benefit grids themselves, utilities, and consumers (FANG *et al.*, 2012). Yet, allowing the creation of new paradigms, such as of the so-called prosumers (GRIJALVA *et al.*, 2011), in which distributed generators (DGs) have the opportunity to offer their surplus local energy production to a grid, for instance, in exchange for an economic reward.

Despite the global agreement on the prosperity of adopting a cleaner and more decentralized grid, from the technical side of this demand, it is imperative for all technologies there employed to provide reliable means of operation, accounting for a high interactive and diversified electrical system. A reasonable explanation for such need is given by the complexity behind integrating several technologies, which are composed of particular architectures and power generation characteristics, being also differently affected by intermittent climate conditions, and not equally responding to grid behaviors. DERs based on wind, photovoltaic (PV) and fuel cell generators, as well as storage systems or electric vehicles are good examples of such diverse architectures.

Switching power interfaces (SPIs) play a key role on DERs integration into grids, dispatching generated power under compliant requirements (KROPOSKI *et al.*, 2010). SPIs are power converters, or even called inverters, capable of converting DC generated power into usable AC power, under specific voltage and current conditions of frequency, amplitude and phase. The compliance of SPIs' operation with legally demanded grid regulations is crucial, as required in countries like USA, Germany and Brazil, through the respective standards, IEEE Std. 1547 (IEEE, 2003), VDE-AR-N 4105 (VDE, 2011), and ABNT NBR 16149 (ABNT, 2013).

Inverter technologies may also be employed in power quality enhancement, which has been increasingly required since nonlinear loads spread over electrical networks (SALMERON; VAZQUEZ, 2007). Nonlinear loads are defined by their unique behavior of not responding as a resistive, inductive or capacitive load, draining non-sinusoidal currents even when supplied by sinusoidal voltages (HART, 2011). That characteristic, which earlier was only particularly encountered in adjustable speed drives, arc furnaces and other heavy duty power equipment, are now proliferated due to intense use of switched-mode power supplies in the design of many kinds of home appliances and small electronic devices.

One of the main inconveniences of such nonlinear behavior of loads is related to the infliction of significant harmonic distortion onto current and voltage waveforms. As described by (ARRILLAGA; WATSON, 2004), heavy harmonic distortion may result in capacitors resonance, overheating and loss of torque in electrical machines, skin effect in transmission lines, unreliability in measurement instruments, false trips of circuit breakers and many other disturbances.

As the nonlinear loads are tied to an intolerable burden in electrical grids, specially by their harmful impact on more sensitive networks, e.g., low-voltage grids (BONIFACIO *et al.*, 2013), defining ways to prevent nonconformities have become compulsory. To reduce the harmonics impact and to comply with electrical requirements, power conditioners as passive, active and hybrid filters, have been extensively proposed, as further discussed in Chapter 2. In addition, expanding to the new model of electrical grids with large amounts of DGs dispersed, the consideration for power quality matters increases even more as a result of dynamic load profiles, complex interaction among nodes, and also by having intermittent bidirectional power flow.

Microgrids (LASSETER, 2002) may be one of the most suitable examples to point out how considerable amounts of nonlinear loads negatively affect power quality in low-voltage grids. This electrical entity, as defined by the U.S. Department of Energy Microgrid Exchange Group, presents a defined boundary, comprising groups of interconnected loads and DERs, being a single-controllable unit able to provide power flow management at a point of common coupling while respecting its power restrictions. Besides, it can operate connected or disconnected (islanded) from the main grid as desired. Based on this definition, dynamic interactions are intrinsically expected to occur inside such microgrids. As a result, the disturbances caused by drawing non-sinusoidal voltages and currents may affect the entire operation of both microgrid and the main grid when interconnected, unless power quality counter-measure actions are taken.

As coordination of distributed units have therefore become relevant, other related recent prospects are showing prominent usefulness due to their flexibility to provide decentralized operation, and reliable interaction of DERs. For such case, cooperatively operated distributed interfaces with plug and play features will likely be one of the most suitable alternatives in a near future on power quality improvement (LIGHTNER; WIDERGREN, 2010). Within that matter, distributed multifunctional SPIs (MARAFAO *et al.*, 2015) are gaining a positive status and strengthening its acceptability to be those interfaces. That may be justified by their fundamental presence in most of DERs, ease for supporting intelligent activities, and for their proved feasibility that many studies have been stating (BRANDAO *et al.*, 2017; YANG *et al.*, 2016; TENTI *et al.*, 2010). Moreover, looking at smart grids' regulatory and market perspectives, interest in their employment and applications are rapidly rising, said to be the future (KROPOSKI, 2016), and may also be evidenced by eminent leading edge regulations, such as the Rule 21 (CPUC, 2013) and the new UL 1741 SA standard (GONZALEZ *et al.*, 2016).

Being attached to the idea of developing flexible tools for supporting power interventions with SPIs, specially focused on power quality duties under disperse coordinated operation over low-voltage microgrids, the main goal of this dissertation is settled. The secondary control layer of a two-level hierarchical control methodology for cooperative operation of multifunctional inverters is herein proposed, aiming harmonic current mitigation at the point of common coupling (PCC) in low-voltage single-phase networks. Regardless of the microgrid's voltage condition, the control methodology, which is herein called Current-Based Control (CBC), aims at standing reliable and consistently providing the sharing of active, reactive, and harmonic terms among distributed SPIs.

Therefore, this work intents to clearly describe the mathematical development of the methodology, and additionally explain its translation into real physical application considering power electronics technologies. Extensive computational simulations are carried out to demonstrate the adequacy of the secondary controller under diverse circumstances. Furthermore, experimental results are performed to validate the adoption of this harmonic current sharing method, and also, start discussions related to possible inherent constraints.

1.1 Dissertation Contribution

Techniques employed on cooperative control of dispersed SPIs, as later presented in the state of the art, have been recently proposed following several approaches. Among many strategies, two approaches must be particularly highlighted to emphasize the motivations of this work, being them: a centralized methodology based on power terms, which is named Power-Based Control (CALDOGNETTO *et al.*, 2015b), and decentralized techniques based on droop control methods (GUERRERO *et al.*, 2013).

The first approach is the foundation of the Current-Based Control methodology since, being developed under a master/slave hierarchical control architecture, it provides power sharing among distributed SPIs driven as current-controlled sources within a microgrid. In addition, this topology takes into consideration the existence of a tertiary upper layer which establishes the power flow requirements at the PCC under interconnected mode, a secondary layer that, based on data exchanging with distributed SPIs, provides accurate sharing of active and reactive power terms, and a lower primary layer responsible for the local control o SPIs and their DERs. The feasibility of such approach has been extensively reiterated (BRANDAO *et al.*, 2017; CALDOGNETTO *et al.*, 2015a) for the *P/Q* power management (SANGWONG-WANICH *et al.*, 2018) in microgrids, coordinating SPIs to attend a demand of active power injection and reactive power compensation in a network, as desired by a central controller.

Nevertheless, the Power-Based Control does not present an intrinsic method for mitigating current and voltage harmonic distortions, depending on the existence of an interactive grid-forming converter connected to the PCC (BRANDAO, 2015) to compensate such disturbances for the entire microgrid. The main reason of such requirement is related to the fact that, being developed to handle power terms based on a conservative manner, this methodology is not able to deal with harmonic power due to its non-conservativeness (TENTI *et al.*, 2011). This means that, particularly for the Power-Based Control approach, if a power quantity does not present a conservative feature, it is not suitable to be partitioned and addressed as a reference for remote control of SPIs (TENTI *et al.*, 2011). Consequently, rising as an alternative for finding a more suitable approach to deal with harmonic compensation under a cooperative perspective, a centralized methodology based, not only on power terms, but on decomposed current parcels allows to attain a more tangible and comprehensive coordinated control. Therefore, the resulting methodology coming from this discussion converged on the herein proposed Current-Based Control.

Decentralized methodologies based on droop control must also be reiterated here due to their wide adoption in microgrid control (HAN *et al.*, 2016a; SREEKUMAR; KHADKIKAR, 2017). When comparing to the Power-Based Control, in a general way, such approach presents the very convenient feature of not relying on communication links to coordinate distributed SPIs within a network. This allows a more flexible operation in terms of plug & play capabilities, also eliminating issues related to data transmission and dependence on grid-forming converters for operation in islanded mode. Nonetheless, classic methodologies of decentralized droop based control (DDBC) are well-known by causing frequency and voltage deviation as a tradeoff upon *P/Q* power sharing (GUERRERO *et al.*, 2013; ZHONG; ZENG, 2016).

Additionally, classic DDBC depends on previous knowledge about line impedances and it is mainly employed with SPIs operating as voltage-controlled sources, which requires more complex control approaches than the one required by the Power-Based Control (ROCABERT *et al.*, 2012). Yet, beyond the fact that most DDBC methods provide power sharing based on power terms, none of them are able to concentrate, in one methodology, the ability to coordinate distributed SPIs in islanded and grid-connected mode, providing sharing of active, reactive and harmonic terms, balancing of SPIs' thermal stresses over the microgrid, and also allowing compensation of harmonic current terms in a selective way. Thus, being able to aggregate all those features, the contribution of the CBC presentation can be reinforced and justified as well.

Having stated the premises of the development of the CBC algorithm, the main contributions of this work are said to be the following:

1. Provide a detailed explanation about the Current-Based Control methodology, its master/slave architecture and operational scheme for active, reactive and harmonic current sharing;

2. Demonstrate the complementary abilities of the CBC on providing proportional coordination of current injection, respecting individual thermal stress capabilities of SPIs, and also on performing selective harmonic compensation at the point of common coupling under generic voltage conditions;

3. Evaluate the CBC operation with several SPIs, considering different network scenarios, along with the dynamic conditions of single-phase microgrids;

4. Present initial considerations on the matter of system stability and data transmission issues, on the matter of the hierarchical topology of the CBC;

5. Implement a single-phase laboratory-scale prototype able to support the interconnection of several SPIs, with the goal of allowing further experimental validation of the CBC and other distributed control methodologies.

1.2 Dissertation Structure

This dissertation is organized following a chronological and sequential approach, allowing readers to follow the evolution of the concepts until the plain understanding of the main proposal for power quality improvement in single phase low-voltage grids, as well as the impacts of its experimental results.

The literature review brought in Chapter 2 aims at showing what has been proposed so far regarding distributed compensation, having the intention to later clarify the contribution of this particular work proposed herein. Chapter 3 brings explanations related to the main topology adopted for the modeling of DC-AC converters to be used in later developments. Along with it, methodologies for the implementation of three-level PWM modulation, the design of LC output filters, and also a synchronism algorithm are presented.

In Chapter 4, the primary control layer of the hierarchical control is approached, focusing on the design and adequate operation of SPIs. Control methodologies for SPIs and their modeling are taken into consideration, with the purpose of determining which may be the most suitable for implementation in simulations and experimentally.

Chapter 5 presents the original Current-Based Control approach, focused on enhancing power quality in single-phase microgrids through harmonic mitigation and support for reactive currents. Discussions related to the methodology of this secondary control proposal, as well as the mathematical development behind it are raised.

Simulations more focused on cooperative operation of SPIs, aiming at harmonic mitigation at the PCC, are carried out in Chapter 6. Some case studies give an overview of the selective and multifunctional capabilities brought by the employment of the Current-Based Control. The experimental work is presented in Chapter 7 for a preliminary validation purpose.

Finally, Chapter 8 concludes and proposes future works.

8 Final Conclusions

Distributed harmonic compensation obtained by means of multifunctional DGs, with accurate current sharing, is a prevailing and real challenging research topic, mainly due to the interactions among phases, nodes, line impedances and passive loads, as well as due to voltage deviations along the feeders. Furthermore, as the trend for more intelligent, robust and autonomous microgrid scenarios (OLIVARES *et al.*, 2014) are consolidated in modern energy systems, alternatives such as the Current-Based Control algorithm will be impulsed to be developed to give support to a more effective use of DGs. Having that in mind, this dissertation brought an alternative to provide a hierarchically coordinated operation of dispersed SPIs over a single-phase low-voltage microgrid, discussing not only this control methodology and its applications, but also presenting how such systems might be designed from the lower hardware level.

Chapter 2 tried to give an overview about how distributed energy systems with capability to employ compensation duties have been evolving and being applied for power quality enhancement. From the initial use of local passive filters, up to the future scenario of having many kinds of power conditioners dispersed, several consolidated methodologies were briefly discussed in a chronological sequence.

In Chapter 3, some of the most basic and general knowledge related to the architecture, modulation of PWM inverters was explained, intending to clarify how such systems operate. Along with that, comments were made on how SPIs can be modeled and may interact in grid-connected mode.

Some of the most employed current controllers were illustrated in Chapter 4, showing that many control approaches may be implemented, with each of them providing pros and cons under different perspectives. An evaluation was also presented aiming at justifying the use of PRes current controllers in simulations and experimental cases.

The foundation of the CBC algorithm was then broken down into three stages Chapter 5. Its active, reactive and harmonic current sharing methodology was discussed, intending to explain how it provides the interaction between a central controller and each of the active energy gateways. Besides, some brief comments on its, still under-development, advancements and constraints were made to explicit that several aspects need to be further evaluated.

Considering different realistic microgrid scenarios, in Chapter 6 the main contribution of this dissertation was presented, showing several simulation cases with focus on distributed harmonic compensation. It has been proved not only the effectiveness of the harmonic current sharing proposed by the CBC, but also the ability and flexibility to adequately to handle active and reactive terms. The simulations evaluated prospective conditions that will likely be, and already are, faced in single-phase low-voltage grids with high penetration level of DERs.

Although simulations are interesting tools for evaluating the performance of systems, complementary physically experimented results, as the one presented in Chapter 7, are able to solidify such statements. Therefore, the last part of this work first targeted the experimental implementation of a single-phase low voltage microgrid, comprising two full-bridge SPIs, with nonlinear load, being able to operate in grid-connected mode. Secondly, the operational capability of the CBC was preliminarily tested considering different operational goals for the grid current at the PCC. It was demonstrated that this methodology can be implemented for real applications, providing active, reactive, and harmonic sharing among distributed SPIs.

As final conclusion, it can be lastly said that the CBC was presented as a new and interesting alternative to provide coordination of DGs, power conditioners, and any other active elements that could interconnect with AC single-phase low-voltage microgrids. Active, reactive and harmonic sharing is achievable through this methodology, in way of that the power capabilities of the EGs are always respected, also allowing a balanced and proportional participation of all agents. The CBC can be, therefore, considered for playing a key role on the forthcoming small-scale distributed energy paradigm.

8.1 Future Works

Although several cases and scenarios were approached in this work, there still remains many questions that should be further evaluated for the consolidation of the Current-Based Control algorithm, and also its proposed methodology for sharing active, reactive and harmonics terms. Therefore, some of the following suggestions are left for development in future work:

1. Extension of the CBC methodology to be applied on current sharing among SPIs in three-phase three- or four-wire systems;
2. Further study the feasibility of the CBC operation considering different microgrid topologies, i.e. meshed and ring shaped, and also with more diversified technologies of DGs and power conditioners;
3. Integrate more intelligence to the reactive and harmonic compensation of the CBC by detecting the most critical terms to be mitigated and adaptively reorganizing the allocation of current capabilities;
4. Build a dense study on the stability matter of the distributed control provided by the CBC;
5. Analyze the impacts, issues and benefits of the CBC methodology under data transmission perspective, focusing on packet losses, intermittent transmission and delays in delivery windows;

6. Compare the effectiveness of the CBC in relation to other hierarchical and decentralized control methodologies, such as the PBC algorithm, and also droop-based approaches;

7. Study how the CBC and the Conservative Power Theory could be integrated to provide current sharing focusing on resistive load synthesis instead of sinusoidal current synthesis.

8. Evaluate if it would be possible to coordinate, based on the CBC, dispersed single-phase SPIs arbitrary connected in different phases of three-phase networks;

9. Expand the actual prototype developed to insert more SPIs, loads and line impedances for evaluation of more complex microgrid scenarios;

10. Implementation of a three-phase laboratory-scale prototype for evaluating the CBC and other distributed control methodologies;

11. Provide a more detailed and specific study on the impacts caused by the CBC operation in other nodes than the PCC, in regard to power quality conditions power losses;

12. Evaluate how the CBC could be enhanced in order to extend its operation to a multi-objective approach, not only aiming a global goal at the PCC, but also respecting local conditions in other specific nodes.

8.2 Correlated Publications

As part of the development of this work, and also throughout the studies directly and indirectly discussed on this master's dissertation, the following correlated publications occurred.

1. BRANDAO, D. I.; ALONSO, A. M. S.; MARAFAO, F. P.; MATTAVELLI., P.; CALDOGNETTO, T. Current-based hierarchical control for active, reactive and selective harmonic current sharing in smart microgrids. *IEEE Transactions on Power Electronics*, 2018. **SUBMITTED**

2. ALONSO, A. M. S.; BRANDAO, D. I.; MARAFAO, F. P. Controle coordenado de inversores multifuncionais para compensação distribuída de harmônicos em microrredes monofásicas de baixa tensão. In: *XXII Congresso Brasileiro de Automatica (CBA)*. [S.l.: s.n.], 2018. **SUBMITTED**

3. SAVOI, L.; ALONSO, A. M. S.; FERREIRA, W. M.; COUTO, H.; BRANDAO, D. I.; MARAFAO, F. P. Estratégia de controle para coordenação de conversores monofásicos e trisáficos distribuídos em microrredes. In: *XXII Congresso Brasileiro de Automatica (CBA)*. [S.l.: s.n.], 2018. **SUBMITTED**

4. FERREIRA, W. M.; BRANDAO, D. I.; SILVA, S. M.; ALONSO, A. M. S.; MARAFAO, F. P. Otimização multiobjetivo aplicado ao controle centralizado de uma microrrede de

baixa tensão: Controle de fluxo de potência e compensação de desbalanço. In: *XXII Congresso Brasileiro de Automatica (CBA)*. [S.l.: s.n.], 2018. **SUBMITTED**

5. MARAFAO, F. P.; ALONSO, A. M. S.; GONCALVES, F. A. S.; BRANDAO, D. I.; MARTINS, A. C. G.; PAREDES, H. K. M. Trends and constraints on brazilian photovoltaic industry: Energy policies, interconnection codes and equipment certification. *IEEE Transactions on Industry Applications*, 2018. **ACCEPTED**

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