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REVIEW ARTICLE
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# Review of Control Techniques in Distributed Power Generation Systems

## Revisión Sobre Técnicas de Control en Sistemas de Generación Distribuida de Energía

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**ABSTRACT.** In this document are revised different control techniques applied to distributed generation systems, including control of active-reactive power, load-frequency control and the identification and control of island mode operation of the generation units, which are the main themes identified. The different control strategies identified are PID, robust, predictive and fuzzy, with applications in the aforementioned subjects. Particularly, applications for the interconnection of generation units and the control of the electric power conversion system DC-AC (inverter) are observed.

**keywords:** Control, Distributed Generation, Power, Review.

**RESUMEN.** En este documento se realiza la revisión sobre diferentes técnicas de control aplicadas a sistemas de generación distribuida. Sobre las principales temáticas identificadas se tiene el control de potencia activa-reactiva, el control de carga-frecuencia y la identificación y control del funcionamiento en modo de isla de las unidades de generación. Sobre las diferentes estrategias de control identificadas se tiene: PID, robusto, predictivo y difuso, con aplicaciones en los temas antes citados. Particularmente se aprecian aplicaciones para la interconexión de unidades de generación y el control del sistema de conversión de energía eléctrica DC-AC (inversor).

**Palabras clave:** Control, Energía, Revisión, Generación Distribuida.

## 1 | INTRODUCTION

Currently, electric energy demands are arising worldwide, whence power plants and transmission lines must be designed attending the demands of consumers. In this regard, the Distributed Generation (DG) costs are lower than those for a power plant and the expansion of the system distribution and transmission. Adequate

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strategies to interconnect the microgrids are mandatory to both to satisfy the increment of charge power as well as the reliability of energy supply.

Likewise, DG systems using a renewable source of energy show an accelerated development. Under this approach, hybrid systems can be used to combine more energy sources; despite the advantages provided by the DG, problems like oscillations in the system frequency, breaches in the energy capacity of the lines, and the increase of voltage may arise. In this regard, there are several strategies for voltage control, particularly, methods of reactive power control which have demonstrated to achieve voltage production inside permissible ranges without reducing the active power.

This paper focuses in the review of the different control strategies for DG systems. Some review studies related to Distributed Generation systems are observed in [1, 2, 3, 4, 5, 6].

Concerning the review of energy conversion systems using inverters, a recounting of the parallel operation of inverters and power filters of active power in Distributed Systems is made in [1]; besides, [2] reviews the topologies and control strategies of inverters connected to multi-functional networks to improve the power quality.

Meanwhile, [3] makes a review of the literature about load-frequency control to conventional and distributed generation systems. The objective of the Load-Frequency Control (LFC) in an interconnected system consists of keeping the frequency in each area into the boundaries and keep the power flow inside some predetermined tolerances through the adjustments in the outputs of the generators.

Another referential paper is [4] where power generation based on an integrated system of renewable energy takes place particularly observing the configurations, storage options, size and control systems.

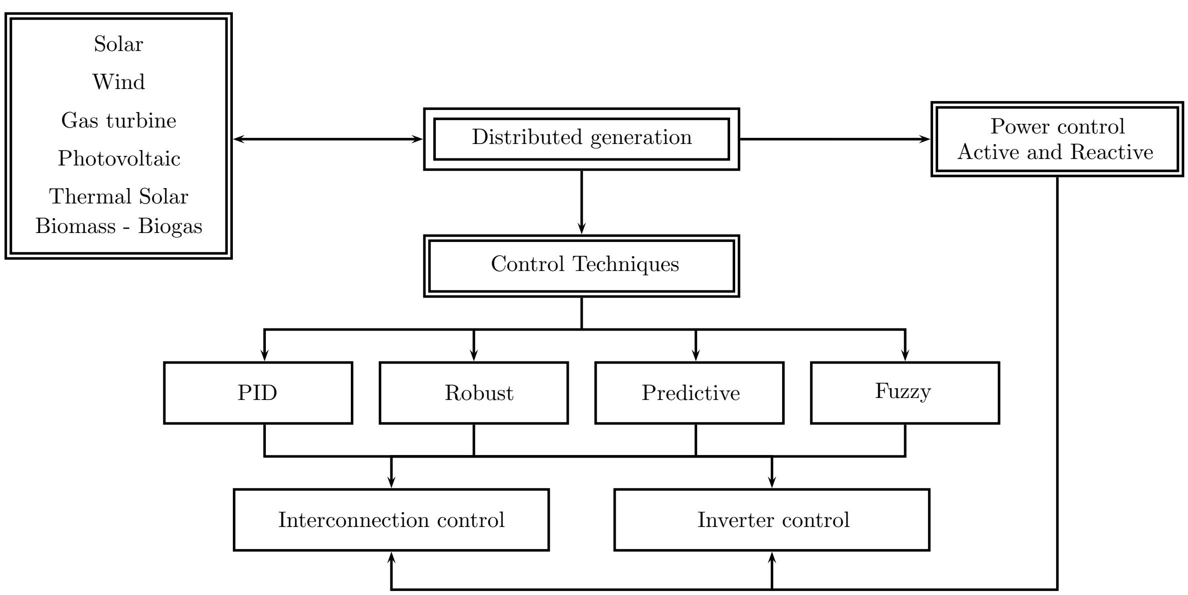


**FIG. 1** Main characteristics identified.

Besides, [5], [6], and [7] is made a recount on the about the control of distributing electric energy systems for applications in microgrids. In [8] can be seen a review of the computational intelligence techniques employed to detect the isle mode functioning of units of distributed generation.

Another aspect considered for distributed generation systems include the methods to locate generators; in this regard, [9] reviews the problem of assigning of DG from the employed algorithm optimization perspective, the objectives, variables decision, DG type, applied restrictions, and the type of uncertainty modeling used.

Together with these review articles, it can be found others with different orientations of applied systems of control used in distributed generation. The first group of works focuses on different strategies employed for control of active and reactive power. From a control techniques perspective, PID-type, predictive, robust, and fuzzy approaches are the most visible. These works display different strategies and applications of control systems highlighting two approaches: one that is focused in the conversion control system loop of electric energy DC-AC (the inverter). The other approach is focused in the control system for the interconnection of the different units of generation of the distributed system. Fig. 1 shows the mentioned relation of control systems applied to the distributed generation ones.

## 2 | GENERAL APPROACHES ABOUT CONTROL IN DISTRIBUTED GENERATION SYSTEMS

In general, the approaches in distributed generation control systems are the active and reactive power control, the interconnection of units of generation, island detection and remarkably, the control of the proper loops of the DC-AC inverter.

The distributed generation units interconnect with the electric supply network through three-phase inverter whereby the applications for controlling the active and reactive power are focused on the strategies to control the inverter. Some works where some strategies for controlling the flow of power can be seen in [10, 11, 12, 13, 14]. Meanwhile, [15, 16, 17, 18, 19] are works focused on reactive power control.

Another key aspect in distributed generation systems is the interconnection of the different units of generation where it is aimed the reduction of distortion effects of voltage signals to obtain a stable system; [20, 21, 22, 23] are related works. A particularly interesting aspect is the interconnection of hybrid systems, that is, generation units of different nature. These works also focus on energy dispatch, for which techniques of prediction are implemented (forecast) to determine the power necessary to supply in specific moments.

Reference [24] displays a focus to coordinate the injection of power of the distributed generators by offering a method for voltage control of a distribution network based on the voltage sensitivity matrix. This matrix is employed to coordinate the complex power injection of the distributed generators, which is determined by observing the effect that each generator has on the nodes in the distribution network.

Operation in Islanding mode is the situation by which a distribution system is electrically isolated from the rest of the generation system and yet it keeps power over a some time. Applications focused on detection and control of the phenomenon are seen in [25, 26, 27].

Finally, several works with the development of strategies can be seen being the inverter the element by which the connection and the energy conversion are made. Such developments aim towards the regulation of electricity, the voltage, and the power supply. Some works on inverter control system can be seen in [28, 29, 30, 31, 32].

## 3 | PID CONTROL

Regarding PID (Proportional, Integral, and Derivative) control applications there exist the control of different generation units, control of the in the interconnection of the generation units, and the control of the proper loops of the inverter.

On the particular control of some generation power plants there exist hydraulic turbines [33], thermal systems [34], wind turbines [35], and photovoltaic systems [36], among others.

In relation with the control of the interconnection of the distributed generation systems, it is observable the works developed in [37, 38, 39, 40, 41] where optimization algorithms are also employed to adjust the control parameters.

Regarding the inverter, in [42] is shown the design of a resounding controller, while in [43] is shown an interface design to integrate the solar photovoltaic generation systems.

Finally, [44] introduces an improved scheme of the Voltage Oriented Control (VOC) to control an inverter connected to a triphasic network. The inverter is considered the central part of the System of Distributed Generation. An optimization method is employed to recursively adjust the controller parameters PID aiming to achieve an ideal performance of the DG unit connected to the network.

# 4 | ROBUST CONTROL

In relation to applications of robust control in systems of distributed generation were mainly identified the interconnection of the control units and the control of the element of conversion of energy (inverter).

Some applications of robust control for interconnection of generation units are observed in [45] for voltage control, in [46, 47, 48] for frequency control and in [49] for conditions of unbalance. Particularly, designs based on $H_\infty$ are presented in [50, 51, 52].

About robust control applications emphasized on the loops of the inverter control, in [53] a robust predictive scheme is presented with intrinsic synchronism for the direct power control. Meanwhile, [54] shows a design of robust control for distributed generation in microgrids using direct control of voltage. In [55] the Lyapunov method is applied for the stable functioning of distributed generation based on a multilevel converter. Moreover, [56] displays the design of a regulator in sliding mode to supply the maximum power. Finally, [57] presents a hybrid robust control for an inverter DC-AC of one single phase with variations in the input voltage.

# 5 | PREDICTIVE CONTROL

About this technique, in [58] design of a predictive control system for a four-arms inverter is presented. Another application [59] consists of the dispatch of energy which is made for the predictive control for the distributed generation.

Another observed application for the predictive control technique consists of the interconnection among the units of distributed generation; in this regard, [60] compares the centralized and distributed predictive control schemes for the regulation of damped electromagnetic oscillations. In addition, [61] and [62] propose predictive control systems for Load Frequency Control (LFC). Those systems aim that after a change of load in each area the frequency error is suppressed in a permanent regimen; moreover, each area must also keep the power flow programmed. Meanwhile [63] shows a study about energy management in local microgrids based on predictive control strategies. On the other hand, [64] presents the design of a stochastic predictive control for energy dispatch in an eolian park. Another work to consider is in [65] where the Economic Dispatch (ED) is incorporated for the operation of a microgrid proposing a methodology of predictive control. The control system is completely distributed, and each distributed generation system is able to communicate with other nodes for the iterative calculation of the optimization process. A microgrid with different sources of energy is simulated to determine the performance compared with a strategy of centralized control.

# 6 | FUZZY CONTROL

There are different applications for this technique, which include:

- PID fuzzy control
- Disturbance detection
- Detection in Island mode operation
- Energy dispatch
- Interconnection of distributed generation systems
- Control of the inverter

## 6.1 | PID Fuzzy control

These applications combine the strategy of conventional control PID with the scheme of approximate reasoning of the fuzzy systems. Particularly, [66] and [67] show the design of PID control systems with gain scheduling. Through the information provided to the fuzzy system the PID controller parameters adjustment is made. Similar work is observed in [68] where a supervised scheme is proposed based on a fuzzy system to adjust the parameters in a PID controller.

Another application that includes a PID adaptive controller is shown in [69], where the loop of the inverter control is detailed presented for the power control and synchronism with the network. Meanwhile, in [70] takes place the optimization of PID fuzzy controller using the differential evolution algorithm.

### 6.2 | Disturbances detection

In relation disturbances detection [71] studies this type of applications for disturbance detection in eolian parks using a neuro-fuzzy system. Moreover, [72] proposes a neuro-fuzzy methodology to determine the load margin when having intermittency in the sources.

### 6.3 | Island mode functioning detection

An approach to the problem of detection in island mode in distributed generation using fuzzy logic can be seen in [73], while [74] develops a fuzzy logic system with a time-frequency hybrid focus for sources of distributed generation. Finally, in [75] a scheme is proposed for island mode detection using Wavelet filtered and a neuro-fuzzy system.

### 6.4 | Energy dispatch

About energy dispatch [76] and [77] show an application for dispatching energy employing fuzzy logic. Here, a sequential quadratic programming algorithm is used to obtain an optimal solution for energy distribution among multiple units of distributed generation. Later, a fuzzy system is implemented to put into practice the optimal strategies previously found. In addition, the parameters of the fuzzy system were adapted by a genetic algorithm; meanwhile, in [78] ca be seen a strategy employed for the prediction of time series to regulate the dispatch of energy.

### 6.5 | Interconnection of distributed generation systems

On works focused on the interconnection of units of distributed generation, in [79] design of a fuzzy system is made for the load frequency control for a multi-area generation system.

Furthermore, in [80], [81], and [82] present a study for the interconnection of units of generation of different nature like fuel cells and bank of batteries. Other strategies of fuzzy control for the interconnection of hybrid systems can be seen in [83] and [84]. The implementation of evolutive algorithms for optimizing the control systems is a particular remark of these works.

In addition, [85] presents the robust fuzzy controller design for an isolated generator connected to an infinite barrage to foretell changes present in the load.

Finally, [86] presents a control system for the interconnection of distributed generation resources to electrical networks by power electronic converters. It is proposed a fuzzy adaptive control system based on the theory of stability of Lyapunov for the converter power loop. With the proposed scheme of control is aimed at an adequate follow-up the current of reference to provide a suitable dynamic response.

### 6.6 | Control of the inverter

Concerning the control strategies focused in the inverter control loops in [87] and [88] can be seen the application of neuro-fuzzy systems in different parts of the system of energy conversion.

Regarding other applications, in [89] is presented the design of a fuzzy controller for a micro-turbine in a distributed generation system. In [90] is observed an application for controlling a fuel cell; in this work is performed the regulation of voltage. Finally, [91] presents the design of a fuzzy controller for an induction generator with a double set of stator coils.

### 6.7 | Discussion

Different approaches can be identified for the control on systems of distributed generation with this revision which, in the first place, obey the variable to control and, in second place, they also obey the focus of the control system. It is remarkable the application of techniques of computational intelligence with neural networks and fuzzy logic as the system of distributed generation presents a degree of complexity where the techniques of soft computing can be a good alternative to implement.

## 7 | CONCLUSIONS

Through this review were visible the most relevant characteristics of the control techniques in distributed generation systems.

As seen through the review the fuzzy control technique presents a higher number of applications, which shows its flexibility to be implemented in different applications of distributed generation.

This review also allows observing the possibility to create new control techniques applied to distributed generation. An alternative consists of a non-linear control technique based on fuzzy sets which can be a type-supervised identifying the power plant to perform the control.

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