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# Microgrid management with a quick response optimization algorithm for active power dispatch

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ABSTRACT

A fast response algorithm has been developed for active-power dispatch to microsources in a distributed generation microgrid. It is capable of adjusting microgrid generation to demand on-line in grid-connected-mode. The algorithm performs an optimization of fuel consumption and emissions costs functions, of microsources using a heuristic approach. It and has been tested to solve different power dispatch cost optimization problems. The tests realized show a maximum execution time of about 1 ms, which is several orders of magnitude faster than the results obtained with other state-of-the-art optimization methods currently employed in these applications. It has also shown better performance in terms of global cost and microsources stability. The fast response implies a substantial reduction of the computational resources needed, allowing the use of a low-cost programmable logic controller or microcontroller for microsources active power dispatching. Thus, the infrastructure requirements and new investments are reduced and the penetration of microgrids based on renewable energies is improved.



## 1. Introduction

Distributed generation can be defined as high-efficiency, low-power generation located close to the demand, allowing energy to be generated near the place where it is consumed, thus minimizing losses in transport and distribution. It includes renewable technologies (wind-power, photovoltaic, biomass, etc.) and high efficiency non-renewable technologies (internal combustion engines, gas turbines, fuel cells and microturbines). The high penetration of distributed generators is a challenge for electrical distribution systems because requires a change in operation strategies and design.

Although the effects of distributed generation may appear to be entirely favorable (environmental benefits, reduction of distribution losses, power reliability, no necessity for new investments, better voltage and electrical power quality, better system stability, easy expansion based on off-the-shelf products, etc.) indiscriminate application of individual distributed generators may cause problems of integration in the electrical system such as: an increase in losses in the distribution system [1]; the necessity to develop new strategies to protect and operate the systems; and a deterioration of the voltage quality in some circumstances [2].

The microgrid (MG) concept involves optimization of the benefits of distributed generation, associating systems composed of distributed generators to loads in a reduced space, so that they are supplied with electrical energy and in some cases with heat (combined heat and power). MGs are connected to the main grid using a simple point of connection sometimes referred to as the point of common coupling [3,4]. MGs can also include storage devices such as batteries, flywheels, etc. These elements are included to compensate for the slow response time of fuel cells, and microturbines to complete the demand required. In [5] an overview of real microgrids set up to work for testing in different projects and countries is developed. It is important for microgrids to be designed to run both in connected-to-the-grid mode and in island mode.

The proximity of microsources and loads in MGs is favorable for the design of MG management systems which, without needing complicated communication infrastructures can optimize microsources operations. Furthermore, the integration of MGs in the electrical system is achieved, without re-designing or re-engineering the system itself [6]. Nowadays, optimization of the operation is considered one of the main topics of research in microgrids [7–11]. Optimization can be achieved according to different criteria. In this work, we adopt two requirements for connected-to-the-grid mode: minimizing costs and adjusting the production of electrical power on site according to demand. This means that the impact of MG integration in the main system is reduced [12].

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It must be taken into account that minimizing costs, specifically fuel consumption costs and environmental costs, implies a selection of a combination of high efficiency and low fuel cost per kW h.

Previous works have designed and implemented software tools to optimize the operation of microgrids but they do not focus on minimizing fuel consumption and greenhouse emissions cost. They are run off-line, so they rely on demand and generation forecasting. In addition, they require specific hardware and software and in some cases, the intervention of highly qualified technicians. The final objective of this work is to promote the penetration of MG into electrical systems through the design of simple software tools that can be easily programmed and run on-line in a low-cost programmable logic controller or microcontroller.

A simple heuristic algorithm for active-power dispatch based on electrical generation cost functions of microsources is proposed. When compared to other state-of-the-art algorithms based on the same principles (minimizing costs and adjusting production to electrical demand) but using exact mathematical approaches, the proposed algorithm not only achieves results with lower global cost, but also gives more stable running conditions in an infinitesimal fraction of the time that other algorithms require to complete.

In this research, it is supposed that reactive power flow to and from the main grid is minimized by adjusting each microsource power factor to the unit (in each Local Controller) and using condenser batteries to compensate for the reactive consumption of the loads.

## 2. Related work

Microgrid management systems have been the subject of various studies into their different requirements [13]. Active-power dispatching, control of storage equipment, electrical and heat demand management, reactive-power and voltage regulation, system black start function, etc.

Management systems, and in particular functions for sharing the generation of active-power energy in connected mode, have been designed from three different perspectives: allowing seamless integration in the system and assuring active-power energy to microgrid loads avoiding possible operation problems; integrating microsources in the power markets; and minimizing fuel consumption thus reducing emissions generated. The following paragraphs outline these three perspectives.

Research carried out in [14] focuses on the integration of microgrids in the distribution system and its potential to improve power quality and system reliability. This reliability is due to the possibility of intentional islanding when large events in the grid or its power quality fall below certain standards. A non-centralized, or peer-to-peer generated power control, hereinafter called "Autonomous Control" is proposed. This control is designed to run in connected-to- the-grid and as well as in island mode, and is integrated in each Microsource Controller. As a consequence, neither a large amount of data, nor very fast sensors are required; the effects of a Central Controller software and communications errors are eliminated; and most importantly, a microsource unit can be placed at any point in the electrical system without re-engineering the system. In this control design, there is not a central active-power dispatch when the microgrid is connected to the main grid. In this case, each microsource can operate in two modes selected by operators in the Microsource Controller: regulating output active-power (in cases of combined heat and power installations depending on the heat demand), or regulating the power flow from the grid. This ensures that energy coming from the main grid stays constant under changing loads conditions, whereas renewable microsources are intermittent sources. In connected-to-the-grid mode, this strategy increases the overall effectiveness of the whole system but does not assure that the running conditions are at the optimum cost.

The second perspective, developed in a project financed by the European Union [15], is focused on including microgrids in the future power markets when in connected-to-the-grid mode. For this purpose a hierarchical-type management is proposed. The MG is controlled and managed by a Microgrid Central Controller that heads the control system. At a second level, controllers located at loads or at groups of loads and at microsources exchange information with the Central Controller and are in charge of their operation. The Central Controller, installed at the substation, operates as a master of the whole system and includes several control functionalities in normal connected-to-grid mode. These functionalities are: dispatching of active and reactive-power to microsources; demand management and control of connection of different elements; and short term tools for forecasting mainly electrical and heat demand and generation capabilities. The small amount of data needed to exchange between network controllers and the reduced dispersion of microgenerators and loads allows the use of a low-cost communication infrastructure. In this project a complex function for active-power dispatch (for normal connected mode), which is integrated in the main control system of the Central Controller and which is a module of a management software tool is described [16]. It is based on a forecast of load and renewable production and information coming from an open market. The result is an economical energy production plan consisting of the settings of the microsources and loads to be supplied over the next hours. However, there is no control of economic or environmental costs and there is no possibility of on-line running which would allow microgrid generation to adapt to demand variations.

The third line of research, more focused on cost and environmental issues, is based on the principles proposed in [12]. These include: minimizing fuel consumption and emissions costs as well as adjusting microgrid production to its demand, avoiding the effects of consuming/injecting energy to and from the main grid. With the same objectives, recent research [17,18] is focused on designing an active-power-dispatch function for connected mode, which minimizes fuel consumption and maintenance costs as well as emissions. At the same time, it constrains power generation to fulfil the local energy demand, making it possible to be implemented in a Central Controller. In this strategy there is no participation of the microgrids in the electrical market but the dispatching function can run on-line and large-scale integration of low-power microgrids in the distribution system (installed in buildings, small production enterprises, etc.) can be achieved. There is a highly non-linear optimization problem to be addressed with regards to the dispatching function, and [17] proposes various mathematical methods to solve it: MADS (mesh adaptative direct search), SQP (sequential quadratic programming) and genetic algorithms. The best results are obtained with SQP. In [17] the whole issue is considered as a single objective problem of costs minimization, while in [13] the problem is solved with a perspective of multiobjective optimization.

## 3. Problem definition

The objective of the research is the design of an on-line method for active-power dispatching to non-renewable microsources in connected-to-the-grid operation. It can be implemented in a Central Controller while renewable microsources are assumed to be working at the maximum power that the environmental conditions allow.

In this investigation, the active-power dispatch functionality of a microgrid has been considered as an on-line solution of different non-linear programing (NLP) optimization problems for each value