

A review of experiences in microgrid optimization as a step towards dynamic electrical topologies

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Abstract— This paper presents a review of interesting experiences related to optimization in microgrid. These experiences have been classified according to the optimization designs that they have. Too, is presented a summary and discussion of the main optimization implementation experiences and the stage of the microgrid project they have been developed. The purpose is to have a state of the art and a starting point for subsequent investigations that lead to having dynamic electrical topologies that allow new optimization techniques in microgrids, especially in direct current microgrids, based on the dynamic change in physical infrastructure of the microgrid during its operation. Those investigations encompassing a similar set of optimization applications have also been considered.

Keywords—Microgrids, optimization, distributed generation.

I. INTRODUCTION

Microgrids (MG) are especially useful for small-scale applications where supply at small loads is desired and with the possibility of implementing local technologies for power generation, storage and distribution. A MG is made up of a group of charges and micro sources that operate as a single system that provides thermal and electrical energy. Another definition establishes that a MG is a low voltage (LV) electrical grid with consumers and producers that allow the export of energy in some circumstances, as well as working in isolation in emergency situations [1].

In [2] a numerical modeling and simulation of a MG in which a power and energy manager is integrated between micro sources (PV plant, wind turbines, electrical storage), electrical loads and the utility network (UN) is presented; and they have developed strategies for directing the flow of energy and power based on demand and supply balances, maintaining nominal work voltages.

In [3], the interconnection processes between direct current MGs (DC MG) are studied and propose a system of operating sub-voltages that can allow the exchange of energy through defined and constant powers for a certain time, called “period” or “state”, equivalent a few minutes depending on the electrical-mechanical inertia and associated storage in the interconnection.

In [4], a proposal is presented in which several energy actors are located in a valley operating under the concept of MG - called Smart Valley -; where biomass is used for local electricity production and biomass management throughout the year in order to produce enough biomass for electricity generation. For this, the information exchange between the different actors (farmers, biomass processing plants, biomass burning power plant, UN, and electrical loads) is considered. In this proposal there is now an element that is transported within the Valley: biomass, which depending on demand can have a surplus (and that is stored) or a deficit; amounts that are used for planning the crops, scheduling and entering (purchasing) of electricity from the utility network.

In [5] the implementation of the strategy described in [3] to the operation of a household electrical load with the actual operating considerations is reported. They discover that central and distributed storage (located in loads, microsources and point of common coupling) is of fundamental importance and with this, new forms of storage participation are proposed.

Optimization is the action and effect of optimizing, which is, finding the best way to carry out an activity. Optimization processes are strongly related to the economy of the electricity business; which includes the payment of taxes and the like, depreciation, maintenance, sales, administration and general expenses; user services (tickets and others), transmission and distribution, fuel costs, return on investment, among others [6]. Given that this becomes a matter of economics, business frameworks are used in the study of this potential market that is being implemented. Figure 1 shows a business scheme.

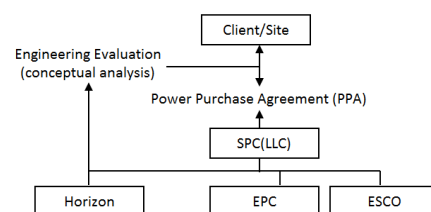


Fig. 1. Horizontal business model of MGs. Horizon box includes solution architecture, high-level integration, testing; EPC have engineering, procurement and construction; ESCO is finance the project operate and maintain; SPC (LLC) are owns the project and tax-basis entity [6].

Therefore, is interesting to know those experiences of MG optimization reported and that are interesting from the perspective of proposing dynamic electrical topologies whose physical connection elements may change during operation. The experiences have been classified into three types depending of the stage in the MG project in which have been developed and they are: (a) during the design and planning of the operation, (b) during operation, and (c) in interconnections between microgrids and with the utility network (UN).

II. EXPERIENCES OF OPTIMIZATION IN MICROGRIDS

A. During the Design and Planning of the Operation.

In [7], a study on analysis, design and validation of distributed generation systems is reported. The electrical arrangement in the service connection to each user is shown in detail in Fig. 2. Each service connection includes the meter and an overcurrent protection element (fuse or circuit breaker for small users). In this, each user is characterized by an allowable maximum current, which corresponds to the nominal current of the overcurrent protection element in the meter cabinet. The distributed generation (DG) source corresponds to micro sources equipped with local storage (batteries or ultra-capacitors) and adequate controls to ensure a concerted regulation between frequency/active power. The considerations on grounding for MGs are the same as those mentioned in the IEC 60364 standard. This study is based on several MG simulations with multi-feeders or multiple MGs connected to the same low-voltage (LV) network.

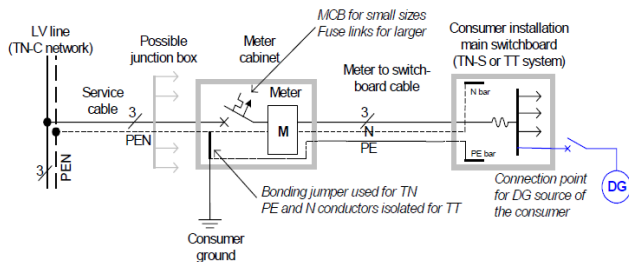


Fig. 2. Typical connection arrangement to the UN [7].

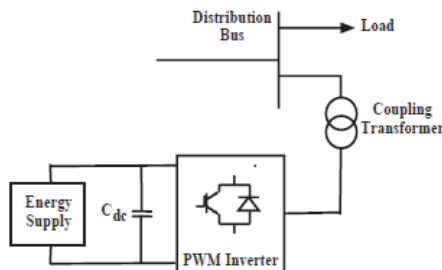


Fig. 3. Schematic diagram for the DC MG proposed in [8].

In [8], an investigation on the steady state performance of Voltage Source Inverter (VSI) devices connected in parallel to the radial distribution electrical grid (see Fig. 3) is reported for the purposes of: voltage regulation, including D-STATCOM's and active interfaces for

Distributed Generation (DG), as also, optimization algorithms developed to calculate the active and reactive power injection required to achieve an optimal voltage profile through the grid for injection sites and already established load conditions. The optimization method ensures the steady state performance of the algorithms used to control these devices. One of the two optimization techniques for electrical systems are: off-line (for example, for generation planning and economic generation dispatch) and that in the event that the MG has central control, it makes computationally expensive and with costs prohibited for rural applications; therefore, they present an off-line tool for planning distribution networks. The algorithms used to control VSI devices are typically calculate injection parameters based on local measurements, thereby ensuring an acceptable voltage at the injection point.

In [9] the economic analysis and environmental impact of the integration of a photovoltaic (PV) panel arrangement within an electric-diesel system for remote villas are discussed. The economic part of the model calculates the fuel consumption, the kW-h obtained per gallon of fuel supplied, and the total cost of fuel. In the environmental part, the model calculates CO_2 , particulate matter (PM) and NO_x emitted into the atmosphere. The simulations are based on a current system in the remote community of Lime Village, Alaska (see figure 4) where three cases were developed: 1) diesel only; 2) diesel-battery; and 3) PV with diesel-battery using a period of one year. The simulation results are used to calculate the recovery of the investment made, the return on investment time for the PV modules and the avoided costs of CO_2 , NO_x and PM. The data that is input to the model is acquired using a Remote Terminal Unit (RTU) that was first installed on the site. The TRU serves for remote data collection and system control while also providing information necessary for modeling the hybrid power system. In this way, the RTU and model can be used to optimize the performance of the hybrid power system. The RTU regulates the flow of power to and from the different units depending on the load. Post-simulation analyzes include comparing the results with those predicted by the Hybrid Optimization Model for Electric Renewables (HOMER) and find that the life-cycle cost (LCC) and air emissions resulting from the developed Simulink model are comparable to those predicted by HOMER (see Table 1).

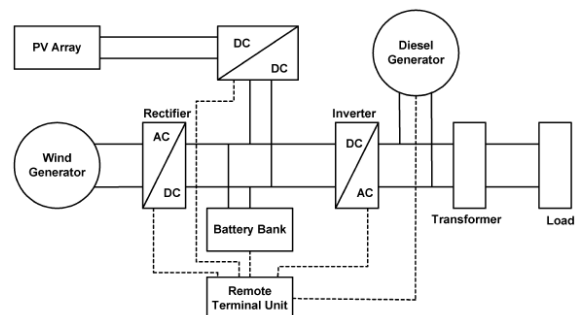


Fig. 4. General diagram of the hybrid electrical system [9].

In [10], is mentioned that the dynamic nature of distribution networks change the stability and effectiveness

of the control of the MG in autonomous mode (see Fig. 6), therefore, they present a non-linear model of a MG operating in autonomous mode. A unique code for modeling, optimization, linearization, and nonlinear simulation in the time domain has been developed. The parameters controllers and power distribution coefficients are optimized in case of autonomous mode. The control problem has been formulated as an optimization problem, where optimization Ant Colony (ACO) is used to find the optimal values of the optimized parameters. In addition, the time-based nonlinear objective function has been proposed to minimize error in power measurement and to improve damping characteristics. They perform non-linear simulations in the time domain to ensure the effectiveness of the proposed controllers under different disturbances and load conditions, the results of which show satisfactory operation with efficient damping characteristics of the MG considered in this study. Voltage source invert (VSI), LC filters, coupled inductances, phase-locked loop (PLL), lines, loads, and power, voltage and current drivers have been modeled. Artificial ants are considered to explore the search space for all possible solutions. The search for ACO begins with a random solution (possibly biased by heuristic information) within the problem decision space. As in nature, as the search progresses over discrete time intervals, ants deposit pheromones in the components of promising solutions. In this way, the environment of a decision space is iteratively modified and the ACO search is gradually pushed towards the most desirable regions of the search space, where optimal or near optimal solutions can be found.

TABLE I
COMPARISON RESULTS WITH HOMER [9]

Parameter	HOMER	Simulink Model
System cost [US\$]	188,983	188,983
System efficiency [%]	29.9	29.96
kW-h per gallon	11.84	12.1
Fuel consumed [gallons]	6,817	6,583
Total cost of fuel [USD]	27,058	26,340
Energy generated		
(a) Diesel engine [kW-h]	87,064	82,497
(b) Battery bank [years]	6.07	5.40
Net present value (NPV) [USD]	585,012	547,322
Emissions		
(a) CO ₂ [Tons]	68.58	64.64
(b) NO _x [Tons]	-	1425
(c) PM [pounds]	-	59.92

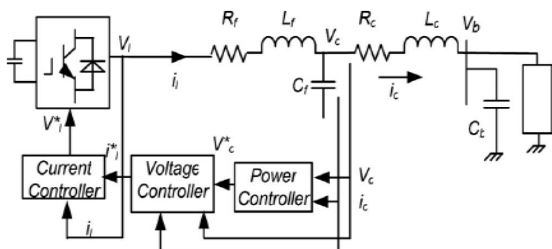


Fig. 5. MG in autonomous mode reported in [10].

B. During operation.

In [11], an analysis is reported to show the technical and economic benefits of a DC MG compared to the usual AC MG considering the socio-economic conditions of a rural area of Bangladesh. The results show that the cost of energy can be significantly lower in the case of the DC MG. The cost comparison between hybrid PV-Diesel AC and DC MG has been considered the following factors: interest rate 10 %, depreciation of panels PV 5%, depreciation of the battery 20%, battery (industrial) 10000 Tk for 100 A-h, 12V; 18 Tk / kW-hr diesel energy price (unsubsidized), land prices and maintenance costs are not included. The DC MG study scheme is shown in Fig. 6. Energy prices for AC and DC MGs are presented in Fig. 7 and 8 respectively. It is interesting to note that, in this paper, the cost of energy is less when the percentage (%) of diesel is lower, which is an important consideration in the design of a small-scale power station and that it encourages the use of the minimum possible participation of diesel in total energy production.

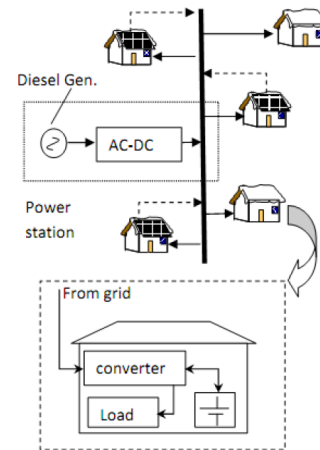


Fig. 6. Schematic diagram for the proposed DC MG. Dotted lines mark the connection of PV to the grid [11].

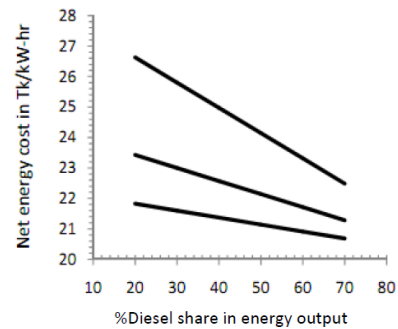


Fig. 7. Net cost of energy with respect to the participation of diesel in the energy output. Lines a, b and c correspond to the PV prices of US \$ 2.5, 2.0 and 1.5 respectively for an AC grid with 24 hours of battery backup [11].

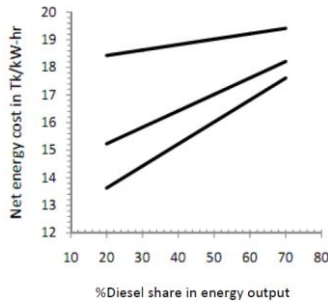


Fig. 8. Net cost of energy with respect to the participation of diesel in the energy that comes out in a DC MG. Lines a, b and c correspond to PV prices of US \$ 2.5, 2.0 and 1.5 respectively with 4 hours of battery backup [11].

In [12] a high frequency (500 Hz) and single phase (HFAC) AC MG is reported, which is shown as a novel solution for the integration of renewable energy sources and the grid in a distributed generation system. A better use of the MG is achieved by solving the problem of power flow and power quality using active filters based on pq theory called: Universal Active Power Line Conditioner (UPLC) and Unified Power Quality Conditioners (UPQC), respectively. A Distributed and Intelligent Energy Management System (DIEMS) is implemented to optimize operating costs. A schematic of the HFAC and DIEMS is shown in Fig. 9. Since optimization generally depends on power generation and the power generated from strongly climate dependent renewable sources, the forecast of power generation is required by DIEMS. A fuzzy ARTMAP neural network is used to predict the optimized output power of each generator hourly and day by day. Fuzzy ARTMAP is a class of Adaptive Resonance Theory (ART) Neural Networks (NN) architecture that performs incremental supervised learning of recognition categories and multidimensional maps in response to input vectors presented in arbitrary order. Depending on the forecast, an optimization scheme is developed using linear programming together with heuristics. The results obtained show the successful implementation of HFAC MG with adequate power flow and energy quality control, as well as the optimization of operating costs by DIEMS with a day-type forecast based on ARTMAP Fuzzy. Improvement in battery life is also achieved, due to optimization of storage charge states using the proposed DIEMS. The function of the system is to generate set points for all sources and storages in such a way that the power dispatch is economically optimized to meet a certain load demand. The proposed DIEMS allow instantaneous optimization of alternative and renewable energy sources. Figure 10 shows the results of two MGs with and without implementation of DIEMS.

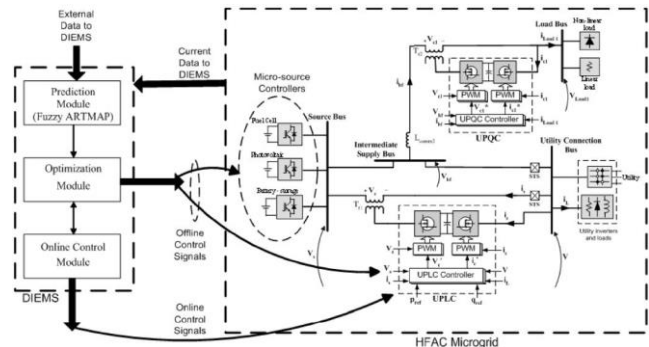


Fig. 9. Single-phase HFAC MG with active filters and DIEMS [12].

	Day Type	Utility (\$)	System (\$)	Storage Reserve (kWh)	Number of Hours (~25% Charge)	Savings (\$)	Savings (%)	Min. Storage (kWh)	DOD (%)
Without DIEMS	Sunny	\$1.45	\$0.84	0.10	6	\$0.61	42.07%	0.10	95
	Cloudy	\$1.23	\$1.01	0.61	14	\$0.22	17.89%	0.10	95
	Very Cloudy	\$1.62	\$1.50	0.36	1	\$0.12	7.41%	0.36	82
	Very Cloudy	\$1.62	\$1.55	0.71	13	\$0.07	4.32%	0.36	82
	Sunny	\$1.45	\$0.85	0.56	0	\$0.60	41.38%	0.56	72
	Total	\$7.37	\$5.75		34	\$1.62	21.98%		
With DIEMS	Sunny	\$1.45	\$0.82	1.50	0	\$0.63	43.45%	0.50	75
	Cloudy	\$1.23	\$0.92	1.20	0	\$0.31	25.20%	0.90	55
	Very Cloudy	\$1.62	\$1.52	1.20	0	\$0.10	6.17%	0.89	55
	Very Cloudy	\$1.62	\$1.49	0.63	0	\$0.13	8.02%	0.53	73
	Sunny	\$1.45	\$0.79	0.51	0	\$0.66	45.52%	0.51	74
	Total	\$7.37	\$5.54		0	\$1.83	24.83%		

Fig. 10. Operating costs for MGs with or without DIEMS [12].

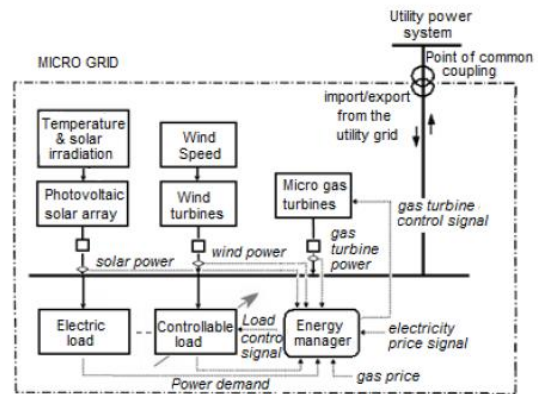


Fig. 11. MG simulated in [13].

In [13] an algorithm for optimizing the dispatch of a MG (see Fig. 11) is reported. The dispatch is the allocation of the demand between the electric generators. The process determines the most profitable cost of operating the power system. The main objective is to minimize the operational cost of all committed units subject to technical and capacity restrictions. Usually there are also restrictions for demand and supply balance. Optimization software based on Branch-and-bound or branch-and-cut techniques, are among the most promising tools for solving what is considered: unit engagement problems. In this study, mixed integral programming algorithms are applied to solve the objective function for the optimization of the dispatch cost; the algorithm evaluates the operating points of the system and moves in the direction of the minimum objective function.

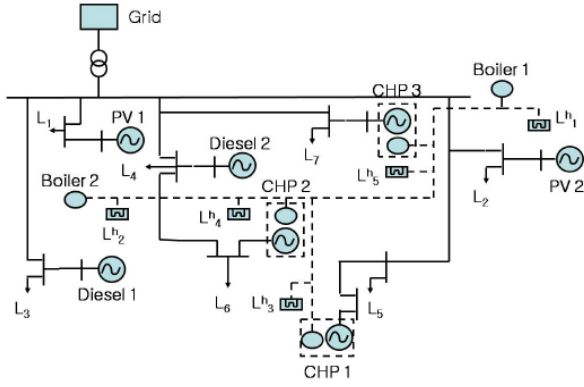


Fig. 12. MG simulated in [14] with .

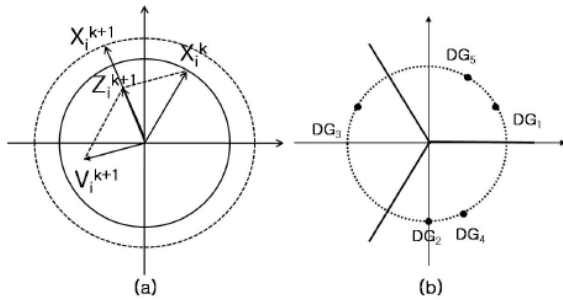


Fig. 13. Phasor space of PDPSO [14].

C. In interconnections between microgrids and with the UN.

In [14] is presented the algorithm Phasor Discrete Particle Swarm Optimization (PDPSO), an effective optimization technique for multidimensional vectors which consist of magnitudes and phase angles. PDPSO is used in the configuration of MGs. MGs can supply electricity to customers and carry out energy transactions through the energy market, by operating the economic dispatch of the various cost functions, through various DGs. If a large number of MGs exist in a distribution system, the algorithm needs to adjust the configuration of the numerous MGs in order to supply energy with minimal generation cost for all users connected to the distribution system (see Fig. 12). Algorithm Discrete Particle Swarm Optimization (DPSO) is one of the typical heuristic techniques that can be applied to the configuration problem of power systems. This modified Particle Swarm Optimization (PSO) algorithm achieves result of the space of continuous search, and achieves fast and correct convergence and wide search space of PSO algorithm. However, if the system has more than one MG, the DPSO algorithm can converge to local optimization and therefore to a global optimum. In the PDPSO algorithm, each component of the particle position vector has a phasor shape where the components of the vector move within a 2-D phasor space, rather than within the circumferential or linear space. The phasor consists of a space that facilitates the arrival of the particle in each MG section, even if there is not a great difference between the numbers of MGs. Each particle position vectors expresses

the configured state of the entire MG in the distribution system (see Fig. 13) [14].

III. DISCUSSION

In the bibliography revised and selected, different MG topologies have been used; there is no standard topology that allows comparing the different optimization algorithms that have been developed in the publications, possibly because the local realities and research interest are totally different for each MG. Of the three types of experiences: (a) during design/construction, (b) during operation, and (c) operation with interconnections; the number of papers is higher for during the design/construction and much less for the operating part with interconnections between MGs. But, in general, all the experiences show fixed electrical topologies and optimization algorithms have been developed on them, this allows the possibility and opportunity for future research to develop dynamic electrical topologies that change according to operating conditions with components that can migrate from one place to another (from one point to another point of the MG, and even, from one point of a MG to a point in another MG) and that can be: electrical storage and some types of micro sources (such as gas micro turbines, cells fuel and flywheels). The algorithms presented are promising in their application to this new conceptual proposal, but care must be taken to research and develop them in such a way that they are adequate because there are no details - in the reviewed publications - of computational costs involved perform these optimization techniques.

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