Hybrid Generation Systems Planning Expansion Forecast: A Critical State of the Art Review

Omar Hazem Mohammed, Yassine Amirat, Mohamed Benbouzid and Tianhao Tang

***Abstract*—In recent years the electric power generation has entered into a new development era, which can be described mainly by increasing concerns about climate change, through the energy transition from hydrocarbon to clean energy resources. In order to power system enhance reliability, efficiency and safety, renewable and nonrenewable resources are integrated together to configure so-called hybrid systems. Despite the experience accumulated in the power networks, designing hybrid system is a complex task. It has become more challenging as far as most renewable energy resources are random and weather/climatic conditions-dependant.**

In this challenging context, this paper proposes a critical state-of-the-art review of hybrid generation systems planning expansion and indexes multi-objective methods as strategies for hybrid energy systems optimal design to satisfy technical and economical constraints.

***Index Terms*—Hybrid energy systems, renewable power generation, generation systems planning expansion, generation unit sizing, energy cost, power generation economics.**

I. INTRODUCTION

In the last ten years production of electric power has significantly increased due to the increased load demand. World statistics indicate that the coming years will see a significant increase in power consumption, which requires the search for energy extra sources that should be of eco-friendly nature (i.e. renewable energies). Although renewable energy penetration in electricity is expected to have a spectacular growth in the forthcoming years, it still however has very low participation rate compared to other nonrenewable energies (Fig. 1) [1].

Renewable energies, such as solar, wind, marine, hydropower, geothermal, and biomass constitute a type of distributed electricity resources and have recently received much attention as alternatives for electricity generation. They supply now somewhere between 15 to 20% of the world total energy demand. Many studies have investigated the potential contribution of renewables to global energy supplies, indicating that in the second half of the 21st century their contribution might range from the present figure of nearly 20% to more than 50% with the right policies in place: About of 30% contribution to world energy supply from renewable energy sources by year 2020 as proposed in [2].

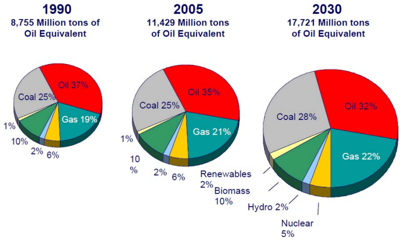

Fig. 1. World electricity energy generation [© IEA].

The main problems with the use of renewable energies have always been how to tap efficiently on the sources and produce sufficient energy for the load demand. Indeed, the energy production using renewable energy sources is often highly dependent on weather and nature conditions. For example, not all climates are suitable for tapping on solar energy; they are more suited for areas near the equator where energy from the sun is accessible all year round. Winds do not blow all the time during these periods. Wind farm turbines would therefore be left idle. To solve this problem and to enhance the energy system reliability, these generation unit should be working together in two or more sources in the so-called hybrid system concept. Hybrid power station concept is not new, but has gained popularity and rapid development in the recent year. There are many types of hybrid energy systems including renewable and nonrenewable sources that have been considered (Fig. 2). Indeed, they offer an alternative and emerging solution for areas where there are substantial resources, leading to a best electricity generating opportunities [3]. The main hybrid energy system layout use diversified renewable resources such as: (1) Diesel, wind turbine, storage battery; (2) Diesel wind turbine, photovoltaic, storage battery; (3) Hydro generation, wind turbine, photovoltaic, storage battery; (4) Wind turbine, marine turbine, photovoltaic, storage battery; (5) Wind turbine, photovoltaic, multi-storage energy; and (6) other configurations that uses classical gas turbine and furl cells.

In this important energy context, this paper is therefore intended as a comprehensive critical state-of-the-art review. In particular, it will deal with a comparative study of methods carried-out to forecast Generation Expansion Planning (GEP) for small stand-alone power systems and general power grid.

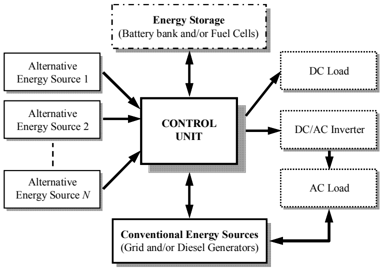

Fig. 2. Hybrid generation systems general architecture.

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The GEP problem is an important issue for decision makers in power utilities. Indeed, GEP specifies optimal sizing schemes, placement, and investments dynamics on generation units to meet the expected energy demand over long-term horizon. The GEP problem is well-known to be a constrained, nonlinear, and discrete optimization problem. Moreover, it inherently involves multiple, conflicting, and incommensurate objectives that should be considered simultaneously [4].

II. HYBRID GENERATION EXPANSION PLANNING METHODS

The methods behind Hybrid Generation Expansion Planning (HGEP), for small autonomous and utility grid power systems, can be classified into three main categories, namely: Reliability analysis; Optimization; and Enumeration.

A. Reliability Analysis

Reliability analysis gathers all the constraints and limitations that are applied and developed in power systems the design to ensure balance between power source and load.

There are many factors for reliability evaluation that are linked to the probability for imbalance between electricity supply and load. The main factors are the *LPSP* (Loss of Power Supply Probability), the *ELF* (Equivalent Loss Factor), the *LOLP* (Loss of Load Probability), and the *LCE* (Levelized Cost of Energy) model [5-6].

B. Optimization

It consists of methods for the objective function representation in optimization equations that use a set of algorithmic steps. As example, for a wind/PV hybrid system optimal sizing and operation, many parameters are considered: wind turbine type, wind turbine capacity, PV panels best tilt angle, etc. Moreover, the followings could also be considered: minimizing the generation system annualized cost (capital cost, replacement cost, operation, and maintenance cost), reduce the fuel consumption while retaining the reliability requirement and CO_2 emission limit, etc. [7-8].

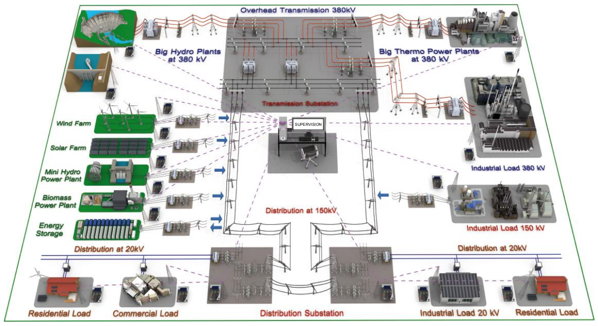
C. Enumeration

Enumeration method and programming algorithm considers various types of techniques to solve the objective function and expansion policy for a given period. There are many computational methods and algorithms to achieve the optimized solution [9-11].

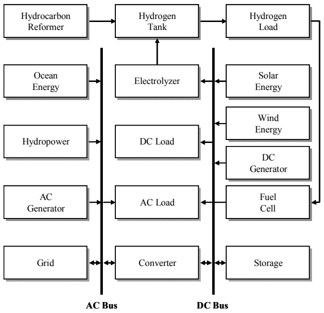
III. HYBRID GENERATION SYSTEMS OPTIMIZATION MODEL

Figure 3 illustrates hybrid generation system energy sources diversity. Indeed, it is clearly shown that there are many hybrid possibilities depending on the available renewable energy sources (i.e. solar, wind, etc.), as well as near or beyond the grid region. In addition to this diversity, there is also power system goals diversity such as size optimization, total coat reduction, gaseous emission reduction, etc.

Hybrid generation system optimization general model is illustrated by Fig. 4. This model show that the objective function mainly depends the system building purposes (i.e. optimal sizing, optimal operation, fuel consumption reduction, etc.).



(a) General overview.



(b) Different components.

Fig. 3. General hybrid power system configuration.

As shown in Fig. 3, a typical hybrid generation system comprises different power sources or units. These power units have different impacts on cost, environment, and reliability. In a hybrid generation system, they are integrated together and complement one another in order to serve the load while satisfying certain economic, environmental, and reliability criteria. The hybrid system can be operated autonomously or connected to the utility grid whose power is from the conventional fossil fuel-fired generators.

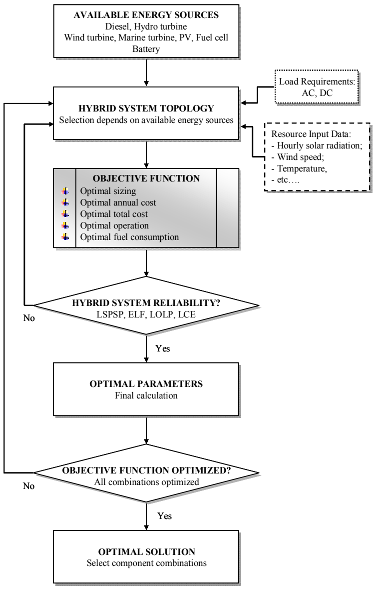


Fig. 4. Hybrid generation system optimization general model.

The optimum design of hybrid generation systems is related to the determination of the optimal configuration of the power system and optimal location, type and sizing of generation units, so that the system meets load requirements, while subjected to physical and operational constraints/strategies [6], [12-13].

A. Objective Function

Hybrid generation systems design can be evaluated through its lifetime cost and emission. The lifetime cost typically consists of Capital Cost (*CC*) and Maintenance Cost (*MC*), together referred to as the fixed cost; in addition to the operational cost. The optimal hybrid generation system therefore seeks a combination of generator types and sizes that result in the lowest lifetime cost and/or emission. Among all possible hybrid system configurations that are optimally dispatched, the configuration with the lowest Net Present Cost (*NPC*) is supposed to be the optimal configuration or the optimal design [6].

$$NPC = \sum_{i=1}^{L} N_i \left(CC_i + RC_i \times K_i + MC_i \times PWA(ir, R) \right) \qquad (1)$$

Where L is the hybrid source number, N_i is the number of each hybrid energy source, and RC is the replacement cost. K_i allows converting replacement cost to present as

$$K_i = \sum_{n=1}^{l_1} \frac{1}{(1+ir)^{nl_2}} \qquad (2)$$

where l_1 and l_2 are the hybrid unit replacement time and lifespan, respectively (for sources, that lifespan is equal to the project one, $K_i = 0$), ir the interest rate (sometimes considered equal to 0.05 or 0.06). PWA is used to convert operation and maintenance annual costs to present as

$$PWA(ir, R) = \frac{(1+ir)^R - 1}{ir(1+ir)^R} \qquad (3)$$

where R is hybrid power system lifespan.

The optimization methods aim is therefore minimizing the *NPC* objective function.

B. Reliability Analysis

Owing to the intermittence of renewable energy sources, power system reliability is considered as an important step in the hybrid power system design process. Power system reliability concept is extremely broad and covers the system ability aspects to satisfy load requirements. There is a reasonable subdivision of the concern designated as *system reliability*, which is represents two basic aspects of a power system: system adequacy and security.

Reliability analyses generally involve *LPSP*, *LOLP*, and *ELF*, which implies the probability for imbalance between electricity supply and load [14-16].

1) LPSP. The most used approach to the application of *LPSP* in a hybrid system design uses probabilistic techniques to integrate the fluctuating nature of the resource and the load. *LPSP*, is in this case described by

$$LPSP = \frac{\sum_{t=0}^{T} \mathrm{Time}\left(P_{available}(t) < P_{needed}(t) \right)}{T} \qquad (4)$$

Where T is hours number (with hourly weather input).

The power deficit time is defined as the time where the load demand is not satisfied by renewable energy sources and the storage is depleted (battery state of charge *SOC* falls below the allowed value $SOC_{min} = 1 - DOD$, where *DOD* is the depth of discharge).

The needed power by the load side can be expressed as

$$P_{needed}(t) = \frac{P_{AC\_Load}(t)}{\eta_{Inverter}(t)} + P_{DC\_Load}(t) \qquad (5)$$

and the available power generated from the hybrid source is given by

$$P_{available}(t) = P_{WT} + P_{PV} + ... + P_{HYBRID} + CV_{bat} \times Min\left[I_{bat\_\max} = \frac{0.2C'_{bat}}{\Delta t}, \frac{C'_{bat}\left(SOC(t) - SOC_{\min} \right)}{\Delta t} \right] \qquad (6)$$

where C is a constant (0 for a battery charging process and 1 for the discharging process), C'_{bat} is the available or practical battery capacity, and $SOC(t)$ is

$$SOC(t+1) = SOC(t)\left(1 - \frac{\sigma \Delta t}{24} \right) + \frac{I_{bat}(t) \Delta t \eta_{bat}}{C'_{bat}} \qquad (7)$$

σ is the self-discharge rate that depends on the accumulated charge and the battery state of health [17].

2) LOLP. It is a basis for accurate and consistent reliability evaluation of hybrid power systems, where component failure and load demand are stochastic in nature [18-19]. Hybrid renewable energy systems reliability analysis uses a capacity outage probability table, which is an array of capacity levels and the associated existence probabilities. This is achieved by combining the generating unit availability and unavailability using probability basic concepts. From the individual probability table, a cumulative probability one is derived. Figure 5, schematically shows the basic elements used to assed power generation adequacy [20].

A hybrid power system is considered to operate successfully as long as it has enough generating capacity to provide the load demand. The cumulative probability of a particular capacity outage state of X-MW after adding a 2-state unit of capacity C-MW with a forced outage rate γ is given as [19], [21]

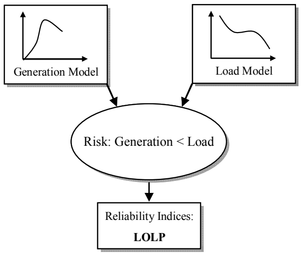


Fig. 5. Generation reliability evaluation basic elements.

$$P'(X) = (1-\gamma)P'(X) + \gamma P'(X-C) \qquad (8)$$

where $P'(X)$ and $P(X)$ denote the cumulative probabilities of the capacity outage state of X-MW before and after the unit is added. $P(X)$ is also the capacity outage probability being greater or equal to X. The above expression is initialized by setting

$$P'(X) = \begin{cases} 1 & \text{for } X \le 0 \\ 0 & \text{otherwise} \end{cases}$$

and the forced outage rate γ is given by

$$\gamma = \frac{\text{Forced outage (hours)}}{\text{Forced outage (hours) in service hours}} \qquad (9)$$

Equation (8) can be modified to include multi-state unit representations.

$$P(X) = \sum_{i=1}^{n} p_i P'(X - C_i) \qquad (10)$$

Where n is the unit states number, C_i is state i capacity outage for the unit being added, and p_i is unit state i existence probability [19], [21]

$$p_i = \sum_{Z=k}^{n} \binom{n}{Z} \gamma^Z (1-\gamma)^{n-Z} \qquad (11)$$

where k is the required units minimum number and

$$\binom{n}{Z} = \frac{n!}{(n-Z)! \times Z!} \qquad (12)$$

The overall probability that the load demand will not be met, which is $LOLP$ (loss of load probability on hour j for state i) is finally given by

$$LOLP = \sum_{r=k}^{n} p_i P(L_j > C_i) \qquad (13)$$

where L_j is the forecast peak load on hour j and P is the loss of load probability on hour j.

3) ELF. It is the ratio of the effective forced outage hours to the total number of hours [22].

$$ELF = \frac{1}{H} \sum_{i=1}^{H} \frac{Q(i)}{D(i)} \qquad (14)$$

Where Q is the loss of load, D is the load demand, and H is the time step number. The ELF contains information about both the number of outages and their magnitude.

C. Enumeration Methods

There are many approaches to provide the above discussed optimal design criteria. Several approaches have been used for hybrid power systems optimal design; such as: linear programming [22], evolutionary algorithms [23], Artificial Neural Networks (ANN) [24-25], Fuzzy Logic (FL) [11], [21], [24], simplex algorithm, dynamic programming, stochastic approach [10] [25], iterative and probabilistic approaches [20], design space based approach, parametric and numerical approaches, response surface methodology, matrix approach, and quasi-Newton algorithm [6], [8].

For sizing hybrid renewable energy systems, it has been particularly proposed the so-called methaheuristic methods that include Genetic Algorithms (GAs) [7], [15], [25-26], Simulated Annealing (SA) [27], Tabu Search (TS) [27], and Particle Swarm Optimization (PSO) among others [9], [13]. Metaheuristics orchestrate an interaction between local improvement procedures and higher-level strategies to create a process capable of escaping from local optima and performing a robust search of a solution space.

In addition to the above popular optimization techniques, some promising techniques have been recently indexed for future use in hybrid system sizing; among them: Ant Colony Optimization (ACO) [28], Artificial Immune System (AIS) [29], Artificial Bee Colony (ABC) [30].

Each sizing methodology has its own features and the recently proposed new methodologies have potential for future use to reach a techno-economically optimum hybrid renewable energy system.

IV. HYBRID POWER SYSTEMS SAMPLE APPLICATIONS

To illustrate the above presented techniques and methods, Table 1 shows a brief evaluation of the above presented hybrid renewable energy systems sizing approaches in relevant selected literature. This brief presentation clearly illustrate that selection of the suitable approach may change due to the application type, user requirements, etc. However, it is suggested that metaheuristics are particularly well-adapted for HGEP problem.

V. CONCLUSION

Hybrid renewable power generation systems optimal design is a very challenging task as far as most renewable energy resources are random and weather/climatic conditions-dependant. In this challenging context, this paper has attempted to propose a state-of-the art review that should help in the optimal design of hybrid generation systems to satisfy technical and economical constraints.

REFERENCES

[1] http://www.unece.org

[2] A.K. Akella, R.P. Saini and M.P. Sharma, “Social economical and environmental impacts of renewable energy systems,” *Renewable Energy*, vol. 34, n°2, pp. 390-396, February 2009.

[3] M.H. Nehrir, C. Wang, K. Strunz, H. Aki, R. Ramakumar, J. Bing, Z. Miao and Z. Salameh, “A review of hybrid renewable/alternative energy systems for electric power generation: Configurations, control, and applications,” *IEEE Trans. Sustainable Energy*, vol. 2, n°4, pp. 392-403, October 2011.

[4] J. Aghaei, M.A. Akbari, A. Roosta, M. Gitizadeh and T. Niknam, “Integrated renewable-conventional generation expansion planning using multiobjective framework,” *IET Generation, Transmission & Distribution*, vol. 6, n°8, 773-784, 2012.

[5] D. Abbes, A. Martinez and G. Champenois, “Eco-design optimisation of an autonomous hybrid wind-photovoltaic system with battery storage,” *IET Renewable Power Generation*, vol. 6, n°5, pp. 358-371, 2012.

Table 1. Brief comparison of some main approaches applied for the sizing of hybrid renewable energy systems.

Ref.	Hybrid Sources	Objective Function	Reliability Technique	Optimization Approaches
[4]	GEP problem	Multiple objectives (i.e. minimization of total costs, emissions, energy consumption and portfolio investment risk as well as system reliability maximization)	*LCE*	Linear programming, FL
[5]	Diesel, wind turbine, PV, battery	Satisfy energy requirements with lowest environmental impact	*LPSP*	Sequential Quadratic Programming and multi objective programming
[9], [13]	Utility grid, wind turbine, PV, micro turbine, battery	Power balance constraint, design variable bounds, optimal energy management, optimal cost, technical constraints	*LCE*, *LOLP*, and LOLF (Loss of Load Frequency)	PSO
[15]	Diesel, wind turbine, PV, battery or multi-storage energy	Optimal sizing, optimal economic analysis, optimal operation control, optimal annualized cost, reduce fuel consumption and CO_2 emission	*LOLP* and CO_2 constraints	GA, Markov model, FL, stochastic programming
[25]	Large scale wind farm, energy storage unit ESU)	Decrease the bid imbalance, ESU optimal operation	*LCE*	GA, ANN
[26]	Diesel, different renewable sources	Cost minimization, minimization of total greenhouse gas emissions of the system during its lifetime	*LCE*	Multi objective GA
[27]	Diesel, wind turbine, PV, biodiesel generator, battery	Cost minimization, optimal design	*LCE, sensitive analysis*	Hybrid SA and TS
[28]	GEP problem	Investment and operation cost minimization under constraints	*LOLP*	Metaheuristics comparison: GA, PSO, SI, TS, ACO, etc.
[30]	Wind turbine, PV, fuel cell	Multi objective optimization: total power loss, total electrical energy cost, and total produced emission minimization, and voltage stability index maximization.	*LCE*	Multi objective ABC
[31]	PV, Micro hydro turbine, fuel cell	Optimal economic analysis and design, optimal sizing minimum investment cost	Black box algorithm constraints	Black box algorithm in the basic Downhill Simplex method
[32]	Wind turbine, PV, marine turbine	Optimal sizing , optimal combination, optimal operation	Timescales for reserve requirements, forecasting	Interaction analysis between the variability characteristics of the utility load, wind power generation, solar power generation, and ocean wave power generation.
[33]	Utility grid, wind turbine, PV, marine turbine	Renewable energy sources optimal mixture, optimal control and stability	Limitations and constraints built-on in large-scale integration program	Administration of large-scale integration

[6] O. Erdinc and M. Uzunoglu, “Optimum design of hybrid renewable energy systems: Overview of different approaches,” *Renewable and Sustainable Energy Reviews*, vol. 16, n°3, pp. 1412-1425, April 2012.

[7] A. Arabali, M. Ghofrani, M. Etezadi-Amoli, M.S. Fadali and Y. Baghzouz, “Genetic-algorithm-based optimization approach for energy management,” *IEEE Trans. Power Delivery*, vol. 28, n°1, pp. 162-170, January 2013.

[8] R. Luna-Rubio, M. Trejo-Perea, D. Vargas-Vázquez and G.J. Ríos-Moreno, “Optimal sizing of renewable hybrids energy systems: A review of methodologies,” *Solar Energy*, vol. 86, n°4, pp. 1077-1088, April 2012.

[9] S.A. Pourmousavi, M.H. Nehrir, C.M. Colson and C. Wang, “Real-time energy management of a stand-alone hybrid wind-microturbine energy system using particle swarm optimization,” *IEEE Trans. Sustainable Energy*, vol. 1, n°3, pp. 193-201, October 2010.

[10] Y. Yuan, Q. Li and W. Wang, “Optimal operation strategy of energy storage unit in wind power integration based on stochastic programming,” *IET Renewable Power Generation*, vol.5, n°2, pp. 194-201, 2011.

[11] P. Thounthong, A. Luksanasakul, P. Koseeyaporn and B. Davat, “Intelligent model-based control of a standalone photovoltaic/fuel cell power plant with supercapacitor energy storage,” *IEEE Trans. Sustainable Energy*, vol. 1, n°1, pp. 240-249, January 2013.

[12] X. Wang and J.R. McDonald, *Modern Power System Planning*. McGraw -Hill, April 1994.

[13] L. Wang and C. Singh, “Multicriteria design of hybrid power generation systems based on a modified particle swarm optimization algorithm,” *IEEE Trans. Energy Conversion*, vol. 24, n°1, pp. 163-172, March 2009.

[14] R. Billinton and R. Allan, *Reliability Evaluation of Power Systems*. Plenum Press, 1996.

[15] Y.Y Hong and R.C. Lian, “Optimal sizing of hybrid wind/PV/Diesel generation in a stand-alone power system using Markov-based genetic algorithm,” *IEEE Trans. Power Delivery*, vol. 27, n°2, pp. 640-647, April 2012.

[16] Y.A. Katsigiannis, P.S. Georgilakis and G.J. Tsinarakis, “A novel colored fluid stochastic Petri net simulation model for reliability evaluation of wind/PV/Diesel small isolated power systems,” *IEEE Trans. Systems, Man and Cybernetics, Part A: Systems and Humans*, vol. 40, n°6, pp. 1296-1309, November 2010.

[17] D. Guasch and S. Silvestre, “Dynamic battery model for photovoltaic applications,” *Progress in Photovoltaics: Research and Applications*, vol. 11, pp. 193-206, 2003.

[18] R. Karki and R. Billinton, “Reliability/cost implications of PV and wind energy utilization in small isolated power systems,” *IEEE Trans. Energy Conversion*, vol. 16, n°4, pp. 368-373, December 2001.

[19] R. Billinton and R. Karki, “Capacity expansion of small isolated power systems using PV and wind energy,” *IEEE Trans. Power Systems*, vol. 16, n°4, pp. 892-897, November 2001.

[20] J. Huang, Y. Xue, Z.Y. Dong and K.P. Wong, “An efficient probabilistic assessment method for electricity market risk management,” *IEEE Trans. Power Systems*, vol. 27, n°3, pp. 1485-1493, August 2012.

[21] S. Narasimhan and S. Asgarpoor, “A fuzzy-based approach for generation system reliability evaluation,” *Electric Power Systems Research*, vol. 53, n°2, pp. 133-138, February 2000.

[22] R.S. Garcia and D. Weisser, “A Wind-Diesel system with hydrogen storage: Joint optimization of design and dispatch,” *Renewable Energy*, vol. 31, n°14, pp. 2296-2320, November 2006.

[23] S. Conti, R. Nicolosi, S.A. Rizzo and H.H. Zeineldin, “Optimal dispatching of distributed generators and storage systems for MV islanded microgrids,” *IEEE Trans. Power Delivery*, vol. 27, n°3, pp. 1243-1251, July 2012.

[24] A. Chaouachi, R.M. Kamel, R. Andoulsi and K. Nagasaka, “Multiobjective intelligent energy management for a microgrid,” *IEEE Trans. Industrial Electronics*, vol. 60, n°4, pp. 1688-1699, April 2013.

[25] Y. Yuan, Q. Li and W. Wang, “Optimal operation strategy of energy storage unit in wind power integration based on stochastic programming,” *IET Renewable Power Generation*, vol. 5, n°2, pp. 194-201, 2012.

[26] Y.A. Katsigiannis, P.S. Georgilakis and E.S. Karapidakis, “Multiobjective genetic algorithm solution to the optimum economic and environmental performance problem of small autonomous hybrid power systems with renewables,” *IET Renewable Power Generation*, vol. 4, n°5, pp. 404–419, 2010.

[27] Y.A. Katsigiannis, P.S. Georgilakis and E.S. Karapidakis, “Hybrid simulated annealing–Tabu search method for optimal sizing of autonomous power systems with renewables,” *IEEE Trans. Sustainable Energy*, vol. 3, n°3, pp. 330-338, July 2012.

[28] S. Kannan, S.M.R. Slochanal and N.P. Padhy, “Application and comparison of metaheuristic techniques to generation expansion planning problem,” *IEEE Trans. Power Systems*, vol. 20, n°1, pp. 466-475, February 2005.

[29] A. Ahuja, S. Das and A. Pahwa, “An AIS-ACO hybrid approach for multi-objective distribution system reconfiguration,” *IEEE Trans. Power Systems*, vol. 22, n°3, pp. 1101-1111, August 2007.

[30] H. Nasiraghdam and S. Jadid, “Optimal hybrid PV/WT/FC sizing and distribution system reconfiguration using multi-objective artificial bee colony (MOABC) algorithm,” *Solar Energy*, vol. 86, n°10, pp. 3057-3071, October 2012.

[31] M. Santarelli and D. Pellegrino, “Mathematical optimization of a RES-H_2 Plant using a black box algorithm,” *Renewable Energy*, vol. 30, pp. 493-510, April 2005.

[32] D.A. Halamay, T.K.A. Brekken, A. Simmons and S. McArthur, “Reserve requirement impacts of large-scale integration of wind, solar, and ocean wave power generation,” *IEEE Trans. Sustainable Energy*, vol. 2, n°3, pp. 321-328, July 2011.

[33] H. Lund, “Large-scale integration of optimal combinations of PV, wind and wave power into the electricity supply,” *Renewable Energy*, vol. 31, n°4, pp. 503-515, April 2006.