MICROGRID DISPATCH OPTIMIZATION USING PSO ALGORITHM

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Abstract: In this paper is proposed an algorithm to minimize the operation cost of a microgrid containing a photovoltaic and wind generation, a BESS, a connection to the main grid and loads that must be supplied. The objective function takes into account the operation and maintenance costs of the sources and the price of the energy exchanged with the grid, the daily price of liquidation (PLD). To solve the optimization problem the Particle Swarm Optimization (PSO) algorithm was used and the results are compared with a dummy algorithm where all the power available in the renewable resources (RES) are dispatched. The BESS is considered a backup energy and should not inject any power unless it's necessary.

Keywords: Microgrid, Optimized Dispatch, PSO, renewable resources.

OTIMIZAÇÃO DE DESPACHO DE MICRORREDE UTILIZANDO ALGORITMO PSO

Resumo: Neste artigo é proposto um algoritmo para minimizar o custo de operação de uma microrrede contendo uma geração fotovoltaica, uma eólica, um banco de baterias, uma conexão com a rede principal e cargas que devem ser supridas. A função objetivo leva em consideração os custos de operação e manutenção das fontes e o preço de liquidação diária (PLD) que é o preço de compra e venda de energia na rede. Para resolver o problema de minimização o algoritmo "Particle Swarm Optimization" (PSO) foi utilizado e o resultado comparado com um algoritmo simples onde toda a potência disponível nas fontes renováveis (RES) é despachada. O banco de bateria é considerado uma energia de backup e não deve ser utilizada a menos que seja necessário.

Palavras-chave: Microrrede, despacho otimizado, PSO, fontes renováveis

1. INTRODUCTION

With the insertion of the Renewable Energy Sources (RES) in the main grid around the world, especially those ones who has great availability of these kind of resource, the power generation became even more distributed, moving beyond the centralized grid mode. The main feature of the Distributed Energy Resources (DER) in power generation is that the energy is closer to the loads and can travel in either direction (to the transmission grids or to the consumers), with large variations (from one season to the next or from one time slot to the next) in supply and demand [1,4].

However, the DER brought a challenge in the load dispatch and power control, since normally these sources are intermittent and it is not possible to store energy. To mitigate these problems, it is common to group different kinds of distributed generation called "Microgrid". By definition, a microgrid is a cluster of DER units, eventually with loads, served by a power distribution system. Normally, the microgrid can operate in two modes: the grid connected mode, where it can exchange power with the main grid; or in the islanded mode, where the microgrid is disconnected from the main grid, and is responsible to provide power to the loads connected to the distribution system [2,3].

Because of both operating modes characteristic, the microgrid needs a special controller system with a Power Management Strategy (PMS). The PMS will be responsible to define in which mode the microgrid will operate and also will apply the dispatch considering the reliability of the system and the current economic operation of the microgrid [2]. To guarantee the power delivery to the grid and the loads in an optimal way, the PMS will run algorithms of interlocking to prevent undue operations, load shedding algorithms and an optimization algorithm to determine the best power dispatch of each source, focusing on economic reasons.

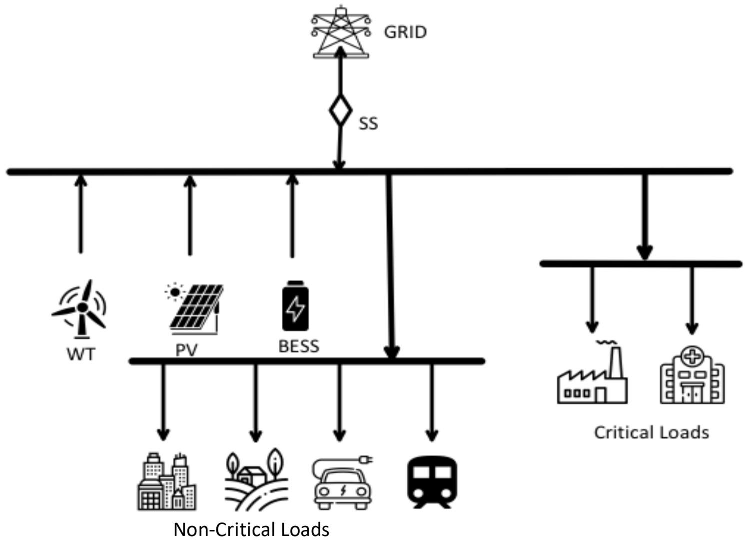
In this context, the main objective of this paper is to verify that the implementation of a PMS with using Particle Swarm Optimization (PSO) algorithm is viable and can be very profitable since it will look for the minimum energy cost for the microgrid dispatch without compromise the power balance of the system. The PSO algorithm is widely applicable in power systems optimization problems due to its fast convergence and high precision [5]. Besides, this algorithm allows to solve the minimization problem for microgrid composed by RES and connected with the grid [6].

2. METHODOLOGY

The microgrid in study, as shown in Figure 1, consists of a Wind Turbine (WT), a Photovoltaic System (PV) and a Battery Energy Storage System (BESS), all connected to an AC busbar which in turn is connected to the main grid by a static switch (SS). In the busbar, there are also critical and non-critical loads that can be supplied by the microgrid, where the non-critical loads will be the firsts to be shed, if necessary to make a load shedding. Besides, the BESS must be a backup energy.

For optimal operation of this microgrid, the proposed approach was defined in three steps: (1) Renewable sources modelling and parametrization, to obtain the instantaneous output power of each asset; (2) Problem formulation, to define the objective function and operation constraints based on economic factors; and (3) Optimization algorithm, to return the optimized output power of the microgrid in order to strategically achieve the best operational profile.

Figure 1. Representation of the microgrid in study



2.1. Renewable Sources Modelling and Parametrization

The microgrid model was done in Python and used some libraries to model the assets: the "PVLIB" library for PV source and the "Windpowerlib" for WT source. Both libraries are open source and based on the mathematical models accepted in the literature [7,8] that validate the power systems representation.

2.1.1. Solar Power Output

To parametrize the PVLIB functions, the latitude and longitude coordinates of the PV system have been collected considering the microgrid located in the city of Casa Nova-BA (-9.18, -40.98), as part of a Research, Development, and Innovation (RD&I) Project between Eletrobras CHESF, SENAI CIMATEC and partner companies.

With these coordinates, the solar position is obtained at that point for each date and time of the year using the algorithms described in [2]. From the solar irradiance data, the total irradiance (I_{Tot}) on the PV system given by the Equation (1).

$$I_{Tot} = I_{beam} + I_{skydiffuse} + I_{ground} \tag{1}$$

where: I_{beam} is the direct beam irradiance, $I_{skydiffuse}$ is the sky diffuse irradiation, and I_{ground} is the ground reflected irradiance, all derived from the data given in [W/m²].

The PV output power also depends of the panel temperature. This value is estimated using the Faiman method [9], which depends of the total irradiance previously calculated, the air temperature and wind speed measured in the local. Finally, the PV system is parametrized with the data from the JA Solar panel model JAM72D30 -540/MB/1500V and 8 inverters of 125kW from SUNGROW, model SG125HV making a total power of 1MW.

2.1.2. Wind Turbine Power Output

In the Windpowerlib, the power output is calculated via power curves and power coefficient curves. So, for this source model only it needs to provide the nominal power, the hub height, the power curve of the WT and the wind speed data. The power curve was retrieved from the turbine model GE 1.5 SLE datasheet. In this microgrid, one single wind turbine was considered because the RD&I Project specification, but it is possible to model wind farms and clusters too.

2.1.3. BESS Power Output

For the BESS, the power output will be instantly injected in the grid. But, to avoid a quick discharge of the battery and consequently, an operation out of the optimal range (20% < SoC < 80%), the input/output power available will be a linear function of the SoC given by the Equation (2).

$$P_{BESS}^{c} = \frac{5}{3}(SoC - 80)P_{BESS}^{Nom} \text{ and } P_{BESS}^{d} = \frac{5}{3}(SoC - 20)P_{BESS}^{Nom} \tag{2}$$

where: P_{BESS}^{c} is the charging power, P_{BESS}^{d} is the discharging power and P_{BESS}^{Nom} is the nominal power of the BESS.

2.2. Problem Formulation

The objective function (F) chosen was to minimize the operational cost of the sources as described in Equation (3).

$$\min F = c_{pv}P_{pv} + c_{wt}P_{wt} + c_{BESS}P_{BESS} + c_{grid}P_{grid} \tag{3}$$

where: P_{pv}, P_{wt}, P_{BESS}, P_{grid} are the PV, WT, BESS and Grid maximum available power; c_{pv}, c_{wt}, c_{BESS}, c_{grid} are the PV, WT, BESS and Grid power costs, respectively.

In the case of the BESS, sometimes it will be a source for the microgrid when discharging and sometimes it will be a load when charging. As if the BESS must be used only in cases power available in the other sources are not enough to supply the loads, the cost of the BESS must be considered much higher than the others.

The power costs of the RES consider the Levelized Cost of Electricity (LCOE) index of each, given by Equation (4). The power exchanged with the grid will depend of the hourly price of the energy in the free market, and so the algorithm will decide if it is better to import or export energy to/from the grid.

$$LCOE\left[\frac{R\$}{MW}\right] = \frac{\frac{CAPEX\left[\frac{R\$}{MW}\right]}{20[years]} + O\&M\left[\frac{R\$}{MWy}\right] + Taxes\left[\frac{R\$}{MWy}\right]}{365[days]\times 24[h]} \tag{4}$$

where: $CAPEX$ is the costs of installation without interests, $O\&M$ is the operation and maintenance costs.

2.2.1. Operation Constraints

- Power Balance: To simplify the analysis, the load will be considered fixed during the day.

$$P_{grid}(t) + P_{pv}(t) + P_{wt}(t) + P_{BESS}(t) = P_{Load}(t) \tag{5}$$

- RES Generation Limits: The maximum power available for the photovoltaic (P_{pv}^{Max}) and wind turbine (P_{wt}^{Max}) sources depend on the total irradiance and windspeed respectively available.

$$0 \leq P_{pv} < P_{pv}^{Max} \tag{6}$$

$$0 \leq P_{wt} < P_{wt}^{Max} \tag{7}$$

- BESS Limit: It depends on the actual SoC that is also limited. Moreover, as the BESS output power depends if it is charging or discharging, the maximum power available must be separated in these phases.

$$20\% \leq SoC \leq 80\% \tag{8}$$

$$-P_{BESS}^{c} \leq P_{BESS} \leq 0 \tag{9}$$

$$0 \leq P_{BESS} \leq P_{BESS}^{d} \tag{10}$$

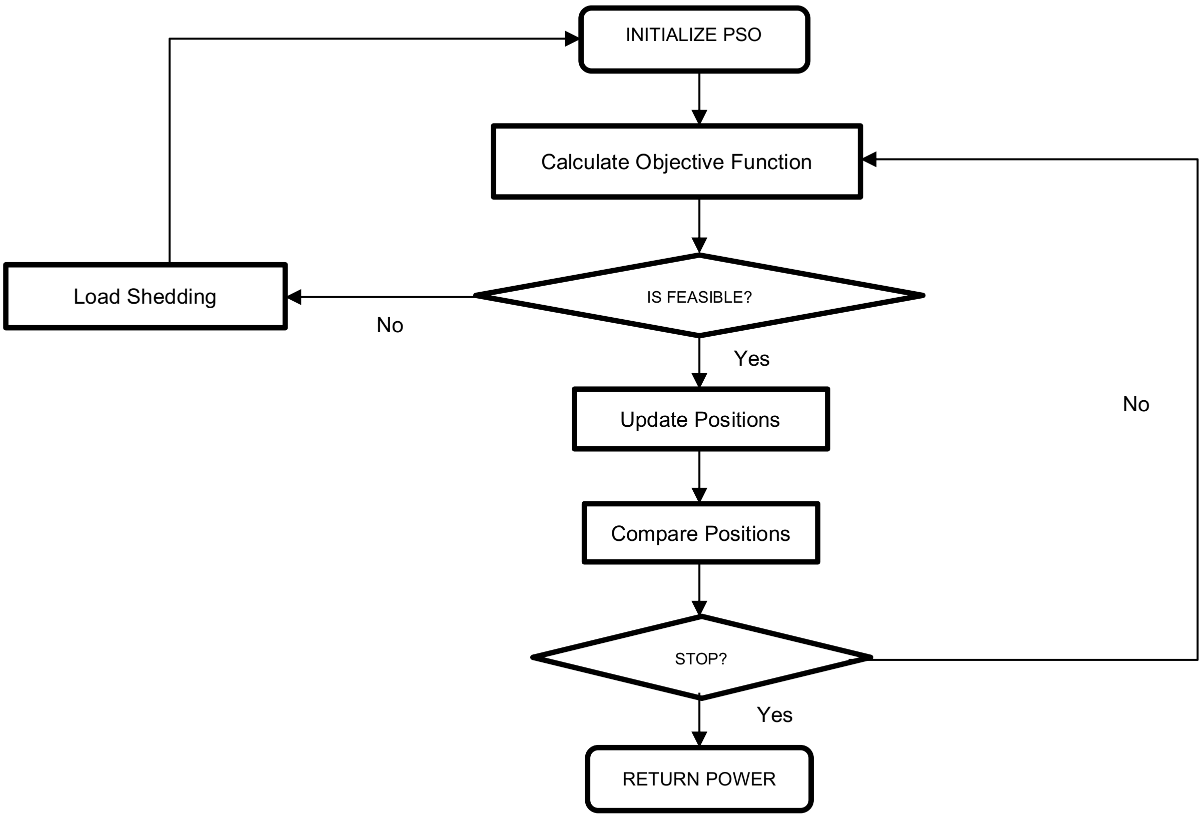
- Grid limits: The power grid is limited by the capacity of the transmission line (P_{line}). Thus, the power is positive when the grid is injecting power in the microgrid and negative when the microgrid is exporting power to the grid. Since it's not possible to minimize the power delivered to the loads, these are not taken account in the cost function.

$$-P_{line} \leq P_{grid} < P_{line} \tag{11}$$

2.3. Optimization Algorithm

The optimization algorithm chosen was the Particle Swarm Optimization (PSO) method, as described in Figure 2, in which to seek to find the minimal operational cost of the microgrid considering the constraints and, in case of not feasible, a decision must assure power balance of the system.

Figure 2. Flowchart for describing the PSO algorithm applied in microgrids.



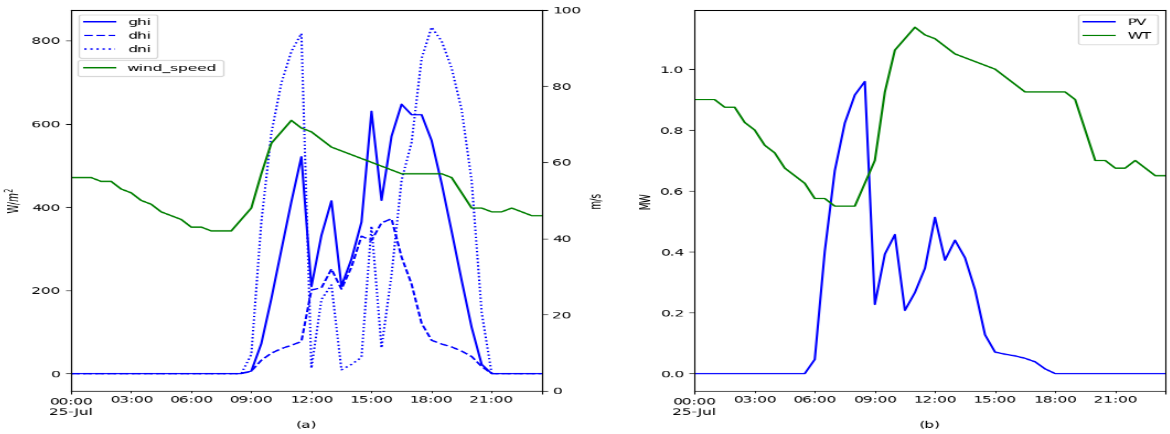
In case of not feasibility of the objective function, a load shedding optimization algorithm should be called to shed the minimum load necessary, in order to assure the power balance of the system, accordingly a pre-determined order of prioritization.

3. RESULTS AND DISCUSSION

The historical data of irradiance $(I_{beam}, I_{skydiffuse}, I_{ground})$ was collected from the National Solar Radiation Database (NSRDB) and wind speed from the sensors presented on the wind turbine. Besides, the maximum power considered for the PV is 1MW, 1.5MW for the WT, 1MW for the BESS and 1MW for the line capacity which connects the microgrid to the main grid.

A random day was selected for the simulations. The data is distributed in intervals of 30 min, giving 48 samples in a day. The maximum power output available for these RES is shown in Figure 3.

Figure 3. (a) Main input signals (Irradiance and Wind data) for RES modelling; (b) Output signals (Solar and Wind Turbine Power Outputs) for RES modelling.



No load profile was considered, instead, a fixed load of maximum of 1.5 MW was defined for all day. The hourly market price for this day was taken from Chamber of Electric Energy Commercialization website. So, to calculate the LCOE of the sources, the Enterprise Research Office report of price parameters was used, as shown in the Table 1. However, the LCOE given to the BESS will not be considered in algorithm to avoid the battery be completely discharged in some scenarios since sometimes is not economically viable charge the battery.

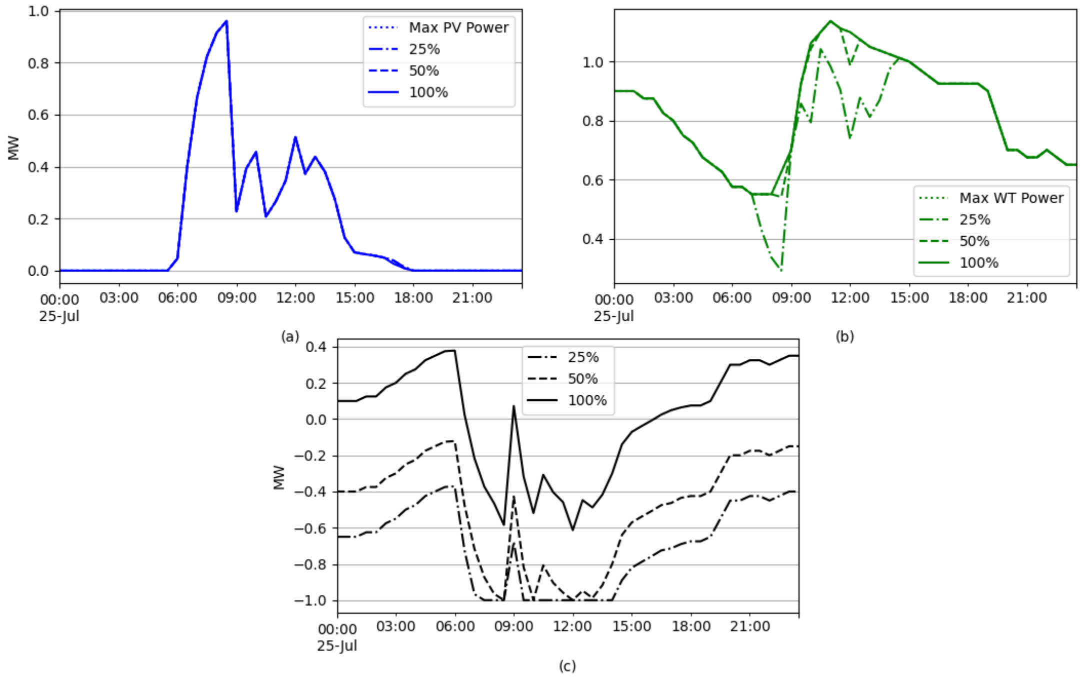
Table 1. Data of costs and the respective LCOE calculated for each RES

Source	*Lifetime [years]*	*CAPEX [R$/MW]*	*O&M [R$/MWy]*	*Charges and Taxes [R$/MWy]*	*LCOE [R$/MWh]*
Photovoltaic	20	4.000.000	50.000	150.000	46.66
Wind Farm (Onshore)	20	4.500.000	90.000	180.000	56.51
BESS	20	7.350.000	70.000	310.000	85.33

To show the advantage of the optimization algorithm, three cases will be considered in Figure 4, with 25%, 50% and 100% of the maximum load and the daily cost compared to the dummy system in the same scenario, with initial SoC equal to 80% for each scenario. In the first case it's possible to see that the PMS prioritized the less expensive sources, before 6 a.m. the system used full power of the WT and imported the rest of the demanded power from the grid. As soon the sunrises and the

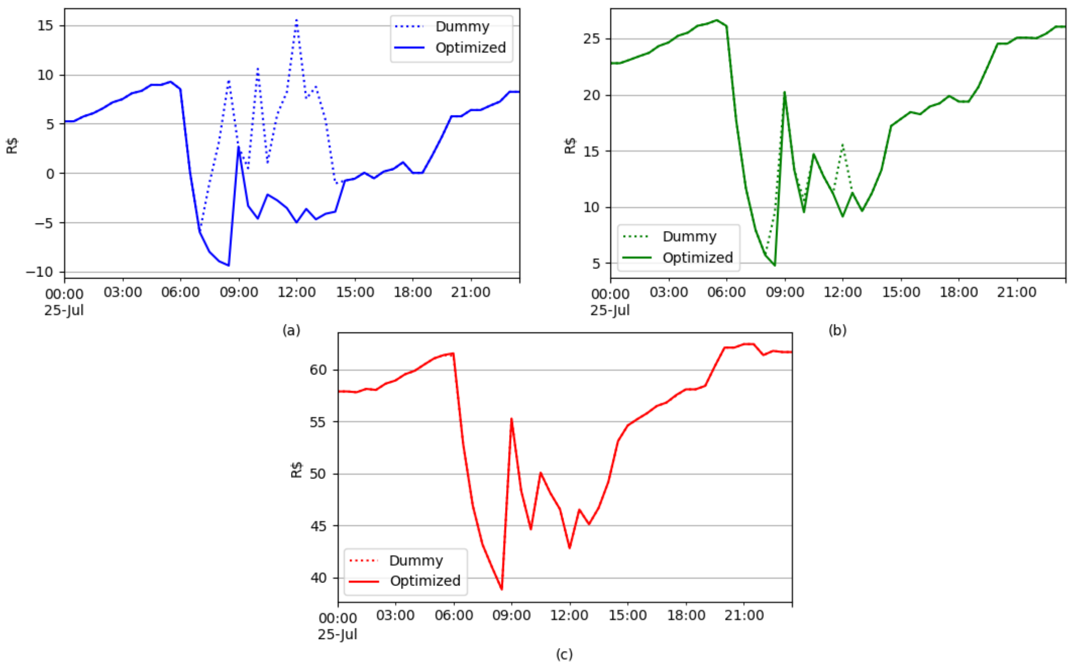
PV have power to input into the microgrid the PMS switched the power to the PV source and this source began to work with full power (because is the less expensive), the WT below full capacity and the system passed to export power to the grid. The BESS was not utilized because its cost is higher and was not necessary.

Figure 4. (a) PV Power output; (b) WT Power Output; (c) Grid Power Exchange



Comparing the scenarios in Figure 5, it's possible to notice that as higher is the load less is the effect of the optimization. It's expected because for higher loads the optimization algorithm has less freedom to define the power of each source.

Figure 5. (a) Dummy x Optimized cost for 25% load; (b) Dummy x Optimized cost for 50% load, (c) Dummy x Optimized cost for 100% load.



4. CONCLUSION

In this paper, the PMS acted like a cost optimizer and was capable of finding the best RES arrangement minimizing the generation cost when possible. In a real implementation, the algorithm will be constantly running and the cycle can be much faster than 30 min, depending on computational power available. The PMS has other attributions to be tested in further works, such as the load shedding using another optimization algorithm that maximize the load supplied. A multi-objective algorithm could also be studied to handle the power of the RES and the SoC of the battery so it would no longer act only as a backup power supply.

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