# OPTIMAL DESIGN OF STANDALONE MICRO-GRID CONSIDERING RELIABILITY AND INVESTMENT COSTS

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## ABSTRACT

*In the regions which are located far from the distribution networks, using standalone microgrid to supply the power demand with minimum cost and best reliability is essential. Optimal sizing of Distributed Energy Resources (DERs) in a typical microgrid is a complex multi-objective problem. In this paper a multi-objective modelling for designing a standalone microgrid with the best reliability and minimum cost for supplying the load demand is investigated and modelled. The proposed method is based on consumers demand and their consumption patterns.Specification index of proposed method is preventing from oversizing of microgrid components.*

## INTRODUCTION

Nowadays electricity Energy for modern societies is an important and inevitable issue. Most of required energy by countries is provided by fossil fuel. Due to the fact that fossil fuels are exhaustible and have environmental pollution, use of Renewable Energy Resources (RERs) for supply electric demands is necessary. RERs are highly depend on environmental conditions, hence they have stochastic behaviours. For modelling power of RERs considering probabilistic methods and specific probabilistic distribution function are necessary. In this method, power modelling for microgrid components is accurate and simulation results will be precise. Optimal sizing of microgrids is an important issue that could make use of microgrid for supplying electric demand, economically. Optimal designing of standalone microgrid must be as cost effective and reliable as grid connected microgrid and this make optimal sizing of microgrid a multi-objective optimization problem with two conflicting objectives of cost and reliability [1]. Most of studies have been conducted for designing standalone microgrids, considered higher reliability, as a results, cause to consider more capacity for microgrid components and this make the microgrid more expensive. To financial limitation considerations, consumers in rural regions in developing societies are unwilling and unable to pay unnecessary and surplus capacity [2]. In this way, designers must choose the best configuration for microgrid with considering consumers reliability requirements and compatible with their budget. Different studies have been done on the topic of cost versus reliability trade-off for standalone microgrids [2]–[4]. In these works uncertainty of renewable energy resource does not considered accurately and studied microgrids is limited to a few components.

In this paper, a proposed method is based on trade-off between cost and reliability parameters and for considering uncertainty of renewable energy resources clustering method based on suitable probabilistic distribution function for each variable parameter is applied.

## PROBLEM STATEMENT

In this section, reliability parameters, microgrid resource's modeling and PDFs for each stochastic variable are proposed as follows:

### Reliability parameters

A standalone microgrid performance can be analyzed by different reliability parameters. Reliability parameters which are used in this paper are unmet load and probability of unmet load. The total unmet load for a standalone microgrid is defined as:

$$UL = \sum_{T=1}^{8760} \left( \bar{L}_h - \bar{P}_{h,a} \right)_i \tag{1}$$

Where, $L_h$ and $P_h$ are the hourly average load and and hourly-average power and the period of $T$ is 1 to 8760 hours [5].

Probability of unmet load is defined as:

$$ULP = \frac{UL}{Total\_load} \tag{2}$$

### Microgrid energy resources modeling

Microgrid resources modeling has been presented as follows:

#### Wind turbine (WT)

The output power of wind turbine according to wind speed can be represented by:

$$P_{WT} = \frac{1}{2}.\rho.V_W^3.A_{WT}.C_p.\eta_{EG} \tag{3}$$

Where, $\rho$, $V_W$, $A_{WT}$, $C_p$ and $\eta_{EG}$ are air density, wind speed, rotor area, rotor power coefficient and overall efficiency of electrical components, respectively [5].

**Photovoltaic panel (PV)**

The output power of photovoltaic panel according to solar irradiance is considered as:

$$P_{pv} = I.A_{pv}.\eta_{PV} \tag{4}$$

Where, $I$ stands for the solar irradiance, $A_{PV}$ is the PV panel area and $\eta_{PV}$ is the overall PV unit efficiency [5].

**Battery power modelling**

The battery which is used in this study is Zn-Br and State of Charge (SOC) of battery is considered in three modes (charging, discharging and standby mode) according to load profile. At off peak period, the battery is charging with constant rate and in on peak period, the battery is discharging. Moreover, the battery parameters is given from [6].

## Probability distribution functions

According to stochastic behavior of wind speed and solar radiation, suitable probabilistic distribution function for wind turbine (WT) and photovoltaic (PV) is considered as follow:

**Beta PDF for solar irradiance modelling**

The probabilistic nature of solar irradiance is considered to follow Beta PDF. Beta distribution for solar irradiance $S_t$ (kW/m$^2$) according to time segment $t$ is given by [7]:

$$f_s^t(s) = \frac{\Gamma\left(\alpha^t + \beta^t\right)}{\Gamma\left(\alpha^t\right).\Gamma\left(\beta^t\right)}.\left(s^t\right)^{\alpha^t - 1}.\left(1 - s^t\right)^{\beta^t - 1} \tag{5}$$

Where, $\alpha^t$ and $\beta^t$ are the shape parameters and Γ represents Gamma function. Shape parameters of Beta PDF can be calculated using mean ($\mu^t_S$) and standard deviation ($\sigma^t_S$) of irradiance for corresponding time segment.

$$\beta^t = \left(1 - \mu_s^t\right).\left(\frac{\mu_s^t\left(1 + \mu_s^t\right)}{\left(\sigma_s^t\right)^2} - 1\right) \tag{6}$$

$$\alpha^t = \frac{\mu_s^t * \beta^t}{\left(1 - \mu_s^t\right)} \tag{7}$$

**Weibull PDF for wind speed modelling**

For considering stochastic behavior of wind speed in a predefined time period, Weibull PDF has been applied [8]. Weibull distribution for the wind speed $V^t$ (m/s) at $t$-th time segment can be expressed as:

$$f_v^t(v) = \frac{k^t}{c^t}\left(\frac{v_t}{c_t}\right)^{k_t - 1}.\exp\left(-\left(\frac{v^t}{c^t}\right)^{k^t - 1}\right) \tag{8}$$

The shape parameter ($k^t$) and scale factor ($C^t$) at $t$-th time segment are calculated as follows:

$$c^t = \frac{\mu_v^t}{\Gamma\left(1 + \frac{1}{k^t}\right)} \tag{9}$$

$$k^t = \left(\frac{\sigma^t}{\mu_v^t}\right)^{-1.086} \tag{10}$$

## PROPOSED METHODOLOGY

A multi-objective modelling for designing a standalone microgrid is modelled and studied. The proposed method considers the best reliability with minimum cost for supplying the owner load demand.
In other word, the proposed method is based on cost versus reliability factor according to the consumers need, and the final solution is obtained from a trade-off between these two parameters.
Reliability parameter which is used in this study, is unmet load. This parameter shows how much of the demand load is not supplied. Suitable value of unmet load for each microgrid is different, so the probability of unmet load is considered as reliability parameter.
For considering the cost versus reliability according to load demand, environmental data and cost of the best configuration of microgrid components for different reliability index is determined. Genetic algorithm is used to find the best configuration of microgid according to the reliability level. More details about genetic algorithm can be found in [9]. Determining the most suitable reliability value and the least cost for microgrid, by resolutions of days of year, the proposed algorithm determines the worst days in the year and evaluate these days by resolutions of hours according to consumers need. If consumers are satisfied by this reliability value, the procedure of finding the optimal size of microgrid is finished, otherwise the designing procedure is continued with higher reliability level. This method is applied in iterative manner.
General procedure of proposed method with complete details is described in figure 1. Upon completion of the process described in Figure 1, graph of total cost of the micro-grid according to different value of reliability parameter (is shown in figure 2) and microgrid

configuration for each point is available. After that another iterative procedure for finding the best reliability parameter with minimum cost according to consumers need is applied. The studied microgrid consists of DER such as wind turbine (WT), photovoltaic panels (PV) and batteries. The generated power of WT and PV are highly dependent on the environmental conditions and for the accurate modelling of these components, probabilistic method is applied. For the modelling of wind speed and solar irradiance, the Weibull and Beta distribution functions are considered respectively, using the clustering method.

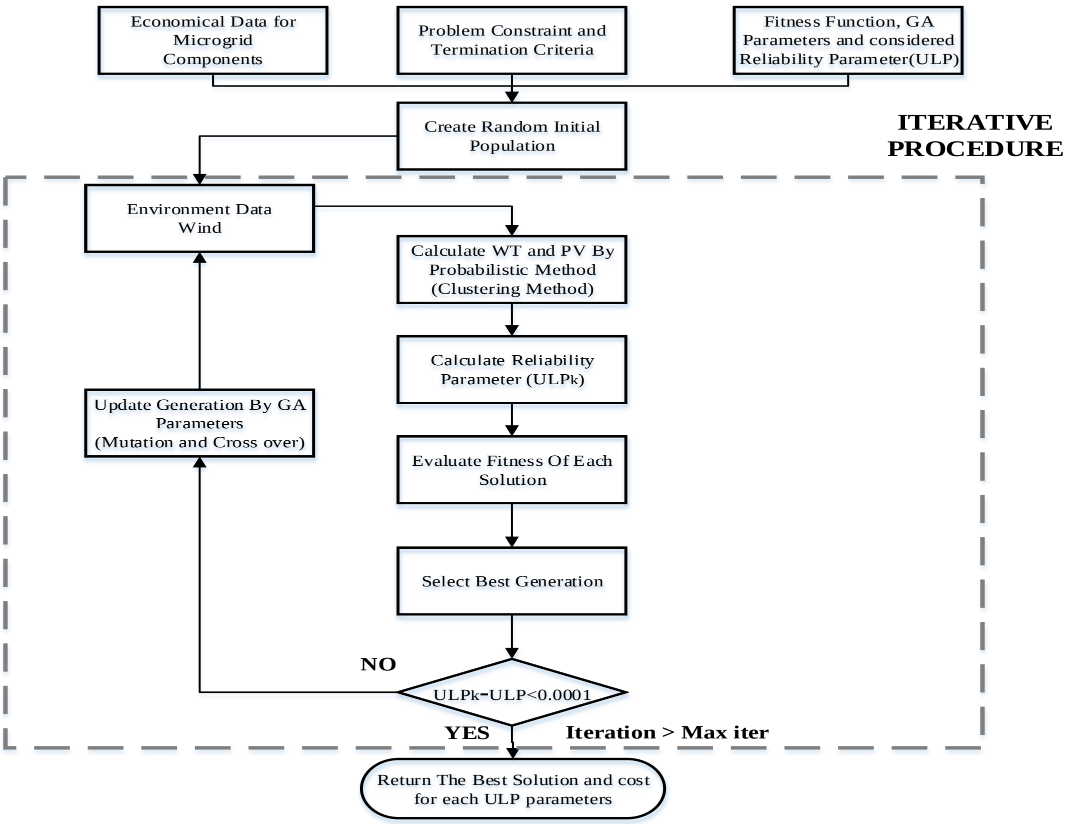


Figure 1. The proposed microgtid under study

In the clustering method, the output power of the solar and wind based DG units are considered as a multistate variables in the planning formulation. The continuous PDF for each of them has been divided into states (periods). In other words, for each time segment, there are a number of states for the solar irradiance and wind speed. To express more about output power of WT and PV with clustering method, calculation method for output power of the wind turbine is described and calculation method for output power of PV is in the same way for more details see [10]. Solar cells can also be calculated in the same way.

The hourly average output power of WT corresponds to a specific $t$th time segment $P^t_{wt}$ can be calculated as follows:

$$P_{WT}^{t} = \sum_{g=1}^{N_s} PG_{WTg} * P_v(v_g^t) \qquad (11)$$

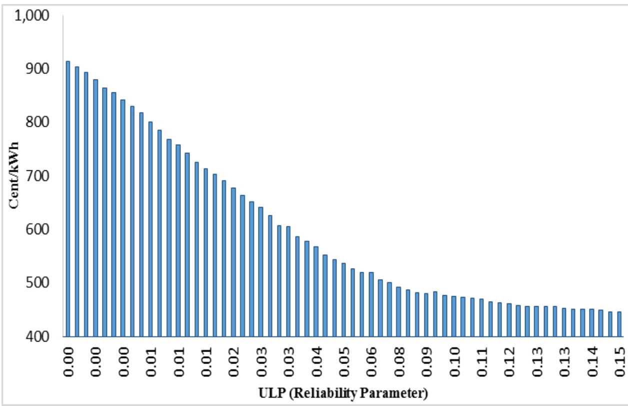


Figure 2. Cost versus Reliability for studied microgrid

The probability of the wind speed for each state during any specific time frame is calculated as [11]:

$$P_v(v_g^t)=\begin{cases}\displaystyle\int_0^{(v_g^t+v_{g+1}^t)/2} f_v^t(v)dv & for\ \ g=1\\ \displaystyle\int_{(v_{g-1}^t+v_g^t)/2}^{(v_g^t+v_{g+1}^t)/2} f_v^t(v)dv & for\ \ g=2.....(N_v-1)\\ \displaystyle\int_{(v_{g-1}^t+v_g^t)/2}^{\infty} f_v^t(v)dv & for\ \ g=N_v\end{cases} \tag{12}$$

## Objective function

The objective function is based on planning costs defined as follows:

$$C_T=C_c+C_{O\&M}+C_r \tag{13}$$

Where, $C_c$, $C_{O\&M}$, $C_r$ and $C_T$ are capital cost, operation and maintenance cost, replacement cost and total cost, respectively.

## SIMULATION RESULTS

Simulations have been carried out on proposed microgird which load demand and environment data are given from [5].

For designing proposed microgrid according to consumers need, it is assumed that, energy shortfalls lasting 4 hours or longer is unacceptable. And this condition by resolution of days of year is applied. In other words, in this paper planning cost is defined as main objective function of the optimization problem and reliability parameter (maximum time of continues shortfall) is considered as a constraint of the optimization problem. Simulation results are shown in table I.

Table I: SIMULATION RESULTS, OPTIMAL SIZE OF PROPOSED MICROGRIDSUBJECT TO MAXIMUM SHORTFALL TIME< 4 HOURS

| Iteration number | ULP | Battery kWh | WT kW | PV kW | Cost Cent/K wh | Max Shortfall time hours |
|---|---|---|---|---|---|---|
| | | | | | MIN | Constraint |
| Initial point | 0.15 | 250 | 120 | 90 | 42.35 | 6.5 |
| 1 | 0.10 | 265 | 135 | 81 | 46.80 | 5.7 |
| 2 | 0.60 | 282 | 140 | 75 | 47.55 | 4.9 |
| 3 | 0.20 | 301 | 145 | 71 | 48.30 | 4.3 |
| 4 | 0.08 | 314 | 145 | 76 | 49.20 | 4.1 |
| 5 | 0.02 | 325 | 150 | 72 | 51.40 | 3.8 |
| 6 | 0.04 | 321 | 145 | 77 | 50.10 | 4 |

## CONCULOSION

In this paper, a practical method for designing the standalone microgrids based on a trade-off between the cost and reliability according to the consumers need is introduced. For accurate modelling of the components, the uncertainty of renewable energy sources is considered using probabilistic methods. In proposed method reliability of microgrid is based on conditions which are determined by consumers need and budget.

## REFERENCES

[1] A. Maheri, 2014, “A critical evaluation of deterministic methods in size optimisation of reliable and cost effective standalone hybrid renewable energy systems”, *Reliab. Eng. Syst. Saf.*, vol. 130,159–174.

[2] M. Lee, D. Soto, V. Modi, 2014, “Cost versus reliability sizing strategy for isolated photovoltaic micro-grids in the developing world” *Renewable Energy*, vol. 69, 16-24.

[3] A Hadj Arab, B Ait Driss, R Amimeur, E Lorenzo, 1995, “Photovoltaic systems sizing for Algeria” *Sol Energy*, vol. 54, 99-104.

[4] Z. Wissem, K. Gueorgui, K. Hédi, 2012, “Modelling and technical economic optimization of an autonomous photovoltaic system” *Energy* vol. 37, 263-72.

[5] A. Maheri, 2014 “Multi-objective design optimization of standalone hybrid wind-PV diesel systems under uncertainties,” *Renewable Energy*, vol. 66, 650-661

[6] M. Sedghi, A. Ahmadian and M. A. Golkar, 2016, "Optimal Storage Planning in Active Distribution Network Considering Uncertainty of Wind Power Distributed Generation." *IEEE Trans. Power sys.* vol. 31, 304-316.

[7] S. A. Alavi, A. Ahmadian, M. Aliakbar-Golkar, 2015, “Optimal probabilistic energy management in a typical micro-grid based-on robust optimization and point estimate method,” *Energy Conve Manage*, vol. 95, 314–325.

[8] A. N. Celik, 2003, “Techno-economic analysis of autonomous PV–wind hybrid systems using different sizing methods,” *Energy Convers. Manage.* vol. 44, 1951–1968.

[9] A. Safari, A. Ahmadian, M. A. Golkar, 2013. “Controller design of STATCOM for power system stability improvement using honey bee mating optimization”. *J Appl. Res. Technol.*, Vol. 11,144-155.

[10] A. Ahmadian, A. Safari, M. Ali Akbar Golkar, 2013. HBMO Based Output Feedback Damping Controller for STATCOM. *Automatika*, 55, 41-52.

[11] F. A. Mohamed, H. N. Koivo, 2007, “Microgrid online management and balancing using multiobjective optimization”, *in proc. of IEEE Power Technology conference*, pp. 639-644.