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Enhacing power reliability using microgrids

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ABSTRACT

This paper presents a predictive probabilistic approach (PPA) for the optimal sizing of new distributed generation capacities in support of the main grid to respond to a fraction of the total load during the supply current interruption duration defined in using renewable-based microgrid assets. The model is used to simulate network failures by disabling the network for a certain time step. The load profile can be changed during network interruptions to represent a critical load. The generation capacity of the microgrid must be able to generate the value in grid-connected mode while supporting a critical load during a grid outage. The probability of loss of load characterizes the adequacy and energy not supplied represents the estimated reliability and the associated cost. The approach allows all technologies in the model to be evaluated, both during grid-connected mode and during grid outages when technologies can continue to power critical loads as part of the microgrid.

Keywords: distribution, renewable energy resources, reliability, outage cost, reliability

NONMENCLATURE

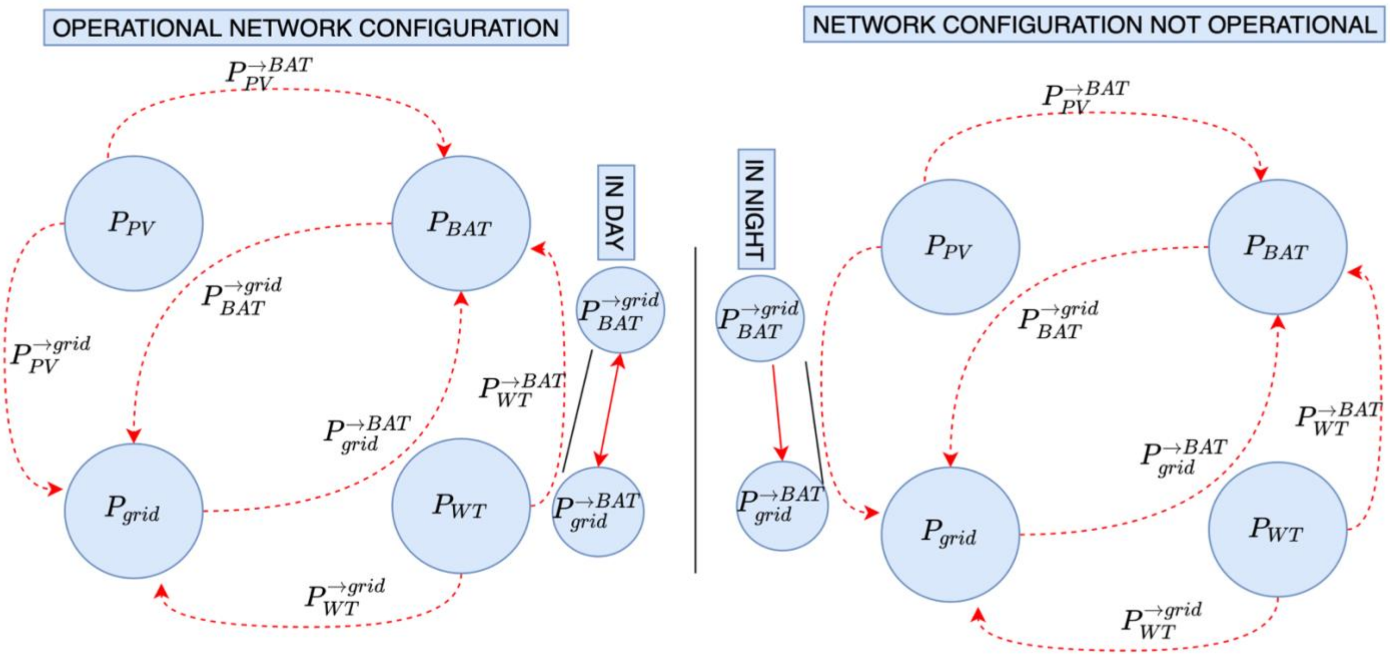
Abbreviations	
SoC	State of charge
Symbols	
Q^{LOSS}, f_i^{avg}	Energy not supplied, average outage rate of load
$P_{BAT,t}^{IN}, P_{BAT,t}^{OUT}$	Battery charging and discharging
$F(v\|\eta,\beta), C_P$	CDF Weibull, Betz Limit
$P_t^{PV}, P_t^{WT}, P_t^{BAT}$	PV power, Wind, battery
$P_{MG}^{\rightarrow grid}, P_{feeder}$	microgrid power, feeder power

1. INTRODUCTION

The basic function of an electrical power system is to provide consumers, large and small, with electrical energy in the most economical and reliable manner possible. The reliability associated with an electrical system is a measure of its ability to provide adequate electrical power for the expected duration under thespecified operating conditions. The application of distribution system reliability concepts focuses more on the customer load point than on the system. Distribution reliability considers all facets of engineering including: design, planning and operation. The distribution system is a vital link between the mass supply system and customers. The literature reports that more than 80% of all customer outages occur due to distribution system failures [1].

Investments in reliability are seen as indicators of value and marginal benefits to consumers, but the challenge is to assess the costs of power outages and the incremental values of those costs. Active network management involves reliability, and reliability goals sometimes conflict with those of economics. Reliability analysis methods are categorized into analytical method and simulation method [2][3]. This study proposes a sizing design methodology for optimal management of grid-connected PV/wind and battery microgrid systems to ensure reliable supply reliability. In this paper, the probabilistic reliability model is proposed in order to study the reliability value of the distribution network and to validate the design reliability of a system. This can be achieved by considering three following stochastic variables for microgrid sizing: solar irradiance, wind speed, and load demand. The microgrid is placed at the end of the low voltage distribution system where it operates in parallel with the main grid and exchanges energy to and from the grid by reinforcing critical points.

2. MOTHODOLOGY



2.1 *Modeling of PV generator*

The irradiance data is usually a bimodal distribution function divided into two groups and each group of which has a unimodal distribution function. The random phenomenon of the irradiance data is described using the pdf Beta for each unimodal(1);

$$f_{h(S)} = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} S^{(\alpha-1)}(1-S)^{(\beta-1)}$$

where S is solar irradiation in KW/m^2; $f_{h(S)}$ is beta distribution function of S and $\alpha \; and \; \beta$ parameters of beta distribution. The instantaneous PV panels efficiency (%) is given by using following Paatero and Lund model (2);

$$\eta_{PV} = \eta_{STC\,[1+\gamma(T_{cell}-25)]}$$

2.2 *Wind speed modeling*

The two-parameter Weibull function to know how often the different wind speeds are met for the annual estimate of the energy production. By setting the scale parameter η and shape β we know how to construct the interest of the wind over a period (3).

$$f(v|\eta,\beta) = \frac{\beta}{\eta}\left(\frac{v}{\eta}\right)^{\beta-1} exp\left[-\left(\frac{v}{\eta}\right)^{\beta-1}\right]$$

Where $f(v|\eta,\beta)$ wind probability density function.

$$F(v|\eta,\beta) = 1 - exp\left[-\left(\frac{v}{\eta}\right)^{\beta}\right]$$

Where $F(v|\eta,\beta)$ is the CDF Weibull; $\eta(2.5)$ and $\beta(6.8)$ is the Weibull scale and shape factor. The energy potential is highly dependent on the speed and the area the wind crosses. The instantaneous power of the wind is rated as follows (8);

$$P = \frac{1}{2}\, C_P \rho \pi r^2 v^3$$

Where is the area of a circle at r the radius of the circle; C_P Betz Limit 59%, ρ(1.225 kg/m^2) air density at 15.55 °C and 101.325 Pa. Electricity production generally starts at wind speeds between 3m/s and 4m/s (6.71 and 8.95min/h) and the energy of the wind.

2.3 *Model of battery energy storage system*

As the battery capacity is limited, the state of charge (SoC) dynamically changes the behavior of the entire system (9);

$$SoC_{(t+1)} = SoC_{(t)} + \Delta_t \, P_{BAT,t}^{IN} \, \eta_{BAT,t}^{charge}, \qquad \forall_{t>0}$$

In (5), the current SoC S(t) can be expressed by the initial SoC of a day in the following (10).

$$SoC_{(t+1)} = SoC_{(t)} + \Delta_t \, \frac{P_{BAT,t}^{OUT}}{\eta_{BAT}^{discharge}}, \qquad \forall_{t>0}$$

2.4 Grid connected

Utility grid is considered to be a component of the microgrid, and it is modeled as an infinite source of energy that can meet maximum demand and an overall load of use as follows (11),

$$P_{grid,t}^{requested} \leq E_1 . u_t = \begin{cases} 1, & if\ grid\ works\ at\ time\ t \\ 0, & otherwise \end{cases}$$

$$P_{grid,t}^{inject} \leq E_2 . 1 - u_t = \begin{cases} 1, if grid\ works\ at\ time\ t \\ \quad 0, \qquad otherwise \end{cases}$$

Where $P_{grid,t}^{requested}$ power requested from the grid kW. E_1 and E_2 maximum power that can be requested and maximum power that can be reinjected respectively in kW. u binary t variable: 1 if the network provides energy for the time t, 0 otherwise(12),

$$P_t^{grid} = P_t^{LOAD} - \sum_{t=1}^{N.of technology} P_t^{WT} + P_t^{PV} + P_t^{BAT}$$

2.5 Objective function

The objective is to optimize energy flows between generation, supply and point of use in order to minimize operating costs and maximize the benefits of renewable resources by minimizing unsupplied energy (13);

$$min. \sum_{t=0}^{T} C_t\,(S_t^{BAT}) + C_t\,(P_t^{BAT}) + C_t\,(P_t^{WT}) + C_t\,(P_t^{PV}) + C_t\,(P_t^{grid}) + \sum_{t\in\tau} C_t(L_t\ \delta_t) + Q^{LOSS}$$

s.c

$$S_{t+1} = S_t + \left(P_{BAT,t}^{IN} - P_{BAT,t}^{OUT}\right), t = 0, \ldots, T-1$$

$$0 \leq S_{BAT,t} \leq S_{BAT}, \forall_{t\in\tau}$$

$$0 \leq P_{BAT,t}^{IN} \leq P_{BAT}, \forall_{t\in\tau}$$

$$0 \leq P_{BAT,t}^{OUT} \leq P_{BAT}, \forall_{t\in\tau}$$

$$P_t^{PV} + P_t^{WT} + \left(-P_{BAT,t}^{IN} + P_{BAT,t}^{OUT}\right) - P_{MG}^{\rightarrow grid} = 0$$

$$P_{MG}^{\rightarrow grid}(t) + P_{feeder}(\mathrm{t}) + L_t = \lambda(t)$$

$$-P_{feeder}(\mathrm{t}) \leq P_{MG}^{\rightarrow grid} P_{feeder}(\mathrm{t})$$

$$P_t^{PV}(t) = \pi_t P^{PV}$$

Where $C_t\,(S^{BAT})$ and $C_t\,(P_t^{BAT})$ are the power and energy costs respectively. $P_{BAT,t}^{IN} + P_{BAT,t}^{OUT}$ represent the charging and discharging power of the battery at the instant t. $C_t\,(P_t^{WT})\ and\ C_t\,(P_t^{PV})$ cost of wind and PV power. P_t^{WT} and P_t^{PV} are wind and PV power. P_{feeder} power available from the feeder at time t. $C_t(L_t)$ exchanged power cost. δ_t electricity price at the connection point. $P_{MG}^{\rightarrow grid}(t)$ microgrid power. $\pi = [0,1]$. Generation cost of non-dispatchable renewable sources such as PV is zero because their primary energy is available in any given time without paying any cost, so the only cost for WT and PV units is the operation and maintenance(O&M) cost defined as follows (14);

$$Cost_{Capital}^{of\ the} = C_t\,(P_t^{BAT}) + C_t\,(P_t^{PV}) + C_t\,(P_t^{WT})$$

3. Metrics related of the power distribution system failures and reliability

3.1 Probability of outage model

Weibull distribution is used to model failure rates and possibly calculates the probability of failure in an electrical system as follows (15).

$$T = 1 - R(t) = 1 - exp{-}\left(\frac{t}{\eta}\right)^{\beta}$$

where T is the probability of having zero failure (0), a failure (1) and two failures (2). Tobs the observation time with the parameters η (the scale parameter) and β (the shape parameter) are the shape and scale parameters of Weibull law: η = 5 and β = 3 and, η = 3 and β = 5. For each scenario, the number of simulations concerned is divided by the total number of simulations. In total 10,000 simulations, we have: 0 failure exactly in 3700 simulations, hence a probability of 0.37; exactly 1 failure in 5900 simulations, probability 0.59 and exactly 2 failures in 400 simulations, probability of 0.04(see tables I, II and III below). For each scenario, a cost is associtated.

Scenario 1 corresponds to the probability without microgrid and scenarios 2 and 2’ correspond to the probabilities in the presence of microgrid.

TABLE III: Scenario 1 probability of outage on the main network

Weibull parameters η=5, β=3		Value	Value
Periodicity			1 day
Number of simulation			1000
Faults	0	1	2
Probability	0.37	0.59	0.04

TABLE IV: Scenario 2 probability of outage using microgrid(1)

Weibull parameters η=3, β=5		value	Value
Periodicity			1 day
Number of simulation			1000
Faults	0	1	2
Probability	0.98	0.015	0.005

TABLE V: Scenario 3 probability of outage using microgrid(1)

Weibull parameters η=5, β=3			Value
Periodicity			2.5 day
Number of simulation			1000
Faults	0	1	2
Probability	0.90	0.09	0.01

The higher the probability, the lower the risk of failure, while that in the absence of microgrid and the lower the probability, the higher the risk of failure. The higher the probabilities of interruptions, the better the reliability of the system, the fewer the III arrays interruptions, IV&V below.

3.2 Energy not supplied

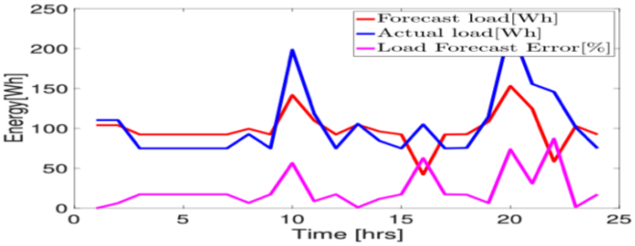
Energy not supplied, Q^{LOSS} as presented above responds well to the stated objectives: (i) constitute a tool for decentralizing decision-making, (ii) guarantee the long-term management of the power system; (iii) but also, take into account the economic efficiency of investments and guarantee the regulation of investments and these values cannot be predicted with certainty(16),

$$Q_{LOSS}^{feeder} = \sum_{i=1}^{I} P_i^{avg} . f_i^{avg} . \Delta_{r,i(s)} / 3600(s)/h$$

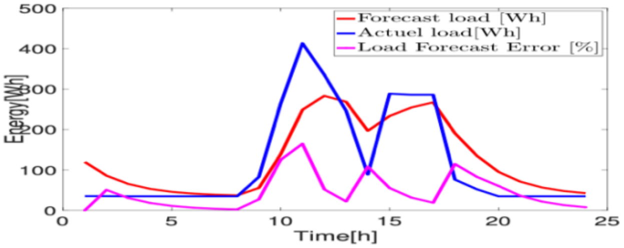
where I is the number of intervals during the duration Δ_r. f_i^{avg} refers to the average outage rate of load and P_i^{avg} is the average power demand of load.

4. RESULTS AND DISCUSSION

Figure 2 (a) indicates the simulation model output graphs (daily household electricity demand urban). Figure 2(b) corresponds to the daily energy consumption profile of a commercial activity. In figure 2 (a) consumption peaks are observed between 8 am and 10 am and between 4 pm and 6 pm. In figure 2 (b), the peak loads are observed between 10 a.m and 5 pm with a small drop in demand between noon and 1 pm. The load profiles for (a) household and (b) small commercial sector correspond to 2496.55 Wh/day and 2873. 08 Wh/day below respectively.



(a) Daily energy consumption profile of an average household



(b) Daily energy consumption profile of a commercial activity

Figure 2. Daily energy consumption profile

The number of PV panels corresponds to a discrete variable and the battery bank capacity to a continuous variable, tables I and 2 below. Scenario 1 corresponds to the probability of having the failure without microgrid. Scenarios 2 and 3 correspond to the probabilities of having the failure in the presence of microgrid.

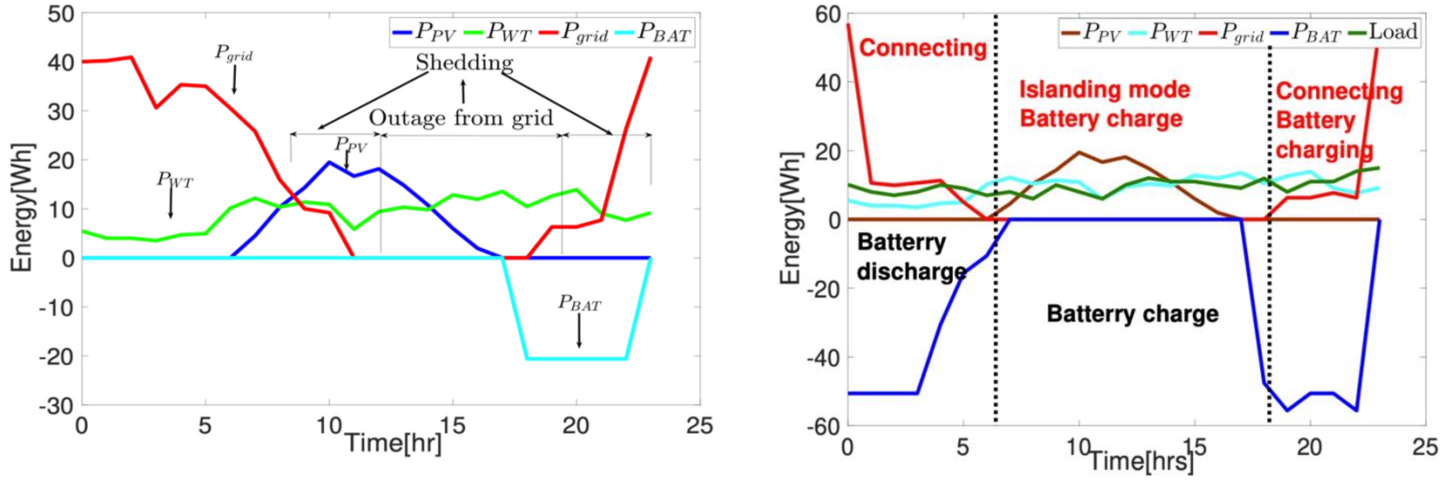
TABLE I: Battery and photovoltaic panels settings

Parameters	Value
P_{PV} in kWp	45.329
Module PV(250) €/W_c	0.57
P_{WT} in kW	2.8
P_{WT} in kWh	59.5
Lifetime PV/Wind(years)	20/30

TABLE II: Result of sizing

Parameters	Value
PV production in Whp/day	133998.09
Capacity factor in %	30
Battery capacity in Wh	132220
Charging η in %	90
Discharging β in %	90
Lifetime(years)	20
LCE in €/ kWh	0.09

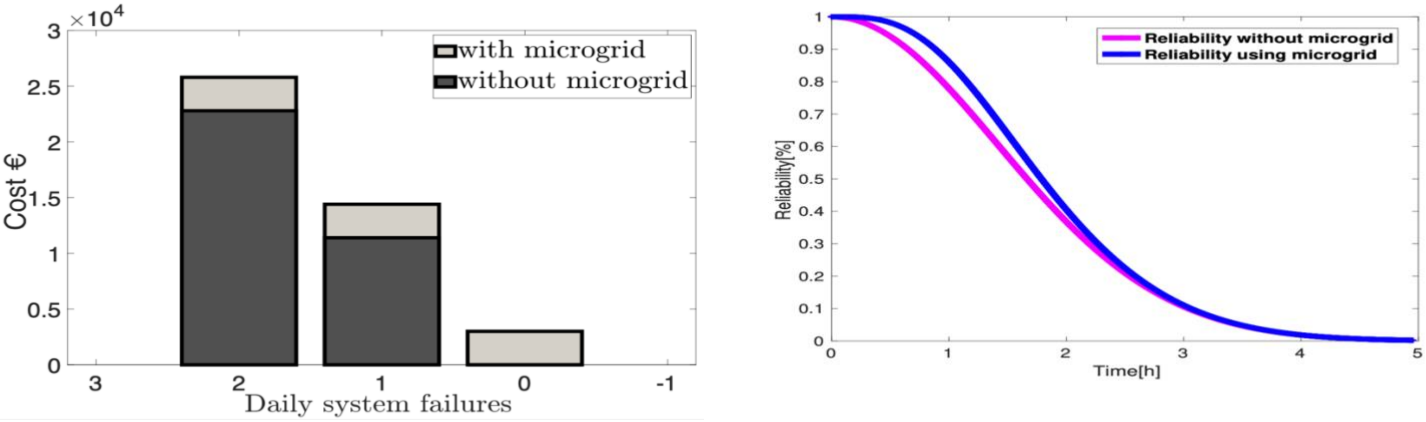
Suppose that faults occurred on the grid between 08:00 am, 06:00 pm and 09:00 pm result in energy losses, load of 526.9 Wh(198.5Wh,227.1Wh and 101.3Wh respectively). In grid-connected mode figure 3 below , microgrid injects all the energy into the feeder and only temporarily depending on the microgrid's capacity, particularly during a breakdown and/or grid load shedding to reduce the duration of the breakdown and/or shedding. The energy deficit is shown in Fig.3(a) and the energy loss compensation of 526.9 Wh/day is



(a)

(b)

Figure 3. Daily power flow and load curve in a day



(a)

(b)

Figure 4. Cost and performance et/or reliability of system

provided by microgrid by smoothing the peak load in Fig. 3(a&b) above. During these time slots, the PV does not produce energy. An occurrence occurred on the electricity grid between'at 10 AM to 4 PM and the load is ensured during this cut-off period with the PV. The PV production being nil at 5 PM and the battery discharges in connected mode. The battery has discharged in the event of a power outage/load shedding from the main grid and/or when the PV or wind fluctuates and/or during the night. The batteries were charged from 8 AM. The energy produced from microgrid is reinjected during normal operation or during the duration of the failure and/or shedding. The network load with faults in the commercial sector and the injection of energy from the microgrid into the network and microgrid compensates for the energy loss of 1055.3Wh/day(286.1Wh) at midday, 413.6 Wh at 10 AM and 335.6Wh at 9 AM) by smoothing the peal load. The more one invests in the microgrid, the higher the costs, the less and therefore there are breakdowns figure 4 below. Indeed, the higher the probabilities of interruptions, the better the reliability of the system. A reliability value of 0.07170 €/kWh represents the value the consumer places on the reliability of electrical service.

5. CONCLUSION

This study proposes a sizing design methodology for optimal management of grid-connected PV/wind and battery microgrid systems to ensure reliable supply reliability. The results indicate that the system costs depend directly on the reliability of its components and the probabilities of failure of the distribution system. Complete evaluation of the reliability and costs of such a system, taking into account the failures of other components as well as the uncertainty of the speed of the wind, solar radiation, and load data, requires computationally intensive algorithms. MATLAB programming environment to serve as a graphical interface.

REFERENCE

[1] Ali Chowdhury and Don Koval. Power distribution system reliability: practical methods and applications, volume 48. John Wiley & Sons, 201

[2] M Th Schilling, MB Do Coutto Filho, AM Leite da Silva, R Billinton, and RN Allan. An integrated approach to power system reliability assessment. International Journal of Electrical Power & Energy Systems, 17(6):381–390, 1995.

[3] COA Awosope and TO Akinbulire. A fixed minimal path array method of evaluating reliability indices of power systems. Electric power systems research, 19(3):167–176, 1990.