Evaluación en la Confiabilidad de una Microred aplicando Escenarios de Gestión en la Demanda

Assessment on Microgrid Reliability Applying Demand Side Management Scenarios

J. Valbuena[1], M. Mancera [2], A. Pavas[3]

[1]PAAS-UN, Facultad Ingeniería Eléctrica y Electrónica, Universidad Nacional, Colombia. Email: jdvalbuenag@unal.edu.co
[2]Facultad Ingeniería Eléctrica y Electrónica, Universidad Nacional, Colombia. Email: mmancerar@unal.edu.co
[3]PAAS-UN, Facultad Ingeniería Eléctrica y Electrónica, Universidad Nacional, Colombia. Email: fapavasm@unal.edu.co

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RESUMEN

Uno de los problemas asociados al uso de fuentes de energía renovables es su intermitencia. Su operación oscila con condiciones de clima, hora de día y estación del año. Este documento, utilizando distribuciones probabilísticas de radiación solar y velocidad de viento, evalúa el impacto de algunas estrategias de gestión de demanda sobre los indicadores de confiabilidad de una microred teórica ubicada en Barranquilla (Colombia). El estudio inicial considera la posibilidad de que ocurran interrupciones en los meses con baja producción eólica en horas pico de consumo. Como resultado de la implementación de estrategias de gestión, se observan disminuciones en interrupciones y energía no suministrada con respecto al caso base. Adicionalmente, una secuencia de seccionamiento es implementado para desconectar algunos grupos de carga del sistema en caso de desbalance de generación-demanda. Se discuten algunos criterios de confiabilidad y energía facturada para definir una secuencia de desconexión.

PALABRAS CLAVE: Gestión de la Demanda, Indicadores de Confiabilidad, Microred, Recursos Renovables.

ABSTRACT

One of the problems with renewable resources inclusion is its intermittency. Its operation always oscillates due to weather conditions, day hour, and season of the year. This paper, using probabilistic distributions of solar radiation and wind speed, evaluates the impact of so Demand Side Management Strategies on the reliability indicators of a theoretical microgrid located in Barranquilla (Colombia). Initial results show a chance of occurring unbalance interruptions in months with low rate of wind speed, and rush hours. When Management Strategies are tested, it is shown decreases of outages and Not Supplied Energy in comparison with the base case. In addition, a switching system is implemented to disconnect several groups from the main bus in case of generation-demand unbalance. Criteria between reliability and billed energy are discussed to define a disconnection sequence.

KEYWORDS: Demand Side Management, Microgrid, Reliability Indicators, Renewable Resources.

1. INTRODUCTION

Microgrids are small-scale, low voltage power supply network designed to supply electrical loads for a small community. It can be a distribution network that becomes to be active when distributed generation units are added to the distribution system, leading to bidirectional power flows within the networks [1][2]. Several differences between microgrids and conventional networks are expected: Smaller capacity generation with respect to the conventional power plants, distribution voltage fed to the utility distribution network, and installations close to the customers premises [1]. This determines its easy controllability and compliance with grid rules and regulations without jeopardizing the reliability and security of the power utility [3][4].

On the other hand, microgrids must guarantee the quality in energy service despite of resources generation variability [5]. Working along a main grid or in a stand/alone mode (island) [1], the balance between demand and generation is a crucial aspect in operating an electric energy system [2].

In that way, implementation of smart electric power systems is not only a generation challenge. Also, it represents a change by end-use costumers [6].

According to [3], actions resulting from management of the electricity demand in response to supply conditions are known as Demand Response (DR). In addition, the process to produce a DR is called Demand Side Management (DSM). Demand Management can be understood as the set of actions performed by an electricity agent, which affect its energy demand and are

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aimed to respond to its strategic objectives [4][7]. Those actions are defined as Management Strategies (MS) to achieve different purposes on the demand profile curve.
This paper presents a reliability assessment of an isolated theoretical microgrid located in Barranquilla (Colombia) with several components (Power sources, storage system and group of customers). It shows how DSM can improve the reliability indicators of the system and each customers group with some MS and a disconnection sequence system.

2. Theoretical framework

2.1. Components of the microgrid

In this study, only the balance of energy needs to be assessed for determining if the system supplies the required demand. Balance of energy must be understood as a positive or null difference between generation and demand. Thus, the locations of specific components and their method of integration to the microgrid are not considered.

2.1.1. Solar energy generation and storage.

For solar generation is used the historical solar radiation data from Barranquilla, provided by IDEAM [8] and shown its mean values in Figure 1.

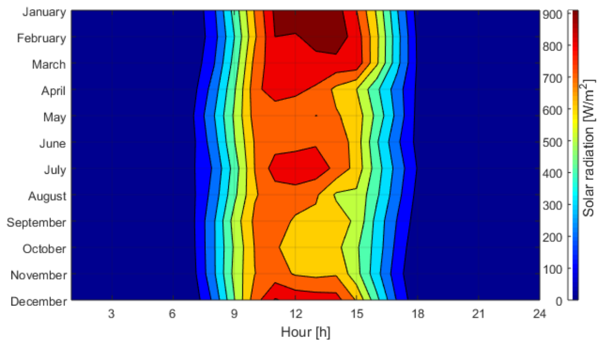


Figure 1. Monthly average solar radiation in Barranquilla, hour by hour. **Source**. IDEAM [8], Authors.

Solar radiation is applied directly on 256 photovoltaic panels of reference Yingli Solar YL280, with a nominal output power of 1000 W/m^2, 17.2% of efficiency and an area of 1.64 m^2. In addition, the microgrid counts with a storage system of 250 batteries Eagle Eye BR-500. This reference has a maximum capacity of 3000W.

2.1.2. Wind energy generation.

IDEAM has collected wind speed charts at 50 meters height for the whole Colombian territory. In Table 1 it is shown values of Weibull distributions parameters to represent wind speed behavior, month by month.

Table 1. Weibull distribution parameters values of wind speed in Barranquilla.

Wind speed parameters in Barranquilla				
Month	**Scale P. (α)**	**Shape P. (β)**	**Mean [m/s]**	**Standard deviation**
January	16,1	7,9	15,15	2,28
February	16,2	8,6	15,31	2,12
March	16,9	7,1	15,82	2,62
April	15,5	5,5	14,31	3,01
May	12,9	4,1	11,71	3,21
June	12,5	3,7	11,28	3,39
July	14,8	5,1	13,60	3,06
August	12,4	3,8	11,21	3,29
September	9,9	4,5	9,03	2,28
October	10,5	3,4	9,43	3,06
November	13	4,3	11,83	3,11
December	15,9	5,7	14,71	2,99

Source. IDEAM [8], Authors.

To take advantage of wind speed, 8 turbines Nordex N90/2500 with nominal power of 2.5 MW are used. Figure 2 displays the turbine performance curve compared with the March and September wind distributions (Maximum and minimum wind speed).

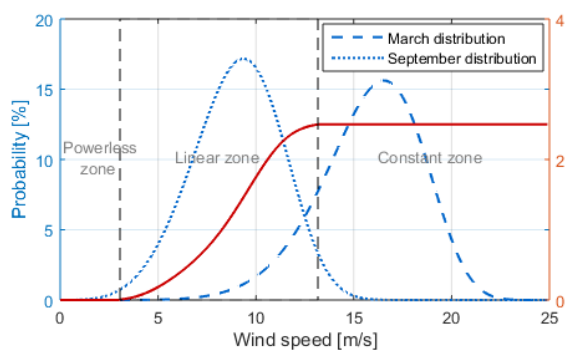


Figure 2. Turbine performance vs wind speed distributions of March and September. **Source**. Authors.

Table 2. Microgrid components power and number of elements (assets or customers) summary.

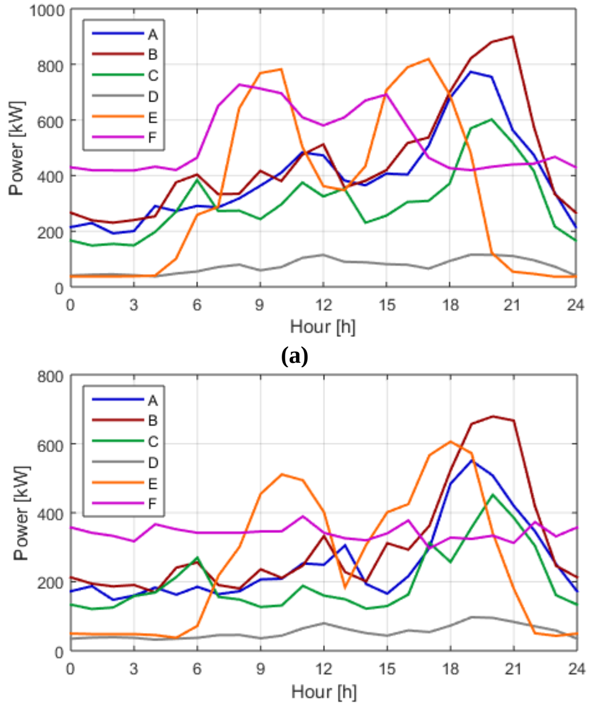
Microgrid components summary									
Power [kW]	**Generation**		**Storage [kWh]**	**Demand profiles groups**					
	Wind	**Solar**		**A**	**B**	**C**	**D**	**E**	**F**
# elements	8	256	250	1280	1100	560	128	600	22
Maximum	20000	84	450	677,8	899,6	601,8	115,6	789,4	727
Mean	15820	22	-	330,48	381,68	256,28	65,47	309,08	433,33
Minimum	0	0	0	164	169	122	32,2	37,8	326

Source. Authors. **Note.** Customers types: Social stratum A:1-2, B: 3, C:4, D:5, E: Commercial sector, F: Industries.

It is observed the September wind distribution is located in the linear zone, and a portion in the powerless. These low availability condition are related to the microgrid reliability behavior.

2.2. Demand profile

In this paper, the demand profile is supposed to show a distinction between weekdays and weekends. Those profiles are used along the year. As it is shown in Figure 3, they are divided into six customers groups determined by social stratum (1-2, 3, 4, 5) or category (commercial and industry).



(a)

(b)

Figure 3. Demand profiles separated by groups on (a) weekdays and (b) weekends. **Source**. UPME [9], Authors.

In addition, Table 2 shows a power values summary of microgrid generation, storage, and demand.

2.3. Demand Side Management

For achieving managed demand profiles, four Management Strategies (MS) are proposed and described in the following. Those belong to the following functions on load shape.

2.3.1. Power peak clipping.

This function pretends to reduce power above the mean power [4]. Two MS implemented for this function are:

- Light bulbs replacement: Substitution from any link of light bulb to use only LED technologies [5][6].
- TV technology replacement: All diversity of previous TVs technologies with a high consumption are changed by recent technologies [5][6].

In [7] it has been shown that the usage of more efficient devices increases the demand flexibility. This option will be considered in future works.

2.3.2. Energy saving.

Any action of change in consume habits to reduce the power demanded is an energy saving. An example is:

- Refrigerator's temperature modification: It has working intervals depending by the thermostat programmed value. E.g. if the set-up temperature changes from 2ºC to 6ºC, the refrigerator's motor use cycle is reduced. Decreases in consumed energy are perceived with a lower cycle operation time. Energy consumed changes from 4.8 kWh to 2.4 kWh per day [5].

2.3.3. Load shifting.

The peak demand is moved to the valley regions [4]. The same energy is expected to be delivered to the customer but in a different day moment. A MS for this function is:

- Working hours change: Industrial customers can modify their shedule to work in low demand hours [2].

3. METHODOLOGY

An algorithm is implemented to recreate a realistic behavior between generation, demand, and storage. The studied time is a year, with execution intervals of an hour. The algorithm starts considering a variation on the renewable resources at a specific time of month, day, and hour. Values of wind speed and solar radiation are used to calculate the generated energy which is compared with the load curve. If generation and storage cannot supply the demanded energy, the system experiences an energy unbalance and power is not delivered to the customers, i.e. an interruption occurs. Instead, if the generation is higher, service is supplied and additional energy is stored in the batteries bank [5]. The process is repeated for all hours of that year.

As a consequence of random values from renewable resources, only a year simulation is not enough for the study purpose. Thus, Monte Carlo method is used to obtain a distribution probability along 1000 years of outages and Energy Not Supplied (ENS).

This algorithm is also used for DSM simulations. Considering the groups of customers separately, schedules of home appliances use are taken from [10] to modify the demand profiles. As an objective of this paper is finding the possible effect out in the microgrid reliability, in all MS cases is applied the maximum management potential. Figure 4 shows the profile modifications under each management action.

The most remarkable change in the demand profile is when light bulbs are substituted, displaying a decrease on night rush hour peak. TV action has a similar behavior but in a minor scale. In contrast, a small reduction by refrigerator strategy has a change along whole day and load shifting of industrial group profile is the only MS with an increment in several hours.

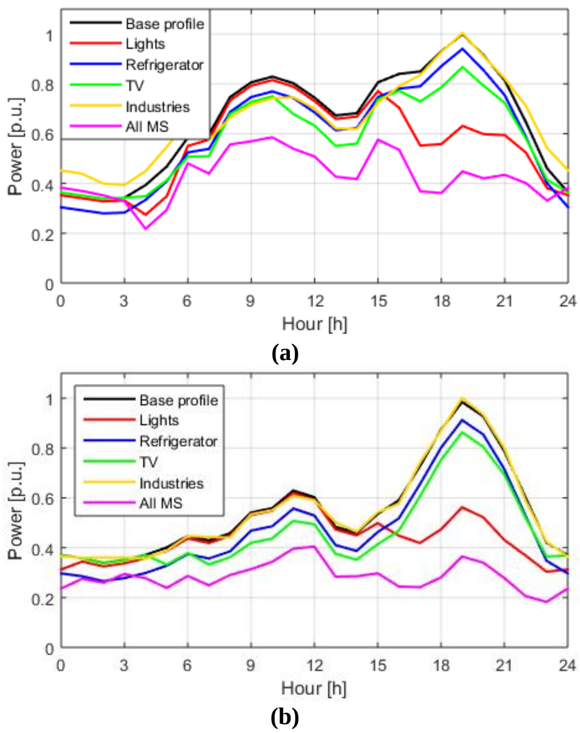


Figure 4. Demand profiles under Management Strategies on (a) weekdays and (b) weekends. **Source**. Authors.

On the other hand, implementing all MS is detected a decrease in energy consumption for each group. Thus, some groups have a quite significant change comparing than others. Quantification of that change is shown in Table 4.

Table 4. Change in each load group of monthly energy consumption after all MS are applied.

Change in monthly energy consumption with DSM			
Group	**Without DSM [MWh]**	**With DSM [MWh]**	**Change [%]**
A	242,96	106,13	56,32
B	277,18	122,08	55,95
C	187,27	99,64	49,79
D	46,99	28,24	39,91
E	219,81	142,42	35,21
F	317,83	301,89	5,02

Source. Authors.

4. RESULTS

Running simulations for all MS, it is obtained outages and ENS probabilities distributions along a year, as it is shown in Figure 5.

After DSM is applied, unbalances between demand and generation occur with less frequency for all MS, except on the industrial strategy. In comparison, the lights case is the most effective in the both indicators, followed by the TV and the refrigerator strategies.

Results can be compared with Colombian regulations about energy availability. The IEEE Std 1336 of 2012 and CREG 094 of 2012 regulations show reliability indicators used by regulators to control the service of network operators and electricity companies. In this paper, the indicators SAIFI, SAIDI, and ENS are applied to analyze the system reliability.

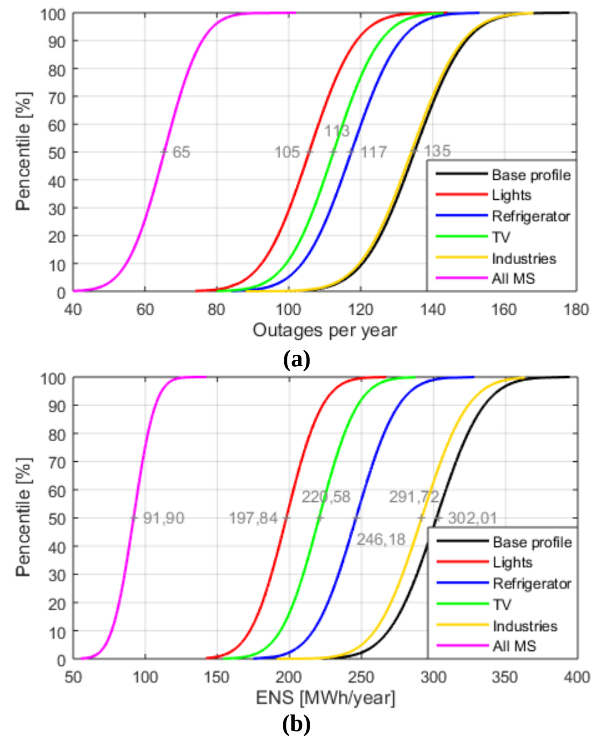


Figure 5. Annual system discontinuity indicators of (a) outages and (b) ENS under Management Scenarios. **Source**. Authors.

SAIDI indicates the average time in hours that network customers do not have energy service, per year [11]. As all interruptions along the year last one hour, the SAIDI value is equal than number of outages per year.

SAIFI is used for regulating the average interruption frequency in the customers service per year [11]. Again, this indicator can be assessed using the outages quantity obtained from simulations.

Energy Not Supplied (ENS) quantifies the energy not supplied to the customer along one year [12]. In this case, group values are different from system value. Reliability indicators for each group are shown in Table 5.

Until now, in our simulations when a unbalance between generation and demand occurs, all the system is affected. It is not considered a chance that generated energy is enough to supply only a demand portion.

It is deduced that all system does not need to experience an interruption. If an energy remnant can supply some customers groups, it is a profit on the system reliability to interrupt a load node when a unbalance occurs. This step, a second management level, is a complement for MS. When them are not enough to prevent an outage, a

Figure 5. Reliability indicators calculated for profiles with DSM.

Profiles reliability indicators with DSM									
Management Strategy	**SAIDI [hours/year]**	**SAIFI [outages/year]**	**Not Supplied Energy (ENS)**						
			System	**A**	**B**	**C**	**D**	**E**	**F**
Base profile	135	135	302,01	58,03	65,96	43,82	10,75	55,84	67,60
Lights	106	106	197,84	36,58	40,31	26,37	6,64	34,97	52,98
Refrigerator	117	117	246,18	44,24	52,32	32,46	8,04	50,09	59,03
TV	112	112	220,58	37,47	41,82	34,45	8,94	41,51	56,39
Industries	134	134	291,72	57,17	65,27	43,35	10,55	52,51	62,86
All MS	65	65	91,90	12,74	14,75	11,89	3,32	18,57	30,62

Source. Own elaboration.

load disconnection is implemented to reduce the total demand. Therefore, the disconnected group suffers an interruption, but not the whole system.

Respect to the disconnected group, it is not an arbitrary decision. A load interruption has several implications for users and network operator. The industrial customers measure its consumed energy as a development indicator. In contrast, for residential users, demanded energy means comfort. Focusing only on energy criteria, two indicators define the disconnection sequence.

Usable Energy (UsE) displays how much energy is available to supply the remaining load, after a disconnection occurs. It is preferred high values for this indicator. Low values suggest that interruption has not a significant effect. In Figure 6, it is shown the usable UsE when each customers group is chosen to be disconnected in an energy unbalance.

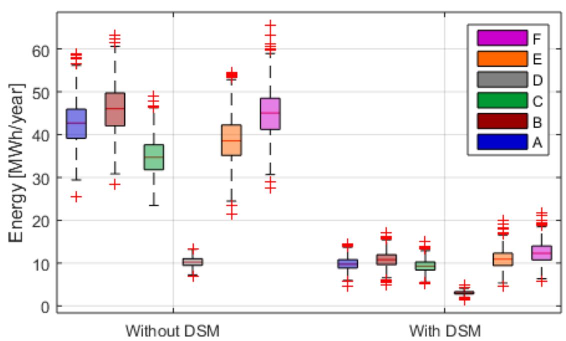


Figure 7. Unbilled energy probability of the disconnected group. **Source**. Authors.

As it is observed, cases without and with DSM are analyzed. When MS are implemented all probabilities decrease, residential group in a greater portion. Anyway, F group has a preference to be disconnected.

In contrast, it is tested the Unbilled Energy (UbE) criterion. When a disconnection occurs, certainly, network operator loses its earnings from interrupted load energy. Thus, for this indicator low values are preferred. Values probability for each group is shown in Figure 7, without and with DSM.

Under this criterion, the chosen load to disconnect would be the D group in the two cases. In addition, it is noticed that all residential groups, after DSM implementation, are preferred to be interrupted.

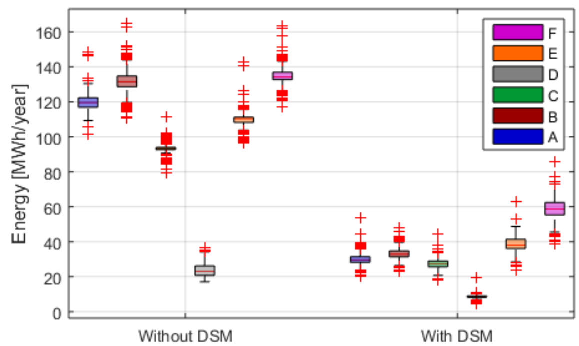


Figure 6. Usable energy probability in the system when a group is disconnected. **Source**. Authors.

Finally, the energy difference between UsE and UbE for each group, suggests us a disconnection disposition as it is shown in Table 6 (Colorful cells mean high disposition to be interrupted).

Table 6. Disconnection sequence indicators under Usable Energy and Unbilled Energy criteria.

Disconnection indicators under energy criteria						
	A	**B**	**C**	**D**	**E**	**F**
Without Demand Side Management [MWh]						
UsE	119,57	131,50	93,37	23,00	110,36	134,26
UbE	42,67	46,07	34,69	10,23	38,54	45,04
Δ	76,90	85,43	58,68	12,78	71,81	89,22
With Demand Side Management [MWh]						
UsE	29,56	32,82	27,38	8,43	38,04	58,67
UbE	9,72	10,82	9,27	3,06	10,91	12,31
Δ	19,84	22,00	18,11	5,37	27,13	46,36

Source. Authors.

It can be observed how DSM influences disconnection preference. Groups as A and after MS are less predisposed to be interrupted.

According with the disconnection disposition, it is created a disconnection sequence which works regarding the microgrid energy balance, i.e., when a unbalance occurs the system disconnects a first group. If the

unbalance remains, a second, a third or a fourth group could be disconnected, until the remaining load can be supplied.
Using the disconnection sequence, Monte Carlo simulations are run. Resulting SAIDI and SAIFI indicators for the system and each group are shown in Table 7.

Table 7. SAIFI and SAIDI indicators of each demand group under disconnection sequence with energy criteria.

SAIFI and SAIDI under disconnections sequence			
	Customers	**Without DSM**	**With DSM**
System	3690	52.86	9.38
A	1280	56	1
B	1100	94	12
C	560	2	0
D	128	0	0
E	600	26	31
F	22	142	70

Source. Authors.

Discontinuity indicators for disconnection system improve in comparison with the base profile for any case, without and with DSM.
Almost all groups do not suffer more outages implementing MS, excepting the E group. That behavior can be explain by the small reduction in demanded energy when DSM is implemented.

4. CONCLUSIONS

The main advantage of implementing DSM on a microgrid is to produce a DR to decrease load curve peaks. MS with clipping power peaks functions, as light bulb replacement, can guarantee the generation ability in low availability conditions. In addition, that MS has the best performance because lights bulbs are the most numerous home appliances in home.
In microgrid with generation oversizing, a leveling of the demand profile, as load shifting of industrial customers, has not an effect on microgrid reliability if it is not reduced the power consume in rush hours.
Generally, reductions in energy consumption of residential customers also has a favorable effect for all microgrid users. E.g. For any MS, the industrial group has better ENS indicators than with the industries MS. In that case, it is more profitable for industrial customers to motive residential users to produce a DR. On the other hand, the disconnection scheme is an effective measure to improve the system reliability indicators. However, under energy criteria, the minor load demand always is rewarded. Disconnecting a big load, the system has more energy available to supply the remain load. In consequence, with a DSM implementation, some groups are benefited with a decrease in energy consumption.

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