Assessment Criteria for a Distributed Energy Measurement and Monitoring System

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***Abstract*—It is well known that the control of energy consumptions in a building or in an organization enables to improve the energy performance (EP). The measurement plan defines the procedure for the design, deployment, utilization, maintenance and improvement of a distributed measurement and monitoring system (DMS). A DMS is able to measure and analyze the EP of the organization according to factors that influence the operation of the site. The paper suggests a method of assessment of a DMS based on different criteria. The paper focused on the criterion of the Level of Coverage. The authors suggest the definition of a Level of Coverage Numeric Indicator (LoCNI) that evaluates the capacity of the DMS to track consumptions by zones and by uses.**

Keywords-Distributed Monitoring Systems;SCADA; Building Automation

I. INTRODUCTION

It is well known that the control of energy consumptions in a building or in an organization enables to improve the energy performance. The standards relating to energy management refer to energy measurement and monitoring as being an important factor in improving energy performance (EP) defined as the measurable results relating to energy efficiency, energy use and energy consumption [1], [2], [3].

In the field of metering systems, the most important standards are ISO 50001, ISO 50004, ISO 50006. The standards define a measurement plan as the procedure for the design, deployment, utilization, maintenance and improvement of a distributed measurement and monitoring system (DMS). A DMS is able to measure and analyze the EP of the organization according to factors that influence the operation of the site.

The DMS consists in a complex architecture of distributed meters and devices with or without a central server with a supervisory system. The DMS provides services as: reading, processing, display, storage. The DMS can be integrated in a supervisory system. More in detail the DMS permits at the users to: (i) see in real time the information about the energy and power consumption, (ii) analyze their consumption and expenses on energy, (iii) use different types of graphs, tabulated and manipulated data. For an electrical DMS the devices can be: - current sensors, voltage sensors, power meters (profiles), power analyzers (quality and THD), supervisory systems.

The energy consumption is defined as the quantity of energy applied in a specific period as a year, for an energy use or for the global uses of the building.

The *measurement process* consists in physically obtaining values which can be reasonably assigned to a quantity. The *metering process* consists in the continuous integration of quantities measured as a function of time.

A DMS has to be able to monitor also the influencing factors defined as measurable or quantifiable parameters which can have an impact on EP and are subject to regular changes. An example of influencing factor is the level of occupancy of the building.

The *monitoring process* is the continuous evaluation of measurements or signals, with the multiple aim of: - the analysis of the EP by the calculation of indicators also in correlation with the influencing factors; - the report of potential system malfunctions; - the provision of alarm indications.

The effectiveness of the DMS depends on different factors one of which is the level of the coverage (LoC) of the DMS considering the energy uses and the zones of the structure(s).

The aim of this paper is to provide a criterion to assess the LoC of a DMS.

II. ZONES, SERVICES, USES AND MESHES

The Standard IEC 60364-8-1 provides requirements and recommendations for the efficient use of energy in low voltage electrical installations [4]. The standard proposes the use of active electrical energy efficiency measures, i.e., "measures for the optimization of electrical energy produced, supplied, flowing and consumed by an electrical installation for the best permanent functionally equivalent service".

The power system is divided into *meshes* defined as: group of electrical equipment powered from one or several electric circuits of the system for one or several *zones* including one or several *services* for the purpose of electrical energy efficiency [4]. The definition can be extended also to the other technical systems.

A *zone* is a part or area of a building or infrastructure or a process and its equipment considered for energy efficiency. An example an industrial appliance/system, a floor of a

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building, a space near the windows or a space away from the windows [4].
The *energy use* is defined as the manner or kind of application of the energy [1]. Examples of energy uses in a building or a commercial/industrial site are ventilation, lighting, heating, cooling, transportation, processes, production lines.
In summary, Standard 60364-8-1 encourages that the measures must:
- Allow verification of consumption as a basis for providing an indication of the situation and suggest the main initiatives to achieve savings wherever are the main consumption;
- Optimize with building automation and control systems everything that consumes energy which should be treated actively if we are to achieve lasting gains;
- Monitor, maintain and improve the electrical system. Since the objectives are fixed for a long period of time, the electrical energy efficiency programs represent a permanent improvement in time.

The standard introduces the concept of "Methodology of the plant life cycle". In summary, the approach to energy efficiency corresponds to the activation of a permanent cycle to be followed during the entire life of the same: starting from the execution of measures, it requires the implementation of measures identified, after which check and maintenance should be carried out regular basis with the succession in time.
A *significant energy use* is defined as the energy use accounting for substantial energy consumption and/or offering considerable potential for energy performance improvement [1]. Taking into consideration the globally determined *significant energy uses* and the *zones*, the authors suggested the introduction of the still *significant energy uses at local level*. For example, a globally determined significant energy use can be the lighting, the lighting of a specific zone as the restrooms can be classified as not significant at local level.
The introduction of the *meshes* allows highlighting the importance of the power system architecture when compared with the *zones* and *significant energy uses at local level* classification. A DMS is able to track the consumptions by zone and by significant use only if the circuits' architecture is organized in such a way that the meters can monitor the energies independently. It is possible to conclude that in the measurement and monitoring plan:
1) the meshes have to coincide with the significant energy uses at local level. This aspect depends on the design of the electric power system, thermal production and distribution system, and, where relevant, other technical systems. Therefore, they represent a requirement for the measurement system designer. Deviations shall be justified.
2) each mesh has to be monitored by independent meters. This aspect depends on the design of the measurement systems. Deviations shall be justified.

III. Method of Assessment of a DMS

The level of the DMS can be evaluated by a method based on minimum tabled recommendations [6]-[7]. The method is comparable with the criteria introduced by AFNOR [5]. The method uses 3 levels: 1 or basic, 2 or medium, 3 or high. The 6 different criteria are:
Level of Coverage: The ability to quantify the energy consumptions by significant energy uses at local level.
Data Acquisition: the ability to take readings from the measuring points at regular intervals.
Influencing Factors: The ability to quantify the influencing factors.
Communication and Storage: The ability to communicate and store the acquired data.
Energy Performance: The ability to view, process, analyze and control energy performance by using the acquired data.
Monitor: The ability to monitor the installation by the management of the acquired data.
The Level of Coverage (LoC) can be defined as the percentage of the yearly energy monitored by the DMS in per unit, independently for significant energy uses at local level, on the global yearly demand. For its evaluation the paper introduces a LoC Numeric Indicator (LoCNI) and an assessment method.
The reference values for the 6 criteria are given in Table I.

Table I. Reference values for the 6 criteria.

	1	**2**	**3**
Level of Coverage			
<=50%	X		
50%<x<=80%		X	
>80%			X
Data Acquisition			
Measurement of the total amount of the data (e.g. energy meter)	X		
Measurement of profiles for the most relevant data (e.g. power meter)		X	
Measurement of profiles for all the data (e.g. power quality analyzer)			X
Influencing factors			
The influencing factor for the most energy consuming item is considered	X		
One predominant influencing factor for the most energy consuming item by significant energy use at local level is considered		X	
The predominant influencing factors for the most energy consuming items by significant energy use at local level are considered			X
Communication and Storage			
Stand alone devices, human storage	X		
Network and central storage		X	
Network, local and central storage with redundancy			X
Energy Performance			
No capacity of processing, only the calculation of the total energy consumed	X		
Processing of load profiles, with a low frequency (e.g. 10 or 15 minutes for electricity) Basic indicators calculation		X	
Calculation of performance indicators			X
Monitor			
Continuous measurements at point of connection (POC)	X		
Continuous measurements at POC and at the distribution level (e.g. distribution switchboards)		X	
Continuous measurements at POC, at the distribution level and at the local level (e.g. major loads)			X

Each criterion shall be seen as being independent, meaning that one criterion can be classified as "basic" while the other is

"medium" and the other "high", depending on the appropriateness of each of the criterion in the context of the project and its intentions.
It is possible also define an overall score equal to the minimum value obtained for the 6 different criteria.

IV. THE LOC NUMERIC INDICATOR (LOCNI)

A DMS can be designed according to several requirements with an architecture that can be distributed or concentrated, and by adopting different standards of communication [8-14]. The effectiveness of a DMS, apart from the mentioned characteristics, is strongly related to the LoC as defined in a previous paper [7].
The LoC of a DMS can be evaluated through an index defined Level of Coverage Numeric Indicator LoCNI with a value that ranges between 0 and 1, where:

- 0 indicates no coverage;
- 1 indicates the highest LoCNI that is obtained by monitoring all the significant energy uses at local level.

In this paper, the authors consider the electrical power systems but the method is extendible to all the kinds of technical systems.
The first step in the LoC assessment of a DMS is to analyze the structure/building under observation and the scheme of the power system (Figure 1).

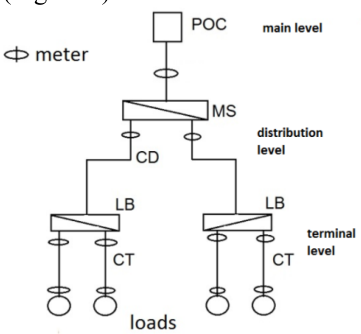

Figure 1. Example of power scheme

Preliminarily, the site is divided in different zones Zj and the energy uses Ui. The organization determines the list of the significant energy uses at local level (UZ) (in a number equal to Z).
Figure 2 shows an example of classification of UZs in a structure.

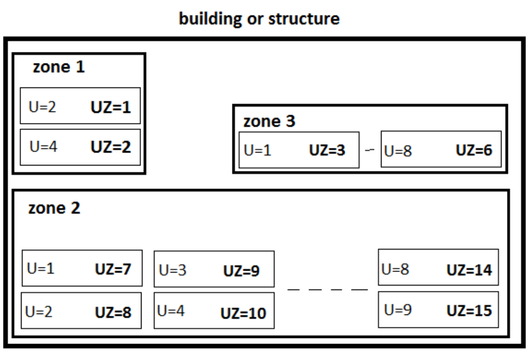

Figure 2. Example of classification in significant energy uses at local level UZs.

The LoCNI of a DMS is evaluated by a bottom up process, starting from the terminal level to move up to the point of connection (POC) with the grid.
The LoCNI depends strongly on the *UZ* classification that depends on the discretion of the energy manager/designer. The same DMS can obtain a high score of LoC if the list of *UZ* is short and sample or a low score if it is long and more detailed.
The LoCNI assessment process consists in several steps:

1. Classification of the UZ for the structure (list of significant energy uses at local level)
2. Analysis of the architecture of the system and detection of levels, switchboards and circuits
3. Combined analysis of the architecture of the system with the UZ classification: the UZC
4. Analysis of the energy weights of the circuits
5. Analysis of the energy weights of the switchboards
6. Analysis of the energy weights of a circuit respect the switchboard
7. Analysis of the energy weights of a UZC
8. Analysis of the level of coverage LoCM of a meter
9. Analysis of the level of coverage LoCLP of a switchboard (relative)
10. Analysis of the level of coverage LoCLP of a switchboard (absolute)
11. Analysis of the level of coverage LoC of a level
12. Analysis of the level of coverage LoC of a switchboard considering the upstream meter (if present)

1. Classification of the UZ for the structure

Given a structure, the energy manager/designer, starting from the list of zones Z, the list of uses U and the list of significant energy uses, defines the list of the significant energy uses at local level UZ.
Each UZ is characterized by a yearly energy spent in p.u. e_{UZ}:

$$e_{UZ}=W_{UiZj}/W_{POC} \quad [\text{p.u.}] \qquad (1)$$

W_{UZ} is the yearly energy spent by the UZ;
W_{POC} is the global yearly energy spent by the structure.
e_{UZ} can be defined as the energy weight of the UZ respect to total.

2. Analysis of the architecture of the system and detection of levels, switchboards and circuits

The energy manager analyzes the architecture of the power scheme detecting:

- The level of distribution (typically, main or POC, distribution and terminal/local);
- The number of Local Panels (LPs) at local level;
- The number of switchboards (SBs) at distribution level;
- For each LP and for each SB, the number of circuits.

It is suggested to adopt a classification of circuits in X.Y.Z being:
X = 1, ... SB, the code that identifies the distribution switchboard (SB), in total number equal to SB.
Y = 1, ... LP, the code that identifies the local panel (LP), in total number equal to LP;
Z = 1, ... NC_Y, the code that identifies the electrical circuit starting from the LP=Y, in total number equal to NC_Y.

In the case of further distribution levels will be necessary to introduce other codes. In the case of absence of main distribution SB, with a unique level of distribution, it will adopt a classification of the type Y.Z.
The starting circuit of a main SB=X that supplies a secondary Y panel, is identified by the code X.Y.0
The starting circuit of a main SB=X that directly feeds a load is identified by the code X.0.Z, with Z= 1, .. NC_X.

3. Combined analysis of the architecture of the system with the UZ classification: the UZC

For each UZ, it is possible to detect the LP (or SB) from which it is supplied and the relevant circuit (or the relevant circuits).
The *use of zone for a circuit* is defined as the combination of an UZ with its power supply circuit Z. Its code of identification is X.Y.Z.U equal to the code of the circuit X.Y.Z with the addition of the U.
As example, the UZ with U=1, powered by the circuit Z=1, starting from the LP with Y=1, powered by the SB with X=1, has markings 1.1.1.1 (Figure 3).

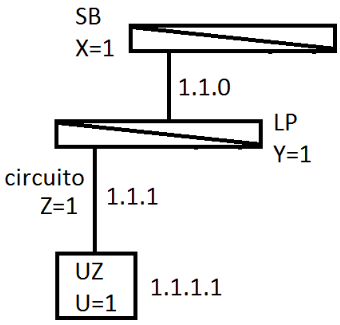

Figure 3. Example of codes

Notable case 1. UZ supplied by several circuits.
A UZ=U can be powered by several circuits, and then determines several UZC defined by different X.Y.Z.U codes.
For each UZ it is possible to determine the number of power supply circuits defining NCUZ parameter.
A UZ powered by several circuits is represented with a number equal to NCUZ codes like X.Y.Z.U.
Figure 4 shows an example with UZ=1 characterized by NCUZ=1 and UZ=2 characterized by NCUZ=2.

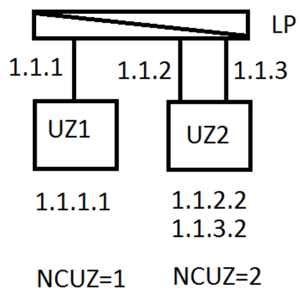

Figure 4. Example of UZ supplied from several circuits.

Notable case 2. A circuit supplies several UZ

An electrical circuit can power several UZs. Given an electrical circuit, NUZ defines the number of UZs fed from the circuit.
Figure 5 shows an example with two uses UZ1 and UZ2, two different circuits 1.1.1 and 1.1.2. The Figure shows NUZ values for the two circuits and NUCZ values for the two UZ.

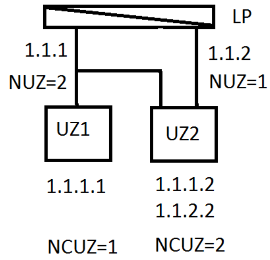

Figure 5. Example of a system with a circuit 1.1.1 supplying two different UZs (UZ1 and UZ2).

4. Analysis of the energy weights of the circuits

Given a LP (or a SB), it is possible to evaluate the energy weight of each circuit respect total using the formula:

$$e_C = \Sigma(e_{UZ,i}/NCUZ,i) \qquad [p.u.] \qquad (2)$$

being:
$e_{UZ,i}$ the energy of the ith UZ supplied from the circuit;
NCUZ,i the number of circuits for the use of zone, of the ith UZ fed from the circuit.
The sum is up to NUZ (number of UZ fed by the circuit).
Figure 5 shows an example of e_C evaluation.

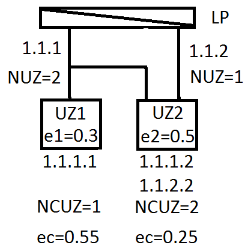

Figure 5. Example of evaluation of the energy weights of the circuits.

5. Analysis of the energy weights of the switchboards

Given a distribution level, for each LP (or SB) the energy weight respect to total is evaluated:

$$e_{LP} = W_{LP}/W_{POC} = \Sigma(e_{C,i}) \ [p.u.] \qquad (3)$$

being:
W_{LP} the estimated annual energy spent by LP [kWh];
$e_{C,i}$ the energy of all the circuits (i) departing from LP [p.u.].
The sum includes all the circuits departing from LP.
The formula (3) is also used for the level of the main distribution, replacing to LP, SB.

6. Analysis of the energy weights of a circuit respect the switchboard

Given a switchboard LP (or SB), it is possible to evaluate the energy weight of each circuit starting from the LP , respect the energy of the LP, as:

$$w_C = e_C/e_{LP} \qquad [p.u.] \qquad (4)$$

The formula (4) is also used for the level of the main distribution, replacing to LP, SB.

7. *Analysis of the energy weights of a UZC*

For each UZC with the code X.Y.Z.U, the UZC energy weight respect the circuit is evaluated by:

$$w_{UZC}=\frac{e_{UZ}}{e_C}\cdot\frac{1}{NCUZ} \quad \text{[p.u.]} \qquad (5)$$

8. *Analysis of the level of coverage LoC_M of a meter*

For each circuit of a switchboard LP (or SB), it is possible to evaluate the level of coverage of the meter (if present) LoC_M respect to the LP (or SB) as:

$$LoC_M = w_C \cdot \max(w_{UZ}) \quad \text{[p.u.]} \qquad (6)$$

If the meter is not present LoC_M=0.

Please note that, the maximum LoC_M value of a meter is equal to w_C.

9. *Analysis of the level of coverage LoC_{LP} of a switchboard (relative)*

For each switchboard LP (or SB) it is possible to evaluate the level of coverage of the switchboard respect the energy of the switchboard, LoC_{LP} as:

$$LoC_{LP} = \sum LoC_M \quad \text{[p.u.]} \qquad (7)$$

The sum includes all the circuits departing from LP (or SB).

Please note that, the maximum LoC_{LP} value is equal to 1, in the case in which the meters are able to monitor the whole energy of the switchboard.

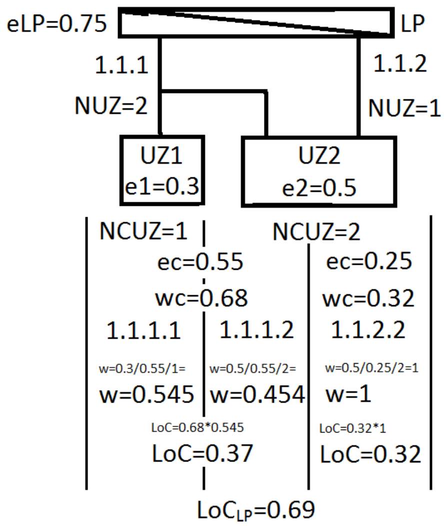

Figure 6. Example of LoCLP evaluation.

10. *Analysis of the level of coverage LoC_{LP} of a switchboard (absolute)*

The absolute level of coverage of the switchboard respect the total, $\widehat{LoC_{LP}}$ is:

$$\widehat{LoC_{LP}} = LoC_{LP} \cdot e_{LP} \quad \text{[p.u.]} \qquad (8)$$

Please note that the maximum $\widehat{LoC_{LP}}$ value is equal to e_{LP}.

11. *Analysis of the level of coverage LoC of a level*

The level of coverage of a given level of distribution is equal to:

$$LoC = \sum \widehat{LoC_{LP}} \quad \text{[p.u.]} \qquad (9)$$

The sum includes all the switchboards of the given level of distribution.

12. *Analysis of the level of coverage LoC of a switchboard considering the upstream meter (if present)*

In the case of presence of a meter located in the circuit upstream of the switchboard, the LoC_{LP} must be corrected to take account of the presence of the upstream meter, using the formula:

$$LoC_{LP} = \sum LoC_M + LoC_{NM} \quad \text{[p.u.]} \qquad (10)$$

being LoC_{NM} the level of coverage of the upstream meter considered as placed on all the non-monitored circuits of the switchboard, considered unified into a single circuit, and evaluated using the formula (6).

Figure 7 shows in an example that the meter placed on the main circuit 1.1.0 (distribution level) corresponds to a meter located at local level to monitor the circuits 1.1.3 and 1.1.4 taken together.

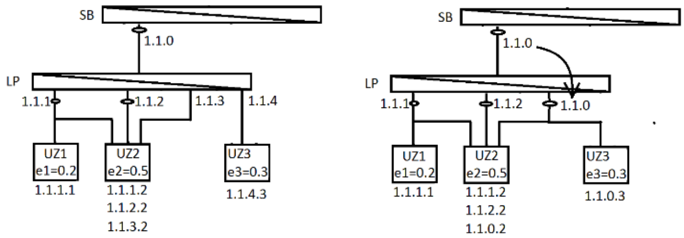

Figure 7. Level of coverage of a switchboard considering the upstream meter.

V. EXAMPLES OF EVALUATION

As case study, let's consider the system shown in Figure 8.

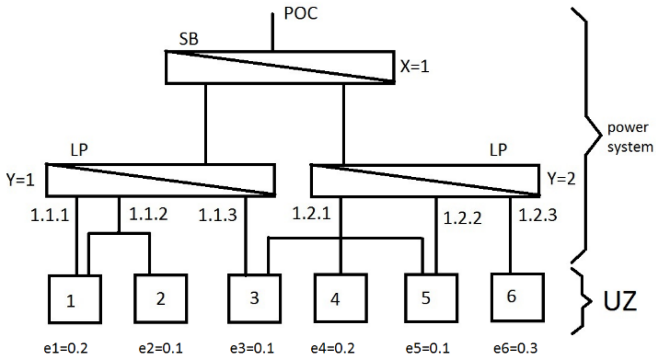

Figure 8. Case study.

a) Analysis of the power system

The power system consists in a two levels distribution with a main switchboard X=1 and two local panels Y=1 and Y=2.

LP with Y=1 has 3 circuits 1.1.1, 1.1.2, 1.1.3.

LP with Y=2 has 3 circuits 1.2.1, 1.2.2, 1.2.3

b) Analysis of the uses of zones UZ

The structure is divided in 6 different UZs. The energy analysis furnishes the e_{UZ} shown in Figure 8.

c) Combined analysis of UZs and the power scheme

The combined analysis defines the UZC of the system. Table II shows the values evaluated for e_C, e_{LP}, w_{UZ} and w_C.

The LoCNI is equal to 0.8. This is the maximum value obtainable given the architecture of the power system and defined the list of UZs.

d) Case 1. Meters on all the local circuits of Y=1 and Y=2.

The first case considers the presence of meters on all the circuits of LPs Y=1 and Y=2. Figure 9 shows the architecture of the system and Table III shows the analysis.

TABLE II. CASE STUDY ANALYSIS.

UZ	UZ	1		2	3		4	5		6
eUZ	p.u.	0,2		0,1	0,1		0,2	0,1		0,3
Circuit	X.Y.Z	1.1.1	1.1.2		1.1.3	1.2.1			1.2.2	1.2.3
NCUZ	#	2		1	2		1	2		1
NUZ	#	1	2		1	3			1	1
eC	p.u.	0,1	0,2		0,05	0,3			0,05	0,3
eLP	p.u.	0,35				0,65				
UZC	X.Y.Z.U	1.1.1.1	1.1.2.1	1.1.2.2	1.1.3.3	1.2.1.3	1.2.1.4	1.2.1.5	1.2.2.5	1.2.3.6
wUZ	p.u.	1	0,5	0,5	1	0,167	0,667	0,167	1	1
wC	p.u.	0,286	0,571		0,143	0,462			0,077	0,462

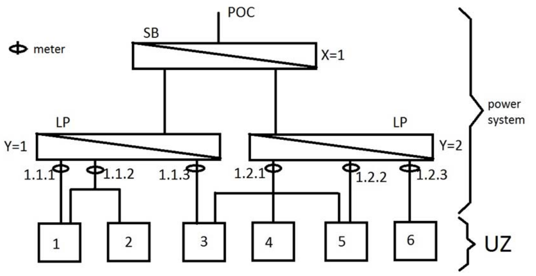

Figure 9. Case 1 architecture.

TABLE III. RESULTS OF CASE 1.

UZ	UZ	1		2	3		4	5		6
eUZ	p.u.	0,2		0,1	0,1		0,2	0,1		0,3
Circuit	X.Y.Z	1.1.1	1.1.2		1.1.3	1.2.1			1.2.2	1.2.3
NCUZ	#	2		1	2		1	2		1
NUZ	#	1	2		1	3			1	1
eC	p.u.	0,1	0,2		0,05	0,3			0,05	0,3
eLP	p.u.	0,35				0,65				
UZC	X.Y.Z.U	1.1.1.1	1.1.2.1	1.1.2.2	1.1.3.3	1.2.1.3	1.2.1.4	1.2.1.5	1.2.2.5	1.2.3.6
wUZ	p.u.	1	0,5	0,5	1	0,167	0,667	0,167	1	1
wC	p.u.	0,286	0,571		0,143	0,462			0,077	0,462
LoCM	p.u.	0,286	0,286		0,143	0,308			0,077	0,462
LoCLP	p.u.	0,714				0,846				
LoCLP,abs	p.u.	0,25				0,55				
LoCNI	p.u.	0,80000								

e) Case 2. Meters on all the main circuits of X=1

The second case considers the presence of two meters on the circuits of SB X=1. The assessment is performed considering that the LoC_{LP} of the two local LPs evaluated with the formula (7) is equal to 0. The LoC_{LP} of the two local LPs considering the presence of the upstream meters is evaluated with the formula (10) which considers all circuits not monitored by the LPs as a single circuit. Figure 10 shows the architecture.

The LoCNI is equal to 0.5. Table IV shows the assessment.

TABLE IV. RESULTS OF CASE 2.

UZ	UZ	1	2	3		4	5	6
eUZ	p.u.	0,2	0,1	0,1	0,1	0,2	0,1	0,3
Circuit	X.Y.Z	1.1.0			1.2.0			
NCUZ	#	1	1	2	2	1	2	1
NUZ	#	3			3			1
eC	p.u.	0,35			0,65			
eLP	p.u.	1			1			
UZ	X.Y.Z.U	1.1.0.1	1.1.0.2	1.1.0.3	1.2.0.3	1.2.0.4	1.2.0.5	1.2.0.6
wUZ	p.u.	0,571	0,286	0,143	0,077	0,308	0,077	0,462
wC	p.u.	0,35			0,65			
LoCM	p.u.	0,2			0,3			
LoCLP	p.u.	0,2			0,3			
LoCLP,ass	p.u.	0,2			0,3			
LoCNI	p.u.	0,5						

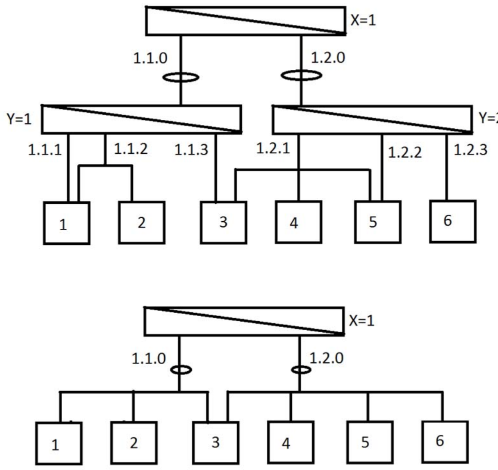

Figure 10. Case 2 architecture.

f) Case 3. Meters on all the main circuits of X=1 plus a meter on circuit 1.2.3

A third case is evaluated considering the situation of the case 2 plus a meter located on the circuit 1.2.3 of the LP Y=2. Figure 11 shows the architecture. In this case the LoCNI is equal to 0.7. Table V shows the assessment.

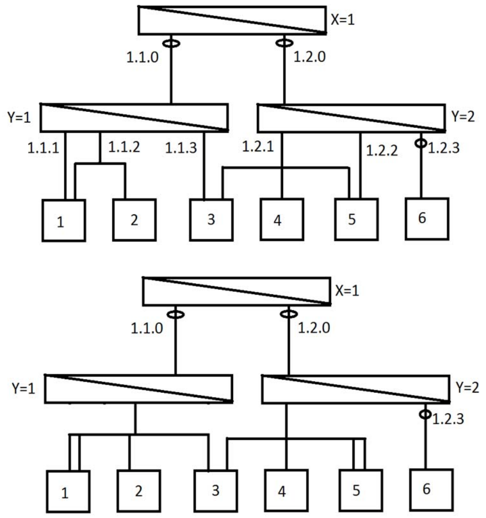

Figure 11. Case 3 architecture.

TABLE V. RESULTS OF CASE 3.

UZ	UZ	1	2	3		4	5	6
eUZ	p.u.	0,2	0,1	0,1	0,1	0,2	0,1	0,3
Circuit	X.Y.Z	1.1.0			1.2.0			1.2.3
NCUZ	#	1	1	2	2	1	2	1
NUZ	#	3			3			1
eC	p.u.	0,35			0,35			0,3
eLP	p.u.	0,35			0,65			
UZC	X.Y.Z.U	1.1.0.1	1.1.0.2	1.1.0.3	1.2.0.3	1.2.0.4	1.2.0.5	1.2.0.6
wUZ	p.u.	0,571	0,286	0,143	0,143	0,571	0,143	1
wC	p.u.	1			0,538			0,462
LoCM	p.u.	0,571			0,308			0,462
LoCLP	p.u.	0,571			0,769			
LoCLP,abs	p.u.	0,2			0,5			
LoCNI	p.u.	0,7						

VI. CONCLUSIONS

A distributed metering system DMS is fundamental, in order to manage and control the energy performance of a building/structure. In this work, a method for the assessment of DMS is presented. The method defines 6 criteria for the overall system grade evaluation. The paper introduces, in particular, a method to assess the level of coverage of a DMS. In a given structure, considering the list of the significant energy uses at local level, a DMS is able to track the consumptions only if the circuits' architecture is organized in such a way that the meters can monitor the energies independently. The suggested method permits to optimize the location of the meters offering a quantitative indicator of the level of coverage.

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