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A Communication and Resources Management Scheme to Support the Smart Grid Integration of Multiplayers Access to Resources Information

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Abstract: The increasing and intensive integration of distributed energy resources into distribution systems requires adequate methodologies to ensure a secure operation according to the smart grid paradigm. In this context, SCADA (Supervisory Control and Data Acquisition) systems are an essential infrastructure. This paper presents a conceptual design of a communication and resources management scheme based on an intelligent SCADA with a decentralized, flexible, and intelligent approach, adaptive to the context (context awareness). The methodology is used to support the energy resource management considering all the involved costs, power flows, and electricity prices leading to the network reconfiguration. The methodology also addresses the definition of the information access permissions of each player to each resource. The paper includes a 33-bus network used in a case study that considers an intensive use of distributed energy resources in five distinct implemented operation contexts.

1. INTRODUCTION

The increasing number of players acting in power systems sector and the Distributed Energy Resources (DER) connected in the distribution network at all the voltage levels create new challenges in their operation and management. Also, the infrastructure of communications must be improved in order to ensure the transmission of all necessary information with high accuracy levels (Ko, *et al.*, 2012). Moreover, the power systems increasingly operate close to its limits. To ensure the system's reliability it is important to monitor and manage the operation of all resources in real-time (Bui, *et al.*, 2012).

Several new DER technologies can be considered in future power systems, namely the Distributed Generation (DG), the Demand Response (DR), the electricity storage systems, the Electric Vehicles (EVs) and new players, as the case of Virtual Power Players (VPPs) which should ensure a reliable, secure, and flexible operation of smart grids (Fang, *et al.*, 2012; (Morais, *et al.*, 2012). The use of distribution network as a resource should be possible considering the use of remote control devices allowing the system reconfiguration or power flows control, limiting or avoiding situations of congestions (Oualmakran, *et al.*, 2011).

This new operation paradigm is usually integrated in the smart grids concept (Fadaeenejad, *et al.*, 2014). Smart grids allow a greater availability of functions in the power system, with the generation of new services, optimizing the management and control of the electric network through the consumer's participation (Faria, *et al.*, 2011). In this new vision, the consumer/producer will be the recipient of the main benefits associated with this change, playing an active role in the energy consumption management, reducing the electricity costs. The amount of consumers' energy bill will tend to lower significantly (Gangale, *et al.*, 2013).

Other important aspect in the smart grids is the increasing requirements of the service quality. In fact, high reliability levels are necessary in order to assure the operation of all available energy resources in different operation scenarios (Gustavsson, *et al.*, 2013). Usually in the transmission networks operation the *N-1* criteria is considered regarding the fail of the most important elements. This approach is not sufficient and adequate in the case of distribution networks.

The high penetration of DER and the remote network reconfiguration capability turns the distribution network more flexible and more capable of "surviving" in critical situations. The identification of these contingency situations in the operation contexts provides a fast service recover for operators or aggregators, or in some cases maintains the system in operation. The context definitions can be done considering a list of the most provable contingencies that can occur in a specific distribution network taking into account the new operation scenario (Vale, *et al.*, 2013).

The present paper is based on the work of some of the authors already presented in (Vale, *et al.*, 2013), (Ko, *et al.*, 2012), and (Gomes, *et al.*, 2013). The innovative aspects relies on the integration of the contexts' identification methodology (Vale, *et al.*, 2013) on the communications infrastructure methodology proposed in (Ko, *et al.*, 2012). The interactions between some of the players involved in smart grids operation (Gomes, *et al.*, 2013) are also discussed. The specific case of a fault in distribution network line is addressed in the case study.

The paper is structured as follows: Section I presents the introduction; in Section II a smart grid communication scheme is presented; Section III presents the proposed methodology considering several operation contexts. Section IV illustrates a case study considering and contingency (line out of service); and the last section presents the main conclusions of the paper.

2. SMART GRID COMUNICATION SCHEME

The smart grids operation should be a cooperative, but also a competitive environment. In fact, each player will try to improve its profits or to reduce its energy bill. New aggregation players should provide a wide range of services trying to provide services in order to reduce the operation and maintenance cost of the players. The aggregators can be of several types such as Virtual Power Players (VPPs), Curtailment Service Providers (CSPs), microgrid operators, etc. (Gomes, *et al.*, 2013). In Figure 1, some possible interactions in future smart grids are presented considering the aggregators and several DER with distinct dimensions.

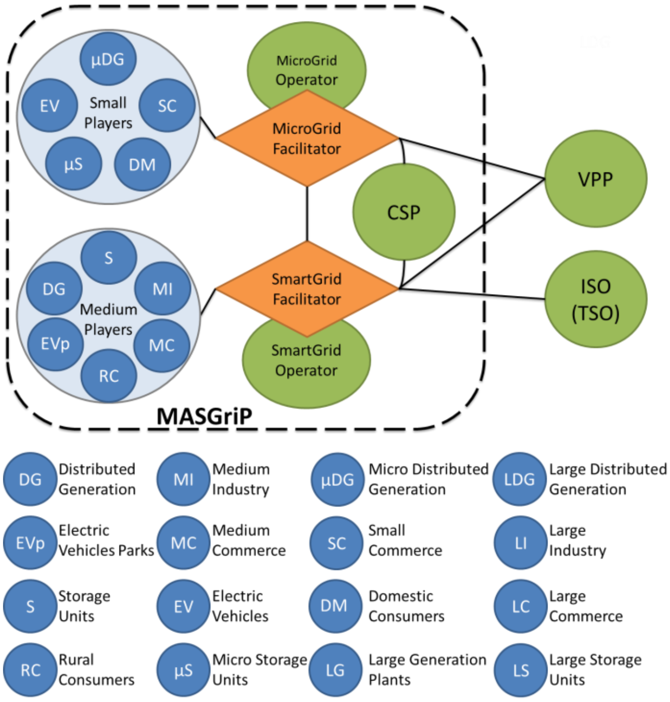

Fig. 1. Smart Grids players interactions

Considering the VPP standpoint, this player aims to provide adequate support for medium and small players acting in the market, providing the best scheduling for the available DERs through the effectiveness of ERM. In this process, large amounts of information should be shared between the VPP and players regarding the consumption/generation measurements, the resources control commands and negotiation tasks.

Several time horizons can be simulated, i.e. the contracts negotiation period, the day-ahead scheduling period, and the real-time operation (Silva, *et al.*, 2012). The most critical is the real-time operation, namely when the VPP aggregates players with renewable generators based on natural sources (wind and solar). In this case, the VPP should ensure some reserves in order to fulfil the established agreements (in bilateral contracts and/or in electricity market). In the real-time operation it is necessary to identify the operation context using the measuring equipment and re-schedule the available resources in order to maintain the system's balance (Chang-Chien, *et al.*, 2007). These new methodologies should be included in future SCADA (Supervisory Control And Data Acquisition) systems.

SCADA is a type of system that allows controlling processes, collect data in real time, monitor and control devices that are physically distributed (Vale, *et al.*, 2009). For many years, energy companies relied on SCADA systems to sense, monitor, gather, and control distributed physical infrastructures. With the advance of technology it becomes necessary to develop real intelligent SCADAs able to operate in the new smart grid concept.

The identification of the distribution networks context is used to support the distributed energy resources management in critical situations. Once a situation is characterized, data and control options available to each entity are redefined according to this context, taking into account the operation normative and *a priori* established contracts. Intelligent SCADA gives Distribution Network Operator (DNO) access to relevant data concerning third-party owned DG, in case of *a priori* contracted situations (e.g. to manage incident situations, to undertake service restoration or to manage voltage profile).

In Figure 2, the dashed lines represent interactions among system players to negotiate contracts; the solid lines represent SCADA actions. The white box (VPP) represents the aggregator. The small boxes represent Player *p*'s components (*Cp1* to *Cpm*). These components can always be operated by their owner – Player *p* – respecting the technical constraints. Some or all of these components can also be operated by any other player, if this player has a contract with Player *p* that regulates their use.

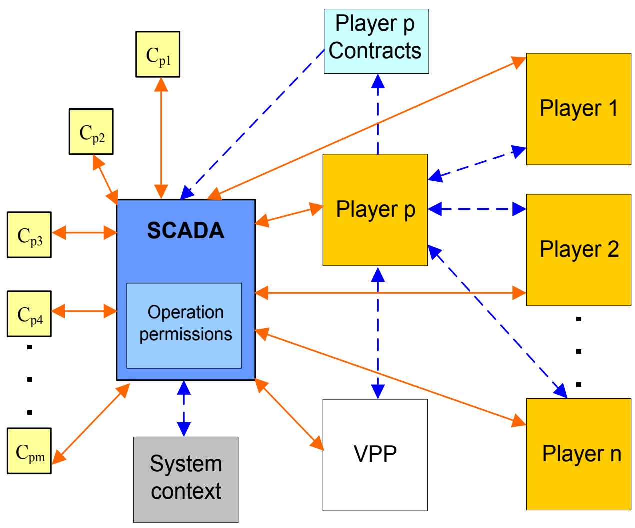

Fig. 2. ERM proposed methodology

3. RESOURCES ACCESS AND MANAGEMENT

The present section explains the resources access and the management methodology, which includes the optimization of the resources schedule in each specific operation context. More details can be obtained from (Vale, *et al.*, 2013).

The resources access and management methodology takes into account the information concerning the operational network context and the contractual agreements between the involved players. The main definitions of the terms used in the methodology are the following:

Additional resource – a resource (r) or a partial capacity of a specific resource that is contracted to be used in a certain context (c);

Context – *a priori* defined network context that can be characterized by the status of network components (e.g. branches, breakers and switches) and/or by other relevant information such as the demand level, the storage status, and the market price. A certain context may occur at any period (t) and can last for several periods;

State – a set of contexts occurring in a certain period (t).

The information concerning the resources' access by each player is organized in the following matrixes:

$$Ct\_M = \begin{bmatrix} ct_{1,1} & \cdots \\ \cdots & ct_{N,T} \end{bmatrix}$$

The occurrence of contexts over time is represented by the *Ct_M* matrix. Each line of this matrix corresponds to a specific context c. The element $ct_{c,t}$ is equal to "1" if the context c occurs in period t; otherwise it is equal to "0". N and T are the cardinality of contexts and periods, respectively.

$$Rc\_ad\_M = \begin{bmatrix} r_{1,1} & \cdots \\ \cdots & r_{N,R\_ad} \end{bmatrix}$$

Rc_ad_M includes the additional (third party) resources that can be used in each considered context c. The element $r_{c,r}$ is equal to "1" if the additional resource r is contracted to be used in context c; otherwise, it is "0". N and R_ad are the cardinality of contexts and additional resources, respectively.

$$R\_power\_M = \begin{bmatrix} P_{1,1} & \cdots \\ \cdots & P_{T,R} \end{bmatrix}$$

R_power_M, registers the information concerning the maximum available power for each resource (matrix row) in each period (matrix column, [$t=1$ to T]).

$$R\_unavailable = \begin{bmatrix} t_1 & t_r & t_R \\ d_1 & d_r & d_R \end{bmatrix}$$

The resources unavailable in a certain period are represented in the matrix *R_unavailable*. It has two rows and R columns, as many as all the considered resources (i.e. the ones owned by the operator and the third party resources, for which the use is contracted). The first row pertains to the unavailability starting period (tr), and the second one to the expected duration (dr) of the unavailability for each resource (r).

$$R\_cost\_M = \begin{bmatrix} c_{1,1} & \cdots \\ \cdots & c_{R,T} \end{bmatrix}$$

R_cost_M registers the information considering the cost of each resource (matrix row) in each period (matrix column, [$t=1$ to T]).

Several other matrixes and sets are defined in order to create information structures that include the information necessary for specific purposes. Some of them are listed below:

- $R\_additional_c$ – additional resources available in context c, i.e. the additional resources available in context c as indicated in *Ct_M*;
- $R\_additional_t$ – additional resources in period t;
- *R_base* – base resources (the ones owned by the operator) that can be used in any context or period;
- R_global_t – the set of resources that can be used in period t, according to the state of the system in that period;
- *R_opt* – the set of resources available in period t;
- $R\_unavailable_t$ – the set of resources unavailable in period t. In this case, the context is not relevant.

Once having all the information structured, in what concerns the resources that can be acceded, namely by the network operator in each context, this player needs to perform the resources' scheduling optimization. In this way, the best economic solution of the resources use problem is determined.

The objective function of the resources schedule problem is defined as in the equation bellow. It considers, for the overall optimization time-horizon, the costs of using each resource in each context, and also the cost of the Non-Supplied Energy (NSE) in each load L. Therefore, the overall costs of using all the resources are minimized.

$$Min$$

$$f = \sum_{t=1}^{T} \left[\sum_{r=1, r \in R\_op_t}^{R} P_{r,t} \times c_{r,t} + \sum_{L=1}^{N_L} P_{NSE(L,t)} \times c_{NSE(L,t)} \right]$$

This is a Mixed-Integer Non Linear Programming (MINLP) problem. All the involved costs are represented by a linear cost function. The following constraints applied for each period t are also considered in the optimization model:

- Network reactive and reactive power balance in each bus b;
- Bus voltage magnitude and angle limits;
- Line thermal limits;
- Maximum active and reactive resources limit;
- Storage units charge and discharge rates and maximum capacity limits.

3. CASE STUDY

This section shows the application of the proposed methodology to a 33-bus network and resources context scenarios (subsection 3.1). The obtained results for the 5 implemented operation contexts are in subsection 3.2.

3.1 Network and Resources Scenario

The 33-bus distribution network, adapted from (Faria, *et al.*, 2011), is illustrated in Figure 3. Information concerning the Distributed Generation (DG) units available in each bus is included. In order to show and support the operation contexts that will be defined bellow, Figure 3 also illustrates the fault that causes the unavailability of line 5-6. The buses 6 to 17, located in the downstream of the unavailable line, are in red. The dashed lines are normally open but they can be used for reconfiguration purposes.

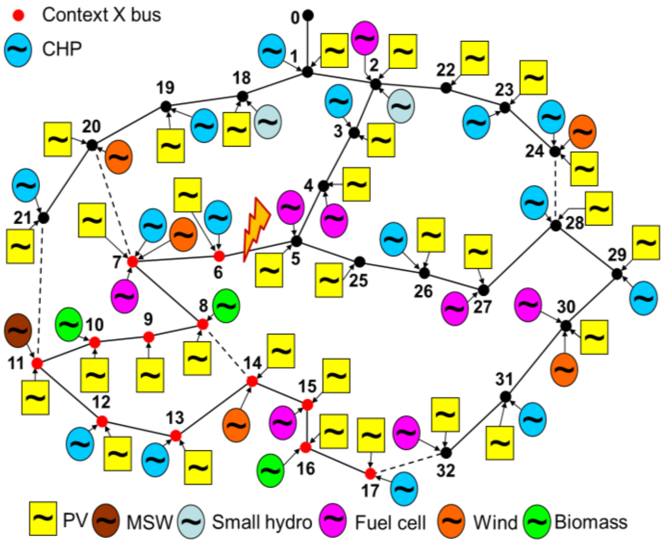

Fig. 3. Distribution network configuration.

For a more detailed characterization of the resources characteristics, Table 1 gives information on the power capacity and resources use prices.

Table 1- Energy resources characteristics

Energy resources	Total Capacity (kW)	Number of resources	Prices (m.u./kWh)
Biomass	350	3	0.090
CHP	1150	15	0.060
Fuel Cell	235	8	0.150
Small Hydro	70	2	0.070
Photovoltaic	549	32	0.200
MSW	10	1	0.100
Wind	800	5	0.150
External Suppliers	–	3	0.600 – 0.150

The use of each resource depends on the context that occurs in each moment, according to the established contracts. In what concerns the illustration of different contexts, five operation contexts have been implemented in this case study. Each one of the contexts is described as follows:

__**Context A**__ – Normal network operation. All the ordinary resources are available and only ordinary resources are used. This is the sole context that does not consider the fault that causes unavailability of line 5-6;

__**Context B**__ – Line 5-6 is unavailable. However, none of the additional resources are used. In this case, several loads will not be supplied, resulting in a certain amount of Non-Supplied Energy (NSE);

__**Context C**__ – Dealing with the unavailability of line 5-6, in this context are used CHP (Combined Heat and Power) resources connected to buses 6 to 17, in order to supply the loads also connected to these buses. CHP generators become responsible for guaranteeing the voltage stability in this “islanded network”;

__**Context D**__ – Dealing with the unavailability of line 5-6, in this context the reconfiguration line 7-20 is used, which is normally open in order to supply the loads connected to buses 6 to 17;

__**Context E**__ – Dealing with the unavailability of line 5-6, in this context, line 17-32, which is normally open, is used as an additional resource. In this way, the loads connected to buses 6 to 17 are supplied.

The present case study considers a one-day scenario with 24 periods. Table 2 presents the information concerning the contexts that occur in each period of the day. In fact, the specific case of Context_A occurs throughout all the periods except in periods 20, 21, and 22 – the ones in which line 5-6 is unavailable and the reaming contexts occur.

Table 2- Case study contexts

Context (*c*)	Period (*t*) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A																			■					
B																				■	■	■		
C																				■	■	■		
D																				■	■	■		
E																				■	■	■		

Each one of the contexts related to the unavailability of line 5-6 is simulated individually in order to compare the impact of each context additional resources. For the simplicity of the results comparison, the ones for the Context_A are only presented for period 19. The additional resources that are contracted to be used in each one of the implemented contexts are presented in Table 3.

Table 3- Additional resources in each context

ID	Additional Resources (*r*) 1	2	3	4	5	6	7
r	CHP-1	CHP-2	CHP-3	CHP-4	CHP-5	L 7-20	L 17-32
Context (*c*) A							
B							
C	■	■	■	■	■		
D						■	
E							■
P (kW)	200	100	200	200	200	-	-

The power available from each additional resource, namely from each CHP resource is also presented in Table 3. The costs related to the use of each additional resource, when applicable, are presented in Table 4.

Table 4- Additional resources cost

	ID	r	Context (c) A	B	C	D	E
Additional resources (r)	1	CHP-1	-	-	0,080	-	-
	2	CHP-2	-	-	0,120	-	-
	3	CHP-3	-	-	0,095	-	-
	4	CHP-4	-	-	0,130	-	-
	5	CHP-5	-	-	0,120	-	-
	6	L 7-20	-	-	-	-	-
	7	L 17-32	-	-	-	-	-

3.2 Results of the Resources Schedule in Each Context

The present subsection shows the results concerning the resources schedule and operation costs in each one of the five implemented contexts, resulting from the optimization that minimizes the operation costs (see Section 3). The focus is given to the additional resources available in each context. In Figure 4, one can see the resources schedule for Context_A. In this way, all the ordinary resources are available during the whole day.

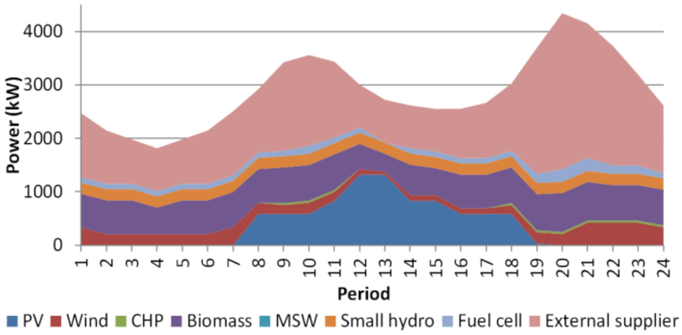

Fig. 4. Resources schedule in Context_A

In what concerns the analysis of the resources use, the network lines power flow, and operation costs, Figure 5 compares the results for each implemented context. The results presented focus on periods 19, 20, 21, and 22, which represent the implemented contexts. It is worthy to remember that the values in kW of Figure 5 refer to the portion of network that becomes affected by the unavailability of line 5-6. So, it is not possible to directly compare it with the values in Figure 4, which refers to the whole network.

In Figure 5.a), one can see the network operation costs. Taking Context_A as reference, it is possible to conclude that the high price (penalty) of Non-Supplied Energy (NSE), which is of 4,5 m.u./kWh, can cause a huge increase in operation costs when the line is unavailable. During this contingency, and making use of alternative additional resources, as represented in the remaining Contexts, it is possible to keep operation costs in an acceptable level (Even in Context_C, in which there are costs associated with the use of additional CHP resources). In what concerns the NSE amount in kW shown in Figure 5.b), one can see that the higher amount is verified in period 19.

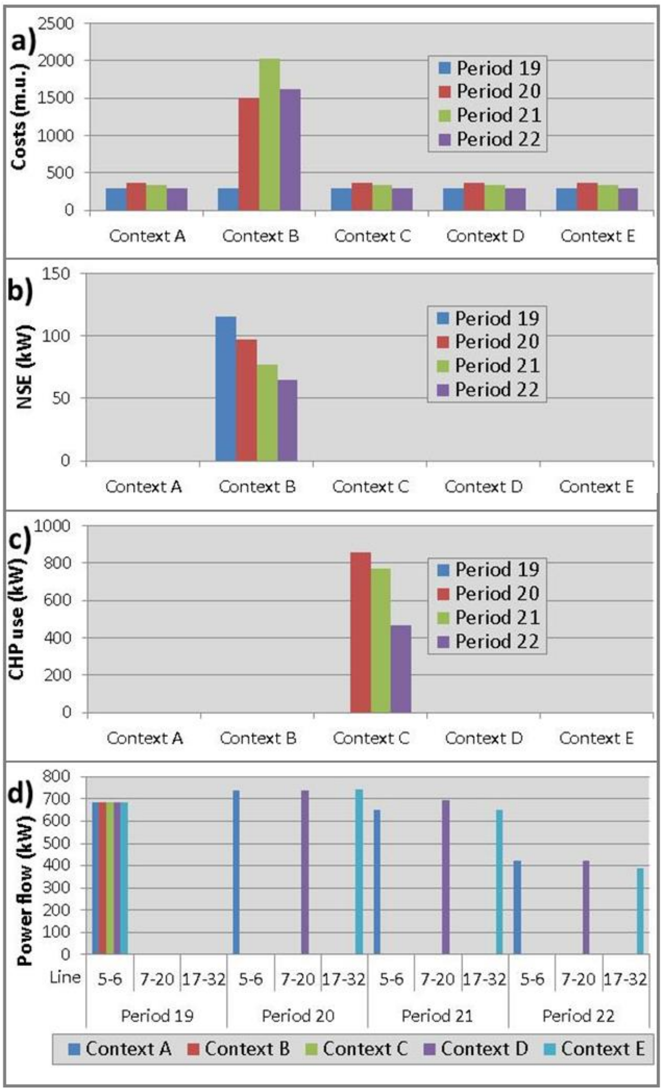

Fig. 5. Comparison of the results for each context

The values concerning the use of CHP additional resources (seen in Figure 5.c)) only occurred in Context_C. They are higher in period 20, which is the one of higher consumption. The detailed additional CHP resources use is presented in Figure 6. It is important to see that these additional resources (or additional capacity of a specific unit) are not used in period 19, in which Context_A occurs. In the remaining periods of Context_C, the CHP units are scheduled according to the cost of usage, size, and location (regarding voltage constraints) in order to attain the consumption needs.

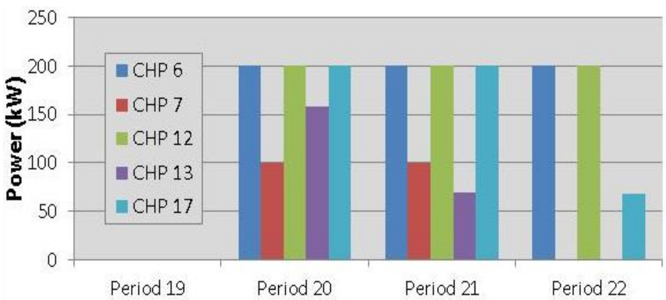

Fig. 6. Detailed use of additional CHP resources

From the power flow analysis, lets us focus on lines 5-6, 7-20, and 17-32 of Figure 5.d). It is important to see that as the resources scheduling algorithm includes constraints for the bus voltages limits, the use of lines 7-20 and 17-32 implies higher power flow values, and obviously higher power losses.

The detailed power losses results, in each context, are presented in Figure 7. Once again, considering period 19 as the reference, one can see that using line 17-32 (Context_E) causes higher losses. When using line 7-20 (Context_D), the losses value is lower than using the ordinary line 5-6. In fact, the use of line 7-20 can cause some problems in the normal operation of the network, i.e. in what concerns reliability levels.

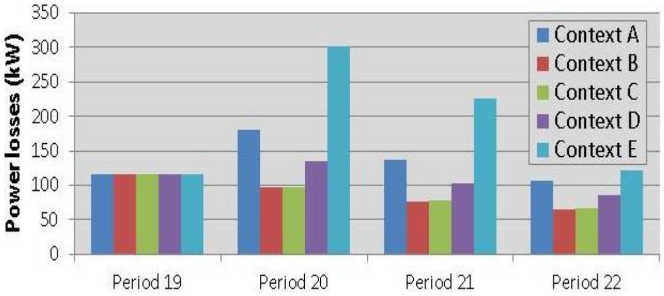

Fig. 7. Power losses in each context and period

In both situations of using additional CHP resources (Context_C), and of causing NSE amounts (Context_B), it can be seen that the power losses are lower as the load balance in each node is physically assured in a distributed and local configuration.

4. CONCLUSIONS

The future context of operation of smart grids and of competitive electricity markets, require the use of all the possibilities in order to attain the goals of each involved player. Network security and reliability levels, as well as the quality of service issues must be adequately addressed.

The methodology proposed in this paper takes into account the permissions that each player can have in acceding and managing each network resource in order to attain its goals. The focus is here given to the goals of the network operator that manages ordinary and additional resources, which can be used in specific contingency contexts.

The case of a fault in a distribution network line has been implemented. Several additional resources and contexts have been simulated, proving the advantages of using the proposed methodology in order to minimize the impacts of the fault.

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