SUPPLY RESTORATION IN ELECTRIC DISTRIBUTION NETWORKS: A MULTI-AGENT APPROACH

Maria F.Q.VIEIRA TURNELL[1], Bernard ESPINASSE[2], Guillaume AVENTINI[2]

1- LIHM – DEE - UFCG, Universidade Federal de Campina Grande, Brazil

fatima@dee.ufcg.edu.br,

2- LSIS – UMR CNRS 6168, Université Paul Cézanne, Marseille, France

bernard.espinasse@univ.u-3mrs.fr

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ABSTRACT

Energy Management Systems can benefit from the multi-agent approach at different levels. This approach offers potential to bring efficient solutions to the problem of system supervision and supply restoration in the event of contingencies. The goal of this paper is to present a supply restoration method for electric distribution based on the repair solution philosophy as opposed to the analytical methods traditionally employed to solve this problem. To implement this restoration method, a multi-agent model of the network is proposed in order to find, by cooperation between agents, a satisfactory balance between the available supply and its restoration in the network. This research is developed on the basis of a study performed on the operation of a real electricity company.

1. INTRODUCTION

An electric power system encompasses two processes: the generation and the distribution of electricity. The distribution is based on a hierarchical network composed of substations at the nodes that are interconnected by electric power lines. The electricity network connects producers and consumers covering entire countries and even crossing country boundaries; integrating local networks and allowing for energy exchanges.

Since electricity cannot be stored it must be generated according to a planned demand. Thus the balance between supply and demand represents an important part of the company's planning activity. Once generated, the electricity is transported across high voltage power lines from the generating plants to the consumers (Tampa 1999). The network is formed by substations, which are installations placed at the nodes of the network, whose function is to lower the voltage levels in order to deliver electricity for local consumers or simply to relay the incoming electricity to neighbour substation nodes in the network. In this paper we classify substations as: primary substations which are placed at the output of the power plants, and secondary substations which lower the voltage levels for local or regional consumption.

A distribution network is typically hierarchical and thus can be decomposed into subnets associated to the substations. Depending on its complexity and size the network supervision and control is distributed amongst various control centres at local and global levels. The distribution network supervision consists in ensuring the correct equipment operation in order to guarantee the electricity supply to consumers. Although the term control has the meaning of performing actions on the system, along this paper the term supervision will be used in the sense of both supervision and control. To supervise and control a distribution network, operators typically rely on computer systems.

Since the electricity supply is a crucial service for the society, all electricity network equipment is subjected to voltage and current constraints in order to operate within safe and efficient levels. For that purpose the status of the network is thus continuously monitored through data acquisition on the system variables. The network control is performed by commands issued manually or electromechanically on fault detection and protection devices such as relays and switch breaks, and usually accounts on informatics systems such as the Supervisory Control and Data Acquisition systems (SCADA) (Lehtonen 1998).

Following an event of a fault, the electric flow in a power line is automatically cut by means of the protection devices. The protection circuits can also detect the faulty sections from the analysis of the signals, which are sent by the different fault detectors installed along the network paths. The faulty sections are then isolated either automatically or manually and the flow of current is re-established along the working sections and paths created by the closing of specific switches. Fault detection and supply restoration are used in the event of an incident. Specific devices support the methods for fault detection; however the detectors themselves can become faulty giving false readings or none at all. Thus the operators are still needed to intervene and locate defective parts. Some research work is directed towards proposing methods for planning under uncertainty and for diagnosis supporting decision-making during fault occurrence.

Our research concerns the problem of supply restoration in a distribution network and was inspired in a real case concerning the Brazilian electricity company CHESF (Companhia Hidro Elétrica do São Francisco). This paper proposes a restoration method based on repair solution approach, which is already used in manufacturing systems rescheduling (Zweben and al. 1993; Tranvouez 2001). This approach consists in introducing cooperation between different autonomous entities of a system in order to reduce the effect of disturbances on the system. To implement this method, a specific multi-agent model of the network is proposed, in order to find through cooperation, a satisfactory balance between the available supply and its restoration in the network.

This paper is organized in 6 sections including this one. Section 2 introduces the supply restoration problem in details. Section 3 presents a modelling of the distribution network through which it is possible to identify the different entities that compose the network as well as their behaviours. The section 4 presents in details the proposed supply restoration method based on repair solution with its different phases. Section 5 presents the multi-agent model of the distribution network used for solving the supply restoration problem along with the proposed method. Finally, in section 6, conclusions are drawn and future directions are proposed for the work.

2. THE SUPPLY RESTORATION PROBLEM

From the literature review, the major problems related to distribution network supervision are: *network protection* in normal operation and in the event of disturbances; and *load sharing*.

The methods for usual protection of the network are based on the estimate of the state of the network at the topological level (Lehtonen 1998), as well as on the load level on the network elements. The methods to solve problems during incidents are based on diagnosis and repair (Thiébaux and al. 1996; Friedrich and Nedjl 1992; Sun and Weld 1992). The problem of load distribution can be solved with knowledge-based methods or with multi-agents systems for networks with distributed sources of energy. Nonetheless there are few, if any multi-agents models of the network itself with the majority of models being analytical

On the other hand, there are analytical methods and agents-based ones for the supervision of distribution networks. In these methods, a particular problem appeared to be crucial, that of energy supply restoration after incidents on the network. These papers deal with the restoration problem within the distribution networks (Thiébaux and al. 1996; Friedrich and Nedjl 1992), and in the transport network (Jennings and al. 1996). However, we did not find in the literature reviewed, methods with an agent modelling approach to deal with network restoration problem.

A multi-agents system for the supervision of substations and distribution network is presented in (Aoki and al. 2002). This system's architecture consists of two components. One component deals with the supervision of the distribution network where one finds the agents which treat the data from the system SCADA and handle the problems of energy distribution; and the other component is devoted to the substation, where agents determine its status. The results from these two components are then joined together in order to establish a restoration plan for the electricity distribution. This system is also based on pre-existent expert systems and enables the diagnosis of the faults and the supply restoration.

It must be pointed out that the supply restoration is a real time problem, since it is almost impossible to associate new power sources to the system, since the generation of energy requires a significant time to be increased or reduced at the power plants.

3. THE NETWORK MODEL

As already mentioned, this research is based on a real case related to the distribution network of the Electricity Brazilian Company: CHESF. This section begins by introducing the case study and then develops a model of the distribution network considered.

Case study

In the electric power system concerned the energy is produced in two thermoelectric plants and six hydroelectric plants. The electricity is then transmitted to the distribution network where substations at the network nodes process and distribute it. Energy is finally delivered to costumers such as industries and other companies, which resell electricity through local distribution networks.

All decisions and operations on the network are previously planned. The electricity distribution follows a daily plan, which determines the behaviour of all the system components. This plan is established on the basis of dispatching methods presented in (Prokopenko and al. 1995, 1996). Due to its complexity the daily plan cannot be recalculated in the event of a fault. This is why the company executes the emergency procedures (named manoeuvres) at different parts of the network. For instance, if a substation cannot supply all of its clients, the operators can perform manoeuvres to maintain the supply according to priorities. Those procedures are planned for all substations and all its clients. At the substations the operators in charge perform the supervision and control of the elements in the installation that allow for building the paths for electricity transmission.

The substations are at the nodes of the network and play a primordial role in the distribution process. In fact, they enable to redirect the flow of energy and to adjust the voltage level according to the consumer‘s specifications. In this work we propose to build an agent based system capable of simulating the behaviour of the primary substation network (Figure 1).

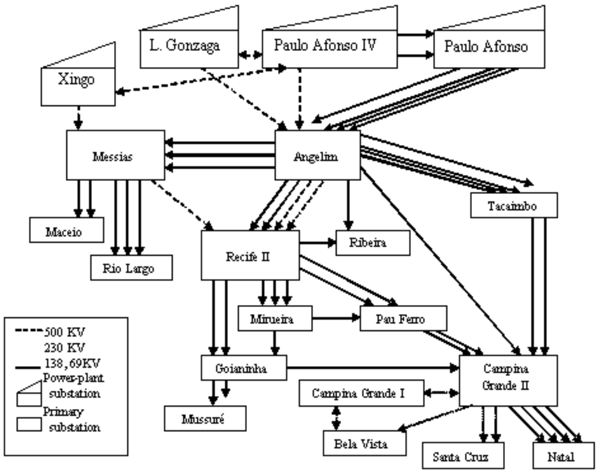

Figure 1: The electric flow and the substation network topology

Three major types of substations can be found: the *power plant substations*, which receive the produced energy and redirect it; the *primary substations*, that process the energy and distribute it; and the *secondary substations* that supply industries and cities' networks.

The power plants supply their own substations, which in turn supply energy to the primary substations networks, but they can also, exchange with other substations at the same level. The primary substations form a network for the exchange and distribution of electricity. The exchanges between primary substations happen at high voltage levels, and then the voltage level is dropped to be delivered to the consumers. Industries and villages have their own substations classed as secondary, which process and distribute the electricity.

Whereas at the CHESF Company the decision-making is centralized, our aim is to build a system capable of locally solving supply restoration problems following an event in the system. Thus we intend to build a system capable of maximizing, according to set priorities, the number of consumers supplied after the network disturbances.

The protection philosophy at the power company has led into the construction of extra power lines to be used in case of failure. We are also interested in the disturbances that lead into the suppression of distribution power lines. Thus, following the suppression of a power line, it is possible to use an alternative line or redirect the energy flow by using the substations interconnections. Flow redirection has a cost and thus it is necessary to minimize it. In fact, energy losses depend on the transmission line's length and on the voltage level adopted in the transmission. It may be that the flow redirection becomes insufficient to supply the network completely. In this case, we can look for a solution to restore the supply to a subset of the network.

Physical model of the network

The physical model of the network concerns the conservation laws of energy to which it is subject. All the entities in the network are subject, to constraints related to the flow of current. For instance, the power lines cannot transport beyond a maximum power and the substations cannot process more than a predefined maximum amount of energy. The conservation laws applied to the substations can be stated as follows: *the sum of the input currents equals the sum of the output currents.*

For example, a substation with two input lines and two output lines will behave as follows. Be V1 the input voltage; V2 and V3 the output voltages; I1 and I2 are the input currents; I3 and I4 the output ones. Thus, the energy conservation law can be stated as: $V1\ (I1+I2) = V2.I3 + V3.I4$. In fact, there are losses due to the transformation.

In Figure 2, the Campina Grande II substation is considered to follow the substations constraints (CHESF). This substation consists of a set of devices and buses interconnecting them. The input bus is connected to an internal bus, which can be associated to transformers whose output is fed to an output bus.

In this context, the main substation characteristics are: Maximum capacity (input flow), Transformation capacity to different voltage levels (output flow) and Transmission capacity (output flow).

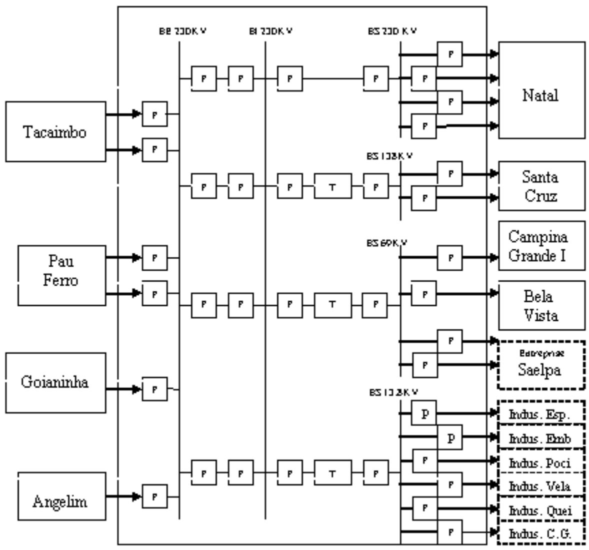

Figure 2: Substation *Campina Grande II- schema*

Organizational levels of the network

The primary substations were sub classified depending on if they supply or not other primary substations. At a decision level, three organizational levels are proposed for the distribution network in order to allow for regulation and management of the supply restoration (figure 3):

- The level 1 (lower level) is composed of primary substations that supply only secondary substations considered as consumers.
- The level 2 concerns primary substations that supply other primary substations.
- Finally, the power plant substations considered the producers, form the level 3.

The consumption of the substations can be expressed in terms of power and classified in three levels of supply: a critical level (hospitals, critical industries…), an intermediate level related to enterprises, and a lower level related to the supply of residential areas.

The substations, which supply other primary substations, have, similarly to the first level ones, direct consumers. These primary substations form a second level. Finally, the power plant substations considered as producers, form the third level. The modelling of the power plant behaviour was not considered since our restoration strategy happens almost in real time. In fact the change in power production at the power plants consists of manoeuvres, which demand a considerable amount of time to be processed.

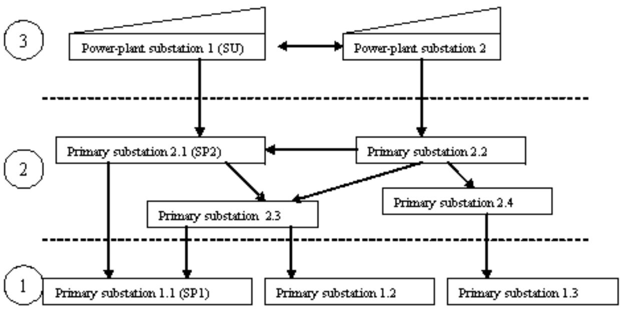

Figure 3: The network levels

Our aim is to build a system capable of finding a local balance between the electricity distribution and load share. As opposed to the company philosophy, we propose a local decision making. Thus we propose a method centred on the entities whose objective is to ensure electricity distribution regardless of the network configuration.

4. THE RESTORATION METHOD

The restoration method proposed is based on a repair solution approach. This approach is already used in manufacturing systems rescheduling (Zweben and al. 1993; Tranvouez 2001) and consists in introducing cooperation between different entities of a system in order to reduce the effect of disturbances on the considered system. This section first introduces this method, its phases and their dynamic; then, each phase is presented in details with its specific steps.

Method overview

To establish the electricity distribution, and according to the previous three levels of the network, we propose a method that consists in performing three major phases:

- The first one applies a bottom up approach to the distribution problem, which consists in establishing the electricity demand between the various entities starting with the consumers towards the power plants.
- The second phase consists in a top down approach to validate the supply to all those entities allowing adjusting the demands according to the system's real offer (supply).
- Finally, the last phase consists in introducing disturbances into the distribution network. Those disturbances have the purpose of modelling events such as the unavailability of specific power lines.

It follows the detailed description of each phase expressing the rules that control their execution. The following schema (Figure 4) shows the process of each phase following the layers on which they happen and the progression between phases. The phases, highlighted in brackets, are decomposed into sub phases (steps).

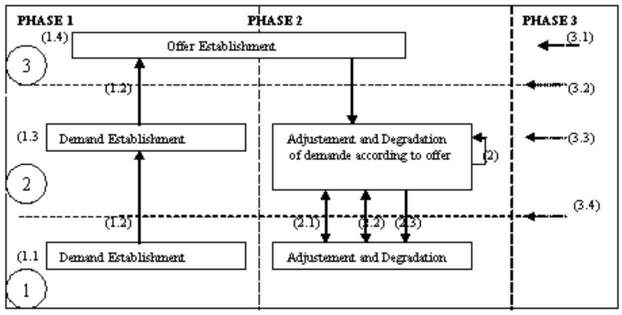

Figure 4: Phases, processes and progression

Phase 1 is decomposed into four steps and takes place at the three network levels. It consists on establishing the demand of all the substations and minimizing the transmission costs. The second phase is decomposed into three steps and takes place at the two first levels. It consists in adjusting the demand according to the offer made by the power plant substations. Finally, the last phase consists in introducing disturbances that lead into line disruption inside and between levels.

The two major principles involved in those phases are: flow redirection and consumption degradation. Figure 5 illustrates these redirection and degradation.

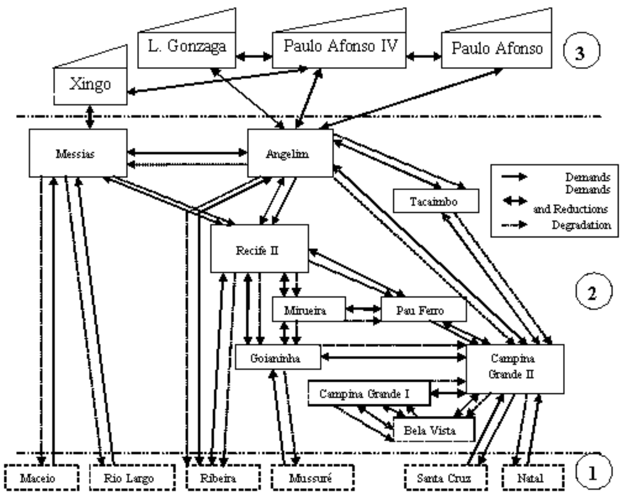

Figure 5: Substation interactions

Flow redirection consists in using interconnections between substations in order to reduce the demand on substations that are overloaded. This principle is applied in the three phases of the method.

The *consumption degradation* is a principle applied when the demand is higher than the offer and consists in reducing consumer demand according to their pre-established priority levels. This principle is applied during the two last phases of the method. It follows a detailed description of the method and its phases. To describe all these phases we will present an example that is based on the maximum capacities of the substations.

Phase 1: Demand Establishment

This initial phase is ascendant (bottom up) and consists in establishing the demand for different entities. It takes place at the three network levels.

Step 1.1

As specified in figure 4, this first step proceeds on levels 1 and 2. The entities which represent the primary sub-stations (SP) start by establishing their demand to the secondary sub-stations. Entities SP of the 1st level establish their total demand and those of the second level establish their partial demand. Indeed, each primary substation supplies the secondary substations, which in turn supply the cities and industries. The main constraint related to this phase is that the substations cannot supply more energy than they receive or can transform. It must be reminded that the primary substations reduce the voltage level before delivering it to the consumers.

Step1.2

Entities SP of the 1st level now transmit their demand to their suppliers. Two cases can then arise: (i) if there is a single supplier, the request is directly transmitted to it; (ii) if the substation has several suppliers, then the demand is transmitted to the substations whose provisioning costs are the lowest. This demand is made according to the capacities of the power lines, which supply the substation.

The costs of provisioning are related to the voltage levels and the distances covered by the transmission lines. For instance, the substation Ribeirao (Table 1) has two low-cost suppliers and thus demands from the lowest cost one (Recife is nearer to Ribeirao than to Angelim) to provide it.

Table 1: Demands from substations at the 1st level

Secondary demand	Transmissison capacity	Demand	Voltage	Supplier
Natal(400)	1000	400	230	Campina II
St.Cruz (130)	300	130	138	Campina II
RioLargo (600)	1000	600	230	Messias
Maceio (300)	500	300	230	Messias
Musssuré (400)	500	400	230	Goianinha
Ribeirão (200)	500	200	230	Recife
Ribeirão (200)	500	0	230	Angelim

Step1.3

This step corresponds to the establishment of the demand from substations at level 2. Each entity SP of level 2 waits until it receives the demand from all its customers before calculating the total demand. If the demand is lower than its provisioning capacity, the entity passes it on to its suppliers. If not, entity SP carries out a request for demand reduction to the primary substations, which have several suppliers. For example (Table 2) the Goianinha substation cannot supply completely Campina II and thus requests a demand reduction. Campina II reduces its demand and redirects its request towards another supplier.

Table 2: Demands from the 2nd level

condary mand	ient emand	Client	upplier lb.	ecept. apacity	Demand	Supplier
CampinaII (200)	100	Campina I	2	500	450	Pau Ferro
	100	Bela Vista	2	500	450:**300**	Goianinha
	400	Natal	1	500	30:**180**	Tacaimbó
Goianinha (200)	130	St Cruz	1	500	0	Angelim
	400	Mussuré	1	500	450	Mirueira
	450:**300**	Campina II	4	500	450	Recife

If it is feasible to obtain the complement of electricity from another substation, and if the demand is then satisfied, the demands are then propagated to the substations of level 2. In the opposite case, it is not possible to supply all the customers demand. During this step, when only the demand is taken into account, it can always be satisfied due to the fact that the substation network has been dimensioned to face these requests. This step finishes when the primary substations (i.e. Angelim and Messias) pass the demand request to the power plant substations.

Step1.4

The entities associated with the power plant substations (SU) receive the demand from entities SP and cooperate (the exchanges between power plant substations are allowed) in order to satisfy them. In the network here presented, each power plant substation supplies only one primary substation, but in principle they could eventually supply other power plant substations. If the demand is higher than the substation output capacity, then the entity transmits a demand to its suppliers. If this energy supplement proves to be insufficient, the entities SU transmit a reduction demand to the entities SP. If the request for reduction is not satisfactory, the maximum capacity of provisioning is transmitted to the primary substations. Phase 1 ends with supply transmission from the entities SU to the entities SP.

Phase 2: Demand degradation and adjustments

Two cases arise during the launching of this phase: (i) either the demand placed during phase 1 is lower than the supply capability of the substations, (ii) or the demand is higher than the supply capacity. In the first case, this phase consists only in the validation of the power transmitted from the suppliers towards the consumers. In the opposite case, it will be necessary to adjust the demands in order to reach a balance between demand and supply.

Step 2.1

Entities SP start by sending requests for reducing the demand of the primary substations directly supplied. If this redirection manoeuvre does not solve the problem, it is then impossible to supply adequately all the consumers.

Step 2.2

The difference between supply and demand is compensated by demand degradation at the secondary substations. This degradation is propagated to all the consumers who are supplied by the energy-overdrawn substation. The overdrawn entity calculates the percentage of degradation necessary to balance its relation between supply and demand, and then the degradation is applied to the secondary substations demand according to priority levels, i.e. keeping the provisioning of the most critical parts of the network (the ones with the highest levels of priority). For that purpose, the substations transmit to their suppliers their degraded demand as well as the last level of priority degraded and the power necessary to satisfy this lower level of priority. For example, if the substation Campina II cannot supply the demand completely, it applies this principle of degradation (Table 3).

Table 3: Demand degradation by Campina II

Substation	emand (2nd)	emand (1nd)	lients	otal Offer
Campina II	200	150	Campina I	800
		150	Bela Vista	
		130	St Cruz	
		400	Natal	

Substation	ons. 1	Cons. 2	ons. 3	egradation	Supplier Level
Campina II	102	42	56: **10**	23%: 46	46
Campina I	55	55	40 : **5,5**	23%: 34,5	34,5
Bela Vista	60	70: **55,5**	20 : **0**	23%: 34,5	14,5
St Cruz	39	39	52: **22,1**	23%: 29,9	29,9
Natal	160	160: **148**	80: **0**	23%: 92	12

Step 2.3

If there are various levels of priority to be reached, a new request for degradation concerning the lowest level is sent, so that all the substations remain on the same level. The surplus thus collected makes it possible to readjust the consumption of the highest levels of priority. For example, the substations Bela Vista and Natal had degraded to their 2nd level of consumption that implies a second degradation followed by adjustments (Table 4).

Table 4: Adjustments after degradation

Substation	ons. 1	Cons. 2	ons. 3	egradatio	Supplier Level
Campina II	102	42	10:**0:2,22**	23%: 46	46
Campina I	55	55	5,5:**0:2,22**	23%: 34,5	34,5
Bela Vista	60	55,5 **: 70**	0**:2,22**	23%: 34,5	14,5
St Cruz	39	39	22,1**:0**:2,22	23%: 29,9	29,9
Natal	160	148: **160**	0: **2,22**	23%: 92	12

Once the energy is completely distributed, consumption is validated, finishing this second phase.

Phase 3: Reacting to disturbances

This phase consists in introducing failures into the network, which are modelled as the faults in the power lines. The users of the lines are then constrained to modify their behaviour by adjusting their consumption. If there are lines of safeguard, the problem is solved by swapping between lines. If this kind of manoeuvre is not possible, it is then necessary to find another strategy to adjust consumption.

A substation that loses a faulty output line finds itself now with a surplus of energy. It can reduce its consumption from its suppliers choosing to reduce it from the most expensive one. A substation with an input faulty line begins by trying to obtain a surplus of energy through flow redirection. If necessary it sends a request for supply reduction to its consumers. If this phase of redirection proves to be insufficient in order to completely re-establish the supply to consumers, the entity associated to the substation begins a process of demand degradation for the secondary substations, amongst its consumers. This degradation process proceeds similarly to phase 2, i.e. by calculating a percentage of degradation according to the original real provisioning and then carrying out adjustments between the priorities levels of consumption.

5. MULTI AGENT MODEL

To implement the restoration based on repair solution presented in the previous section, a specific multi-agent model of the network is necessary. The aim of this model is to find through cooperation, a satisfactory balance between the available supply and its restoration in the network. In this section is described the multi-agent architecture, and formalized the knowledge and the rules which define the behaviour of the different agents to perform the restoration method. Finally, the interactions between agents performing the restoration method are presented.

Agent Architecture

The previous network model identified different types of entities with specific behaviours that lead to the conception of major agents. The multi-agent architecture, illustrated in Figure 6, is based upon the definition of three network levels identified during network modelling. It follows the description of the three defined agents: SU agents, SP2 agents, and SP1 agents. The SU agents are associated to the power plants substations, whereas the SP2 agents are associated to the primary substations in the second level of the network hierarchy and finally the SP1 agents are associated to the substations at the first level.

In this model, the agents interact with agents at the same level as well as with agents at higher and lower levels. These interactions are determined by the network topology and by the method's phase of interaction; meaning that the agents interact with other agents which play the roles of suppliers and consumers of the substation which it represents. A disturbance agent (PRT) was introduced to model the network disturbances, and relates to all other agents in the system.

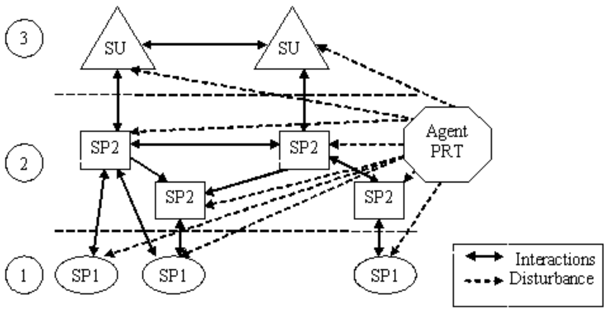

Figure 6: Agent's Architecture

Agent Model

It follows the description of the knowledge and the rules that determine the internal behaviour of the different agents. It is assumed that agents associated to the substations have an object model of the substation. Although they have a partial knowledge of their environment this knowledge is restricted to the properties associated to their substation and respective power lines. To introduce the agents' models, initially it will be presented their knowledge and then the rules that determine their local behaviour.

The SP1 Agents

The SP1 agents are associated to substations at lower levels of the network hierarchy. These agents start by establishing their demand and can be taken into redirecting it as a consequence of the status of their suppliers. Thus, they must be capable of degrading their demand whether by request from their supplier or as a consequence of shortage of energy from their consumers' point of view. The **knowledge Agent SP1 needs** to perform these actions and the associated rules are defined as follows, and is issued mainly from the network object model:

C – maximum capacity
C1 consumption priority 1
C2 consumption priority 2
C3 consumption priority 3
Suppliers (n)
Offers (n)
Demand (n)

The behaviour of SP1 agents is defined according the following set of rules:

R1: Expression of secondary demand b ≤ c: This rule allows establishing a demand as a function of the substation's own demand.

R2: Demand Establishment: This rule allows establishing the demand for the different suppliers as a function of the cost of provisioning them. The costs are calculated in relation to the properties of the power lines that supply electricity.

R3: Demand Redirection: This rule allows modifying the demand redirecting it to different suppliers.

R4: Demand Degradation: This rule allows degrading the substation demand. Two different cases are possible: the energy supplied is insufficient or a request for demand degradation is received.

The SP2 Agents

Agents SP2 are associated to primary substations at the network second level. Their behaviour is almost identical to that of agents SP1. They establish the demand near their suppliers' levels according to their needs and those of their consumers. They can be brought to reduce or degrade this demand according to the provisioning offer that is made to them; or according to their supplier's requests. If the agent initiates degradation, it must be able to adjust consumption accordingly. The *knowledge Agent SP2* needs to perform these actions and the associated rules are defined as follows**:**

C – maximum capacity
C1 consumption priority 1
C2 consumption priority 2
C3 consumption priority 3
Suppliers (n)
Offers (n)
Demand (n)
Consumers (m)
NbFourConso (m) number of suppliers per consumer)
Needs (m)

The following set of rules defines the behaviour of SP2 agents:

R1: Secondary demands Expression b ≤ c: This rule allows establishing a demand according to the substation's needs.

R2: Demand Establishment: This rule allows establishing the demand with the various suppliers according to their provisioning costs. The costs are calculated in relation to the properties of the power lines that provide electricity. The demand can only be established when all the demands of the agents at the first level, which they supply, have been established.

R3: Demand Redirection: This rule allows modifying the demand made to the various suppliers. If a request for reducing the demand by a value v, is received by a supplier "fk" then: if there exists i>k such that d(fi) < t(fi) and "fi" did not request redirection; then a part of v is redirected. If the redirection does not absorb the totality of the demand for reduction a request for reduction is transmitted to the consumers of the sub-station.

R4: Demand Reduction: A request for reduction is sent to the consumer having the highest number of suppliers. If there are several suppliers, the surplus is distributed between them. If this process fails, the request is sent to other consumers having several suppliers. It is important to remark that this reduction process has little chance to fail during the first phase. $S = \sum bj - cap$.

R4: Demand Degradation: This rule allows degrading the substation demand. Two different cases are possible: the energy supplied is insufficient or there is a request for demand degradation. If O<D and O>0, then v = 100*(O/D). If a demand for degradation of value v (percentage) then V=D*v is the quantity to be degraded, if not a level of priority of consumption is provided. The last case is the simplest: the level concerned is put at 0.

R5: Adjustments of consumption: This rule allows adjusting consumption according to the levels of consumption reached during degradation. These levels are provided by the consumers, as well as the amount necessary to reach the lower level. In general, only two levels are reached by degradation. A request for degrading the highest level is then transmitted to the substations concerned. The surplus thus obtained is then distributed with the substations requiring the highest amount of energy in order to change level.

The SU Agents

The agents SU are associated to the power plant substations. They must be able to exchange energy between them and to establish the offer to agents SP2. The principles applied to their (SU) behaviour are identical to those applied to the behaviour of the agents (SP2), but since they are regarded as the producers of energy, their knowledge and respective rules differ from those which apply to the other agents. The *knowledge Agent SP2* needs to perform these actions and the associated rules are defined as follows**:**

C – maximum capacity
Cp production capacity
Suppliers (n)
Offers (n)
Demand (n)
Consumers (m)
NbFourConso (m) number of suppliers per consumer)

The behaviour of SP1 agents is defined according the following rules:

R1: Demand Redirection and Reduction: $S = \sum bj - C$. A request for redirection is sent to the consumer having the greatest number of suppliers. If there are several, the surplus is distributed between them. If this process fails, the request is then sent to the other consumers also having several suppliers. It is important to notice that this reduction process has little chance to fail at the first phase
If a request to reduce the demand, by a value v, is received by a supplier fk then: if there exists i>k such that d(fi) < t(fi) and "fi" did not request redirection then a part of v is redirected. If v cannot be completely absorbed then one applies the rule of demand reduction to the consumers.

R2: **Establishing the offer**: If $d \leq cp$ then if $\sum bj \leq cp - d + f$ then apply the Demand establishment Rule, else it is impossible to supply the SU with the demand bj. Else it is impossible to completely provide the primary substation with the demand d.
To be able to correctly supply the system, a request for reduction in the demand is transmitted to the primary substation. If this reduction process fails, the maximum supply of energy within capability will be provided.

The Agent PRT

The disturbance agent (PRT) is the only one in the system to have the complete topology model of the electrical supply network. It intervenes only at the time of the last phase of the method and its goal is to inform the agents associated to the substations about the disturbances to which they are subjected. This agent can at the user interface level when the system is implemented. Table 5 illustrates part of the topology of the network.

Table 5: Network Topology at levels *3 and 3/2*

Substation (Level 3)	ubstation	Power Lines
L. Gonzaga	Paulo Afonso IV	05C1
L. Gonzaga	Angelim	05L5
Paulo Afonso IV	Xingó	05V6
Paulo Afonso IV	Paulo Afonso	05T7-05T8
Xingó	Messias	05V4
Paulo Afonso	Angelim	04L1-04L2-04L3-04L4

Agent interactions

Here it follows the description of the interactions between the various agents during phase 1 of our solution; the other phases are very similar. To describe these interactions it was adopted the Message Sequence Chart (MSC) illustrated in Figure 7, as well as the specification of the role protocols associated to this phase.

The MSC diagram contains three types of messages that are informative and directive.

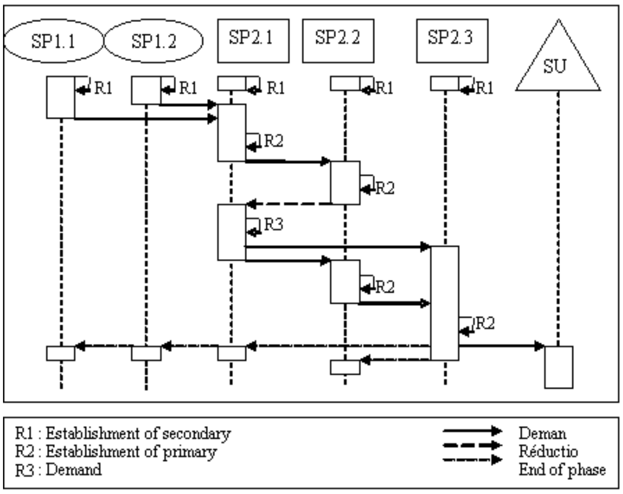

Figure 7: MSC Representing Phase1

For instance, the demands are represented as messages that contain the needed power for provisioning the substation. The messages for reduction are both directive and informative in the sense that they involve an action (redirection) at the receiver while transmitting information (power to be redirected). The message "end of phase" has only the informative character.

6. CONCLUSIONS AND PERSPECTIVES

This research, developed on the basis of a study performed on the operation of a real electricity company, has presented a supply restoration method in electric distribution based on the repair solution philosophy. To implement this restoration method, a multi-agent model of the network has also been proposed in order to find, through cooperation between agents, a satisfactory balance between the available supply and its restoration in the network.

In its current state, this work produced a context description that enabled us to understand the problems associated to electrical supply networks. It was also proposed a conceptualization of the distribution and restoration problems adopting a distributed approach. The method and the multi-agent model proposed constitute a conceptual solution of the supply restoration problem.

The present results open many prospects, amongst them it is proposed to model the interactions between agents for phases 2 and 3 of the proposed method. Also, as future work, a prototype has to be developed. This prototype will allow performing a set of tests to validate the restoration method in terms of execution time. This validation is crucial in order to develop an operational system to assist the supply network supervision, since the network supervision is a real time task.

Finally, since this model was restricted to the East part of the network, the modelling of the complete network will enable us to evaluate the restoration method performance as compared to the centralized approach currently adopted at the company.

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