# Towards a future SCADA

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***Abstract* — Currently, Power Systems (PS) already accommodate a substantial penetration of DG and operate in competitive environments. In the future PS will have to deal with large-scale integration of DG and other distributed energy resources (DER), such as storage means, and provide to market agents the means to ensure a flexible and secure operation. This cannot be done with the traditional PS operation.**

**SCADA (Supervisory Control and Data Acquisition) is a vital infrastructure for PS. Current SCADA adaptation to accommodate the new needs of future PS does not allow to address all the requirements. In this paper we present a new conceptual design of an intelligent SCADA, with a more decentralized, flexible, and intelligent approach, adaptive to the context (context awareness). Once a situation is characterized, data and control options available to each entity are re-defined according to this context, taking into account operation normative and a priori established contracts.**

**The paper includes a case-study of using future SCADA features to use DER to deal with incident situations, preventing blackouts.**

**Index Terms — SCADA, Distributed Energy Resources, Distributed Generation, Power Systems**

## I. Introduction

CURRENTLY, Power Systems (PS) already accommodate a substantial penetration of DG and operate in competitive environments. In the future PS will have to deal with large-scale integration of DG and other distributed energy resources (DER), such as storage means, and provide to market agents the means to ensure a flexible and secure operation. This cannot be done with the traditional PS operation. PS operation in a centralized way, easier to design and conform to the power industry practice leads to a lack of flexibility (e.g. inflexible predetermined automation schemes and limited robustness to failures), limiting DG increase, as some DG connections are refused due to technical constrains.

PS have been evolving in the last decades, adopting new methods and techniques but the overall philosophy of PS operation remains the same, with punctual changes. In order to evolve to future PS able to address the new challenges in a flexible and secure way, the technological and methodological changes must be addressed in global terms. Distribution networks require new protection, control and operation philosophy to cope with these challenges. DG, namely renewable-based producers, must have the means to play in the competitive environment.

SCADA (Supervisory Control and Data Acquisition) is a vital infrastructure for PS. Current SCADA adaptation to accommodate the new needs of future PS does not allow to address all the requirements. In this paper we present a new conceptual design of an intelligent SCADA, with a more decentralized, flexible, and intelligent approach, adaptive to the context (context awareness). Once a situation is characterized, data and control options available to each entity are re-defined according to this context, taking into account operation normative and a priori established contracts. Intelligent SCADA should, for instance, give distribution network operators (DNO) access to relevant data concerning third-party owned DG, in case of a priori contracted situations (e.g. to undertake service restoration or to manage voltage profile using these DG resources).

Future PS will operate using the decentralized paradigm and also a re-aggregation philosophy, led by strategic coalitions. Future SCADA are designed to support multi-level decentralized decisions and actions. These are the result of smart and strategic behavior of the involved agents, including power suppliers, networks and users and also of smart components and control.

Section II addresses some important points concerning the evolution of power systems and Section III presents the new proposed intelligent and context awareness SCADA. Section IV includes a case study concerning an example of using future SCADA features to use DER to deal with incident situations, preventing blackouts. Finally, some conclusions are presented in Section V.

## II. Power systems: present and future

Distributed Energy Resources (DER), including Distributed Generation (DG), has been increasing, introducing new challenges and difficulties for Power Systems (PS) planning and operation [1-3] and also relevant economic implications [4]. DER should still increase at a high rate in order to attain energy policy targets, namely in the frame of EU [5-11]. Energy markets are urging Energy Systems (ES) players to adopt adequate strategies in a new challenging competitive environment.

Competitive electricity markets (EM) are not only requiring huge changes in what concerns economic and financial issues but also imposing important technical changes at all levels of ES [13, 14].

Tremendous changes are necessary in the activities of ES players, which will require new planning and operation

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strategies and tools [14-18]. ES and PS are critical infrastructures [19] and security of supply must be assured. Reliable and efficient SCADA are crucial for assuring this [20, 22].

A single critical infrastructure facility can have thousands of devices, such as in supervisory control and data acquisition (SCADA) systems that spread over hundreds of miles. The devices themselves are typically in a physically protected environment; yet the interactions among them, on the other hand, go through the cyber space which poses a challenge to us and calls for a paradigm that is interactions and coordination centric (http://www.qhdctc.com/wcps2008/center.htm).

This will significantly affect the operation and control [23,24] of electrical networks, as these have not been designed and built in this perspective. The whole electrical network should be rethought in order to comply with the new context, making use of currently available technology. This affects automation, control and supervision, and also network architectures and protection systems, to name just a few important issues. It is important to stress that information and communication technologies, although already intensively used in current ES, can be used in a much more adequate way allowing facing the new challenges with reinforcement in the reliability. ES This corresponds to a new philosophy of planning, design and management and represents profound changes.

Providing context awareness to SCADA systems [25] is important for achieving a really intelligent SCADA for the new ES, characterized by large-scale penetration of DG and a need to efficiently integrate of DG in competitive markets.

This new philosophy requires two new paradigms: Cyber-Physical Systems (CPS) [26]; and Multi-Agent Systems (MAS) [16].

CPS are computing systems that interact with physical processes. The tight integration between the computation and the physical system is what differentiates CPS from other forms of computing, making CPS a kind of an embedded system. However, unlike more traditional embedded systems, CPS are typically designed as networks of interacting elements instead of as standalone devices [27]. CPS use computations and communication deeply embedded in and interacting with physical processes to add new capabilities to physical systems [28]. Cyber-physical systems must be dependable, secure, safe, and efficient and operate in real-time. They must also be scalable, cost-effective and adaptive (http://varma.ece.cmu.edu/cps/CFP.htm). The integration of computational and physical processes exhibit complex behavior that can not be analyzed by the computational or physical sciences alone. These systems also transcend traditional computer-controlled systems approaches of their scale, dependence on man-machine interaction and their rich communication infrastructure that is enabled by the Internet (http://www.qhdctc.com/wcps2008/center.htm).

ES, as other critical physical infrastructures (such as oil, gas, and water networks) depend crucially on SCADA for sensing, monitoring, gathering, and control of information from distributed sensing devices. Although a great work has been done in the area of SCADA systems for ES, it is clear that their present functionalities are not adequate to address the new context.

MAS refer to the algorithmic solutions of problems dealing with agents; how agents should interact, avoid conflicts or organize concurrent behavior (cooperative behavior in order to fulfill common goals or competitive behavior). MAS provide a powerful computational technology, for which dynamic aspects are based on interactions between agents, rather than centralized control. To do their functions the agents have the ability to communicate with others and with the system. Agents are particularly adapted to complex systems modeling, in which environments are unpredictable and simulation is required.

In the future context of EM, aggregation of players of diverse nature must be taken into account in PS and EM organization and operation. MAS are adequate for the implementation of the concept of virtual power producers (VPP) and for modeling and simulating EM.

### A. *SCADA and T&D Automation*

SCADA systems have been used for years in power utilities with great success. They have evolved trough times according to technological evolution and to some utility needs. It seems that SCADA systems, as we known them, may rapidly become a thing of the past. However, this is itself an old idea, born in the nineties, when terms such as open and flexible promised a complete revolution in this area. Although heavy efforts have been made and are going on [30], this evolution seems to be some steps behind what would be feasible in the present context. A significant part of the on going research is concerned with cyber security issue, which became even more sensitive after 11th September 2001.

Some characteristics of SCADA systems presently commercialized can be pointed out [30]:

- Today's SCADA systems are able to take advantage of the evolution from mainframe based to client/server architectures. These systems use common communications protocols like Ethernet and TCP/IP to transmit data from the field to the central master control unit;
- SCADA protocols have evolved from closed proprietary systems to an open system, allowing designers to choose equipment that can help them monitor their unique system using equipment from variety of vendors;
- SCADA systems are widely used to monitor and control critical infrastructure utilities;
- While SCADA protocols are more open today, there is not yet a clear consensus of which protocol is best.

At this time, utilities still purchase SCADA systems and are mostly dependent from SCADA vendors to customize it, at the moment of purchase and later. Even if this is the reality, the present state of the art would allow a different concept of SCADA to be already in daily use. As the required technology exists and diverse factors are urging SCADA systems to a radical change, one can guess that significant changes are about to appear.

SCADA systems have been used in transmission networks for several decades. They provide control center operators with real-time data concerning the network state and allow remote manual, automatic or semi-automatic procedures.

For distribution networks, automation is a relatively new reality, which has mainly been implemented during the 1980s and 1990s. For distribution networks monoeuvres (e.g. switching, capacitor and transformer tap control) assume an important role, giving place to Distribution automation (DA). Using remote communications a larger or smaller number of these monoeuvres can be remotely done. In certain cases, the manoeuvres are not only remote but also automatic, allowing easing the operation of the large number of distribution network components that require to be controlled.

DA meant a significant advance for distribution network operation allowing handling in a much easier and quicker way network switching and outage situations. Although the initial emphasis has been on the use in transmission, SCADA system rapidly appeared as a good solution also for distribution network. SCADA allows remote manoeuvres and also provides network operators with a picture of the network state.

### *B. Present and Future Energy Systems*

Daily use of automation features has proved its advantages and transmission and distribution (T&D) automation evolve over time. Currently, T&D systems are remarkably reliable in most developed countries. However, this does not mean that there is no need for change as several new factors have appeared imposing significant changes in power network operation.

Power system structure has changed from the paradigm of a vertically integrated utility to a new paradigm that involves deregulation, companies focused on one function (generation, transmission or distribution) and the emergence of a complex new set of players in a market environment [3,16,30]. These players include generation companies (GENCOs), transmission companies (TRANSCOs), distribution companies (DISCOs), and other very relevant players (system operators, market operators, brokers, marketers). This new paradigm gives place to a competitive environment where the players need to have adequate strategic behavior in order to accomplish their goals.

Another significant change is the increase of distributed generation resources [5-11]. These have a significant contribution of renewable sources contributing to accomplish energy policy goals related with environment (helping to contain greenhouse effect gas emissions increase). On the other hand, power generation with a more local vision can help increasing the whole power system efficiency (reducing losses in transmission and distribution and using more adequate primary sources for each energy requirement type).

These changes result in a completely new paradigm for energy systems, requiring power systems to adopt new planning and operation methodologies. As the adoption of new methodologies has, in many cases, to be supported by equipment changes the overall costs can be very huge. At the present state, significant changes have already occurred in power systems, with most developed countries adopting competitive electricity market paradigms and accommodating a significant amount of distributed generation.

In the future, power systems will have to deal with a much larger-scale integration of DG and other distributed energy resources (DER), such as storage means, and provide to market agents the means to ensure a flexible and secure operation. In fact, the new paradigm allows a much richer interaction involving a much higher number and diversity of players. As these are acting in a competitive environment and each of them envisages maximizing its profits, the new methodologies for network planning and operation must take this into account.

This cannot be done with the traditional power system operation. Power system operation in a centralized way, easier to design and conform to the power industry practice leads to a lack of flexibility (e.g. inflexible predetermined automation schemes and limited robustness to failures), limiting DG increase (as some DG connections are refused due to technical constrains) and players actuation.

Power system have been evolving in the last decades, adopting new methods and techniques but the overall philosophy of power system operation remains the same, with punctual changes. In order to evolve to future power system, able to address the new challenges in a flexible and secure way, the technological and methodological changes must be addressed in global terms. Distribution networks require new protection, control and operation philosophy to cope with these challenges. DG, namely renewable-based producers, with diverse dimension, must have the means to play in the competitive environment.

Another important aspect is that in the traditional paradigm of power system operation the strategic decisions were taken by a small number of large size actors and were mainly based on supply and network resources. Recent changes have proven that the demand side can have a relevant influence on the whole process [15,16,18]. In this new paradigm consumers and electricity buyers can play a much more active role and a lot of strategic decisions are to be taken by the demand side.

Electricity buyers can present diverse sizes, from small domestic consumers to large industrial plants. These can aggregate themselves, using adequate strategic decision-support in order to accomplish their goals. As a result, the most probable scenarios for the future energy systems will include a diversity of aggregators. A part of these will be mainly concerned with the development/aggregation of distributed energy resources with consumer/buyers needs in mind.

The demand side can take advantage of these aggregation philosophy in terms of the access to the aggregated resources (namely generation resources) but also benefit from an increase in scale resulting from the aggregation (gaining access to a set of decision-support and operational means that are inaccessible to small size individual players). Access to these means can allow to address topics such as energy efficiency, demand response, and distributed generation, and storage planning and use in a much more intelligent (and profitable) way.

The problem is that the present paradigm of electrical networks is not able to cope with this new philosophy. Apart from technical limitations directly derived from the network equipment (e.g. protection devices not prepared for two-way flows in distribution networks) that must be changed where required, the main problem deals with the current centralized decision and control philosophy.

## III. Intelligent SCADA

Making the new paradigm possible requires decision decentralization and the adequate means to implement it. This is certainly not the case of current SCADA systems. These are intended for the monitoring and supervision of equipments owned (or at least operated) by a very limited number of entities (one in most cases). It is assumed that there is a fixed entity to operate each piece of equipment (there is of course flexibility to operate at different levels, such as locally or remotely, but in the scope of the same entity such as a distribution or transmission company).

In the future DER owned by a large set of diverse entities will represent a significant part of the overall resources. It is not possible to adequately plan and operate the system if DER are not considered as taking part in the solution of power system problems. For this, it is required to have decentralized intelligence and decision ability. It is equally important to have SCADA based on a power system model which is based on the new paradigm.

This imposes to consider both the physical part of each power system component and its cyber dimension, which requires a SCADA based on a cyber-physical model of the power system. Power system components are important because of:

a) the relevance of their physical existence and operation features (P);
b) the availability of relevant information we may have about them in decision centers (I);
c) the permission to operate them (O).

The relevance of one specific component for the solution of a particular problem must be evaluated considering simultaneously a), b) and c). In fact, it is not at all relevant to have a component with the adequate characteristics to solve a problem if one does not have access to the required information about it in due time to take a decision. None of these is of any value if one does not have the permission to operate this component.

In the current state of arte, SCADA systems consider these three conditions in a very limited way, using the logic of serving a single entity that uses each SCADA. In the future, SCADA will have to consider the same three conditions in the scope of competitive environments where each entity SCADA has direct access to its own components. When negotiated, each SCADA can also have access to information and operation of other players owned components. Moreover, in many cases, once these permissions, and the conditions under which they should become active, are defined, the permission should be automatic and transparent to the users. Like this, real-time operation is guaranteed and market and ownership issues are respected.

Let us consider a distribution company (DISCO) operating a network where there are several players that own resources relevant to network operation. Considering:

| | |
|---|---|
| $n$ | Number of players which resources are to be considered by the DISCO |
| $S_k$ | Situation / Scenario k |
| $C_{pi}$ | Component i of player p |
| $P_{pi}$ | Physical relevance of component i of player p (real value in the interval [0;1] |
| $I_{pi}$ | Cyber relevance of component i of player p (real value in the interval [0;1] |
| $O_{pi}$ | Operation permission for component i of player p (binary variable: 0 or 1) |

the effective value of $C_{pi}$ for situation $S_k$ can be evaluated as:

$$\left(V_{C_{pi}}\right)_{S_k}^{M_j} = \left(O_{pi}\right)_{S_k}\left(I_{pi}\right)_{S_k}\left(V_{C_{pi}}\right)_{S_k} \quad (1)$$

where:

| | |
|---|---|
| $\left(V_{C_{pi}}\right)_{S_k}$ | Value of $C_{pi}$ in scenario k considering that it is freely operated by DISCO |
| $\left(V_{C_{pi}}\right)_{S_k}^{M_j}$ | Value of $C_{pi}$ in scenario k considering that DISCO must respect the conditions of the market ( $M_j$ ) |

The value $\left(I_{pi}\right)_{S_k}$ reflects the reliability of SCADA information and control concerning $C_{pi}$ for situation $S_k$ n. This allows considering the reliability of the SCADA systems to be used by DISCO to obtain information about the component $C_{pi}$ and also possible limitations imposed by $S_k$.

$\left(V_{C_{pi}}\right)_{S_k}$ is obtained through power system analysis studies, considering the existing resources that can be used by DISCO. It is important to note that the value obtained by (1) allows DISCOs to take decisions to found contracts with agent players concerning the use, under specific conditions, of players' components.

The value of $O_{pi}$ depends both on the component $C_{pi}$ and on the situation that is being considered. For components owned by DISCO, p=DISCO and $O_{pi}$ is equal to 1 in all situations. For components owned by other agents, the value of $O_{pi}$ depends on the contracts established between DISCO and player p. These contracts determine in which situations the DISCO has permission to access the information and operate $C_{pi}$ . Considering z different scenarios, the contracts can determine that:

$$\left(O_{pi}\right)_{S_k} = 0 \qquad \text{for} \quad k = k_1, \ldots, k_m$$
$$\left(O_{pi}\right)_{S_k} = 1 \qquad \text{for} \quad k = k_{m+1}, \ldots, k_z \tag{2}$$

The contracts also determine the value to be paid by the DISCO to player p for assuring operating permissions. This value can have two terms:

a) Fixed term, only dependent on the contracted availability;
b) Variable term, dependent on the effective use of the permission.

As the permission to operate most of components must be considered by SCADA and by automation systems, these have to be based on an adequate model of the power systems, which includes this information.

So, the model to be used must be of cyber-physical nature and address component ownership and permission changes, allowed by contracts. Moreover, it has to be dynamic over time, in two different perspectives:

- permissions depend on the situation of the power system, according to contract clauses;
- permissions can change over time due to the establishment of new contracts or to the ending of contracts, without renewal.

For this, SCADA systems have to be aware of each situation (context awareness).

Figure 1 shows the schematic representation of the proposed SCADA, with context awareness abilities which determines operation permissions. In this figure lines in blue represent interactions among system players to negotiate contracts; lines in red represent SCADA actions.

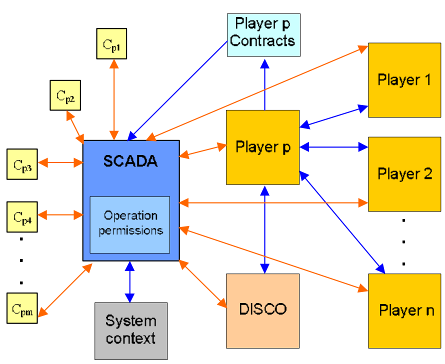


Figure 1- Proposed SCADA

## IV. Case-study

The proposed concept of an intelligent SCADA is being tested on a simulation environment implement in PSCAD. The simulation studies consider a network which is evolving over time. The basic network is similar to the one presented in [31]. We have used this network both in its normal configuration, as used in [31], and in an optimized configuration (obtained using an optimal power flow with the aim to reduce losses with a minimum number of monoeuvres). This network is used for the initial year (2008) of the simulation studies. Table I presents the most important data concerning this network. Starting with this network, evolution scenarios have been built, using evolution tendencies from several references [5-12].

Figure 2 presents the network used for 2010; solid lines are closed and dotted lines are open. Figure 3 presents the considered network for year 2040.

TABLE I
2008 NETWORK DATA

| Line Characteristics | | | | | Bus j Load | | |
|---|---|---|---|---|---|---|---|
| Line | Bus i | Bus j | R (Ohm) | L(H) | PL (kW) | QL (kVAr) | Suply contract |
| 1 | 0 | 1 | 0.0922 | 0.0001496 | 100 | 60 | FS |
| 2 | 1 | 2 | 0.4930 | 0.0007993 | 90 | 40 | RL |
| 3 | 2 | 3 | 0.3660 | 0.0005933 | 120 | 80 | CL |
| 4 | 3 | 4 | 0.3811 | 0.0006178 | 60 | 30 | FS |
| 5 | 4 | 5 | 0.8190 | 0.0022505 | 60 | 20 | RL |
| 6 | 5 | 6 | 0.1872 | 0.0019697 | 200 | 100 | FS |
| 7 | 6 | 7 | 0.7114 | 0.0007483 | 200 | 100 | FS |
| 8 | 7 | 8 | 1.0300 | 0.0023555 | 60 | 20 | RL |
| 9 | 8 | 9 | 1.0440 | 0.0023555 | 60 | 20 | RL |
| 10 | 9 | 10 | 0.1966 | 0.0002069 | 45 | 30 | CL |
| 11 | 10 | 11 | 0.3744 | 0.0003941 | 60 | 35 | FS |
| 12 | 11 | 12 | 1.4680 | 0.0036765 | 60 | 35 | FS |
| 13 | 12 | 13 | 0.5416 | 0.0022692 | 120 | 80 | CL |
| 14 | 13 | 14 | 0.5910 | 0.0016743 | 60 | 10 | RL |
| 15 | 14 | 15 | 0.7463 | 0.0017348 | 60 | 20 | RL |
| 16 | 15 | 16 | 1.2890 | 0.0054781 | 60 | 20 | CL |
| 17 | 16 | 17 | 0.7320 | 0.0018271 | 90 | 40 | RL |
| 18 | 1 | 18 | 0.1640 | 0.0004982 | 90 | 40 | FS |
| 19 | 18 | 19 | 1.5042 | 0.0043144 | 90 | 40 | RL |
| 20 | 19 | 20 | 0.4095 | 0.0015228 | 90 | 40 | FS |
| 21 | 20 | 21 | 0.7089 | 0.0029835 | 90 | 40 | RL |
| 22 | 2 | 22 | 0.4512 | 0.0009813 | 90 | 50 | FS |
| 23 | 22 | 23 | 0.8980 | 0.0022571 | 420 | 200 | RL |
| 24 | 23 | 24 | 0.8960 | 0.0022317 | 420 | 200 | RL |
| 25 | 5 | 25 | 0.2030 | 0.0003291 | 60 | 25 | RL |
| 26 | 25 | 26 | 0.2842 | 0.0004606 | 60 | 25 | CL |
| 27 | 26 | 27 | 1.0590 | 0.0029721 | 60 | 20 | RL |
| 28 | 27 | 28 | 0.8042 | 0.0022301 | 120 | 70 | FS |
| 29 | 28 | 29 | 0.5075 | 0.0008228 | 200 | 600 | CL |
| 30 | 29 | 30 | 0.9744 | 0.0030653 | 150 | 70 | CL |
| 31 | 30 | 31 | 0.3105 | 0.0011520 | 210 | 100 | RL |
| 32 | 31 | 32 | 0.3410 | 0.0016877 | 60 | 40 | RL |

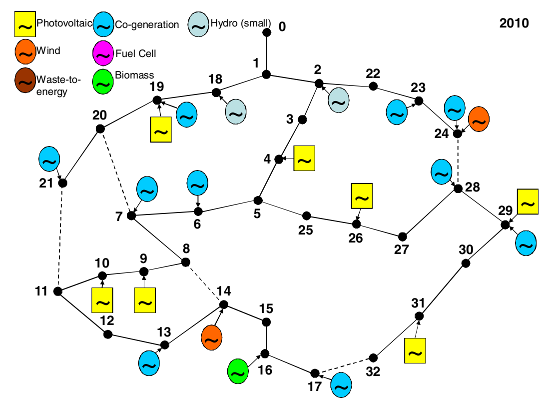


Figure 2 - 2010 network

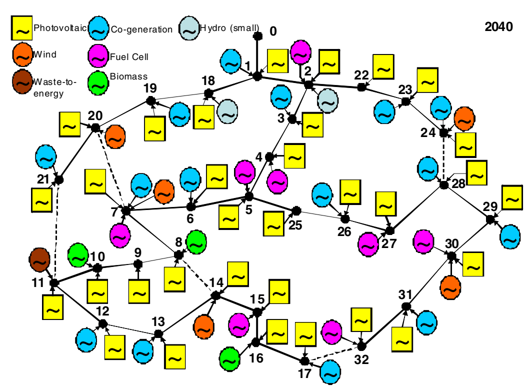


Figure 3 - 2040 network

Table II presents aggregated increase of generation and load.

TABLE II
GENERATION AND LOAD INCREASE

| | Year | | | | | |
|---|---|---|---|---|---|---|
| | **2008** | **2010** | **2015** | **2020** | **2030** | **2040** |
| | **Generation increase (%)** | | | | | |
| Photovoltaic | 0.31 | 0.37 | 2.05 | 3.39 | 5.76 | 8.48 |
| Wind | 7.41 | 8.52 | 8.89 | 9.19 | 9.90 | 9.95 |
| Waste-to-energy | 0 | 0.00 | 0.00 | 0.03 | 0.05 | 0.07 |
| Co-generation | 3.16 | 12.47 | 12.54 | 12.59 | 12.05 | 11.10 |
| Fuel Cell | 0 | 0.00 | 0.00 | 1.50 | 2.50 | 3.58 |
| Biomass | 2.94 | 3.29 | 4.37 | 5.24 | 4.94 | 4.44 |
| Small Hydro | 0.87 | 0.99 | 1.10 | 1.18 | 1.19 | 1.18 |
| | **Load increase (%)** | | | | | |
| | 0.00 | 4.00 | 12.50 | 11.11 | 24.94 | 17.80 |

For the case study presented in this paper, the simulation studies added the following production technologies to the initial network: photovoltaic, co-generation, mini-hydro, wind, biomass, waste-to-energy, and fuel cells. All these productions technologies are considered for the 2040 scenarios; only photovoltaic, co-generation, mini-hydro, wind, and biomass are considered for 2010 scenario.

A short circuit in line 0-1 has been simulated in the 2010 and 2040 scenarios. With line 0-1 out of service, DG can be used for supplying a part of the loads. Due to the identified situation, SCADA allows adopting the permissions intended for this situation. This allows the DISCO to use DG and to cut a part of the loads. For this purpose, loads are classified in several groups:

a) Critical loads (CL) which should be supplied in every situation;
b) Loads with flexible supply contracts (FS), which have contracted with the DISCO the priority of their circuits in case of loss of supply. Financial terms for this supply flexibility are established in the supply contracts.
c) All other loads (RL).

Tables III and IV show the results obtained for the considered incident scenarios, respectively for 2010 and 2040. For 2010, the total supplied load in a normal situation is 3.81 MW; after the occurrence of the incident the DISCO is able to supply 1.07 MW (approximately 28% of the total load), using DG. For 2040, the total load in normal conditions is 7.05 MW; after the occurrence of the incident, the DISCO is able to supply 2.28 MW (approximately 32% of the total load).

TABLE III
RESULTS FOR 2010 INCIDENT SCENARIO

| Bus | 2010 | | | | |
|---|---|---|---|---|---|
| | Load | | Generation | | Voltage |
| | PL(pu) | QL(pu) | PG(pu) | QG(pu) | (pu) |
| 1 | 0.02574 | 0.01410 | - | 0.02828 | 1.024 |
| 2 | - | - | 0.02194 | - | 1.024 |
| 3 | 0.09853 | 0.08070 | - | 0.04624 | 1.023 |
| 4 | 0.02304 | 0.00700 | 0.00305 | - | 1.022 |
| 5 | - | - | - | - | 1.021 |
| 6 | 0.05104 | 0.02350 | 0.01098 | - | 1.020 |
| 7 | 0.05108 | 0.02350 | - | - | 1.021 |
| 8 | - | - | - | - | 1.021 |
| 9 | - | - | 0.00305 | - | 1.020 |
| 10 | 0.04922 | 0.03021 | 0.00609 | 0.01665 | 1.019 |
| 11 | 0.01538 | 0.00826 | - | - | 1.019 |
| 12 | 0.01543 | 0.00820 | - | - | 1.017 |
| 13 | 0.13190 | 0.08100 | 0.01097 | 0.04642 | 1.017 |
| 14 | - | - | 0.24480 | - | 1.019 |
| 15 | - | - | - | - | 1.019 |
| 16 | 0.06628 | 0.02035 | 0.10970 | - | 1.020 |
| 17 | - | - | 0.05486 | - | 1.021 |
| 18 | 0.02316 | 0.00940 | 0.02095 | - | 1.025 |
| 19 | - | - | 0.06096 | - | 1.027 |
| 20 | 0.02320 | 0.00952 | - | - | 1.027 |
| 21 | - | - | 0.05487 | - | 1.028 |
| 22 | 0.02316 | 0.01180 | - | - | 1.025 |
| 23 | - | - | 0.10970 | - | 1.027 |
| 24 | - | - | 0.22070 | - | 1.028 |
| 25 | - | - | - | - | 1.021 |
| 26 | 0.06525 | 0.02500 | 0.03047 | - | 1.021 |
| 27 | - | - | - | - | 1.020 |
| 28 | 0.03036 | 0.01600 | 0.05488 | - | 1.020 |
| 29 | 0.21560 | 0.59500 | 0.05793 | 0.63730 | 1.019 |
| 30 | 0.16130 | 0.06920 | - | - | 1.019 |
| 31 | - | - | 0.00305 | - | 1.020 |
| 32 | - | - | - | - | 1.020 |
| **Total** | **1.06967** | **1.03274** | **1.07894** | **0.77489** | **-** |

TABLE IV
RESULTS FOR 2040 INCIDENT SCENARIO

| Bus | 2040 | | | | |
|---|---|---|---|---|---|
| | Load | | Generation | | Voltage |
| | PL(pu) | QL(pu) | PG(pu) | QG(pu) | (pu) |
| 1 | 0.11250 | 0.05784 | 0.08162 | 0.05694 | 1.026 |
| 2 | - | - | 0.05928 | - | 1.026 |
| 3 | 0.18430 | 0.13590 | 0.00040 | 0.09021 | 1.025 |
| 4 | 0.09350 | 0.02560 | 0.05700 | - | 1.024 |
| 5 | - | - | 0.05721 | - | 1.022 |
| 6 | 0.20780 | 0.08620 | 0.04169 | - | 1.022 |
| 7 | 0.20810 | 0.08630 | 0.34530 | - | 1.022 |
| 8 | - | - | 0.18830 | - | 1.023 |
| 9 | - | - | 0.03114 | - | 1.024 |
| 10 | 0.09323 | 0.05154 | 0.11050 | 0.03383 | 1.024 |
| 11 | 0.06207 | 0.02999 | 0.01369 | - | 1.024 |
| 12 | 0.24414 | 0.02989 | 0.00005 | - | 1.026 |
| 13 | 0.24760 | 0.13600 | 0.01345 | 0.08926 | 1.027 |
| 14 | - | - | 0.24540 | - | 1.028 |
| 15 | - | - | 0.03274 | - | 1.028 |
| 16 | 0.12450 | 0.03435 | 0.11330 | - | 1.029 |
| 17 | - | - | 0.05521 | - | 1.029 |
| 18 | 0.09449 | 0.03490 | 0.04820 | - | 1.026 |
| 19 | - | - | 0.06184 | - | 1.027 |
| 20 | 0.09216 | 0.03300 | 0.10770 | - | 1.027 |
| 21 | - | - | 0.06160 | - | 1.028 |
| 22 | 0.09137 | 0.04125 | 0.00904 | - | 1.026 |
| 23 | - | - | 0.11400 | - | 1.028 |
| 24 | - | - | 0.21960 | - | 1.029 |
| 25 | - | - | 0.00936 | - | 1.022 |
| 26 | 0.12510 | 0.04339 | 0.13610 | - | 1.021 |
| 27 | - | - | 0.05324 | - | 1.019 |
| 28 | 0.12460 | 0.06020 | 0.08155 | - | 1.018 |
| 29 | 0.41230 | 1.03200 | 0.06134 | 1.29600 | 1.017 |
| 30 | 0.31080 | 0.12020 | 0.27060 | - | 1.015 |
| 31 | - | - | 0.08152 | - | 1.015 |
| 32 | - | - | 0.07755 | 0.00000 | 1.015 |
| **Total** | **2.82856** | **2.03855** | **2.83952** | **1.56624** | **-** |

## V. Conclusions

The present paper has presented a new concept for SCADA systems able to deal with the needs of future power systems, operating in the context of a high penetration of distributed generation and in a competitive market environment. The proposed SCADA is decentralized, flexible, and presents intelligent behavior, being dynamically adaptive to the context of the power system. It has as main advantage to deal in an efficient and flexible way with both technical and economic/contractual issues.

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