VERIFICATION & VALIDATION ENVIRONMENT FOR AUTOMATION FUNCTIONS SUPPORTING DEMAND-SIDE INITIATIVES

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ABSTRACT

In recent years the Italian power sector has been undergoing considerable changes: EU Directive on electricity (2003/54/EC, ex 96/92/EC) established common rules for creation of internal markets and required privatisation of Italy's dominant energy monopolies. Since July 2004 all business customers may choose their energy supplier, unbundling will be extended to all domestic customers by July 2007. This will involve a new role for the final user: from passive consumer to active participant. Final users participation to the market will be substantially represented by their ability of modulating their own load profiles as result of market signal (price) or network signal (emergency). To take this opportunity it is necessary to provide a platform that will perform several functionalities: communication with distributor/retailer, interaction with user, load management, energy storage and management of distributed micro-generators. In this way, the final customer house will become an active "node" of the network. Altogether several nodes may also provide services to the network.

A Verification & Validation Environment for the integration of Demand-side Initiatives (DSI-VVE) has been created with the aim to follow the whole "V" life-cycle for above mentioned functions. This paper describes the method adopted and the whole life-cycle for one function.

INTRODUCTION

CESI RICERCA activity is focusing on the provision of a technological infrastructure supporting demand side management [3] [9] for medium/small LV customers (business customers became eligible in 01/07/2004, residential customers will become eligible in next July). Recent studies [4, 6, 7, 8] regarded: state-of-the-art for digital technologies & communication, current and future technologies applicability for demand side management, possible critical situations for cohabitation with existing automation systems and their possible solutions, innovative demand side technologies.

Results permit to evaluate the feasibility of management by Time-of-Use tariffs, contractual power reduction, automated meter used as "gateway" for communication with final customer. An architecture that interacts with Energy Management System (EMS), Distribution Management System (DMS) and HV/MV substation devices was put forward. A demonstration infrastructure was made for verifying demand side strategies on a test facility connected to a MV/LV substation. A platform, named *FRIDOM* (demand flexibilizator), was proposed to verify strategies for medium/small LV customers [10]. The system for demand flexibilization here described can be considered a *single* distributed and scalable automation system: it may include millions of peripheral units (MV and LV customers) [11]. This system (see figure 1) needs elaboration resources located in distribution network operation centres, traders, retailers, secondary substations to manage information flows between stakeholders.

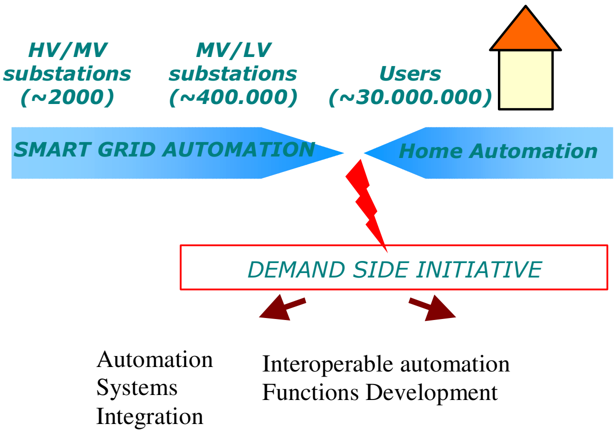

Figure 1*: Initiative to optimise Electrical Grid and Final Users interactions*

The biggest problem that Electric System (ES) must face comes from the huge degree of complexity of operating the electric network. A lot of state and transitions are possible, additionally there are many stakeholders and an impressive number of devices which interact at different levels. This complexity doesn't permit to consider in advance all normal and exceptional situations that may occur (concurrent failures, for example) and therefore it is not possible to explore all hazardous conditions. The adoption of rigorous methods for the various phases (i.e. analysis, requirement, design, development and test) is used to overcome complexity and crucial situations.

Hazards arising from a non rigorous approach, that don't allow anticipation of critical situation, on the one side, extend time-to-market, on the other side, may involve heavy consequences on the quality of service and ES security.

For these reasons in automation application it is crucial that specification phase, normally only a informal phase, is followed by a technical requirement specification phase supported by methods and tools that permit a structured and formal description. Afterwards their adequacy must be evaluated according to application requirements.

AUTOMATION SYSTEM LIFE-CYCLE

The development process of the application is managed according to the so-called "life-cycle" model [2]. Each model foresees different stages, where specific activities take place and results are produced. Number and complexity depend on specific applications, however fundamental phases are quite standardized and shared between various model.

Among the widely adopted models, waterfall model and spiral model are the ones more often used for SW development. In industrial applications, the so-called V-model (fig. 2) is employed: it is recommended by IEC 61508 and EN 51129 standards. According to this model, each phase is detailed from its results rather then activity, and developing steps are distinguished from evaluation steps.

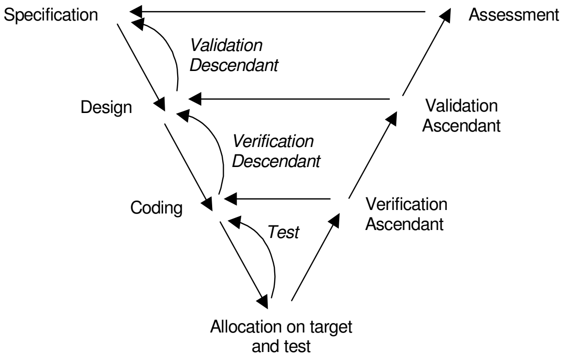

Figure. 2 *"V" life-cycle for automation functions of the LV distribution networks in DSI-VVE*

With reference to the above scheme:

Specification. *Specification phase* states requirements using a natural language.

Design. A formal method "State and Transition Diagram Notation" is used in the *Design phase* to represent functions.

Coding. The source code of each function is formally written and embedded into a library of functions that can be called by a Labview™ application.

Verification-descendant. The library of functions is verified using Labview™ on a simulated field and then on a real case.

Allocation and allocation test. *"The verified library of functions"* is allocated on a real target and integration test is performed on a real case.

Verification-ascendant. Multiple *"functions allocated on the real target"* are tested altogether on a real case to check that they may work together.

Validation-ascendant. Multiple *"functions allocated on the real target"* are tested to check they meet functional specifications.

Assessment. The system is assessed to check it meets all user requirements.

The proposed *DSI-VVE* allows to design, verify and validate different functions, eventually to identify further improvements before implementing them in a real case. This environment was firstly used for a platform which demonstrates the feasibility of *demand response* initiatives and that permits the evaluation of their impact on a population of up to 400 domestic customers. Hereafter the paper will explain the "V" life-cycle of a local energy manager that combines signal received from retailers (energy tariff) and user preferences to control power flow from the network to the customer and vice versa.

AUTOMATON HIERARCHY

To consider complex automation systems [1], like power stations and electricity distribution systems, a remarkable idea is to model them as a huge, cyclic state machine with state variables that must be preserved in a stable memory, so that at the next input cycle computation can resume from a valid state. Because of its complexity, the automation system has to be decomposed into a network of communicating *automata*, a solution not uncommon in other real-time control systems specified using StateChart or UML state-modelling features. ENEL (the Italian board of electricity) has introduced long ago this automation software architecture (ASFA), which has been successfully applied to large plants.

In order to dominate the growth of the complexity when the number of automata becomes significant, the essential idea is to impose a rigid hierarchy on the network topology, which is organised as a tree (Fig. 3). This mechanism is the same at each level of the hierarchy: given an automaton, the inferior levels send signals/communications to the automaton, which interprets such signals and communicates them to the superior levels; then, it receives orders from the superior levels that it processes and propagates to the inferior levels. Therefore each computation phase performed by automata is necessarily divided in two distinct phases, called the *upward phase* and the *downward phase*. In the former, signals generated at the bottom level are progressively computed and propagated to the upper levels of the hierarchy, until the root of the hierarchy is reached.

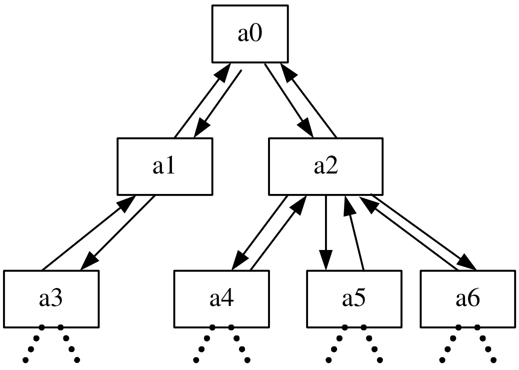

Figure 3. *Automaton Hierarchy.*

At this point, the downward phase is started and orders are processed and transmitted to the lower levels of the hierarchy; observe that each automaton can send orders to several automata, while can receive orders only from one single automaton.

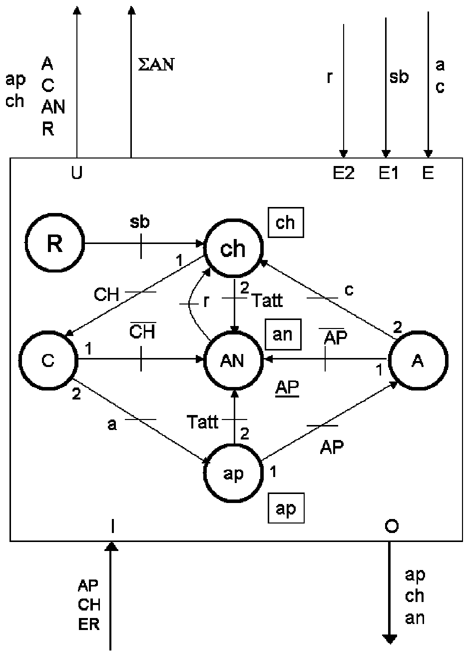

Figure 4. *A single Automaton example.*

This approach could be favourably employed also in smaller plant, as residential application, where complexity is obviously to a lesser degree but in any case reliability and stability are strong requirements. Figure 3 shows an example of automaton described with state-transition diagram. This automaton controls an actuator for appliance management: according to central management, it switch off/on its device to maintain power flow under desired threshold.

DEVELOPMENT OF FUNCTIONS

The main functionality to be implemented is actually represented by *load* and *heating management*, i.e. the possibility of switching off some appliances when particular circumstances occur or decide whether if it is better to use electric or gas devices for HVAC purposes.

The platform specified is a Local Energy Management System combining signal received from retailer (tariffs) and user preferences regarding comfort. It provides automatic load disconnection and re-connection to maintain maximum power flow with the network under a specified threshold (that may change every hour). For heating aspects, two different system simultaneously are considered: gas heating (boiler + fan coils) and electric air-air heat pump. Electric air conditioning is spreading in residential and especially tertiary buildings and most of these devices could be used also in cold season. On the other hand, air conditioner (together with electric water heater) is one of devices that could be simply switched off when a power reduction is required for short time.

As above described, the first development phase gives requirements for the function using a natural language. Requirements are then represented in a formal scheme using state and transition diagrams (*design phase*). Further step is the source code writing (*coding*); the code is then embedded into external libraries called by a LabVIEW™ application specially developed (*verification*).

These functions are at first evaluated in a *virtual environment*, i.e. an application that simulate power profiles, thermal behaviour, etc. The same code is then used to evaluate functions performance in a real case on the CESI RICERCA facility in the validation/assessment phases.

VIRTUAL TESTING

The virtual environment simulates a real field, i.e. a residential building, a family and their appliances. Each load is represented by an average consumption over 15 minutes or a more accurate daily average profiles obtained from measurement on real appliances. To test the system with different schemes, besides current flat energy tariff for domestic user other profiles are considered. A complete thermal model of the test facility and outer environment has been developed to include several parameters as daily temperature profile, heat pump performances and thermal behaviour of the specified building.

The implementation of the model has been made with LabVIEW™ and it can communicate during the simulation with the FRIDOM using IP connections. The choice of IP connections (Ethernet in our facility) provides easy transition from the virtual testing to the real testing.

REAL TESTING

According to the preliminary results achieved from the virtual tests, different strategies could be applied to evaluate their performance and reliability in reply to system or market signals coming from outside the house (utility, retailer). In the CESI RICERCA facility [3] [12] not only it will be possible to carry out several tests on different algorithms but also it is possible to simulate the user presence thanks to an appropriate system that controls each domestic appliance as if a real family is living in the facility. Current experimentation is concerned above all about load control and the procedures to implement suitably functionalities in a more or less complex *home automation* system. Starting from a simple load management, it is possible to move towards an overall energy management comprising not only electric loads but also storage units and local generation. This test facility (Fig. 5) already comprises a photovoltaic conversion generator and in short term also a micro-cogenerator (µCHP) and a storage unit will be installed; they will be included in the *manager* strategies in following months.

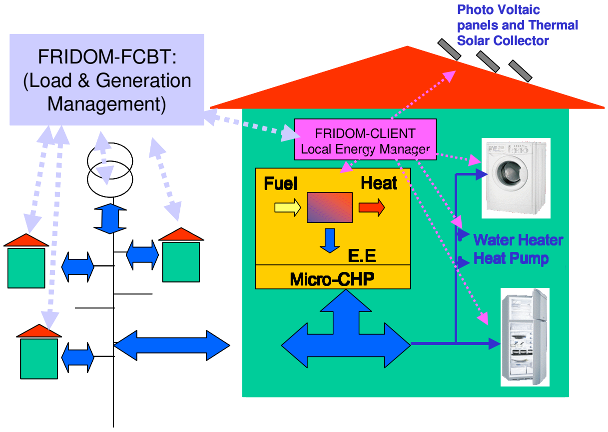

Figure 5. Test facility: *LV dispatching and energy flows' management through MV/LV transformer, LV Customer with the network; Energy management at customer premise (Demand-side Initiative-DSI)*

CONCLUSION AND FUTURE ENHANCEMENT

Liberalisation process and demand side initiatives offer to smaller customers opportunities until now available only to large consumers. This condition will imply a larger diffusion of automation systems, beside home communication networks: they could help cooperation with distributor and create new services "after metering". Multiutilities (water, energy, gas) will offer more telemetering and services to their customers.

In that scenario, local generation could come into conflict with distribution network; this requires adoption of new automation systems that guarantee load/generation balance and optimisation for plant operation both at local and system levels. Algorithms, methods and technologies devoted to integrated management of loads and micro-generation should be provided [13]. These applications must help managing of complex condition where different systems interact. Adoption of Verification & Validation Environment for automation functions supporting Demand-side Initiatives, as here described, could help to overcome these problems.

Acknowledgments

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