MULTI AGENT SYSTEMS: AN EXAMPLE OF DYNAMIC RECONFIGURATION

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Abstract – a multi-agent framework for monitoring and control of power electronics systems may comprise agents with different tasks: strictly measurement, control, computation, decision making, simulation and more. Each task is best performed within a dedicated environment: LabVIEW, Matlab, custom simulators and more. The focus of this work is a heterogeneous agent-based monitoring and control system; the aim of this work is to allow the use of interactive and proactive capabilities proper of agents within this complex environment.

For this purpose interfaces between the agent environment and the measurement, control and simulation environment have been implemented. The application presented in this work is a limited-power, power electronics system.

The experimental results of this application demonstrate how a multi-agent architecture can be usefully employed to coordinate the roles and operations performed by the agents. In particular, the results show the capability of the multi-agent system to perform load reconfiguration to allow for a sudden increase in power demand.

Keywords: Agency, Diagnosis, FIPA, JADE

I. INTRODUCTION

The monitoring and control of complex power systems with limited power generation capability is a topic of growing interest. Mobile power applications, such as ships and aircrafts, as well as hybrid systems, powered by alternative energy sources, belong to this category. A flexible and intelligent measurement system is the key to successful coordination of loads and exploitation of simulation techniques to support system operation.

The application of multi-agent monitoring and control systems to power applications poses significant challenges in data management, command exchange and distributed systems synchronization. An overview of multi-agent systems in power applications is given in [1]. An application of monitoring and diagnostic based on multi-agent technology has been described in [2] where the agent capabilities are not fully exploited, though; in that application in fact, the monitoring, control and diagnostic agents do not actively exchange information and commands but rather statically perform the same operation all the time.

In a flexible and reconfigurable system the individual agents have to be equipped with the code to handle communication with other agents and to perform their own functionality. The agents in a multi-agent monitoring system though, may have to interact with different environments. For example, in the monitoring and diagnostics systems presented in [3] the simulation agent has been implemented within a Virtual Test Bed environment, while the other agents are implemented within a LabVIEW environment.

In [7] a measurement application that builds ActiveX technology on the top of socket programming to enable users to easily configure the agents of a distributed system is introduced. As a result, users in different network locations may request services to external applications to accomplish complex tasks such as diagnosis or transient simulation for the analysis of “what-if” scenarios.

In this work the agents have been all developed in Java Agent Development framework (JADE) and interfaces to monitoring, control and simulation environments have been implemented. The multi-agent system has been applied to load management in a power electronics system with limited power capabilities.

II. THE SYSTEM UNDER ANALYSIS

Three main factors, in the authors’ view, can lead to a significant progress the monitoring and control of complex power systems with limited power generation capability. One first factor is flexible power distribution. Competing loads fed by power electronics systems can be regulated, based on the state of the system. As a consequence, though, reconfiguration becomes an even more complex problem than load shedding [8]. The second factor is the knowledge of “what if” scenarios, [9], [11]. This is made possible by simulation, based on a reliable model of the system. The third and major factor is the flexibility of the data acquisition system. On one hand the acquired data can be fed to the simulation system so that the simulation is consistent with the current state of the system. On the other hand the data...
acquisition system should be ready to change configuration and operating parameters, based on external requirements. These requirements may originate, for example, from the need of diagnostic tests during normal operation, or can originate from the need for a reliability check of the system model.

In this work the experimental systems is a simple power electronic system. In particular the structure has been chosen to exemplify one section of a DC zonal system, as it is under consideration for the power distribution of the future all electric ship of the US Navy. The DC bus is fed through a power supply. The power limit is set as maximum current limit. The three loads are: one induction motor drive and two regulated RL networks. A scheme of the system is shown in Error! Reference source not found.. The power supply is a Xantrex XRF 60/20, the motor is Baldor ZDM3581T, the inverters are IRAMS10UP60A switching at 20kHz. The loads are controlled with a dSpace board ds1103. The data acquisition system is a NI PXI. The load current sensors are LEM built in the inverter boards.

![Figure 1: scheme of the power electronic power system](image-url)

III. THE MULTI-AGENT SYSTEM STRUCTURE

The features of multi-agent systems are making them more and more an appealing option for monitoring and control of power applications [1].

A multi-agent system structure has been chosen to realize the integration between the data acquisition, the control and the simulation sections, [3], [4], [7]. In particular we can mention the following categories of agents:

- data-acquisition agents: this category of agents is able to provide measurement data to the agent-system. It provides all the features of a smart sensor and a high capability of reconfiguration. In the experimental activity proposed here, upon request, it acquires load current, broadcasts a buffer of current values to the peer agent that requested the service, reconfigures the data acquisition based on the request of a peer agent. A PXI-LabVIEW platform is chosen for data acquisition.

- simulation agent: it provides the interface to a simulation engine to be used for analysis of what-if scenarios. In the experimental activity proposed here it provides the forecast of a future scenario. Parameters of the simulation can be changed at run-time upon request of another agent. The Virtual Test Bed (VTB) is chosen as simulation environment

- intelligent load agent: this agent is the interface between the monitoring structure and the local control. It is able deliver power to a local load, subject to availability and conditions determined by the monitoring system. In the experimental activity proposed here a dSpace platform is chosen for control purpose.

- Diagnostic agent: this agent determines whether or not the load change can be implemented; it is based on the system limitations and the operating state and the forecast current of forecasted

Each agent interacts with the software environment under its control to fulfill the needs of the system. For example, the simulation agent is capable of understanding when simulated data are needed and controls the VTB simulation platform.

The agents have been implemented in JADE and are designed to interact with other software environments with the capability to perform required actions. Creating an interface between JADE and COM components is a significant challenge. The objective of this work is the development of a multi-agent platform with Agents that are developed in and communicate in Foundation of Intelligent Physical Agents (FIPA) compliant standards.

For the development of the interface between JADE and COM components, two options were considered:

1. Using JADE with third party libraries that enable users to invoke ActiveX components in the java platform.
2. Using JadeLeap that allows users to run JADE agents in the .Net platform making it easier to instantiate ActiveX components.

The two options were investigated and compared, while the conclusions up to this point can not be considered exhaustive, the experience has proven useful and has led to the choice of using JADE with third party libraries for the experimental activity in this work.

The development of a JADE interface with VTB has been performed using a third party library called JACOB project. Following the choice to use Jade with JACOB project jar files, allowed the instantiation of ActiveX components in the java platform. The details about the Jacob Project can be found in http://danadler.com/jacob/. Thus an interface was created between Java and VTB using the interface provided by the JACOB library.
The same libraries were used to interface Jade with LabVIEW. Notice that this interfacing technique is more flexible and easier to than those provided by National Instruments.

![Diagram of the multi-agent system]

**Figure 2: scheme of the multi-agent system**

The multi-agent system is designed to react to a change in load configuration with the purpose of

1. managing load reconfiguration (load shedding and gentle load performance deterioration) to accommodate changed power demand

2. managing data acquisition re-configuration for diagnostic purpose

The main highlights of the system are: use of simulation for future scenario analysis and decision making aid, agent negotiation, agents interaction with a very diversified set of environments.

A significant effort has been dedicated to develop the agent system in compliance with the FIPA standard. The FIPA is an IEEE computer society standards organization for Agent based technology. FIPA has defined a set of standards to promote the interoperation of heterogeneous agents and the services that they can represent. The Agent-based system in Error! Reference source not found. describes a multi-agent system where a custom protocol was developed in LabVIEW for supporting the Agent communication. The multi-agent system described in this literature takes the capabilities of the previous agent system few steps forward, one of them being using an Agent development platform that is compliant with the FIPA defined standards. JADE, the agent development platform used in this system, follows standards defined by FIPA for Agent communication. FIPA defines many standard interaction protocols for Agent communication. In particular the agents in our system use the FIPA-QUERY and FIPA-REQUEST interaction protocol [15]. Many conversations and messages exchanges between agents in our system do not use the standardized FIPA interaction protocols implemented in JADE but still strictly adhere to the ACL (Agent Communication Language) standard defined in FIPA. This standard allows adding many auxiliary parts in addition to the content of a message like the intended recipients, the sender and the message type. JADE also allows users to develop Ontologies that define the concepts and the language that the agents would use for communication. These ontologies can be derived from higher level ontologies like LISP (LISt Processing) and CYC (enCYClopedia) that are currently being developed as world standards for ontologies.

IV. OPERATIONS DURING LOAD RECONFIGURATION IN THE CASE STUDY

For purpose of test and validation of the proposed approach a case study has been considered. The operational steps of this scenario are summarized in Figure 3.

![Flowchart of operations during load reconfiguration]

**Figure 3: block scheme of the sequence operations**

V. EXPERIMENTAL RESULTS

The experimental results that are presented in this paragraph demonstrate the capability of the agent system to manage load reconfiguration and reconfigure data acquisition.

Assuming the system is operating in normal steady state conditions, suppose the activation of only one load, a specific power level is entered at control agent level. In the experimental setup presented here, the load to be activated is an induction motor drive, with set reference speed equal to 50Hz. The command is not immediately implemented, since, due to the limited power capabilities of the system, due to current loading, the increased power demand may not be accommodated.

The activation request is dispatched to the Load Agents and before is accepted and implemented, a “what if” scenario corresponding to the load change is analyzed in simulation.
The simulation agent needs collaboration from the peer agents since it needs data on the current loading state and the entity of the load change request. For this purpose the monitoring and control agents are activated. The Monitoring Agent manages the data acquisition system to provide the current values of the active loads. For this purpose, the Monitoring Agent interacts with LabVIEW Real Time, through a custom developed interface: it runs the data acquisition VIs to acquire the current and has the data sent out to the Simulation Agent. The control agent provides the speed reference as was initially entered.

The Simulation Agent is designed to interface with the Virtual Test Bed (VTB), the simulation environment chosen for this experiment. The Simulation Agent receives the input from Monitoring and Control Agents and it is capable of opening the simulation file containing the scheme of the system under observation, changing the system parameters according to the current state and run it.

The consistency of the VTB model of the system with the physical system under analysis has been previously validated, as presented in [7].

The simulation represents the system scenario in case the load change requested is granted and the motor is started. The most significant variable, for the purpose of this application, is the total current drained from the DC bus. In this experiment, the total load current must not exceed the limit of 1.2A as this is the value that has been set for the power supply that is feeding the dc bus.

More sophisticated criteria can be adopted to define the limits of a given application. While these criteria are being considered, the focus on maximum current chosen in this case study is a meaningful exemplification of limited power capability. The check on the maximum current value is performed by the Diagnostic Agent. This agent receives simulated data from the Simulation Agent, verifies that steady state has been reached during the simulation and verifies whether the maximum allowable current has been exceeded.

In the first scenario that has been considered, there is virtually no load fed by the DC bus, so we expect to be able to run the motor drive without any other load to be shut off.

The simulation is fed with the current values of the loads other than the motor. These currents are virtually zero. The simulation is set to run with zero current from the two loads and 50Hz reference speed for the motor. Simulated DC bus current obtained in these conditions is shown in Error! Reference source not found.. In this case the maximum current is not exceeded in the forecast, thus the maximum value and limit comparison provides a negative answer and the diagnostic agent broadcasts an approval flag to load change. The Control Agent at this point implements the load activation with 50Hz reference speed. The actuation is performed through the dSpace controller board, that controls all the loads by creating the PWM switching signals. In this experiment the interface between Matlab/Simulink and JADE is not available, therefore the interaction between the Control Agent and the actuator is not direct. This case is particularly interesting to show the survivability of the agent-based decentralized monitoring and control system. This feature of agent-based system is of great interest in particular for military applications or for any application that must be
capable of surviving damage. In fact, if the system is hit and parts of it are destroyed, it is possible that part of the intelligence that controls the system is destroyed with it. In such situation, the ability for a neighboring agent to step-in for one that is out of service is critical. As in the case described here, the Control Agent may not have the capability to communicate directly with its actuator. It can anyway do so though another agent that has that capability. In particular, the Control Agent (in JADE) can not communicate directly with Matlab/Simulink (dSpace), but it can communicate with the Monitoring Agent (JADE) that can interface LabVIEW, that in turn can interface Matlab/Simulink.

![Figure 5: dc bus transient current [A] vs time [s] at motor start-up in simulation; no other load is active at this time](image)

In the second scenario that has been considered, the two RL loads are up and running and absorbing a current of 0.3A each. The Monitoring Agent runs the Vis to acquire these two load currents and sends the value to the simulation. The simulation runs the system schematic with load current 1 and 2 equal to 0.3A and reference motor speed equal to 50Hz.

The new configuration is negotiated by the load agents. In this application this negotiation is based on priority levels, under the assumption that each load agent knows its own priority but it is not aware of the presence of other load agents and their own priority levels. Notice that in general load agents can be added or eliminated from the agency without notice to the other peers. As a consequence, for example, a load agent whose priority is 2, does not know in general if a priority 1 load is present or not in the system.

More sophisticated negotiation criteria are under consideration and are described in the future work section.

The negotiation identifies the load to be sacrificed. In this application a simple load shedding is performed at this point, for sake of simplicity so the load agent with least priority forces the control to shut down its corresponding load. In this experiment load 1 had lowest priority therefore it is shed. The RL load currents are shown in Error! Reference source not found., where the signals are captured at the time in which the negotiation has been completed and the load 1 agent has implemented the outcome of the negotiation shutting off load 1.

![Figure 6: dc bus transient current [A] vs time [s] at motor start-up in simulation; the other loads are active at this time](image)
The authors are working on the implementation of gentle performance deterioration criteria, that would allow keeping all the loads active while accommodating the new power demand. This could be easily done in a situation where there is always a power converter as interface between the DC bus and the load: a modulation of the duty cycle control can achieve virtually any value of power absorption.

At this point the motor drive is started. This simplified procedure, based on knowledge of the system does not perform any further verification of the state of the system, while in fact the simulation/negotiation procedure could be reiterated to validate the load management decision. The system though is set to perform an a posteriori validation. For this purpose the monitoring agent, whenever a decision based on negotiation is implemented, modifies the virtual instrumentation set-up, running a specific Virtual Instrument. This VI is capable of measuring the currents that are being drawn by the two resistive loads and also has the capacity to drop the measurement of a certain load that has been shed for the next round of negotiation i.e. when the user decides to make another change in the system, the measurement VI measures the current only from the active loads on the system.

VI. CONCLUSIONS AND FUTURE DEVELOPMENTS

An example of dynamic reconfiguration of the measurement and control agent in a multi-agent system has been presented. The basic capabilities of an integrated environment for simulation-assisted monitoring and control of power electronic systems have been demonstrated. Many of the multi-agent system capabilities are under-exploited at this point of this research work, while issues such as timing and systematization of limits still are to be tackled. The authors are planning to extend their work both in depth and in breadth. The application of this multi-agent system to AC power systems, with particular consideration for power quality issues in under development. At the same time the following topics are being considered:

- Step-ability: this feature would allow an agent to advance the simulation one step at a time performing the scheduled verification at every step; more sophisticated management of the simulation duration is also being considered. The overall issue is the choice of simulation mode for minimum computational burden

- Use of the JADE agent database for registering agents and their features, to make the process of addressing a specific agent completely automatic

- Negotiation criteria based on current state (priority depending on current state, or more in general operational state, based on more complex criteria. In this respect the impact of one load on harmonic pollution in an AC systems represent a target case study

- Verification of the negotiation outcome for consistency and feasibility

- Gentle performance degradation instead of basic load shedding: this approach requires tackling many issues on the criteria to be followed

ACKNOWLEDGMENT

This work has been partly supported by the US Office of Naval Research under contract number: N00014-02-1-0623

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