Multi agent based islanding and load management system for microgrids

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Abstract: This paper presents a novel dual layered multi agent system (MAS) based control system for use in microgrid operations. A microgrid is a localized cluster of power generation, storage and users, where distributed local power sources are used to supply power to local consumers. In developing a smarter grid capable of withstanding disturbances/outages and providing quality service to the consumers, reliable microgrid control architecture is vital. The innovative micro grid control system presented, makes the microgrid capable of isolating the local grid from effects of any upstream disturbances in the main utility grid (by operating disconnected from the main utility) via islanding, and allows the most critical local loads to be supplied by any, available, local power source during such islanded operation. Multi agent system based control architecture is developed to provide a microgrid with dynamic islanding and load balancing capabilities. The presented MAS control architecture is developed using the JADE platform and it is used to control a test network simulated in MATLAB. The results of these simulations show the capability of developing MAS based reliable control mechanism for islanding and load management of microgrids based on the proposed concept.

Keywords: Distributed control, intelligent agents, intentional islanding, load management, microgrid, and multi agent systems

1. Introduction

The modern world moves forward with an ever increasing demand for electricity. This growth in demand for electrical power is becoming a major challenge for the electrical supply authorities worldwide with today’s energy crises. Dwindling oil reserves, consequent rise in electricity costs and the mounting need to address concerns regarding climate change due to the emission of greenhouse gases (GHG) are forcing utilities to look at new concepts in electricity generation, transmission, distribution and utilization.

The present grid systems which have mostly been built over the last century are rapidly aging. Legacy power distribution systems are facing a tough challenge in meeting the needs of a rapidly evolving electricity market. Time is ripe for a smarter grid, capable of meeting the present and future power delivery requirements. The need to reduce GHG emissions have ushered in the need for greener electricity generation and incorporating renewable energy sources in to the energy mix. These complications demand a paradigm shift from large scale fossil fuel based sources towards small scale lower emission systems. The incorporation of smaller distributed generation (DG) units with maximum renewable energy penetration becomes vital in meeting these demands.

Grids with such DG systems require the ability to handle active generation and loads; which existing legacy system designs are unable to address. Smaller “micro’ grids comprising local generation is a concept put forward to cater this requirement [9]. These microgrids can be operated either in island mode, where the local loads are fully supplied by the local generation, or in grid connected mode, where the microgrid is either exporting or importing power from the main grid. With the local generation and loads coming into the picture, local distributed control is essential for the grid stability.

Therefore, these power systems have to become smarter with local distributed control capabilities and more reliable and robust in taking on renewable energy sources without losing stability and efficiency. Smarter microgrids are an answer to this situation. As an innovative method in providing this flexible
distributed control requirement, Multi Agent Systems (MAS) are stepping forward.

This paper proposes a novel MAS which provides a scalable and robust distributed control architecture for microgrid applications. The MAS model is designed using the JADE platform and is implemented on a simulated test-bed in MATLAB/SIMULINK. Rest of the paper is organized as follows. An introduction to micro grids is given in Section 2. Section 3 gives a brief overview of MAS and Section 4 discusses the applications in microgrid applications and different architectures used. A novel dual layered architecture is presented in Section 5. Simulation results of a conceptual microgrid operation based on the proposed MAS model is discussed in Section 6. The conclusions are presented in Section 7.

2. Microgrids and their growth

Centralized, bulk generation facilities are giving way to more distributed and small scale generation systems. Distributed generation (DG) introduces the capability of embedding a wide range of low emission and potentially lower cost generation options. Such options can include internal combustion (IC) engines, micro-turbines & non-conventional renewable energy sources such as solar photo voltaic, wind, biomass, mini/micro-hydro and even waste-to-energy systems. These smaller generation technologies allow the sources to be placed optimally with respect to the loads, thus reducing emissions and transmission losses, while also allowing for local control instead of central dispatching [9].

Such DG systems provide the potential to take a sub-system approach in working with microgrids. During a disturbance in the main utility grid, local generation and their loads can separate from the utility and isolate the local loads from the disturbance, while maintaining the integrity of the main utility grid. This isolation is carried out at a single point of connection to the main utility known as point of common coupling. This capability, known as islanding, requires high reliability and flexibility from the microgrid. These requirements can be met by having peer-to-peer control and plug-and-play capabilities in each entity within the microgrid.

A conceptual microgrid model is shown in Fig. 1. This can be either a small scale distribution level network or an electrical system of a building. Certain loads, which are critical, will have local power sources. Non-critical loads will have no local supply.

Once an upstream disturbance takes place on the main grid, the microgrid can separate from the main grid at the point of common coupling and isolate the local loads from any outage, providing a higher level of service, with minimum effect to the stability and the integrity of the main grid. This capability of intentional islanding will deliver a higher reliability than legacy power systems [9]. Thereafter, the microgrid has to manage the local loads to make sure that the most critical loads are supplied by the available limited local capacity. This requires priority based shedding of non-critical loads.

3. Multi agent systems (MAS)

With the need of peer-to-peer control, plug-and-play capabilities required in successfully implementing microgrids; more robust distributed control architectures are being required. Multi Agent Systems (MAS) have been successfully used to fulfill this requirement. MAS are a collection of intelligent agents with limited local knowledge, but with enhanced communication capabilities, that can cooperate to achieve a global objective [3].

The notion of agent or agency had been developed for use in mainly computer science applications. A comprehensive comparison of the numerous definitions found alongside with their benefits and drawbacks have been presented in [5]. The authors prefer the definition proposed by Wooldridge [3], as found in many of the recent literature. An agent is defined as a software entity in side an environment able to autonomously react to any changes. Here the notion of an agent, an
environment and the ability of autonomy is defined. The environment suggests everything external to the agent. In order for an agent to behave in an environment it should, at least in part, be observable or alterable by the agent. In the microgrid paradigm, the environment and the agent are situated in the power system, which is observable through power-electronic sensors, and alterable through power-electronic devices (i.e. closing or opening a breaker to reconfigure the power flow).

Definition in [3] differentiates agents from existing systems and objects in programming with the concept of flexible autonomy. Characteristics of agents: Reactivity - ability to react to sensible changes in the environment; Pro-activity - make intuitive decisions and display goal-oriented behaviour; and Social-ability - be able to communicate with other agents using a common language and initiate conversations.

Existing control systems and software objects might exhibit reactivity, but an agent with flexible autonomy differs from them by displaying a degree of intuition, alongside social ability. Integration of two or more such intelligent agents coordinating to achieve a global objective by trying to fulfil local goals is a MAS.

Readers interested in a detailed guide to the concepts, methodologies, technical problems and the applicability of MAS in power systems applications are referred to [1]. An in depth discussion on the standards, tools, ontologies, design requirements and specifications can be found in [2].

4. MAS and distributed control of microgrids

Agent systems are inherently distributable owing to their separation from their environment. An agent can be copied to a different location without losing reasoning capabilities or the goals. This allows for an agent to react in different ways to two different environments, given both environments support the intended tasks.

A basic issue for distributed generation is the technical difficulties related to control of a significant number of micro-sources. Research into implementing MAS for microgrid applications has been rising in the recent years [1] and has mostly recently centered on distributed control, electricity trading, and power system restoration [7].

Intelligent agents can be assigned to each entity in a microgrid; i.e. circuit breaker, electricity generation unit, loads, users etc. This assignment will determine the MAS architecture. Several different architectures for microgrid applications have been proposed up to now. Single layered architectures are the most pre-dominant type in the literature. For example, single layered architectures have been proposed for microgrid applications such as resolving real and reactive power mismatch [4] and load restoration [10]. In these single layered agent topologies, agents are tasked with multiple objectives. For instance, main controlling agent in these architectures is commonly tasked with islanding; load shedding, load management and process control simultaneously. This becomes a shortcoming in improving the scalability and in building robust distributed control models. Therefore, the appropriate delegation of objectives to secondary level agents will improve the robustness of the model. Such secondary agents can be tasked separately with islanding control and load shedding, while overseen by a primary agent on the primary layer.

Several multiple level control architectures have been presented in the literature [6], [11]. However, in these multi layered topologies, the layers address different strata of the distribution grid and not of the control architecture.

5. A dual-layered MAS

Fig. 2 shows the conceptual design of the proposed dual layered control architecture for microgrids [8]. The MAS system is developed using the JADE platform [12]. The model presents a dual layer distributed control architecture. The primary layer comprises of three major agents; DG Agent, User Agent and Control Agent. The three major agents will be tasked with sensing and controlling the components of the microgrid. The DG agent will collect several information related to the DG; (i) availability, (ii) connection status, (iii) power rating, (iv) energy source availability and (v) cost of energy. The control agent is in control of a secondary layer comprising of a Load agent and a Low Voltage (LV) agent, overseeing the load control and microgrid connection control capabilities.
During an upstream fault, the LV agent will island the microgrid, by tripping the circuit breaker at the point of common coupling, if the Control agent allows it. During island operation the load shedding will be carried out by the Load agents to ensure that power is delivered to the most critical loads on the priority basis set by the Control agent. This will be implemented by Load agents opening circuit breakers at each of the controlled local loads.

The User agent behaves as the gateway for the user to interact with the system, to obtain real-time information and set system goals. A utility agent acting in the form of a database agent is utilized to store system information and data and messages shared between the agents. The priority list used for load management is also hosted by the database agent. The database agent will act as the access point for data for all the agents and users.

The control agent will be the centre of the primary layer holding influence over the DG agent and controlling the LV and Load agents. The MAS is developed for the load management during the islanded phase. As local generation capacities will most definitely be limited with respect to local loads, load shedding will be unavoidable during islanding. Proper load management during load shedding will provide better protection to the most critical loads. By assigning priority values to the local loads, the most critical loads can be identified for protection during islanded mode. By allowing priority level updates during operation the control over load shedding/management can be improved.

The control flow chart given in Fig. 3 describes this load management during islanded mode. The user agent is allowed to update priority levels during runtime. By revising priority levels a user can restore power to a load that was previously considered non-critical.

When the local capacity is deemed unable to meet the local demand load shedding is initialized based on the priority values of the local loads. Then the load agents with lower priorities are advised to disconnect while maintaining supply to the most critical loads. When the priority list is updated by the user agent, it is hosted by the database agent and is broadcast to all the other connected agents. This triggers a re-evaluation of capacity and demand, and thereafter any necessary load shedding is carried out based on the revised/updated priority list.

Proposed architecture allows for self-organizing control. As each agent acts independently, once an agent is created/initiated it can logically interface with the existing agents. This is done via a directory service provided by a utility agent acting as a database. A newly initiated agent can register in the directory and advertise its capabilities and requirements to the others. This will provide self-organization capabilities to the control framework. Therefore, if one agent goes offline, the other agents can reorganize to cope with the loss. This ability increases the scalability and robustness of the controller.
6. Simulations and results

The microgrid test bed used for the simulations (shown in Fig. 4) consists of a 480V, 15 kW embedded generator, acting as a DG unit, supplying part of the local demand, and two main local loads 15 kW each. It is assumed that the DG units can operate at full capacity without fuel limitations during any outage. This simulation test bed is modelled using MATLAB/SIMULINK. An external TCP/IP server [13] is used to connect the MAS to the simulated test bed.

![Microgrid diagram](image)

Figure 4. The simulation testbed

The local loads are given two priority levels as shown in Fig. 4. Local load 01 is given a priority level of 0.7, and load 02 is given a priority level of 0.4. This initial setting designates load 01 as a higher priority load, and load 02 as a lower priority, by their respective load agents.

The objective of the test setup is to demonstrate the ability of the proposed MAS to island the microgrid after an upstream fault is detected, and maintain supply to the most critical loads. Initially, the microgrid is operating in the grid-connected mode, with the embedded generator supplying only part of the local loads while the rest is supplied by the utility grid. The demands supplied initially by the DG and the grid are depicted in Fig. 4. At the beginning of the simulation, breakers A, B, C and D are closed. While the microgrid is in grid connected mode and upstream fault is introduced at 0.05 s as seen in Fig. 5. The microgrid is switched to island mode thereafter. Line-to-line voltages are measured from points A, C and D as shown in Fig. 4.

6.1 Grid connected mode

When the microgrid is in grid-connected mode, the total demand is 30 kW, comprising two 15 kW local loads. During the grid-connected mode the embedded generator only provides 10 kW output and the other 20 kW is provided by the main grid. A fault is introduced on the main grid at time $t = 0.05$ s.

![Voltage measurements](image)

Figure 5. Voltages measured during simulations (line-to-line) at; (a) Main grid voltage at breaker ‘A’, (b) load 01 measured at ‘C’: switches from high priority to low priority, (c) load 02 measured at ‘D’: switches from low priority to high priority.

6.2 Transition period

When the upstream outage is detected at time $t = 0.05$ s the control agent informs the LV agent and the Load agents to switch to island mode operation. Upon receiving the islanding order the LV agent trips the main circuit breaker ‘A’, at the point of common coupling isolating the microgrid from the utility (Fig. 5(a)). The Control agent then queries the DG agent and the load agents regarding their available capacities the DG can provide to the microgrid and the power requirements of the connected loads.

As the total load of 30 kW exceeds the available maximum capacity of 15 kW, the control agent commands the load agents to shed the 15 kW non-critical loads to match the DG capacity and the DG unit to increase output to 15 kW. Soon as the microgrid is put to island mode the supply to the critical loads is maintained (see Fig. 5(b)). The load agent at the lower priority load 02 sheds them from the system by opening breaker D (see Fig. 5(c)).

6.3 Islanded mode

At $t=0.05s$ the microgrid is separated from the main grid and the load agents balance the local demand. After the microgrid switch to island mode the total local demand is met by the embedded generator supplying 15 kW.
During the island operation, the user agent can revise the initial priority assignment. This can be pre-initiated or a user can change the priorities during the islanded mode. At $t=0.14$, the user agent revises the priority value of load 02 from $p=0.4$ to $p=0.9$ and communicates the revise-request to the load agent at load 02. This update is forwarded to other agents via the directory agent, and the control agent reinitiates load management procedures. Still the DG unit is unable to meet the total demand of 30 kW, and has to shed loads to maintain power to the new highest priority load, load 02. Therefore, the control agent commands the load agents to shed the load 01 of 15 kW to match the DG capacity. Thus, the supply to the new most critical load, load 01 is provided by reclosing ‘D’ (see Fig. 5(c)). The load agent at the now lower priority load 01 sheds them from the system by opening breaker ‘C’ (see Fig. 5(b)).

All agent operations are carried out rapidly, from detecting fault, opening the main breaker, connecting the local source and shedding loads, to stabilize the microgrid within 0.02 s. the load reconnection after the priority update is done again within 0.02 s of the revision being sent from the user agent. Therefore, the system is able to disconnect from the main utility grid and maintain the supply to the critical loads without suffering a brownout and/or blackout.

7. Conclusions

The proposed dual layered MAS is able to successfully island the microgrid during an upstream outage within 0.02 s of detecting the fault. As the local generation capacity is unable to meet the total local demand, the MAS initiates load shedding upon pre-set priority levels of the loads. This enables the MAS to maintain the supply to the most critical load/s by shedding least critical loads until DG capacity can meet the demand. When the load priorities are revised by a user via the user agent, the MAS is able to reconfigure the system, in order to provide power to the new most critical load. The reconfiguration is also done within 0.02 s of the revision and successfully reconnects the new critical load. The results show the capability of the MAS to safely island and maintain the supply to its critical loads, even if the critical loads are revised. These results validate the effectiveness of the MAS in controlling DG units to protect and control a microgrid. The MAS can be implemented on a physical test bed to further validate the results.

References


