Microgrid Intelligent Agent Control

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***Abstract*—Microgrid control is complex due to its need to accommodate the intermittence of renewables, balance generation with load, transit between grid-connected and islanded modes, and maintain reliable power supply to customers. Much research has addressed microgrid control complexity in both centralized and decentralized settings. This paper presents an intelligent software agent control with advanced autonomous capabilities to address the intermittent nature of renewables and their integration in real-world scenarios. Such capabilities include data acquisition, load and renewable generation forecasting, energy management, scheduling, optimal power flow, and real-time control to maintain generation-load balance in a secure and reliable microgrid environment. Accurate AI predictive models, machine learning algorithms, and non-linear optimization will be at the core function of the control agents.**

Keywords—Microgrids, Controllers, Intelligent Control, Agents

I. Introduction

The bulk of electric power generation worldwide comes from fossil fuels. The planet is, therefore. contaminated with carbon dioxide emissions that impact the climate and drive extreme weather conditions. Microgrids emerged as alternative renewable energy resources that produce green power for customers in urban and rural communities [1],[2],[3]. Renewable resources are intermittent and bring various operation and control challenges, especially when generation and load disturbances are abrupt and power outages are severe [4]. Such challenges include providing stable and reliable power to balance customer load in real-time, maintaining consistent voltage and frequency power characteristics, and managing operational and economic uncertainties in renewable power generation.

Therefore, microgrid control is complex and requires a high degree of real-time coordination and operation [5],[6]. The control technologies in conventional utility grids require substantial customization and adaptation and often do not meet microgrid requirements. Microgrid uncertainties are addressed by various technologies that provide power, improve reliability, reduce carbon emissions, and lower operational costs through a mix of renewable resources, energy storage, and responsive load [7].

This paper introduces a novel intelligent agent control for microgrids based on a distributed, coordinated, and optimized use of resources in real-time with minimal human intervention. We apply research discoveries in AI and energy to make microgrids efficient, reliable, resilient, and sustainable. The control agents are designed to enable individual solar panels, wind turbines, bus inverters, storage batteries, and end-user load components to operate and self-organize their controls in real-time autonomously. This research is in the preliminary phase, and further testing and validation are still required.

The remainder of this paper is organized as follows: Section II reviews related research in microgrid control. Section III presents a generic microgrid model. Section IV presents the architectural design model of agent control. Solar, Wind, Load, and Operator Agent Controls are presented in Sections V, VI, VII, and VIII, respectively. Finally, the paper is concluded in Section IX.

II. Related Research

Various microgrid controls have been presented in the research [8],[9], ranging from distributed agent-based to centralized cloud-based controls specifically targeted toward supervisory controls of utility grids and microgrids. [10] provides architectural insights for using SCADA (Supervisory Control and Data Acquisition System) controls in smart grid and microgrid systems. [11] presents a design of controls that includes online monitoring of energy consumption in smart grid infrastructure. Multi-agent systems have also been introduced in [12] as alternative controls for utility grids with a comprehensive review of concepts, platforms, and applications.

The generic SCADA has tremendous limitations for microgrids and may incur large complexity for adaptation and customization [13]. It often generates many fault records in an hour that require manual analysis [14]. [15] presents multi-agent alternatives to operate distributed energy resources in microgrids. The general design of multi-agent systems comprises several agents working effectively and seamlessly [16] and has potential implications for future microgrid systems [17]. [18] presents a set of open-source tools for designing SCADA by adding new features and increasing acquisition time in the context of IoT adoption. These tools are preliminary and will need further investigation to check their applicability in the microgrid environment [19], and in the broader control strategies of renewable energy resources [20].

III. Microgrid

A microgrid is a group of interconnected loads and distributed energy resources in a single controllable entity that typically transits between grid-connected and islanded modes [21]. In a grid-connected mode, the microgrid operates in sync with the utility grid, trading in and out power deficit and excess.

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In an islanded mode, the microgrid thrives on balancing generation and load in real-time and maintaining reliable power flow and stable voltage and frequency [22],[23]. In remote and fragile areas, the islanded microgrids are isolated, have no interconnection with the utility grid, and operate as stand-alone power systems.

Figure 1 shows a microgrid's topology consisting of renewable wind and photovoltaic (PV) power generating units, controllable load, battery energy storage system (BESS), AC (Alternating Current)/DC (Direct Current) inverters, AC bus system, and a substation to couple with the utility grid. A microgrid can also include other resources, such as small-scale diesel, fuel cell, or natural gas generating units and electric vehicles. We provide a design of an agent control for wind turbine, solar PV, load, inverter, BESS, and the system operator that manages and operates the microgrid in real-time to ensure power availability and reliability.

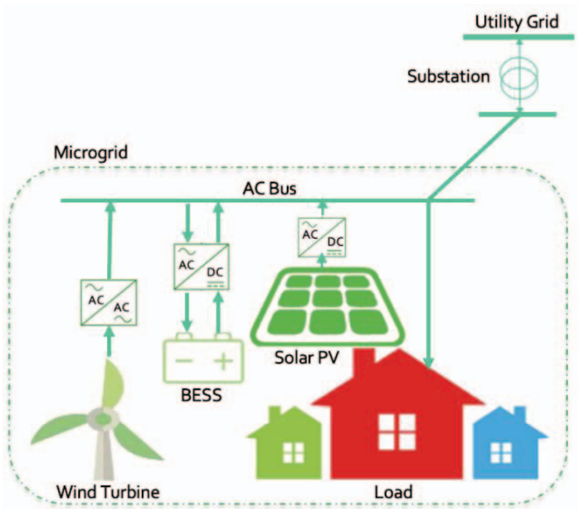

Fig. 1. A topology of a microgrid

IV. AGENT CONTROL

Agent control is introduced as a technology to transform a microgrid into an intelligent and self-organizing system that is economical, efficient, reliable, resilient, and sustainable. Solar panels or wind turbines are made intelligent nodes to forecast short- and long-term power generation actively. Buildings, inverters, coupling substations, and battery storage are also made intelligent nodes to operate autonomously in various self-organizing microgrid scenarios.

The agent control interacts with the microgrid environment through an array of input sensors and output controls and coordinates with the other agents in a distributed manner. It also has a set of indicators to show the status of communication, on/off, fault, voltage, frequency, and current. Agents coordinate and optimize the use of resources in real-time with minimal human intervention. We use machine learning, non-linear optimization, and open-source technologies in the architecture of the agent control. Figure 2 shows the internal architectural design of a generic agent control. The main components include the knowledge base, the generic agent model, and agent communication.

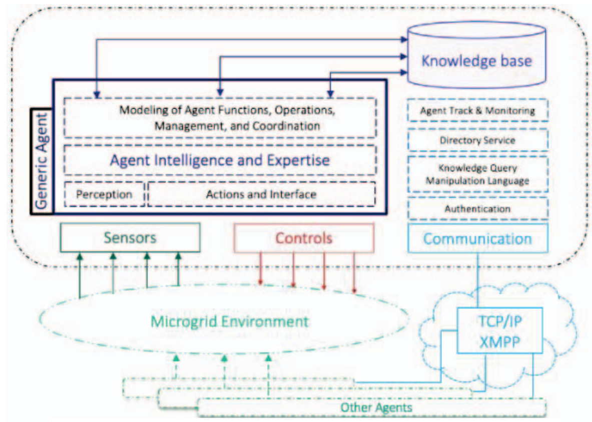

Fig. 2. Agent architectural design

Agents perceive the microgrid environment through sensors and provides actions through controls. They are designed based on their services and degree of perceived intelligence and capability. The standard design models are simple, model-based reflex, learning, and goal- and utility-based agents. The agent's knowledge base is based on a production model of knowledge representation in the specific function and interaction with declarative rules of conduct. Agents use reliable connection-oriented TCP/IP protocol with XMPP (..) for communication with the other microgrid agents. KQML (knowledge query manipulation language) is used for communication and a directory service, authentication, tracking, and monitoring are used for distributed control and self-coordination. We use models of intelligence for different functions and operations of the microgrid resources. In the next sections, we give the specific models of solar, wind, load, and operator agent controls. The design of the battery, and inverter agents are not complete at this stage.

V. SOLAR AGENT CONTROL

The accurate forecast of the weather and solar radiation provides good estimates of PV power, which helps in the optimal scheduling of the generation-load balance in the short- and long-term timestamps. As shown in Figure 3, the main components of the solar agent are prediction modules for weather, temperature, radiation, and solar power. Details of neural networks and deep learning methods for photovoltaic power forecasting are given in [24],[25],[26]. The solar power forecast: p_s is then computed as a function of the solar radiation:

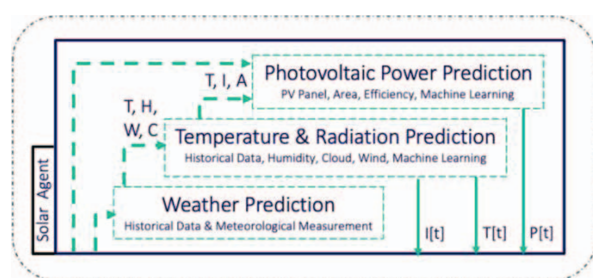

Fig. 3. Solar Agent Control

G, temperature: T, area of the panel: A, efficiency: η, and degradation factor: α at any given timestamp t, given as:

$$p_s[t] = \eta AG(1 - \alpha(T[t] - 25)) \quad (1)$$

VI. Wind Agent Control

The forecast for wind power: p_w depends on the wind turbine's area: A, air density: ρ, and wind velocity: v intercepting A at any given timestamp t, given as:

$$p_w[t] = \frac{1}{2}\rho Av^3[t] \quad (2)$$

The air density and wind velocity can be predicted using machine learning using atmospheric, geographic, and topographic data and multi-layer backpropagation learning algorithms. Figure 4 shows the linkage between these algorithms and weather forecasting data models, which largely depend on the metrological measurements and the characteristics of the wind power plant.

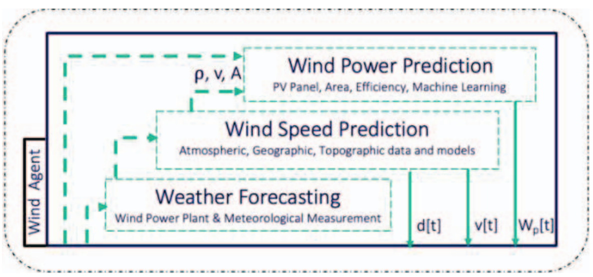

Fig. 4. Wind Agent Control

VII. Load Agent Control

As shown in Figure 5, the modules of load agent control are load forecasting, load shedding, and energy management. Load forecasting provides estimates of the power demand at different load points (e.g. buildings) in the microgrid in the short- and long-term. Time series, neural networks, and wavelet packet transform are examples of models used in short-load forecasting [27][28]. The inputs are historical data and metrological measurements like temperatures, wind, humidity, week or weekend day, and hour of the day.

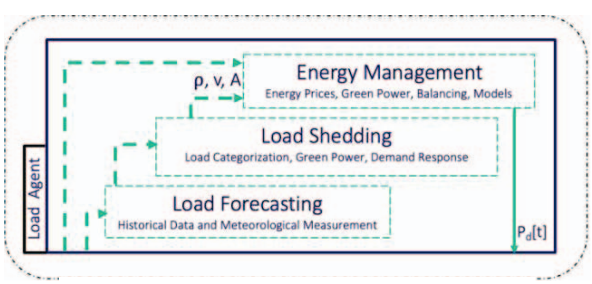

Fig. 5. Load Agent Control

Load shedding is the primary function of resiliency. Reference [29] studies how to protect microgrids when a fault occurs in the main grid while continuously supplying the critical loads using intelligent control and predictive load shedding algorithm. Reference [30] proposes a coordinated load-shedding control based on double-Q learning and Markov's decision to achieve balance in power supply and demand and stability of frequency and voltage during unintentional islanding. Reference [31] applies an agent-based model to forecast generation and load, optimize demand via load prioritization, and implement proper means of shedding and rescheduling.

The primary goal of energy management is to balance generation and consumption in a steady state through strategies and tools that maximize efficiency and enhance competitive positions [32]. Home automation systems embed these tools and strategies to efficiently control home energy consumption and increase consumer participation using advanced analytics, actionable information, and control features while ensuring ease of use, availability, security, and privacy [33]. Energy Balancing [34],[35] and load balancing [36] are common strategies of energy management.

VIII. Operator Agent Control

The primary goal of the operator agent control is to balance generation and load, provide adequate voltage and frequency control, and maintain a reliable, stable, and resilient microgrid power network. Figure 6 shows three levels of controls: tertiary, secondary, and primary control to ensure accurate scheduling and optimal power flow that minimizes operating costs while maintaining generation-load balance and accurate voltage and frequency of the microgrid power.

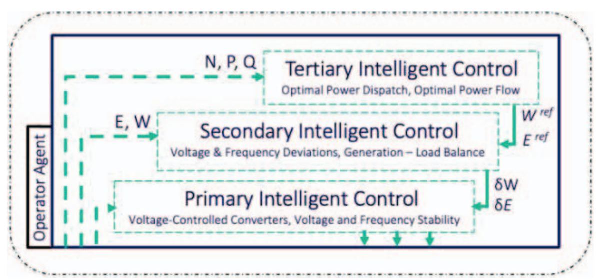

Fig. 6. Operator Agent Control

The tertiary control includes optimal power flow and dispatch functions that identify the day-ahead power schedules and the reference setpoints of frequency: W^{ref} and voltage: E^{ref}. These points are computed based on the network conditions: N and the schedules of active power: P, and reactive power Q. In the hour-ahead schedules, the secondary control produces a generation-load balance schedule and manages deviations of frequency: δW and voltage: δE. These deviations are controlled in real-time in the primary control that includes relay protection and coordination, frequency control in islanding mode, volt/VAR and reactive power control and grid-connected to islanding transition.

Like large-scale power grids, microgrids offer ancillary services to maintain reliable and secure power balance, voltage, and frequency. They include day-ahead and real-time demand response [37], power reserves and congestion management [38], spinning reserves [39], frequency regulation [40], phase balancing [41], active and reactive power [42], power factor support [43], and black-start capacity [44], [45].

IX. Conclusion

This paper presents a novel intelligent agent control for microgrids that are intermittent in nature. The functions of microgrid controls are complex because of the diversity of the renewable generation mix, the renewable intermittence, and the requirement to operate in either an islanded or grid-connected mode. The design of the control agents is modular and adapted to the requirements of the individual microgrid component: solar panels, wind turbines, bus inverters, storage batteries, and end-user load. Agents operate and coordinate autonomously and self-organize their controls to maintain generation-load balance and consistent voltage and frequency with the ability to sustain abrupt disturbances in the event of microgrid islanding and transitioning of renewable generation. This research is in the preliminary phase and further testing and validation are still required.

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