Supervision Control and Energy Management Strategies for Grid-Connected Microgrids Using Finite Automata

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The recent trend of renewable energy development is integrating Distributed Generation (DG), Energy Storage System (ESS) and conventional generation to form a small scale grid called microgrid. Microgrid mainly has two operation modes, grid-connected and islanding mode. Such microgrids provide more flexible and self-sufficient system compared to individual DG. The presence of DGs and ESSs impose significant and fundamental changes in the configuration of the power system topology and power flow direction [1]. Therefore, control and energy management strategies are necessary to coordinate the operation of the different DGs, and to maintain the reliability and stability of the microgrid. A hierarchical control structure with energy management is presented in [2], this approach is based on dynamic programming that optimizes the power flow management into a grid-connected PV with storage. Also, four layers control supervision system is designed using Petri Nets to model the power system that consists of Photovoltaic system (PV) and ESS [3]. The supervision control takes into consideration the power production and load demand forecasting, grid power limitation, time of use tariffs, energy cost optimization and power balancing. In [4] a supervisory control is developed for high level control of the operation of a custom power park using Supervisory Control of Discrete Event System (SCDES). Three modular supervisors are synthesized using TCT software packaging in a decentralized fashion which simplifies the implementation of the controller. The previous studies handled microgrids using different approaches for implementing the supervision and energy management system as well as modelling them. However, developing a systematic method to design a comprehensive multi-layer supervisory control approach by splitting the system into smaller subsystems based on the behaviour of each subsystem has not been fully covered in the literature. This paper proposes a comprehensive supervisory control approach for grid-connected microgrid. Fundamental to this approach is multi-layer control system to guarantee the optimal performance of microgrid components with given operating conditions. The supervision system is designed in a three-layer structure: forecasting, energy management and action layer. These layers take into consideration the power generation and load forecasting, storage capability, energy exchanged with the grid, energy cost optimization. To attain the self-automation between the microgrid and supervision system, the behavioral modeling for each component in the microgrid is implemented using Finite Automata (FA), by identifying the possible states of each component and the conditions that govern the transfer from one state to another. This is followed by behavioral analysis of the microgrid to facilitate supervision control design. To this end, the proposed supervision control is capable of managing power flow in the microgrid, controlling power exchange between the microgrid and utility, increasing self-sustainability by maximizing the usage of the sources, using metadata to increase accuracy, performing energy management strategies and cost optimization. To validate the effectiveness of the proposed approach, various case studies of real data will be extensively investigated. Modeling microgrid components using FA can be implemented using PHAVer tool and then simulated using Stateflow/Simulink. The microgrid in this study, shown in Fig.1, consists of PV, ESS, Electrolyzer (EL), hydrogen tank, water tank, and Fuel Cell (FC) connected to AC bus. The power generated by the FC and PV will be used to charge the ESS which in turn supply the load and the electrolyzer. Furthermore, if there is not enough generation and ESS is empty, energy will be imported from the grid to ensure service continuity. On the other hand, the extra PV generation will be sold to the grid. The supervision design overview is also illustrated in Fig.1, the forecasting layer predicts the power production from the PV and FC and the load consumption. Based on these forecasted values, energy management will optimize the power flow through the microgrid with the goal to perform the best power distribution among the sources. The action layer is responsible for the power balancing across the microgrid with consideration of the energy management performed in the upper layer. Fig.2 shows an example of modeling ESS using FA, there are predefined conditions that rule the transition from one state to another, once the condition is satisfied, the ESS will enter a new state. Finally, the proposed systematic procedure is straightforward and simple to implement, also it is easy to modify to accommodate changes to control specifications or objectives. In addition, using FA can provide an abstract overview about each component in the system and to the overall system behavior.

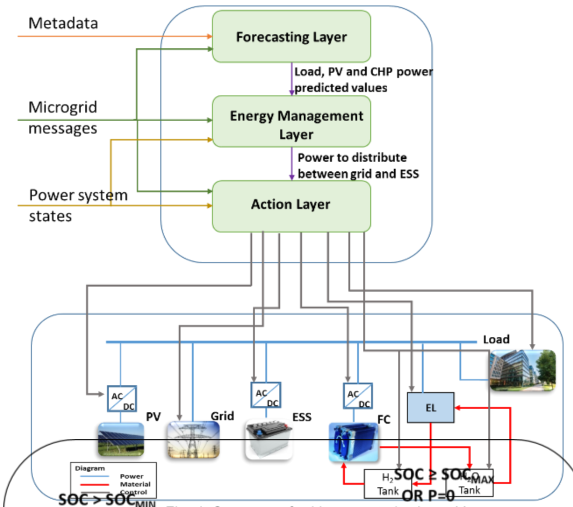

Fig. 1: Structure of grid-connected microgrid

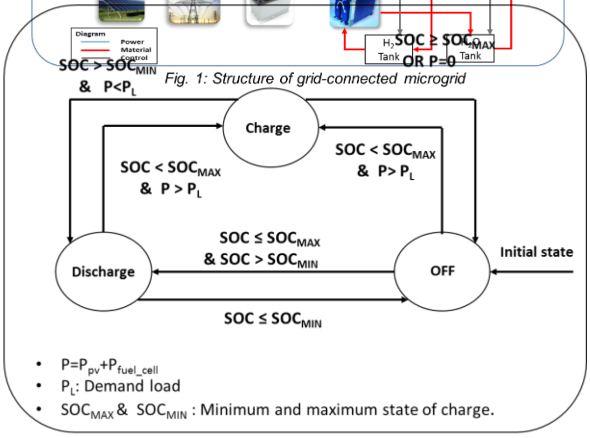

Fig 2: Finite automata model for the Battery

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