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A multi-agent based distributed energy management scheme for smart grid applications

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ABSTRACT

A multi-agent system based distributed EMS (energy management system) is proposed in this paper to perform optimal energy allocation and management for grids comprising of renewables, storage and distributed generation. The reliable and efficient operation of smart grids is slackened due to the presence of intermittent renewables. As the load demand and renewables are uncertain throughout the day, an energy management system is essential to ensure grid stability and achieve reductions in operation costs and CO_2 emissions. The main objectives of the proposed algorithm is to maintain power balance in the system and to ensure long cycle life for storage units by controlling their SOC (state of charge). The proposed EMS scheme is tested and validated on a practical test system, which replicates a small-scale smart grid with a variety of distributed sources, storage devices, loads, power electronic converters, and SCADA (supervisory control and data acquisition) system. This system is also connected to the utility grid and the power exchange is controlled with the help of a battery system through a fuzzy based decision-making framework. The proposed algorithm is also extensively verified and tested using a series of sensitivity analyses and benchmarking with existing algorithms.

1. Introduction

Over the last decade, the uncertainty associated with load profile and intermittent renewables has reiterated the vital importance of maintaining energy balance in the system. Improving reliability, increasing flexibility for power consumption and ensuring electricity is available at the cheapest price possible are the main goals of grids for the future [1–3]. Power grids with distributed energy sources is a promising solution to reduce greenhouse emissions and to provide improved power quality with efficient and higher reliability. An EMS (energy management system) is required to ensure efficient utilization of all available renewable energy sources and control the optimal power flow between the various nodes of an electrical power grid. EMS comprises of algorithms to perform various operations like setting operating point of individual elements in the system, controlling energy delivered and stored by energy storage systems and managing energy used by the loads. When the system operates in islanded mode, the main goal of the EMS is to reduce operating costs by efficiently scheduling the energy sources in the system with the help of optimization algorithms. When the system operates in grid-connected mode, smooth and robust energy exchange between the system and the utility is maintained while increasing revenues for the system. A lot of work pertaining to energy management for microgrids has been already reported in the literature. In Ref. [4], an EMS is proposed for the optimal control of a VPP (virtual power plant) comprising of combined heat and power plants. The main objective was to ensure minimal electricity generation cost and maximum utilization of renewables. Lu D [5] presents an EMS for a microgrid comprising of photovoltaic panels and a gas turbine, which takes into account power and load forecasting done a day ahead. The EMS focuses on providing real-time set points for operation of the microgrid. Decision making is a vital step when energy planning and scheduling is required to be performed.

Tsoutsos T [6] discusses a multi-criteria analysis for solving the energy planning problem in the Island of Crete. The decision making proposed in this work is based on multiple criteria algorithms that assist each other towards solving the main goal. Another multi-criteria decision making approach is proposed in Ref. [7], where a decision making methodology is formulated to determine the clean energy option. The algorithm proposed is a combination of fuzzy measure and choquet integral. In Refs.

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Nomenclature

EMS	energy management system
MAS	multi-agent system
VPP	virtual power plant
PV	photovoltaics
DER	distributed energy resource
FLMAS	fuzzy logic multi-agent system
SCADA	supervisory control and data acquisition
ISDM	ideal single diode model
SOC	state-of-charge
ESS	energy storage system
SN	social network
FDM	fuzzy decision module
PLC	programmable logic controller
FIPA	Foundation of Intelligent Physical Agents
MTS	message transport service
HRES	hybrid renewable energy system
AMS	agent management system
PSO	particle swarm optimization
JADE	Java Agent Development Environment
i/j	index for generating unit
t	time period
N	total number of generators
η_R	reference efficiency for solar generator
N_{PT}	MPPT efficiency
β_T	temperature co-efficient
T_C	PV module temperature in (°C)
T_R	PV module reference temperature in (°C)
T_A	ambient outdoor temperature in (°C)
U_L	heat loss coefficient in (W/m^2 per °C)
τ,α	transmittance and absorption coefficient for PV modules
A_M	total module area (m^2)
G_T	solar radiation data (W/m^2)
P_{WG}	output power of the wind generator (kW)
P_R	rated output power (kW)
V_R	rated wind speed of the wind generator (m/s)
V	wind speed of the wind generator (m/s)
V_{CI}	cut-in speed of wind turbine (m/s)
V_{CO}	cut-out speed of wind turbine (m/s)
c	temperature co-efficient
n_1, n_2, n_3, n_4	wind power coefficients
V_O	reference wind speed at height H_o (m/s)
H	height of wind turbine (m)
H_O	reference wind turbine height (m)
$\propto_1$	wind shear component
P_{PV}	output power of PV array (kW)
γ_{Bj}	efficiency of the battery
P_{Bj}	power capacity of the battery *j* (kW)
SOC_{Bj}	state of charge of the battery
v	velocity of the PSO particle
x	position of the PSO particle
pbest	particle best
gbest	global best

[8–10], various other power management approaches have been presented for microgrids comprising of renewable energy sources and storage systems. However these EMS demands access to the power measured at every node of the electricity grid, which is practically impossible taking into consideration the conventional distributed generators in preset day electrical systems. Note that most of the above mentioned works deal with a centralized EMS, which is easily susceptible to single point failure. If a failure occurs, the EMS might make undesirable decisions and the system efficiency would be compromised. Concurrently, MAS (multi-agent system) technology has been found to be a successful solution to model electrical power grids as suggested in Ref. [11], therefore in this work we utilize MAS to implement a distributed control strategy for Smart Grids. MAS is one of the most widely used paradigms for achieving distributed control. It comprises of individual agents which can be programmed based on varying requirements and have the added capability of communicating with other agents in the system to form a larger intelligent entity [12,13].

There have been many applications of MAS in distributed systems. Li J [14] used a MAS to ensure optimal energy exchange between the DER (distributed energy resources) and the loads for a microgrid, in grid-connected and islanded mode. This is achieved due to the collaborative behavior of all the agents working together in the MAS. It is also applied for dispatching distributed energy sources and providing voltage support in a distributed feeder system as investigated in Ref. [15]. Another important and well known application of MAS is to simulate the electricity market scenario. Logenthiran T [16] examined the use of MAS as an essential tool to co-ordinate the available energy sources in a reliable and cost-effective manner. Fuzzy logic systems are widely known for their ability to mimic human decision making, and hence are incorporated into the MAS to make decisions pertaining to energy management. Fuzzy logic controllers, due to their non-linear nature and ability to handle uncertain data can give more intermediate values between 0 and 1 [17]. Conventional EMS methods perform the optimal scheduling problem based on forecasted values of available load, wind speed and solar irradiation. However there is a consistent error is such forecasted values and hence a fuzzy based optimization technique is proposed where such errors are accounted for using fuzzy sets. Kabir G [18] discusses a fuzzy analytic hierarchy process has been proposed for location selection of power substations. Fuzzy systems are proposed to minimize the system cost taking into consideration a variety of factors like environmental, social and economic. In this work, the EMS developed using fuzzy systems monitors and controls the storage system in order to adjust the power supplied by the grid during the peak and off peak period and thereby reducing system operating cost and the CO_2 emissions.

In this paper, we propose an intelligent EMS to optimize the usage of energy resources by curtailing the operational costs and CO_2 emissions to a minimum level. Every agent of the MAS is modeled to make decisions by coordinating effectively with each other and the decision making is decentralized. The MAS is implemented as distributed modules in order to achieve high system efficiency. The remainder of the paper is organized as follows – Section 2 describes the HRES (hybrid renewable energy system) on which the proposed EMS is going to be tested. Section 3 explains the proposed control strategy in detail. Sections 4 and 5 describe the fuzzy based decision making and the cost optimization algorithm. Section 6 presents the software used and techniques adopted for the implementation of the proposed algorithm. The results and inferences are discussed elaborately in Sections 7 and 8 concludes the entire study.