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Multi objective particle swarm optimization of hybrid micro-grid system: A case study in Sweden

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A R T I C L E I N F O

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A B S T R A C T

Distributed energy resources DERs are small scale energy system which could provide local supply when placed at customers' premises. They aggregate multiple local and diffuse production installations, consumer facilities, storage facilities and monitoring tools and demand management. The main challenges when assessing the performance of an off-grid hybrid micro-grid system HMGS are the reliability of the system, the cost of electricity production and the operation environmental impact. Hence the tradeoff between three conflicting objectives makes the design of an optimal HMGS seen as a multi-objective optimization task. In this paper, we consider the optimization and the assessment of a HMGS in different Swedish cities to point out the potential of each location for HMGS investment. The HMGS consists of photovoltaic panels, wind turbines, diesel generator and battery storage. The HMGS model was simulated under one-year weather conditions data. A multi objective particle swarm optimization is used to find the optimal system configuration and the optimal component size for each location. An energy management system is applied to manage the operation of the different component of the system when feeding the load. The techno economics analysis shows the potential of HMGS in the Swedish rural development.

1. Introduction

In recent decades, the climate change and gas emissions are the greatest challenges to the sustainable development. Therefore, most states have adopted actions to reduce greenhouse gas emissions resulting in larger increase in distributed generation DG. Electrical systems in most developed countries are undergoing significant changes. These changes are the result of electricity market liberalization and the increase of renewables in the energy mix [1]. The topology of the electrical system has not changed since its creation in the early twentieth century. At that time, a centralized architecture was implemented: electricity is produced in power plants of high power, transported between regions through networks of high voltage and distributed to consumers through low voltage networks. This centralized architecture was the one that best met the constraints this time, it also ensured a fast network development and quality of supply. Thus, most of the country has a rather centralized electrical system and "vertically integrated". However, in recent years, this system begins to be questioned in order to enable a broad liberalization of the electricity market and increasing the share of electricity generators using renewable energies while maintaining constant quality of the energy supplied to consumers.

Also called mini smart grids or intelligent micro-networks, micro-grids are small power systems, designed to provide a reliable electricity supply and better quality for a small number of consumers. They can be connected directly to the grid or operated in island mode. The micro-grids are sometimes called sustainable communities, because of strong emphasis on energy management and optimal use of renewable energy resources [2,3]. In the concept of sustainable city, the environment is not divorced from urban development projects or economic, cultural or social orientations of the city. This desire for integration takes into account a development in the long term and a global perspective. "Smart Grid Cities" are the cities designed primarily to manage more effectively their customer energy consumption. This requires, inter alia, local optimization of energy supplies and energy consumption [4], intelligent network management and a balance between the production and the consumption to facilitate the integration of renewable resources of energy and new electricity uses (electric vehicles). The role of new information and communications technology (ICT) is key here to meet these challenges [5].

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Nomenclature

α, β	coefficients of fuel consumption
COE	Cost of electricity
CB	Capacity of the battery
CRF	Capital recovery factor
DERs	Distributed energy resources
DG	Diesel generator
DOD	Depth of discharge
EG	Available power from renewable sources
EL	Loads demand
EMS	Energy management system
ESS	Energy storage system
GA	Genetic algorithm
G_{ref}	Solar radiation at reference conditions
HMGS	Hybrid micro-grid system
HPS	Hybrid power systems
LPSP	Loss of power supply probability
P_{out}	Output power
P_r	Rated power
PRG	Production gross of renewable fraction
PSO	Particle swarm optimization
PV	Photovoltaic
RF	Renewable factor
SOC	State of charge
T_{amb}	Ambient temperature
$V_{cut\text{-}in}$	Cut-in wind speed
$V_{cut\text{-}out}$	Cut-out wind speed
V_r	Rated wind speed
WT	Wind turbine

Due the increasing energy demand, up to 53% by 2035 [6], the penetration of renewable energy resources has been steadily increasing over the past decades to remedy the acute issues of high energy demand and global warming [7,8]. Defined as group of interconnected loads and DERs operating with clear electrical boundaries, the HMGS offers a cost-effective solution for remote areas promoting localized renewable resources [9]. For instance, HMGS provides electricity supply to remote areas where required transmission and distribution facilities are not available or expensive to deploy. DERs could be seen as a micro-grid when three characteristics are met; the electrical boundaries are predefined, it includes energy management system and the power generation capacity must exceed the peak critical load [10,11].

The design of a HMGS requires a thorough analysis on decision making of the optimal power mix and component size as per load requirement. Various key factors to be considered on the decision making. First the cost of electricity COE which refers to the cost of operation to satisfy the load demand. Here a lower COE makes HMGS investment more profitable. Second the system reliability need to be at maximum level so that the power delivery interruptions are avoided. Different metrics can be used to describe the HMGS reliability such the loss of power supply probability LPSP, described in the next sessions. The third factors to be considered on HMGS design refers to the environmental impact of system operations when the conventional sources (e.g. diesel generator) are used in combination with renewable sources. A conventional energy source is used as complementary system to the renewable resources to avoid power interruption when weather conditions are not favorable for power generation. Then the task of a HMGS here is to minimize the utilization of non-renewable resources so that is environmental impact is minimized. The tradeoff between the aforementioned conflicting factors needs an optimal solution that balances between the three objectives.

2. Literature review

In the literature several studies show a significant development in HMGS design, configuration and optimization over the last decade [12–16] [17]. studied a hybrid photovoltaic PV/wind turbine WT with hydrogen-based energy storage system ESS system considering the system components outages and using particle swarm optimization PSO. The study reveals the impact of components outages on the cost of the system and its reliability [18]. used ant colony algorithm to achieve the minimum power loss and better load balancing to solve the problem of optimal switching operation of distributed generation. In Ref. [19] proposed an approach to maximize the reliability of PV/WT with battery energy storage system by minimizing the loss of power supply probability LPSP using non-dominated storing genetic algorithm [20]. introduced a structural methodology to transform existing radial distribution network into autonomous micro-grid. The authors used genetic algorithm GA and PSO to find the optimal sites for the autonomous operation [21]. proposed a hybrid simulated annealing-Tabu search method which add-up the advantages of each method to solve the problem of optimal sizing of an WT/PV/Diesel generator DG/Biodiesel. The objective of the optimization considers only the COE [22]. investigates an operating policy to achieve high renewable energy resources penetration levels involving WT/PV and battery energy storage system in small scale island system. the GA is used to optimally size the studied configuration based on two objectives the levelized energy cost and the renewable energy sources penetration levels. In Ref. [23] the authors reported an optimization framework based on the simulated annealing algorithm to find out the optimal size of DG/battery system and the optimal charge/discharge battery schedules for a daily load demand. Besides to the aforementioned methodologies developed for HMGS design an optimization, software tools are widely used for HMGS performance study. The commonly used software tools are HOMER [24] and HYBRID2 [25]. However, the main drawbacks of this software tools are the black box utilization [26]. A comprehensive review on the advantages and the limitations of the available software that are used for the analysis of HMGS is stated in Ref. [27].

Although there are many research works about HMGS design and optimization [28–35], but there are few works that consider more than one or two objectives. In this work, a multi objective PSO based approach is adopted to the design of the optimal HMGS and to find the tradeoff between three conflicting objectives; the reliability, the cost of operation and the environmental impact. It could be stated as well that an assessment of the applicability of HMGS in some specifics regions such as Nordic countries, is still lacking, where initial believes that these areas are not suited for HMGS operation due to its weather conditions.

Since the oil crisis of the early 1970s, Sweden has invested heavily in the search for alternative energy sources. Its ultimate goal is to completely abandon the use of oil. It is interesting to note that the fulfillment of his plan is on track since 1979. Subsequently, in 1997, the current energy policy has been implemented and the Swedish Energy Agency was created to achieve the intended objectives. The objectives are quite clear: by 2020, Sweden wants to increase its use of renewable resources to at least 50% and completely eliminate the use of oil [36]. Therefore, even though the