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Review

A review on recent size optimization methodologies for standalone solar and wind hybrid renewable energy system

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ABSTRACT

Electricity demand in remote and island areas are generally supplied by diesel or other fossil fuel based generation systems. Nevertheless, due to the increasing cost and harmful emissions of fossil fuels there is a growing trend to use standalone hybrid renewable energy systems (HRESs). Due to the complementary characteristics, matured technologies and availability in most areas, hybrid systems with solar and wind energy have become the popular choice in such applications. However, the intermittency and high net present cost are the challenges associated with solar and wind energy systems. In this context, optimal sizing is a key factor to attain a reliable supply at a low cost through these standalone systems. Therefore, there has been a growing interest to develop algorithms for size optimization in standalone HRESs. The optimal sizing methodologies reported so far can be broadly categorized as classical algorithms, modern techniques and software tools. Modern techniques, based on single artificial intelligence (AI) algorithms, are becoming more popular than classical algorithms owing to their capabilities in solving complex optimization problems. Moreover, in recent years, there has been a clear trend to use hybrid algorithms over single algorithms mainly due to their ability to provide more promising optimization results. This paper aims to present a comprehensive review on recent developments in size optimization methodologies, as well as a critical comparison of single algorithms, hybrid algorithms, and software tools used for sizing standalone solar and wind HRES. In addition, an evaluation of all the possible combinations of standalone solar and wind energy systems, including their assessment parameters of economical, reliability, environmental, and social aspects, are also presented.

Contents

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Nomenclature

LPSP	loss of power supply probability
LOLP	loss of load probability
LOLR	loss of load risk
LOLE	loss of load expectation
LOEE	loss of energy expectation
UL	unmet load
DPSP	deficiency in power supply probability
EENS	expected energy not supplied
ENS	energy not supplied
EIR	energy index of reliability
ELF	equivalent loss factor
D	net dump energy
TED	total energy deficit
WRE	wasted renewable energy
REP	renewable energy penetration
FEE	final excess of energy
K_l	energy fluctuation rate
$P(R)$	risk state probability
ASC	annual system cost
TIC	total investment cost
LCC	life cycle cost
COE	cost of energy
LCOE	levelised cost of energy
LEP	loss of energy probability
TC	total cost
TAC	annual total cost
E	total CO_2 emissions
EE	embodied energy
LCA	life cycle assessment
HDI	human development index
JC	job creation
SCC	social cost of carbon
SOC	state of charge
TPC	total precent cost
NPC	net precent cost
NPV	net present value
$P(H)$	percentage of healthy state probability
TC	total cost

1. Introduction

Electrical power is one of the most commonly sought commodities of mankind. Currently, more than 70% of the global electricity demand is supplied by burning fossil fuels, such as crude oil, coal, and natural gas [1]. With the growth of economies and world population, the demand for electricity increases and as a result the fossil fuel consumption increases. However, conventional fuel reserves are finite and depleting rapidly which require immediate attention and sustainable approaches to avoid potential energy crisis in the future. Additionally, fossil fuels account for harmful emissions, including greenhouse gasses (GHGs), which contribute to the global warming [2,3]. In the current context, these problems are addressed in several ways. One of the popular approach is to widen the public awareness on reducing energy consumption in domestic and industrial spheres and promote energy efficient technologies. Another approach is to promote renewable energy systems (RES) and develop associated technologies to make them reliable, cost-effective, environmental friendly and affordable even to the general public to use in their residential applications. The latter has drawn more attention in the research community, industries, and governments and as a result, many countries and regions have taken strong initiatives to increase their renewable energy capacity.

In Europe, the European Technology Platform for Electricity Networks of the Future, also known as ETP Smart Grids (ETP SG) produced the Strategic Research Agenda 2035 (SRA 2035) which expected that by 2020, approximately 34% of the total electrical energy consumption will come from renewable energy and will have gone more than that by 2035 [4]. The European Union (EU) council adopted the Energy Roadmap 2050 in June 2012 which declared that decarburization by 80% reduction (compared with the estimated level in 1990) of GHG emissions in European energy system will be technically and economically feasible. This can be achieved by implementing numerous strategies, such as increasing the development of renewable energy generation, which can be seen clearly where the local and small-scale generation from renewable energy sources has remarkably increased in Europe from 312 GW at the end of 2012 to 380 GW at the end of 2014 [4]. In Italy, 11.4 GW of photovoltaic (PV) power capacity had been connected to the distribution network in December 2012 [4]. In Germany, as of September 2015, RESs accounted for 47% of installed net generating capacity [5]. Furthermore, the annual energy production at about 38.850 GW comes from PVs in August 2015 keeps Germany with the largest amount of installed PV capacity in the world [5,6], and about 41.353 GW are from onshore and offshore wind turbines in September 2015 [5]. Similar trends are observed in other countries and regions such as the USA [2,7,8], with over 16 GW of installed solar power in 2014 [6]. This trend increased the total installed PV power globally to reach over 177 GW [4].

The aforementioned renewable energy capacities include large scale wind and solar systems, as well as residential PV systems. Majority of the residential PV systems work in the grid connected mode, in which excess power is injected to the grid during the day time and power is received from the grid at night. However, in remote areas where the grid extension is not feasible, HRESs are used in the standalone mode for individual houses or in microgrids (MGs) where several houses are connected to form a small power grid [9,10]. The second approach is becoming popular in islands and rural areas [11] as it provides a cost-effective alternative where power grid extensions is expensive and fuel transportation is difficult and costly [12]. Currently, the population in islands is estimated to be over 740 million worldwide based on geographic information system (GIS) analysis [13]. Another study has shown that many islands in the Indian and Pacific Oceans spend up to 30% of their gross domestic product (GDP) on conventional energy resources, such as fossil fuel [14]. In the Caribbean islands, power systems mainly depend on fossil fuel where the oil price can reach up to four times higher than the prices in the mainland [15]. In recent years, the energy demand is increasing in islands and remote areas, which means that it is not a cost-effective to keep