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Determination of reliability constrained optimal resource mix for an autonomous hybrid power system using Particle Swarm Optimization

Priyanka Paliwal*, N.P. Patidar [1], R.K. Nema [2]

Department of Electrical Engineering, Maulana Azad National Institute of Technology (M.A.N.I.T), Bhopal 462051, MP, India

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ABSTRACT

The determination of type of generation technology suitable for an autonomous power system calls for comprehensive planning. In this paper, a systematic approach for determination of optimal mix of resources is presented for an autonomous hybrid power system. The considered constituent resources comprise of diesel, photovoltaic, wind and battery storage. A techno-socio-economic criterion is formulated in order to determine optimum combination of resources. Reliability evaluation forms the basis of planning problem and has been carried out using analytical technique. The proposed formulation has been analyzed for different resource mix configurations for an autonomous power system located in Jaisalmer, Rajasthan, India. Particle Swarm Optimization (PSO) has been used to determine optimal component sizing for each of the configuration.

1. Introduction

Autonomous power systems are meant to provide solution for electrification of a remote area when access to a large transmission network is not economically viable or technically feasible. Rural areas in developing countries without necessary grid infrastructure are candidate locations for autonomous power system. Depending on local area requirement, the size of an autonomous power system can range from few hundred watts to tens or hundreds of MW.

Autonomous power system can be based on renewable energy sources (RES) such as wind, solar, hydro, biomass etc. or on conventional generation technologies such as DGs. DGs offer advantage of low capital cost and high reliability. However due to increasing environmental concerns and escalating fuel prices, system planners are now resorting to other technologies. Hybrid power systems are seen as a solution to these problems. A combination of different but complementary energy generation systems based on RES or an appropriate mix of RES with DG or storage systems constitute basic structure of hybrid power system.

The planning of autonomous hybrid power system (AHPS) can take advantage of locally available resources and present more economical and environment friendly option. However, increased penetration of RES can pose reliability issues due to their stochastic nature. Integration of storage can play a crucial role in soothing the impact of intermittency. Considering present global scenario with strict environmental regulations, not only do we need to increase the penetration of renewables, but also need to come up with ways of utilizing system more effectively and efficiently through proper planning.

Planning of AHPS is a well addressed issue in area of power system research. The objective of optimal planning is to determine a minimum cost plan complying with technical constraints. Primarily two criteria have been used in optimal planning problems: (i) Reliability (ii) Economics.

For reliability evaluation of AHPS both system well being criteria [1–3] and probabilistic indices [4–13] have been used in literature. Different economic evaluation criteria such as Annualized capital cost [11], Total life cycle cost [14], LCOE [5,7–9,15–17] and Cost-benefit analysis [18] have been used by system planners for presenting a cost effective planning.

The optimal sizing problem of an AHPS is a constrained combinatorial optimization problem. Various techniques such as Iterative optimization [8,16], Particle Swarm Optimization [11], Genetic algorithm [17] have been proffered by researchers to solve this problem.

Based on literature review it has been concluded that objective of optimal planning studies reported in literature has been to determine optimal component sizes [5,7,8,10–12,15–17,19,20]. However none of these analyses focus on determination of optimal combination of different resources based on meteorological

* Corresponding author. Tel.: +91 9893020105.
E-mail addresses: priyanka_manit@yahoo.com (P. Paliwal), nppatidar@yahoo.com (N.P. Patidar), rk_nema@yahoo.com (R.K. Nema).
[1] Tel.: +91 9424454028.
[2] Tel.: +91 9425376497.

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Nomenclature

B	battery storage unit
BSM	battery state model
CC_j	capital cost associated with jth configuration, $
C	converter unit
DG	diesel generator
$EENS_j$	annual expected energy not served for jth configuration, kWh
$LCOE_j$	levelized cost of energy of jth configuration, $/kWh
MC_j	present worth of maintenance cost of jth configuration, $
$N(H)$	number of hours over study period when system meets capacity reserve criteria
$N(R)$	number of hours over study period when generation is inadequate to supply load
N_p	number of years in project lifespan
OC_U	present worth of utility outage cost of jth configuration, $
OC_j	present worth of operation cost of jth configuration, $
PDF	probability density function
PVA	photovoltaic array
Q_n	energy supplied from hybrid system in nth year, kWh
r	nominal discount rate
RC_j	present worth of replacement cost of jth configuration, $
SC_j	present worth of social cost of carbon emission of jth configuration, $
SOC	battery state of charge
SV_j	present worth of salvage value of jth configuration, $
T	number of time segments in study period
WTG	wind turbine generator

Index

i	index representing type of component in jth configuration (PVA, WTG, DG, B, C)
j	index representing a particular configuration

conditions of considered area. Thus a mathematical formulation for systematic comparison of different resource mix is required for efficient system planning.

Moreover, for reliability evaluation studies, analytical technique has been widely used for hybrid system without battery storage [3,4]. However with inclusion of storage, reliability evaluation is carried out using computationally expensive Monte Carlo simulation (MCS) [21]. MCS is computationally cumbersome and is unsuitable in planning problems where repeated production costing simulations are to be performed [4].

This paper proposes a systematic formulation for determination of optimal resource mix based on techno-socio-economic criteria. The proposed work is carried out in two stages:

Stage I Different hybrid system configurations are defined. Optimal component sizes for each configuration are determined based on techno-socio-economic criteria. A meta-heuristic called as Particle Swarm Optimization has been employed for solving optimal sizing problem. The reliability assessment studies are carried out using analytical technique based on discrete state frame analysis.

Stage II Configurations are compared on the basis of *LCOE*. The configuration which fetches minimum *LCOE* is chosen as optimal resource mix.

The block diagram of proposed methodology is presented in Fig. 1.

2. Problem formulation

For determination of optimal resource mix, following assumptions are made in this study:

i. Optimal resource mix is determined based on present load scenario.
ii. The candidate units are available only in discrete sizes.
iii. The generating units are assumed to have lifetime equal to number of planning years.
iv. Initial costs are assumed to vary linearly with size.
v. The operation and maintenance cost is associated only with generators and battery storage.
vi. The salvage value of battery storage and converters is assumed to be zero.

2.1. Configurations for AHPS

The first step in determining optimal resource mix for an AHPS comprises of defining possible hybrid system configurations. Based on constituent generation technology used, following configurations are analyzed for AHPS:

Configuration-1: Only diesel generating units
Configuration-2: WTGs and diesel generating units
Configuration-3: PVAs and diesel generating units
Configuration-4: WTGs along with battery storage
Configuration-5: PVAs along with battery storage
Configuration-6: WTGs and PVAs along with diesel generating units
Configuration-7: WTGs and PVAs along with battery storage

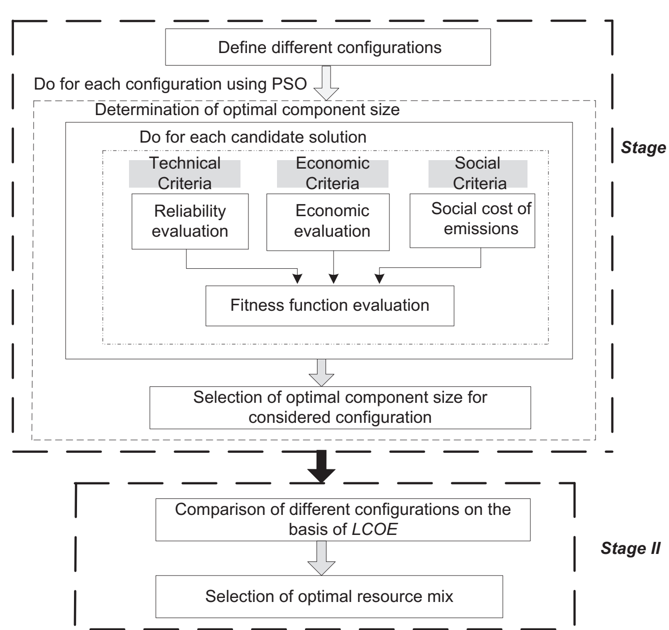

Fig. 1. Block diagram of proposed methodology.