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Surender Reddy Salkuti *Editor*

Energy and Environmental Aspects of Emerging Technologies for Smart Grid

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Green Energy and Technology

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Energy and Environmental Aspects of Emerging Technologies for Smart Grid

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Preface

Electrical energy is a tremendous requirement in the modern world, and environmental awareness is increasing its importance throughout the world. The electrical power system is evolving at the generation, transmission, and distribution levels. The ever-increasing power demand, production costs, and environmental concerns have triggered efforts to develop emerging technologies for power systems. The smart grid is the next generation of the electrical grid, which will enable the smart integration of conventional, renewable, and distributed power generation, energy storage, transmission and distribution, and demand management. A smart grid is an essential component of every nation's strategy, especially when there is responsibility for the environment and sustainability. The concept of the smart grid emerged to take advantage of information and communication technologies in the modern power system, to provide for increasing the penetration of renewable energy by deploying the advanced metering infrastructure and smart appliances. The deployment of the smart grid is revolutionary, and also imperative around the world. It involves and deals with multidisciplinary fields like energy sources, control systems, communications, computational, generation, transmission, distribution, customer, operations, markets, and service providers. Smart grids are emerging in both developed and developing countries, intending to achieve a reliable and secure electricity supply. Further, smart grid technologies will enable a reduction in carbon emissions. Smart grids will eventually need standards, policies, and a regulatory framework for successful implementation. This book will present the new models that are necessary to analyze future scenarios and define strategic roadmaps.

The growing penetrations of RESs have been the driver for the development of the future grid. Recently, due to technical, economic, and societal aspects, smart grids have been empowered as one of the key variations in shaping the electric power infrastructure. The increasing penetration of RESs has presented profound challenges and opportunities to the power industry. The inherent variability and uncertainty associated with weather-dependent renewable sources have changed many aspects of power system control, operations, and planning. This book discussed the challenging task of the integration of high penetration of renewable energies and the integration of electric vehicles. This book presents the application of emerging technologies such as big data, machine learning, Blockchain, and the Internet of Things for future smart grids. The book consists of 31 chapters. This book presents the emerging technologies that are required for sustainable and resilient future smart grids.

Chapter "Energy Management in Microgrid with Battery Storage System" proposes two optimization problems for energy management in microgrid (MG). The first one is the single objective problem that aims to minimize the total operation cost. The second problem is multi-objective containing cost and emission both in the objective function. A population-based Jaya algorithm embedded with a chaotic map is employed to manage the two microgrid problems optimally. The chapter "Wind Energy Conversion Systems: A Review on Aerodynamic, Electrical and Control Aspects, Recent Trends, Comparisons and Insights" makes an effort to provide a comprehensive insight into each part and shows the wind energy conversion system (WECS) aerodynamics and mechanical and electrical aspects. Wind turbine models and classifications, applications of various types of wind generators, requirements and demands of power electronics technologies on WECS and common topologies and configurations of power converters, various control strategies in WECS, important findings, current research, and future possible developments for the WECS are discussed. Chapter "Buck-Boost Converter-Based Sliding Mode Maximum Power Point Tracking System for Photovoltaic Systems" presents a novel sliding mode approach for accurately tracking the peak output of a PV system in the presence of variations in irradiance and temperature. The utilization of a robust controller enables the implementation of a sliding technique for effectively tracking the dynamic and stable maximum power point. The proposed technique exhibits a distinct advantage over the usual Perturb and Observe (P&O) maximum power point tracking (MPPT) technique in terms of both accuracy and response. Chapter "Optimized Control of an Isolated Wind Energy Conversion System" utilizes an admittance-based algorithm to estimate reference current values for an off-grid wind energy conversion system (WECS). This system's controller is designed to manage voltage and maintain frequency levels within specified limits when dealing with both linear and nonlinear loads, accommodating varying wind speeds effectively. The chapter "Emerging Technologies for the Integration of Renewable Energy, Energy Storage and Electric Vehicles" discusses the need and status of electric vehicles (EVs) around the world. This chapter also presents the modeling issues of renewable energy sources (RESs), energy storage, and EVs. The techno-economic aspects of RESs, battery storage, and EVs are also presented. This chapter could find suitable solutions to increase the interoperability of the grid under high penetration of renewable energy, storage systems, and electric transport. Chapter "Coordinated Control Strategy for LFC in an Islanded Microgrid: A JAYA Algorithm Based Cascade PD-PI Approach" proposes an intelligent coordinated control strategy based on JAYA optimization for fine-tuning cascade proportional derivative—proportional integral (PD-PI) controller gains. A single-area MG Simulink model is used to validate the proposed control approach. MG dynamic responses to specific load and RESs variations are observed. In the chapter "Simulation and Analysis of Solar-Wind System for EV Charging", a particular charging station design with wind and solar energy is discussed. The solar-wind energy-based charging system significantly reduces the amount of fossil fuels utilized to produce electricity, which also reduces CO_2 emissions and other pollutants associated with carbon. Chapter "Performance of Grid–Connected Shunt Active Filter Equipped PV System" discussed the performance of a grid-interactive solar system with an active filter for changing meteorological conditions and varied load demands. A MATLAB-based solar array model with maximum power point tracking is created. The photovoltaic inverter's functionality has been strengthened by the addition of active filtering features. Chapter "Smart Energy Management Model for Electric Vehicles" proposes a bidirectional inverter, voltage boosting, and self-voltage balancing achieved with the use of less number of components. With the use of this inverter topology, the performance parameters stator current and electromagnetic torque of the Permanent Magnet Synchronous Motor (PMSM) have been improved than that of the Induction Motor (IM) in the closed loop speed control. In the Chapter "Improved Linear Sinusoidal Tracer Based Control for Three-Phase VSC in Photovoltaics", a three-phase photovoltaic (PV) system is introduced which is designed for grid connection that serves two purposes: feeding extracted solar energy into the grid and improving power quality within the distribution system. The system achieves tracking of the maximum power point by using a variable DC link voltage and an instantaneous compensation technique to ensure a fast dynamic response to changes in PV power.

Chapter "Analysis, Modeling and Implementation of Electric Vehicle Converter Configurations" examines the advantages and disadvantages of several kinds of power controllers, converters, and charging stations. In addition to serving as the foundation for controllers such as PI controllers and fuzzy controllers, basic converter design also plays a significant role. Chapter "Integration of Electric Vehicles with Smart Grid" delves into various types of charging infrastructure, such as level 1, level 2, DC fast charging, and wireless power charging, which further enhances the convenience and accessibility of EV charging. Additionally, the establishment of charging infrastructure can occur in a variety of locations, ranging from residential areas to public spaces and commercial buildings. In the chapter "Installation of UPQC in Radial Distribution System for Enhancement of Voltage Profile", the enhancement of voltage profile using the installation of UPQC has been discussed in detail. It focuses on suitable location and sizing of UPQC for reactive power compensation in a radial distribution system to ultimately improve the voltage profile. Chapter "Infinite Impulse Response Peak Filter with Salp Swarm Optimization Technique for Improvement of DVR Reliability" discusses the reliability aspects of a dynamic voltage restorer (DVR) using an infinite impulse response (IIR) peak filter with linear/nonlinear loads to control voltage sag/swell, voltage sag unbalance, and voltage harmonics. In the chapter "Design of Fuzzy Logic Controller Based BLDC Motor", the speed of a Brushless Direct Current (BLDC) motor is administered using PI, PID, and fuzzy logic controllers. The role of this controller is to stabilize the motor during load changes while monitoring the speed changes. Fuzzy logic seems to be the most accurate method for reasoning about uncertain concepts. Chapter "Impact of Discrete-Time Modeling on Dual Input Modified SEPIC Converter" addresses aspects of the two-input modified Buck-SEPIC DC-DC (TI-MBS) converter. This integrated converter is processing power from two sources, two switches, and four energy storage elements. The designed converter is processing 48 V from two sources 36 V and 60 V. The transfer function modeling of this converter plays an important role in addressing crucial aspects like controller design, stability, and robustness issues. Chapter "Directional Relaying Issues in Power Transmission Networks" deals with the issues arising due to the presence of aforesaid devices. Next, new directional relaying techniques are presented to counter their effect. Various test cases are modeled using EMTDC/PSCAD. The proposed methods are analyzed using MATLAB. Numerous scenarios are taken in each case and few of them are discussed.

Chapter "Passivity Based Modeling of a Two-Input DC–DC Power Converter with Constant Power and Constant Voltage Load" presents the passivity-based mathematic modeling of a two-input integrated modified Buck SEPIC DC-DC converter. The two-input integrated modified Buck SEPIC DC-DC converter is considered for power processing using four energy storage elements. The Euler–Lagrange models are developed for this converter, and these are used to establish the average equivalent model. Chapter "SVPWM Based Transformerless Z-Source Five Level Cascaded Inverter with Grid Connected PV System" presents a novel solar input-dependent space vector pulse width modulation (SVPWM) algorithm for the single-phase five-level inverter, and the root cause of the DC-side condenser voltage imbalance is investigated. The chapter "An Empirical Analysis of Campus Energy Monitoring Systems Using Cloud-Based Storage" proposes a high-performance cloud-based campus energy monitoring system (CEMS). The energy monitoring system is very important to easily visualize the consumed energy or power in load centers. In the chapter "Development of Power Quality Disturbances Dataset for Classification Using Deep Learning", the detailed procedure to develop the PQ disturbance dataset is discussed. A total of 13 power quality (PQ) disturbances were considered while developing the dataset. Discrete Wavelet Transform (DWT) with Daubechies wavelet is used to extract the features from the PQ disturbance signal. Chapter "Short Circuit Analysis and Relay Coordination of Power System Network" describes the modeling of an IEEE 14-bus system utilizing Mi-Power software for symmetrical three-phase fault analysis. The output of a three-phase fault on bus-1 is utilized for circuit breaker selection and overcurrent relay setup, which improves system performance, protection, and dependability. Chapter "Power Quality Disturbances Data Dimensionality Reduction Using Autoencoder" suggested a data-driven autoencoder methodology for reconstructing data with fewer features in order to train models based on deep learning to categorize PQ disruptions. The ideal model is selected based on testing loss as well as data volume after training and testing autoencoder topologies with multiple neurons in the latent space. The chapter "The Metamorphic Influence of Nascent Technologies on Intelligent Grid Networks" embarks on a comprehensive exploration, peering into the intricate dynamics of these technological strides and illuminating their profound implications for energy efficiency and environmental considerations. At the heart of this study lies the pivotal facet of renewable energy integration. Chapter "A Novel FSD Reconfiguration Technique for Dynamic Shading in Photovoltaic Systems" discusses three such static reconfiguration techniques (SRT) which are analyzed for dynamic shading by considering the dynamic movement of the shade in horizontal and vertical directions and are compared with the proposed Futo-Sumdoku (FSD) reconfiguration technique. Chapter "Wavelet-ANN Based Detection of Fault Location of Renewable Energy Sources Integrated Power Transmission System" proposes a novel Wavelet-Artificial Neural Network (ANN)-based method where the wavelet multi-resolution analysis is used to obtain Detailed (D1) coefficients from the fault current signals, and this data is used for training and testing ANN. Chapter "Smart Grid and Energy Management Systems: A Global Perspective" summarizes a comprehensive exploration of smart grid (SG) development and energy management systems (EMS) opportunities across different regions, focusing on the USA, China, Europe, and India. The USA, driven by the Electric Power Research Institute (EPRI), emphasizes advanced technologies such as smart meters and carbon capture. Chapter "Active Power Load and Electrical Energy Price Datasets for Load and Price Forecasting" presents an active power load dataset and electrical energy price datasets along with various statistical features and other data pre-processing techniques. To prepare the active power load dataset and electrical energy price dataset, practical hourly load and price data are collected from the Indian Energy Exchange (IEX). Chapter "Design and Analysis of Digitally Operated PV Emulator with Resistive Load Using Newton-Raphson Method" introduced a test system that can demonstrate the entirety of the equipment and programming parts of the proposed PV emulator in MATLAB, henceforth supporting us in planning and testing the PV emulator before actual execution. Chapter "Design and Analysis of Digitally Controlled Newton–Raphson Method Based Hardware Integrated PV Emulator with Resistive Load" introduces a test system that can demonstrate the entirety of the equipment and programming parts of the proposed PV emulator in MATLAB, henceforth supporting us in planning and testing the PV emulator before actual execution. In the chapter "Optimal Location Selection of Electric Vehicle Charging Stations and Capacitors in Radial Distribution Networks Using GJO Algorithm", an intelligent technique for simultaneous optimal EVCS and capacitor allocation in RDN is developed. The suggested method reduces active power loss, maintains voltage profile, and improves reliability by using capacitors.

This book aimed to develop a smart grid that involves and deals with multidisciplinary fields like energy sources, control systems, communications, computational, generation, transmission, distribution, customer, operations, markets, and service providers. Challenges of increasing penetration of renewable energy, electric vehicles, and the adaptation of emerging and advanced technologies into the existing power will be solved in this book. This book will be highly beneficial for graduate students, academicians, researchers, and industry experts who are working toward the future grids to meet customer demands without increasing CO_2 levels with affordable and clean energy.

Happy Reading!

Daejeon, Korea (Republic of) Surender Reddy Salkuti

About This Book

This book presents the new models that are necessary to analyze future scenarios and define strategic roadmaps. Renewable energy sources (RESs) and electric vehicles (EVs) play an important role in a gradual transition from traditional power leading toward the decarbonization process of the electrical system, and a consequent increase in renewable energy generation. This book presents mathematical models of various RESs such as wind energy systems, solar PV systems, battery energy storage systems, pumped-storage hydropower, biomass, and EVs. It also discusses the challenging task of the integration of high penetration of renewable energies and EVs within existing power systems. The uncertainty related to RESs, electric vehicle charging, and load demands is also modeled.

The distribution control system has to manage a charge and discharge strategy to support mismatching between load and renewable generation through vehicle-to-grid (V2G) technology. During the last few years, several new paradigms have emerged, such as EVs, microgrids, smart grids, V2G technologies, application of big data, machine learning, Blockchain, and the Internet of Things for future smart grids, and electrical markets. The book provides illustrative and comprehensive practical case studies to enable a complete understanding of the proposed methodologies. This book will consider the nuances of all these new paradigms, smart grid components, technology, and the impact of energy storage, EVs, and distributed energy resources, in the power networks.

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Energy Management in Microgrid with Battery Storage System

Vishal Chaudhary, Hari Mohan Dubey, Manjaree Pandit, and Surender Reddy Salkuti

Abstract A microgrid (MG) system is an innovative approach to integrating different types of energy resources and managing the whole system optimally. Considered microgrid systems knit together diesel generators, wind turbines, fuel cells, and battery storage systems. Two optimization problems are formulated; the first one is the single objective problem that aims to minimize the total operation cost. The second problem is multi-objective containing cost and emission both in the objective function. A population-based Jaya algorithm embedded with a chaotic map is employed to manage the two MG problems optimally. For a single objective microgrid system obtained results by chaotic Jaya (Ch-JAYA) are validated by comparison with reported results using another algorithm such as the Cuckoo Search Algorithm (CSA), Spotted hyena and Emperor penguin optimizer (SHEPO), and Manta ray foraging optimization (MRFO). As the results of the multi-objective microgrid (MOMG) system considered for analysis are not reported yet, therefore for validation purposes this system is implemented and analyzed one by one using Ch-JAYA, JAYA, Particles swarm optimization (PSO), and Differential Evolution (DE). The impact of battery storage systems on operational costs and emitted emissions are also analyzed over 24 h a day. By comparison of results with and without integration of a battery storage system, it is observed that the total operational cost is reduced in both single and MOMG systems, and pollutant emissions are decreased

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significantly due to the integration of a wind turbine and a battery storage system in MOMG system.

Keywords Microgrid · Distributed energy resources · Renewable integration · Battery storage · Chaotic Jaya algorithm

Nomenclature

MG	Microgrid
ED	Economic dispatch
RER	Renewable energy resources
DER	Distributed energy resources
WT	Wind turbine
PV	Photovoltaic
FCP	Fuel cell plant
DG	Diesel generator
BESS	Battery energy storage system
η_FC	Fuel cell efficiency
SOC	State of charge
η_c	Charging efficiency
η_d	Discharging efficiency
Ch	Chaotic
SO	Single objective
MO	Multi-objective
BCS	Best compromise solution

1 Introduction

The modern trend of power system operation has become more dependent on economic operation as well as the utilization of eco-friendly energy resources to enhance the power, quality, and reliability of services. This can be achieved by utilization of more renewable energy resources (RERs) like wind turbines, solar photovoltaic (PV) systems, and fuel cell plants. Microgrid (MG) systems knit together consumer load and a cluster of distributed energy resources (DERs) such as diesel generators (DGs), wind turbines (WTs), PV systems as well as battery energy storage systems (BESSs). An MG system may be stand-alone or grid-connected; it helps to maintain the electricity supply in case of an outage improves the reliability of the whole system, and reduces the burden on nonrenewable resources. Various works in the area of energy management of microgrids is reported in the literature related to finding either the best cost-effective solution under the given constraints or managing the pollutant emission released from the conventional generating resources.

An MG system comprises DG, WT, and fuel cell plant (FCP) used to solve power dispatch using the Cuckoo Search Algorithm (CSA) [1]. An artificial bee Colony with a Markov chain is used to minimize the operation cost of the MG system [2]. Chaotic binary PSO is used to maximize the economic benefit and minimize network loss of the system [3]. For a stand-alone MG system, an economic dispatch solution has been investigated using an improved genetic algorithm [4]. The hybrid spotted hyena and emperor penguin optimizer (SHEPO) [5] and MRFO [6] approach is used to solve the economic dispatch (ED) problem of a hybrid MG system containing conventional and renewable energy resources (RERs).

Cogeneration refers to the concept of simultaneous analysis of both thermal energy and electric power optimally. A stochastic programming approach was used to schedule a CHP-based MG system comprised of renewable and conventional resources in an optimal manner [7]. The sparrow search algorithm was used to get the solution of combined cooling, heating, and power (CCHP) based economic dispatch of an MG system considering biomass pyrolysis and gasification [8]. A combination of NSGA, coevolution theory, and beetle antennae search algorithm was used to achieve the global optimal solution of a based MG system having a wind turbine, FC plant, PV system, and gas turbine system in reference [9]. Here real-time wind power output was computed using the beta function. A policy-based deep reinforcement learning approach that includes offline training and online operation for optimal energy management is proposed in [10]. Here historical data are used to handle the uncertainty of renewable energy and load consumption. Hybrid whale optimization and pattern search optimization are used in [11] to minimize the total operating cost across the scheduled period. Here the power production of the PV unit and optimal scheduling of the MG were investigated considering different climate conditions.

For the energy management of MG, the environmental aspect through both decarbonization and low carbon emission is also considered, to minimize the total operational cost of the whole system and emitted pollutant emissions from conventional power generating resources. Reference [12] utilizes the Equilibrium optimization (EO) to maximize the profit of system operators by reducing the operation cost of a hybrid thermal-solar-wind system. Here Impact of RES integration on cost and emitted emission reduction was analyzed. A fuzzy selection mechanism is used in [13] to get the best compromise solution (BCS) among the two conflicting objectives cost and emission. The sparrow search algorithm (SSA) is used to solve the multi-objective function of an MG system to minimize cost and emission. Here ANOVA tests are applied for the performance evaluation of SSA over other algorithms. Harris Hawks's optimization (HHO) was implemented to minimize the cost and emission of an MG system in reference [14]. Here TOPSIS was considered as a tool to get the best compromise solution among the conflicting objectives. For a multi-energy multi-microgrid (MMG) system operation cost was investigated considering operational constraints and emissions [15]. Here Gurobi is used to solve the problem. The technical and economic problems of an MG were investigated using a multi-objective genetic algorithm in reference [16]. Reference [17] proposed an energy management system that combines model predictive control (MPC), multi-objective optimization, and a decision tool to solve the problem. MPC was used to mitigate the uncertainty in the predictions. Various work in the area of energy management for an MG system is reported in the literature [18, 19]. References [20, 21] present a comprehensive review of various robust optimization approaches addressing uncertainty associated with RESs in the MG system.

Generally, reported methods utilized in managing the MG operation have complexity, slow convergence, and time consumption. Therefore in this chapter, a Jaya algorithm, which is free from algorithm-specific control parameters, is selected to manage the MG operation in an optimal manner. An MG System is graphically presented in Fig. 1. In this work, the objective function is formulated for a complex constrained MG system that combines DGs, WT, FC, and BESS to fulfill load demand under dynamic conditions. A chaotic Jaya algorithm is proposed for its solution. Dynamic economic emission dispatch has been performed to analyze the best cost solution and emission. The impact of BESS integration on operational costs and emitted emissions is also analyzed.

The remaining part of the chapter is as follows: Sect. 2 describes the formulation of the objective function for a complex constrained MG system with different types of energy resources and BESS. A brief introduction of the Ch-JAYA algorithm and its implementation for the solution of the objective function is described in Sect. 3. The test cases considered for analysis and the outcome of simulation results are presented in Sect. 4. Finally, concluding remarks are drawn in Sect. 5.

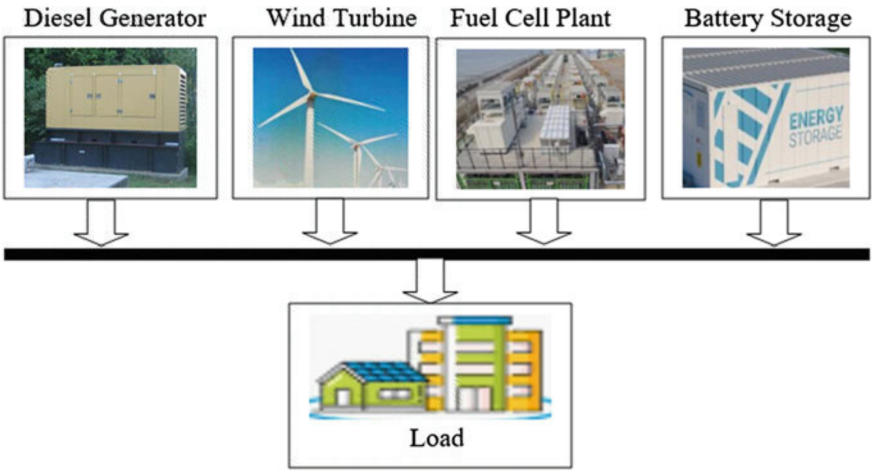

Fig. 1 Layout of a microgrid system

2 Formulation of Microgrid System with Battery Storage

The planning action of the MG system aims to perform ED with RESs. Two main parameters are considered in ED, total operational cost and pollutant emission generated. It is essential to minimize both operational costs and emitted emissions to enhance the operation. An MG system considered for analysis combines DGs, WT, FC, and BESS. The combined operational cost of the submission of all individual distributed energy resources is described below [1, 5, 6].

$$\boldsymbol{F_C = F_{Diesel} + F_{Wind} + F_{FC}} \tag{1}$$

2.1 Diesel Generator

The operational cost of a diesel generator is represented as [14, 26]:

$$\boldsymbol{F_{Diesel}} = \sum_{t=1}^{T}\sum_{i=1}^{N_{dg}}\left(\boldsymbol{a_{dg,i} \times P_{dg,it}^{2} + b_{dg,i} \times P_{dg,it} + c_{dg,i}}\right) \tag{2}$$

where $\boldsymbol{F_{Diesel}}$ is the total cost associated with diesel generators, $\boldsymbol{P_{dg,i}}$ is the power output in kW of the $\boldsymbol{i}$th unit. $\boldsymbol{a_{dg,i}}$, $\boldsymbol{b_{dg,i}}$ and $\boldsymbol{c_{dg,i}}$ are the fuel cost coefficients of $\boldsymbol{i}$th unit. $\boldsymbol{N_{dg}}$ is the number of committed diesel generators. *t, T* is time indices in $\boldsymbol{hr}$ for the scheduled time of operation.

2.2 Wind Energy Source

Wind energy is freely available, however variable in nature. Wind energy is converted into electrical energy using the velocity of the wind. It is represented as [1],

$$\boldsymbol{F_{Wind}} = \sum_{t=1}^{T}\sum_{i=1}^{N_{w}} \boldsymbol{\beta_{w,i} \times P_{w,it}} \tag{3}$$

$$\boldsymbol{P_{w,it}} = \begin{cases} \boldsymbol{P_{w\_r}} \times \left(\frac{V_{it} - V_{cutin\_i}}{V_{r,i} - V_{cutin\_i}}\right), & \boldsymbol{V_{cutin\_i} \le V_{it} \le V_{r,i}} \\ \boldsymbol{P_{w\_r}}, & \boldsymbol{V_{r,i} \le V_{it} \le V_{cutout\_i}} \\ 0, & \boldsymbol{V_{it} < V_{cutin_i} \, and \, V_{it} > V_{cutout\_i}} \end{cases} \tag{4}$$

where $\boldsymbol{\beta_{w,i}}$ (\$/kW) is the operation and maintenance cost, $\boldsymbol{V_{cutin\_i}}$, $\boldsymbol{V_{cutout\_i}}$ and $\boldsymbol{V_{r,i}}$ are the cut-in, cutout, and rated velocity of wind in m/sec for the $\boldsymbol{i}$th unit of the wind turbine. $\boldsymbol{P_{w\_r}}$ is the rated power in kW.

2.3 Fuel Cell Plant

The operational cost of a fuel cell is represented as,

$$F_{FC} = \sum_{t=1}^{T}\left(b_{natural} \times \sum_{i=1}^{N_{FC}} \frac{P_{FC,it}}{\eta_{FC,i}}\right) \tag{5}$$

where $b_{natural}$ ($/kg) is the cost of natural gas, $P_{FC,it}$ is power generation from ith unit of fuel cell plant at time t, and $\eta_{FC,i}$ is the fuel cell efficiency of ith unit.

2.4 Battery Energy Storage System (BESS)

BESS helps to improve stability in system operation incurred due to the integration of variable RER [22]. State of charge (SOC), which indicates the amount of power available at a particular time $P(t)$ is the vital parameter in scheduling and operation of a BESS.

When BESS is charging, i.e., $P(t) < 0$, then

$$SOC_i(t+1) = SOC_i(t) - \frac{\eta_c \times P(t) \times \Delta t}{E_{\max}} \tag{6}$$

When BESS is discharging, i.e., $P(t) > 0$, then

$$SOC_i(t+1) = SOC_i(t) - \frac{P(t) \times \Delta t/\eta_d}{E_{\max}} \tag{7}$$

In ideal mode, $P(t) = 0$ then

$$SOC_i(t+1) = SOC_i(t) \tag{8}$$

where $SOC_i(t)$ is the state of charge is the ith BESS at the time t. η_c, η_d is the charging efficiency and discharging efficiency respectively. Δt is the scheduled time interval and $E_{\max}$ is the maximum capacity of BESS.

2.5 Emission Dispatch

Thermal power generating unit produces emission. The relationship between emission coefficients and active power output in the thermal generation process is expressed below [14, 26]:

$$\boldsymbol{F_{EC}} = \sum_{t=1}^{T}\sum_{i=1}^{N_{dg}}\left(\boldsymbol{\alpha_{dg,i}} \times \boldsymbol{P_{dg,it}^2} + \boldsymbol{\beta_{dg,i}} \times \boldsymbol{P_{dg,it}} + \boldsymbol{\gamma_{dg,i}}\right) \tag{9}$$

where $\boldsymbol{F_{EC}}$ is the total emission emitted from a thermal plant. $\boldsymbol{\alpha_{dg,i}}$, $\boldsymbol{\beta_{dg,i}}$ and $\boldsymbol{\gamma_{dg,i}}$ are the emission coefficients of $\boldsymbol{i}$th unit. Here, the objective is to minimize $\boldsymbol{F_C}$ and $\boldsymbol{F_{EC}}$ both expressed as,

$$\mathbf{Min}[\boldsymbol{F_C}, \boldsymbol{F_{EC}}] \tag{10}$$

Subjected to the following operational constraints.

Power balance constraints:

$$\boldsymbol{P_{Dt}} = \sum_{i=1}^{N_{dg}} \boldsymbol{P_{dg,it}} + \sum_{i=1}^{N_w} \boldsymbol{P_{w,it}} + \sum_{i=1}^{N_{FC}} \boldsymbol{P_{FC,it}} + \sum_{i=1}^{N_{BSS}} \boldsymbol{P_{BSS,it}} \tag{11}$$

Power generation limit constraints:

$$\boldsymbol{P_{dg,i}^{\min}} \le \boldsymbol{P_{dg,i}(t)} \le \boldsymbol{P_{dg,i}^{\max}} \tag{12}$$

$$\boldsymbol{P_{w,i}^{\min}} \le \boldsymbol{P_{w,i}(t)} \le \boldsymbol{P_{w,i}^{\max}} \tag{13}$$

$$\boldsymbol{P_{FC,i}^{\min}} \le \boldsymbol{P_{FC,i}(t)} \le \boldsymbol{P_{FC,i}^{\max}} \tag{14}$$

BSS constraints:

$$\boldsymbol{P_{BSS,i}^{\min}} \le \boldsymbol{P_{BSS,i}(t)} \le \boldsymbol{P_{BSS,i}^{\max}} \tag{15}$$

$$\boldsymbol{SOC^{\min}} \le \boldsymbol{SOC_i(t)} \le \boldsymbol{SOC^{\max}} \tag{16}$$

2.6 Fuzzy min Ranking

The membership value $\left(\boldsymbol{\mu_{i,j}}\right)$ of $\boldsymbol{j}$th objective having a value $\boldsymbol{F_{i,j}}$ for its $\boldsymbol{i}$th the solution can be computed for the minimization problem expressed as [27]:

$$\boldsymbol{\mu_{ij}} = \begin{cases} 1 & \boldsymbol{if\ F_{ij} \le F_j^{\min}} \\ \frac{\boldsymbol{F_j^{\max} - F_{ij}}}{\boldsymbol{F_j^{\max} - F_j^{\min}}} & \boldsymbol{if\ F_j^{\min} \le F_{ij} \le F_j^{\max}} \\ 0 & \boldsymbol{if\ F_{ij} \ge F_j^{\max}} \end{cases} \tag{17}$$

For an 'n' objective problem, the $\boldsymbol{Fuzzy\_min}$ index of the $\boldsymbol{i}$th, the solution is expressed as,

$$\boldsymbol{Fuzzy\_}\mathbf{min}_i = \mathbf{min}\left(\mu_{ij}\right) \quad \boldsymbol{where}\ \boldsymbol{m} = 1, 2, 3, \ldots.\boldsymbol{n} \tag{18}$$

3 Chaotic Jaya Algorithm

Jaya algorithm is a simple algorithm developed to solve an optimization problem that utilizes the concept of moving the obtained solution towards the best solution for the given problem by avoiding the worst solution [23]. It is a population-based algorithm and does not have any algorithm-specific parameters to tune for better convergence. However, it suffers from premature convergence; therefore, it can be trapped in the local minima. Literature suggests that the random numbers generated using chaotic sequences enhance the population diversity and boost the search capability of evolutionary algorithms [24, 25] thus helping in avoiding stuck in the local optima solution. Therefore, for analysis purposes tend map' embedded with the original Jaya algorithm called the Ch-JAYA algorithm is proposed to manage the operation of MG in an optimal manner [30]. The tent map is expressed as [24, 25].

For n = 1, $\mathcal{X}_{\boldsymbol{n}} = \boldsymbol{rand}$

$$\mathcal{X}_{\boldsymbol{n}+1} = \begin{cases} \left(\frac{\mathcal{X}_n}{0.7}\right) & \mathcal{X}_{\boldsymbol{n}} < 0.7 \\ \left(\frac{10}{3}\right) \times (1 - \mathcal{X}_{\boldsymbol{n}}) & \mathcal{X}_{\boldsymbol{n}} \geq 0.7 \end{cases} \tag{19}$$

The behavior of the tent map over 100 iterations is presented in Fig. 2.

The step-by-step solution procedure adopted the optimization using Ch-JAYA is described below in Sect. 3.1 and also shown using the flow chart in Fig. 3.

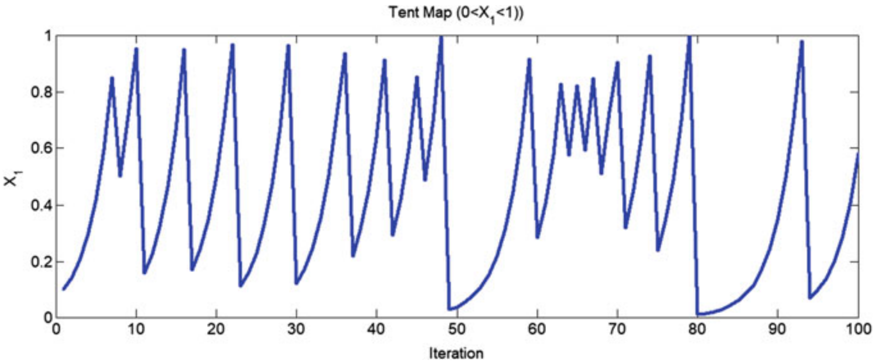

Fig. 2 Variation of the random parameter by tent map

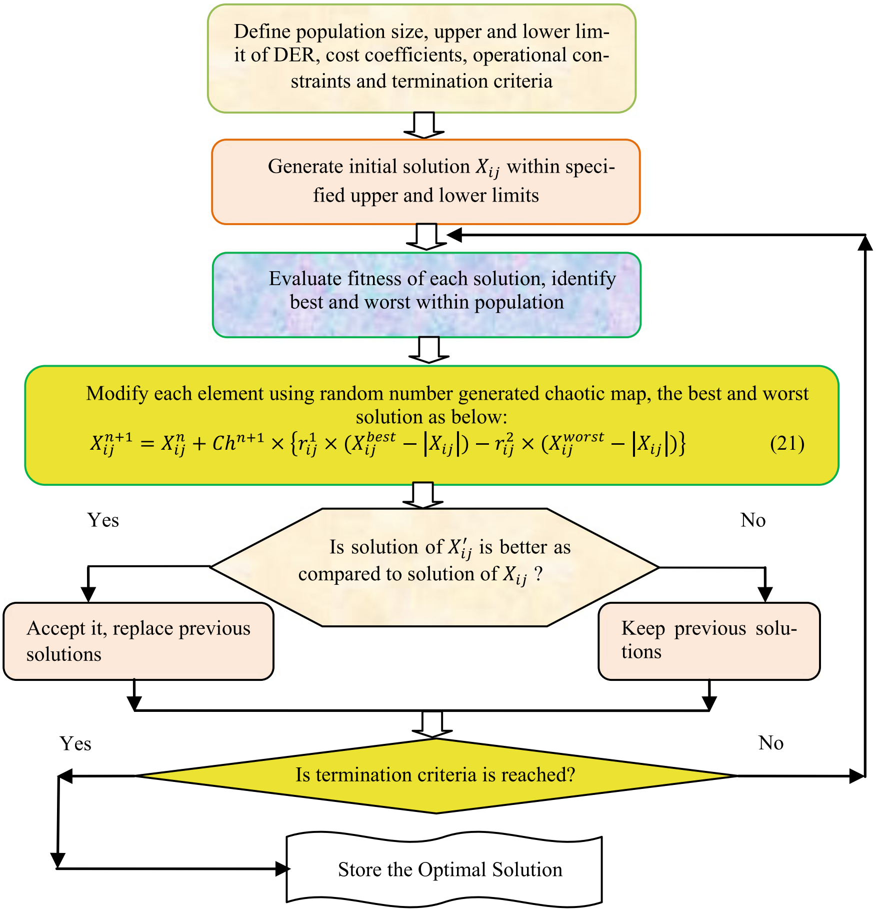

Fig. 3 Flow chart for optimization of MG problem by Ch-JAYA algorithm

3.1 Implementation of Ch-JAYA for Energy Management

First define MG data as number DER, respective cost coefficients, upper and lower limits, associated constraints, population size, and stopping criteria as maximum iteration. Then the step-by-step solution procedure using Ch-JAYA is carried out as follows:

- Step 1: The populations are randomly initialized within the upper and lower limits of DER.

$$P_i = P_i^{\min} + rand \times \left(P_i^{\max} - P_i^{\min}\right) \tag{20}$$