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The Optimal Energy Management Methods of The Hybrid Power System

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ABSTRACT

The hybrid renewable energy system is a particular type of energy system which can be used as Distributed Generation (DG) resources to reduce network losses and increase its efficiency. Overall, in the design phase, there are two major constraints: first, availability, and second, the cost of equipment. In this paper, most of these constraints were taken into consideration by means of DGs as Renewable Energy Sources (RES) including wind turbines and photovoltaics, The problems of traditional energy are many and varied, and the percentage of the pollution that comes from it is also many, so people began to search for renewable energy sources with problems, pollution, and lower cost. Therefore, several studies have been conducted on integrating different types of renewable energies to generate electricity and meet the consumer's needs. This paper provides a comprehensive overview of the recent methods used to Improve and manage hybrid energy systems.

Acronyms:

Notation	Definitions	Notation	Definitions
DG	Distributed Generation	UPS	Uninterruptable power Supply
RES	Renewable Energy Sources	CPU	Central Processing Unit
PV	Photovoltaic	WT	wind turbine
GW	Gigawatt	PMSG	permanent magnet synchronous generator
EU	European countries	SOC	state of charge
PHEVs	plug-in hybrid electric vehicles	DOD	depth of discharge
HVDC	High Voltage Direct Current	HNMCS	Hybrid Nelder-Mead and Cuckoo Search
FC	Fuel Cells	FPC	forecasting power control algorithm
MTDC	Multi-Terminal Direct Current	HSA	Harmony search algorithm
VSC	Voltage Source Converter	SAA	Simulated annealing algorithm
LCC	Line Commutated Converter	PSO	Particle swarm optimization
PFC	Power Flow Controllers	DP	Dynamic programming
EVs	Electric vehicles	GA	Genetic algorithms
HESS	Hybrid Energy Storage System	FL	Fuzzy logic
ESS	Energy Storage System	MPC	Model Predictive Control
ANN	Artificial neural networks	ChOA	Chimp Optimization Algorithm
FO-PID	fractional-order proportional-integral-derivative	SSCs	Source-Side Converters
IWO	invasive weed optimization algorithm	GWO	Grey Wolf Optimizer
NPC	net present cost	EO	Equilibrium Optimizer
IHBO	improved heap-based optimizer algorithm	PF	power flow
TFWO	Turbulent Flow of Water-Based Optimization and Battle Royale Optimization (BRO-[TFW-BRO])	TFWO	Turbulent Flow of Water-Based Optimization
HIL	Hardware-in-the-Loop	REDG	Renewable Energy Distributed Generators

1. Introduction

Current trends indicate that global electricity distribution grids are experiencing a transformation towards DC at both generation and consumption equal. This kind of tendency is powered by the outburst of different electronic loads and, simultaneously, with the struggle to meet the high set aims for a portion of RESs in satisfying total demand [1]. Meanwhile, with increasing energy growth and reduction in fossil fuel resources, renewable energies such as solar and wind can play an energetic role in the growth of countries; accordingly, due to environmental problems and global warming, we need to preserve our environment, decreasing air pollution, and considering electricity constraints and energy supply for urban, remote and rural areas. On the other hand, the political and economic backing of countries depends on their productivity from fossil fuels. Reducing fossil fuel resources is not only a threat to the economies of the exporting republics but also a major concern for other energy-consuming countries. Another issue that should be considered is the security of the power system.

Maintaining a high level of system security is one of the most important aspects of power systems that should be noted as well as the economic operation of these systems [2]. In addition, energy consumption prediction can play an important role in project, planning then management of power systems. It can be said that precise forecasting of electric energy consumption provides an additional realistic spectrum for ingesting of future nations' energy resources to move towards sustainable development in globalization [3]. As can be seen from the reference [4], at the beginning of the year 2016, the amount of installed Photovoltaic (PV) and wind energy in the European (EU) countries reached the volume of approximately 95.5 Gigawatt (GW) and 141.6 GW respectively, that correspond to 10.5% and 15.6% of the total EU electricity generation capacity. In addition, the amount of RES has increased its share from 24% in 2000 to 44% of total power capacity at the beginning of 2016; also, during 2016, at least 75 GW of solar PV capacity was added globally which is equivalent to the installation of approximately more than 31,000 solar panels every hour. By 2020, wind power is expected to feed nearly 10% of global electricity. Over the past several decades, with the development of cheap, the electricity demand of the whole world increased dramatically, which causes the energy system to experience stress frequently.

At the same time, the pressure of natural resources and environmental problems have attracted great attention to the combination of clean, renewable generation sources, such as wind and solar power. However, due to the variable and indecision characteristics, the increasing penetration of renewable generation sources introduces further challenges to the power system. In addition to these factors, the emergence of a large number of plug-in hybrid electric vehicles (PHEVs) has the potential to increase peak demand significantly, overload distribution lines, degenerate distribution transformers, and threaten the reliability of the power system [5].

The first alternating current power grid system was installed in 1886 in Great Barrington, Massachusetts. At that time, the grid was a centralized unidirectional system of electric power transmission, electricity distribution, and demand-driven control. In the 20th century, local grids grew over time and were eventually interconnected for economic and reliability reasons. By the 1960s, the electric grids of developed countries had become very large, mature, and highly interconnected, with thousands of 'central' generation power stations delivering power to major load centers via high-capacity power lines which were then branched and divided to provide power to smaller industrial and domestic users over the entire supply area. The topology of the 1960s grid was a result of the strong economies of scale: large coal-, gas- and oil-fired power stations in the 1 GW (1000 MW) to 3 GW scale are still found to be cost-effective, due to efficiency-boosting features that can be cost-effective only when the stations become very large.

Power stations were located strategically to be close to fossil fuel reserves (either the mines or wells themselves or else close to rail, road, or port supply lines). Siting of hydroelectric dams in mountain areas also strongly influenced the structure of the emerging grid. Nuclear power plants were sited for the availability of cooling water. Finally, fossil fuel-fired power stations were initially very polluting and were sited as far as economically possible from population centers once electricity distribution networks permitted it. By the late 1960s, the electricity grid reached the overwhelming majority of the population of developed countries, with only outlying regional areas remaining 'off-grid.

2. Literature Review

In recent decades, DC technology has entered into a new renaissance period, because of several generations after Westinghouse and Edison’s public battles facing AC versus DC in the famous ‘‘war of currents’’, back by 1880. In this regard, we provide an overview of transmission and distribution systems in AC and DC grids. The reference has expressed that DC systems rebooting started in 1954, when ABB company linked the island of Gotland to the Swedish mainland by a High Voltage Direct Current (HVDC) link, delivering the world’s first commercial HVDC system. According to the type of load flow and load demands, the microgrid can be categorized as an AC microgrid or DC microgrid. Some relative topics including harmonic current, the flow of reactive power, transformer failures, and unbalanced phases in AC microgrids open the door to promoting DC microgrids with DC loads and DC supply from PV and Fuel Cells (FC) and other RES. Some professions are of the view that a normal distribution grid system consists of both AC and DC loads, which AC power cannot be completely neglected as connecting a DC resource to a high AC load gains harmonic content and converter losses [6]. Furthermore, in this field, one of the interesting topics that recent researchers are working on is Multi-Terminal Direct Current (MTDC); hence, in the references [7], some critical challenges and prospects for this kind of emerging MTDC networks, along with a foreseeable technology improvement road map, with a particular focus on decisive operational and control issues that are associated with MTDC systems and networks are presented.

As explained in these references, two serious power conversion technologies have traditionally dominated by HVDC designs, titled the Voltage Source Converter (VSC), and the Line Commutated

Converter (LCC); which both have been deployed and commercialized across today's global grids. Figure.1 shows a simple typical representation of an AC overlaid MTDC network containing several LCCHVDC and VSC-HVDC terminals. Also, the reference presented a new approach to select an optimal place and control variable setting for Power Flow Controllers (PFC) including series, cascaded, and interline PFCs in MT-HVDC networks based on sensitivity analysis method to enhance static security. In order to study the topic of DC systems, we should carefully consider the following issues: mainly, there are two major constraints in using DC resources: first, accessibility to generated electricity (availability), and second, the cost of equipment [8]. Simultaneously, it can be said that DC systems are becoming more popular than AC systems owing to their higher efficiency and reliability and their easy connection to renewable energy resources. In addition, to reduce fluctuations of power generated in a hybrid system, a battery bank could be used as energy storage, which absorbs power surplus and power supply shortages in working conditions.

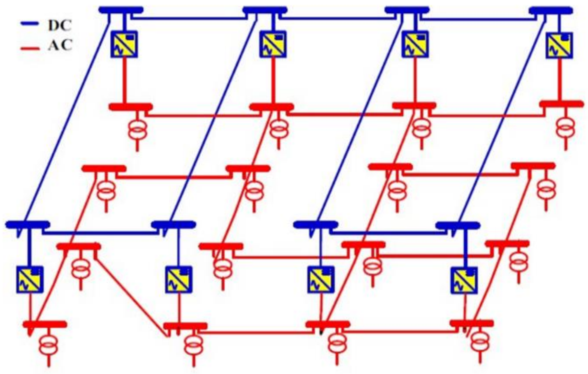

Figure 1. AC Overlaid MTDC Network Containing Several LCCHVDC and VSC-HVDC Terminals.

Recently, the latest expert guidance is based on improving power quality, power output, and interest in the use of smart DC microgrids. They conclude that modern electrical loads and scattered energy resources are DC type inherently using DC microgrids prevented from added translational AC/DC or DC/AC. On the one hand, some researchers recommended stability analysis in a hybrid AC-DC microgrid to achieve higher energy output. Overall, a hybrid microgrid combines two or more components: the DC component and the AC component. Scattered energy resources and DC inherent loads connected to the DC component and inherent AC resources and loads linked to the AC component. For power quality optimization, energy storage, like batteries, might connect to DC components

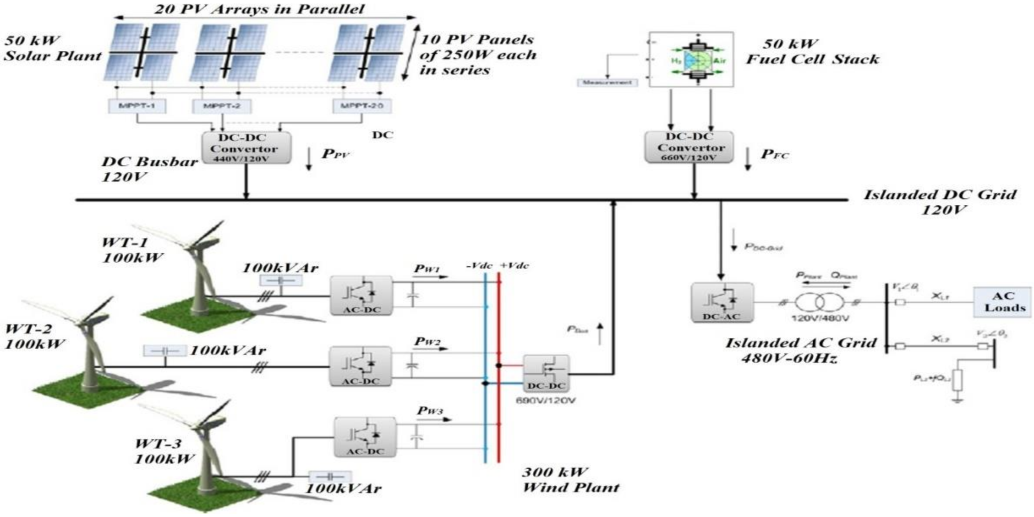

Figure 2. the islanded hybrid microgrid system with AC and DC deputizes networks.

On the other hand, system stability plays a significant role in microgrid systems. In this regard, in the references [9], a hybrid microgrid composed of a wind turbine, PV unit, and AC and DC loads are simulated using MATLAB software. Considering solar and wind instability features, control plans are designed for the invertors to preserve the stability performance of the hybrid microgrids. Similarly, for electric vehicles (EVs), the authors of the papers [8] proposed a battery-ultra capacitor in Hybrid Energy Storage System (HESS). Another issue of interest in the microgrid is their islanding states. In this case, serious and necessary controls should be considered in the various fields of protection and security of the microgrid. Herein, in order to minimize the power loss in hybrid AC/DC microgrid systems by optimizing the output power of REDG, the authors of sheet [10] presented a Hybrid Nelder-Mead and Cuckoo Search (HNMCS) algorithm. A typical diagram of the modeled system is displayed in Figure 2, where the islanded hybrid microgrid system is displayed with AC and DC subgrids. Traditionally, converters use a two-stage AC/DC/AC system to convert the input AC voltage and current to the variable frequency and/or the variable amplitude. This kind of instrumentation yields the need for bulky DC-link storage such as an electrolytic capacitor [10]. In recent years, most microgrids accept conventional AC grid systems; thus, the distributed energy resources need some form of power converters to transfer and convert power from these energy resources to the AC grid system. For instance, wind turbines require back-to-back power converters to synchronize and adjust the output frequency and voltage level with the AC grid system [12]. In this regard, S. Jain, M. B. Shadmand, and R. S. Balog in the reference [13] presented an auto-tuning method for online selection of the cost function weight factors in Model Predictive Control (MPC), where in this paper, a forecasting power control algorithm which decouples active and reactive power for grid integration of PV systems using a quasi-Z-source inverter was proposed. The structure block of a typical smart AC microgrid system, including RESs (wind turbine and solar PV), EVs, AC loads, Energy Storage System (ESS) (flywheel, uninterruptable power Supply (UPS), and battery bank), household appliances (PC, cell phone, and fan), AC–DC converters, communication protocols, and Central Processing Unit (CPU).

3. Hybrid System Configuration

The hybrid power supply system considered in this article consists of the wind turbine system, PV system, storage system (battery bank), and biodiesel generator system, as shown in Fig.3. The supply priority is such that the load is initially met by the renewable energy generators (WT and PV) and the battery comes in when the renewable energy generators' output is not enough to meet the load, provided it is within its operating limits. If the load demand is high and the storage system energy is inadequate to meet the total energy need, the biodiesel generator satisfies the remaining load. The battery bank (storage system) is charged when the total generated power is above the load requirements. Renewable energy supplies the load and/or battery, depending on the instantaneous magnitude of the load and the battery's state of charge. As the figure shows, a dump load has been considered in the system. A dump load is an electrical resistance heater that is used to handle the full generating capacity of the system. Dump loads can be water or air heaters and are activated by the charge controller whenever the system cannot accept the energy being produced, to prevent damage to the system. Excess energy is shunted to the dump load when necessary. Fig. 2 islanded hybrid microgrid system with AC & DC subgrid.

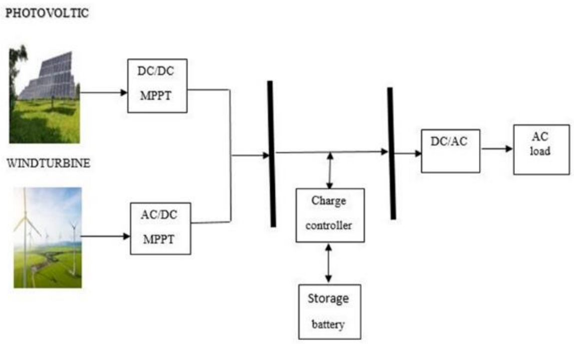

Figure 3. Hybrid system configuration

3.1 Wind Energy Subsystem

The wind is the movement of air masses and it has kinetic energy. This kinetic energy of the wind can be converted into mechanical energy using a wind turbine with rotor blades. Then through using a generator the mechanical energy is converted to electrical energy. The PMSG is used to convert wind power into electrical power. Comparing all the type of generators that are used in wind turbines the PMSG have the highest advantages because during normal operation they are more stable, and secure and will provide higher efficiency in lower-speed applications essentially the wind's kinetic energy in the rotor which is mechanically coupled to generators comes from the wind turbine. [14]. The fundamental equations are as follows:

$$\boldsymbol{Pwind = 0.5A\rho V^3} \qquad (1)$$

Where ρ is the air density, A is the rotor's swept area, and v is the wind speed. Only a part can be extracted or used from the total wind energy. The power coefficient Cp is a part of the available energy in the wind. The maximum value of the theoretical coefficient is 0.59, which is called the Betz limit.

$$\boldsymbol{Pturbine = 0.5cpAV^3} \qquad (2)$$

The coefficient of power is a function of the tip-speed ratio λ

$$\boldsymbol{\lambda = r\frac{\Omega}{V}} \qquad (3)$$

Where r is the rotor's radius and Ω indicates the angular rotor's speed [40].

3.2 Photovoltaic Energy Subsystem

The Photovoltaic energy system is a process of generating electrical power by converting the power from sunlight into D.C electricity using semiconductors that show the photovoltaic effect. Photovoltaic power generation, solar panels, consists of a group of cells containing the semiconductor material. The main part of the PV array is a photovoltaic cell, which is just a simple p n junction device. Current is developed when solar irradiation strikes the solar cell. The typical model of the solar cell is represented by an equivalent circuit shown in fig.4 [15].

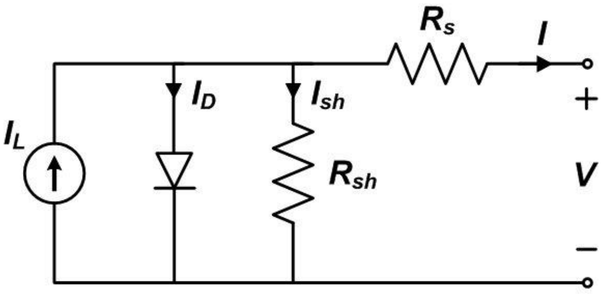

Figure 4. The Equivalent electrical circuit of a solar cell

Where I_L represents the current source of the photocurrent cell. Rs and Rsh are the series and shunt resistances radical of the solar cell, Rsh is very large in value. Where Rs is very small, hence it can be ignored to simplify the analysis [41]. The net current of the cell is represented by the following equation:

$$\boldsymbol{I = I_L - Is\left[\exp\frac{q(V+IRs)}{NKT} - 1\right] - \frac{(V+IRs)}{Rsh}} \qquad (4)$$

3.3 Battery Energy Subsystem

The battery is used to store surplus generated energy, regulate system voltage, and supply load in case insufficient power generation occurs from the hybrid system. Battery sizing depends on the maximum depth of discharge (DOD), temperature, and battery life. A battery's state of charge (SOC) is expressed as follows: [16]. During the charging process:

$$\boldsymbol{SOC(t+1) = SOC(t).[1-\sigma(t)] + \left[Ibat(t).\Delta(t).\frac{\eta c(t)}{Cbat}\right]} \qquad (5)$$

$$\boldsymbol{SOC(t+1) = SOC(t).[1-\sigma(t)] - \left[Ibat(t).\frac{\Delta(t)}{\eta dis(t)}\right]Cbat} \qquad (6)$$

$$\boldsymbol{With\ (1-DOD) \le SOC(t) \le 1} \qquad (7)$$

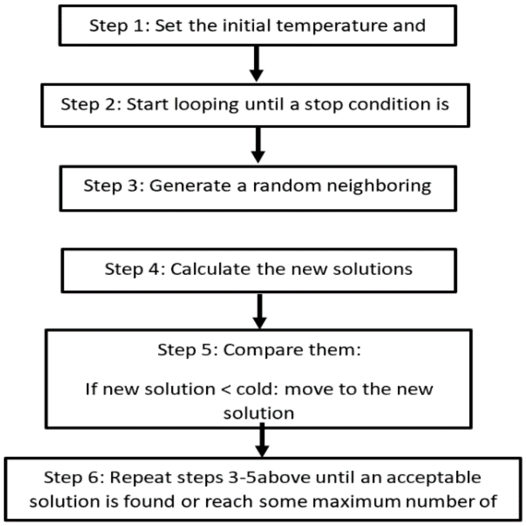

Figure 5. The Steps of HAS implementation.

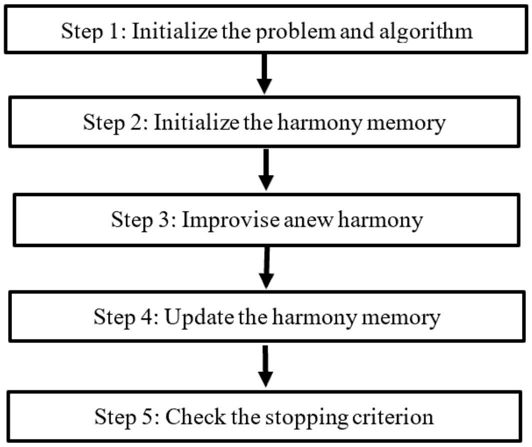

Figure 6. The Steps of SAA implementation

4. Hybrid Optimization Techniques

The harmony search algorithm has been inspired by the music improvisation process in which several Since the optimization of a hybrid renewable energy system is a non-linear and non-convex optimization problem, for effectively solving such problems, a superior optimization technique is needed [17-22]. None of the individual methods could perform better than all the other methods on all kinds of problems. However, new generation optimization approaches like artificial intelligence-based, heuristic algorithms are found to be more acceptable than traditional algorithms because of their ability to search global and local optima, fast convergence speed, and good calculation accuracy [22-30]. Since the using hybridization of two or more algorithms to overcome the limitations of a single algorithm, in this section, at first two metaheuristic methods are introduced (HSA and SAA). Then, a combination of harmony search with SA is proposed to optimization of each component [31-35].

4.1 Harmony Search Algorithm (HSA)

musicians adjust the pitch of their instruments to sound a pleasing harmony. The HS used in this study is the same as that proposed in Refs. [36-39], which is called discrete HS. The steps in the procedure of the harmony search algorithm are shown in Fig. 5.

4.2 Simulated Annealing Algorithm (SAA)

Simulated annealing, which mimics material annealing processing, was developed by Kirkpatrick, Gelatt and Vecchi in 1983. To implement the SAA, the steps shown in Fig.6 are followed. Details on this algorithm can be found elsewhere [40-43]. In this paper, a synopsis of current energy management System (EMS) experiments based on rules/algorithms is offered in Table [1]

5. Optimizations Procedures Features And Drawbacks:

It's known that Power systems are very large, complex, and geographically distributed. Therefore, to take advantage of simplifying the problem and its implementation is necessary to utilize the most efficient optimization methods. Related to the power system operation numerous activities require optimum searching techniques K Wang Lee. Et al. (2008) Many researchers are working with optimization techniques to solve the economic issue, reliability, quality, optimal load flow, protection, and cost. D. Hoer. et al. (2013) presented Artificial

Intelligence methods such as GA, PSO, BFO, and Artificial neural networks that are used for optimal power flow and economic load dispatch problems. Table 2 shows a comparison of the main advantages and disadvantages of most algorithms used to obtain optimization in energy management.

TABLE 1. Energy management system (ems) experiments based on rules/algorithms.

Ref	Objective	Approach	Configuration
[28]	enhancing the performance of smart integrated energy systems	Offline and HIL simulations	PV/WT/Biomass/solar
[5]	Lowest the cost and control of the system's PF	The combination of TFWO and BRO-[TFW-BRO] method /Matlab program	PV/ WT/ /Micro-turbine turbine/ Fuel cell/DG/battery
[26]	The best design with the NPC	HOMER	PV/CONVERTER /DG
[29]	Reduces the cost of power	PSO Via C Language	PV/BATTERY
[30]	Keeping the cost of a microgrid system to a minimum	IHBO	PV/Wind/Diesel/Battery
[31]	Designing a smart grid for public buildings on a modest scale	To measure and regulate the loads inside the building, a multi-agent management system is being developed.	WT/PV/BATTERY
[32]	create a hybrid smart grid for the Energy Management System	The fuzzy logic/Matlab	PV/WT/ FC/ BATTERY
[33]	decrease costs, increase system stability, and cover the load in a variety of climates	EO	PV/WT/DG/BATTERY
[34]	NPC, the penalty cost of emissions, and CO2 emissions	the MOPSO, PESA II then SPEA2 algorithms/ new compromise method based on the Six Sigma tool	PV/WT/DG/BATTERY
[35]	Microgrid system optimization/cost reduction	GAMS/SCENRED Software	PV/WT
[36]	maximizing the present value of the net present cost function	ChOA/IWO/GWO	PV/WT/BATTERY
[37]	optimal performance of the suggested MG	PSO	WT/ MT/PV/ fuel cell/ electrolyzer/H2 storage tank /reformer / a boiler/ electrical / thermal loads
[25]	present a detailed review of a variety of technologies and approaches for addressing the shortcomings of renewable energy sources, as well as their remedies	PSO/ GAO/ Neural network/ FL	WT/ PV/ fuel cell
[38]	Increase network availability while lowering network expenses.	PSO	PV/WT/DG/BATTERY
[39]	Minimize the hybrid energy schemes' life cycle cost while keeping some limits in mind.	metaheuristic algorithm (harmony search algorithm/ simulated annealing algorithm)	WT/PV/BATTERY/Biodiesel
[40]	Algorithm research and testing on a test bench for smart grid applications.	Matlab	PV/WT/BATTERY
[14]	Constant output power and a reliable service	fuzzy logic and FO-PID controller/Matlab	PV/WT/BATTERY/ SSCs
[41]	determine the system's best configuration	Matlab	The cluster of loads/ PV/ WT/ DG/BATTERY

Table 2. Comparison of optimization procedures

Optimization procedures	Drawbacks	Feature
The mixed-integer linear programming(MILP)	When dealing with non-differentiable and continuous objective functions, it demonstrates the limited ability.	Linear programming (LP) Because the linear constraints lead to a convex feasible region, the global optimal solution is reached in many circumstances, it is a rapid technique to solve issues.
Neural Networks	A lot of computing power is required.	It's used in instances where a rapid assessment of the learned target function is required.
Particle swarm optimization (PSO)	Computational needs that are difficult to understand.	In scattering and optimization issues, you may expect good outcomes.
Dynamic programming (DP)	The implementation is complicated due to the high number of recursive functions.	It can break down a problem into smaller parts, optimize each one, and solve issues in sequential order.
Genetic algorithms (GA)	Crossover and mutation parameters, as well as population and halting parameters, must be established.	Population-based evolutionary algorithms use processes like crossover, mutation, and selection to find the optimal solution at a reasonable convergence pace.
Fuzzy logic (FL)	They lack the ability to learn that neural networks possess.	FL gives the greatest solution for analyzing the system's choice.

6. Conclusion

We have presented in this paper a contemporary review of optimal energy management strategies of hybrid energy systems. The previous studies were compared and tabulated according to the multiple objectives of those researches and according to the approaches and techniques used to solve these problems, as well as the availability of multiple sources of hybrid energy systems in the area under study. Studies have proven that the methods used have a major role in obtaining optimization in energy management, as well as the proximity of the hybrid energy system to the national grid is a decisive factor in choosing the components of hybrid energy systems. This paper outlines the design and investigation of energy management for any hybrid power system. The studies were classified according to many criteria and appropriate solutions were given to reach optimization through smart technologies and algorithms.

Prospective study

In future studies, more than one addition may be made and completed, and there are several suggestions for future work which include the study of linking the system to the national grid or studying different regions inside and outside Iraq or studying the protection of smart grids, and finally adding a variety of renewable and traditional sources.

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