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Enhancing the Optimization of Hybrid Renewable Energy Systems by Using Statistical Calculations and Data Mining Analysis

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Abstract- According to numbers and charts reported recently in the global renewable status and international energy agency, Renewable energy sources (RES) surpassed the natural gas and occupied the second position as a source of electricity. However, the intermittent nature of RES, causes a big problem of trifold dimensions: System cost, environmental impacts, and system reliability. Studies found that, using diverse RES combined in hybrid renewable energy systems (HRES) can handle these issues efficiently by using suitable optimization techniques. Therefore, this paper introduces a novel technique based on statistical and datamining analyses to derive the key parameters for optimizing HRES in two main steps. Firstly, it conducts a comprehensive review of hundreds of the most recent research papers on HRES . Secondly, it runs statistical calculations and data mining analysis on the big data that are collected by the first step. The outcomes of this step are represented in form of statistical results and frequent patterns rulesets. The statistical results have been validated with the frequent pattern rulesets to verify the correctness of the overall results. As a result, the paper produces two databases. The first one which is obtained from the comprehensive review, introduces a great guide for researchers to determine the best techniques for optimizing HRES systems. The second database that is resulted from statistical calculations and data mining analysis, determines the key parameters for optimizing HRES and hence developing the renewable energy systems in order to increase the system reliability and reduce the cost as well as environmental impacts.

Keywords Hybrid renewable energy systems; Statistical analysis; Data mining; linear regression; Sizing and optimization HRES

1. Introduction

Numbers and charts can tell more than words. Thereby, the last global status report showed a significant increase in the global renewable energy production of electricity. It recorded 6.3% of the total electricity production has been generated from RES during the past year thanks to the main two sources wind and solar energy [1]. In addition, it includes charts and statistics that mark the ratio of electricity production from RES to that generated from the conventional sources. Moreover, it shows the details of the production of RES and the growth in the global renewable power capacities for the last decade up to year 2018. These charts and statistics show that, solar PV and wind are the largest two sources as regard to the growth in power capacity during the recent decade. On the other hand, the international electricity agency reported that, RES became the second largest source of electricity after Coal [2]. Furthermore, it reported in form of chart and numbers that, electricity production of RES is about 25% of the global electricity production. However, the most of RES have intermittent nature due to the dependency on the weather conditions which are seasonally changed. For example, electricity production from solar PV, depends on irradiance and temperature. It is active and larger in winter than that in Summer [3]. Similarly, electricity production from wind depends on the wind speed which is changed seasonally. This intermittent nature of RES is a major problem as regard to system stability and the total system cost. These issues can be handled by combining two or more sources of RES which have a complementary nature. For instance, Solar PV and Wind have a typical complementary nature because the solar radiation is active in the time the wind speed is very low and vice versa. Therefore, one source of energy can complement the shortage of production of the other source and hence increasing the system reliability and stability. In other words, combining RES in hybrid topologies is feasible solution to overcome the intermittent nature of RES production. In addition, optimizing HRES is very important to maximize the system reliability and decrease the system total cost. However, there are dozens of possible combinations of RES components, cost calculation methods, reliability determination techniques, optimization algorithms, control techniques, software packages and tools. Therefore, determining the optimum techniques, algorithms, software packages and tools for optimizing HRES of specific RES components, is the main target for developing HRES systems.

Researchers have done immense amount of research contributions for optimizing HRES in trifold: system reliability, economical, and environmental dimensions. These contributions yielded hundreds of researches on different combinations of HRES components, control and optimization techniques, cost calculation methods, as well as reliability determination methods. Reviewing such researches for collecting some information about HRES is a simple task and has been conducted by many reviewing articles. But it does not help to determine the key parameters of selecting the optimum techniques, methods, algorithms, and software packages for specific criteria of HRES. Therefore, running statistical calculations and datamining analysis on the big data which are collected by reviewing these researches can help in predicting these parameters.

This paper introduces a novel technique based on statistical and frequent pattern datamining techniques to determine the key parameters to select the optimum techniques, algorithms, software packages and tools for reducing the cost and increasing the reliability of HRES systems in two stages. In the first step, a comprehensive review on HRES is conducted to yield big dataset. In the second stage, a linear statistical analysis [4] and frequent pattern mining algorithms [5-6] is run on the collected database from the first step. The results of the statistical calculations and data mining analysis are represented in form of numbers, charts, and rulesets. The comprehensive review is conducted in trifold dimensions: HRES system reliability, cost and economics, and environmental impacts. The survey includes all aspects, parameters, and specifications of HRES like system components, size and power capacity, topologies, optimization techniques for increasing reliability, reducing total system cost, minimizing the environmental emission. It also covers the optimization algorithms, software packages and tools that are commonly used in sizing and optimizing HRES systems. The paper is organized as follow: Section 2 introduces the methodology of reviewing all aspects of HRES systems, statistical calculations, and datamining analysis; Section 3 presents and discusses the results of the conducted review in tabular format and the results of statistical and datamining analyses; Section 4 concludes the work.

2. Methodology:

2.1 introduction

The paper firstly reviewed hundreds of the most recent research papers on HRES [7-114] to produce a big dataset. It then run statistical calculations and data mining analysis on the collected big dataset. Reviewing of details of HRES optimization techniques and methods are not aimed in this section, instead of that, it collects the most possible statistics and information about the possible components of typical HRES , the optimization techniques of the three angles of interest: environmental impacts and emission, economical optimization and system cost, and system reliability. In addition, it covers load dispatch strategies, HRES topologies, optimization algorithms, software packages and tools that are commonly used in sizing and optimizing HRES. Moreover, it introduces the most common statistical regression techniques as well as frequent pattern datamining algorithms which will be utilized in the proposed analyses and numerical calculations.

2.2.1 Components of HRES

HRES is defined as any combination of two or more energy sources including at least one of the RES. The conducted survey includes the most possible RES that may be one of HRES components. These components are listed in Table 1. In addition, a unique numerical ID has been assigned to each item to be used later in the statistical and data mining analyses.

Table 1. HRES possible components

ID	HRES Component	ID	HRES Component	ID	HRES Component
1	Solar PV	2	Wind	3	Fuel CELL
4	Hydro	5	Hydrogen Tank	6	Biomass
7	Biogas	8	Biodiesel	9	Diesel
10	Battery	11	Supper capacitor	12	ELECTROLYZER

2.2.2 HRES *Topologies*

HRES can be configured in different topologies. The most common topologies are listed in Table 2.

Table 2. HRES Topologies with their IDs

ID	Topology
15	Stand Alone (SA)
16	Grid connected (GC)
17	AC Bus
18	DC Bus
19	Hybrid AC/DC

2.2.3 *Load dispatch strategies*

There are many strategies that can be used for fulfilling the load requirements. The performed survey includes the listed techniques in Table 3.

Table 3. Load dispatch techniques with their IDS

ID	Load Dispatch Technique
20	Load Following (LF)
21	Cycle Charging (CC)
22	Unit Commitment (UC)

2.2.4 *Optimization techniques*

There are dozens of techniques and methods that have been used in HRES optimization according to the surveyed papers. There are three dimensions of interest for optimizing HRES: reducing environmental impacts and minimizing emissions, reducing the system cost, and maximizing the system reliability.

2.2.4.1 *Environmental optimization techniques*

According to the conducted survey, the most common sources of pollution are listed in Table 4.

Table 4. Emission sources with IDs

ID	Emission	ID	Emission
25	CO2	26	CO
27	SO2	28	NOx
29	Green House Gases GHG	30	Embodied Energy EE

2.2.4.2 *Economical optimization techniques*

By surveying hundreds of papers on HRES, it is found several methods of system cost optimization. The most commonly used techniques are listed in Table 5.

Table 5. Methods of cost calculation with their IDS

Id	Method	Id	Method
31	Capital Recovery Factor (CRF)	32	Total Annual Cost (TAC)
33	Annual System Cost (ACS)	34	System Total Cost (STC)
35	Cost of Energy (COE)	36	Reserved
37	Total Cost (TC)	38	Capital Cost (CC)
39	Total Initial Cost (TIC)	40	Payback Period (PP)
41	Levelized Cost of Energy (LCE)	42	Net Present Value (NPV)
43	Interest Rate of Return (IRR)	44	Cumulative Savings (CS),
45	Life Cycle Cost (LCC)		

2.2.4.3 *Reliability optimization techniques*

The survey reported many techniques for optimizing the system reliability. Table 6. lists the most frequently used methods in optimizing HRES system reliability with their IDs.

Table 6. Reliability determination methods with their IDs

ID	Method	ID	Method	ID	Method
50	Loss of Power Supply Probability (LPSP)	51	Correlation Coefficient (CC)	52	Deficiency in Power Supply Probability (DPSP)
53	Loss of Energy Expected (LOEE)	54	Excess Energy (EE)	55	Expected Energy Not Supplied (EENS)
56	Energy Index of Reliability (EIR),	57	Energy Shortfall Probability (ESP),	58	Equivalent Loss Factor (ELF)
59	Final Excess of Energy (FEE)	60	Loss of Load Probability (LOLP/LLP)	61	Loss of Load Risk (LOLR),
62	Energy Fluctuation Rate (K)	63	Loss of Load Hour (LOLH)	64	Unmet Load (UL)
65	Net Dump Energy (NDE)	66	Renewable Energy Penetration (REP)	67	Risk State Probability (R),
68	Percentage of Health(H)	69	Loss of Load Expectation (LOLH)	46	System Performance Level (SPL)
47	Wasted Renewable Energy (WRE)	48	Total Energy Deficit (TED)	49	State Of Charge (Soc)

2.2.4.4 *optimization algorithms*

Several algorithms of HRES optimization are reported in the conducted survey. The most commonly used algorithms are listed in Table 7.

Table 7. Algorithms used in optimization with their IDs

Id	Algorithm Name	Id	Algorithm Name	Id	Algorithm Name
70	Linear Programming (LP)	71	Evolution Algorithm (EA)	72	Homey Bee Mating Algorithm (HBMA)
73	Ant Colony (ACO)	74	Genetic Algorithm (GA)	75	Bacterial Foraging Algorithm (BFA)

76	Artificial Immune System (AIS)	77	Tabu Search (TS)	78	Game Theory (GT)
79	Particle Swarm Algorithm (PSO)	80	Simulated Annealing (SA)	81	Simplex Algorithm (SAL)
82	Numerical	139	Iterative	83	Stochastic
84	Probabilistic	85	Parametric Approach (PA)	86	Artificial Bee Colony (ABC)
87	Fuzzy Logic (FL)	88	Graphical Construction (GCA)	89	Graphical User Interface (GUI)
90	Biography Based Optimization (BBO)	91	Bee Inspirit Algorithm (BIA)	92	Cuckoo Search (CS)
93	Direct Search Algorithm (DSA)	94	Gravitational Search Algorithm (GSA)	95	Chaotic Search (CHS)
96	Flower Pollination Algorithm (FPA)	97	Big Bang Big Crunch (BBBC)	98	Imperial Competitive Algorithm (ICA)
99	Improved Fruit Fly Algorithm (IFF)	100	Intuitive Method (IM)	101	Last Generation Algorithm (LGA)
102	Discrete Harmony Algorithm (DS)	103	Enumeration Based Iterative (EBI)	104	Grey Wolf Optimization (GWO)
105	Differential Evolution Algorithm (DE)	106	Exhaustive Search Technique (ES)	107	Clonal Search Technique (CST)
108	Two Point Estimate Method (TPEM)	109	Markov Method (MM)	110	Mine Blast Algorithm (MBA)
111	Mixed Integer Linear Programming	112	Modified Electric System Cascaded (MESC)	113	Monte Carlo Method (MC)
114	Multi Objective Programming (MOP)	115	Natural Selection (NSA)	116	Pareto Optimization (PO)
117	Preference Inspired Coevolution Method (PIC)	118	Trad Off Technique (TOT)	119	Analytical
140	artificial bee swarm optimization (ABSO)	141	A-strong algorithm (AS)	142	Neural Network (NN)
143	hybrid teaching learning-based optimization (TLBO)				

2.2.4.5 *Optimization tools and software packages*

The conducted survey showed several software packages and tools are commonly used in optimizing HRES. The most common optimization tools and software packages are listed in Table 8.

Table 8. Optimization software packages and Tools with their IDs.

ID	Name	ID	Name
120	Hybrid Optimization Model of Electric Renewable (HOMER)	121	GeoSpatial Planner for Energy Investment Strategies
122	The Hybrid Power System Simulation Model (HYBRID2)	123	Grid-connected Renewable Hybrid Systems Optimization (GRHYSO)
124	Hybrid Optimization using Genetic Algorithm (HOGA)	125	H2RES
126	The General Algebraic Modeling System (GAMS)	127	RETSCREEN
128	Optimization of Renewable Intermittent Energies with Hydrogen for Autonomous Electrification (ORIENTE)	129	RAPSIM
130	Dividing Rectangles (DIRECT)	131	PVSYST
132	Determining Optimum Integration of RES (DOIRES)	133	INSEL
134	Simulation of Photovoltaic Energy Systems (SIMPHOSYS)	135	OPTQUEST
136	WDILOG2	137	LINDO
138	MATLAB	144	TRNSYS

2.2.5 *Statistical analysis*

Linear regression analysis has been applied on the obtained database. In [4], linear regression is introduced as the forecasting of a dependent variable Y based on previous independent variable X. Equations (1,2) formulate the linear relationship between variable Y and X and the regression (r). It also defined correlation as the measurement of linearity between the two variables. Also, it described the usage of the P value as an indicator to measure the significance of correlation between these variables.

$$Y = m\,x + b \qquad (1)$$

$$r = \frac{\sum_{i=1}^{n}(x_i - \check{x})(y_i - \check{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \check{x})\sum_{i=1}^{n}(y_i - \check{y})}} \qquad (2)$$

Where m is the slope; b is the intersection with y axis; $\check{x}$, $\check{y}$ are the mean value of x, y respectively; and r is the regression value.

2.2.4 *Data mining techniques*

There are many data mining methods and algorithms for analyzing big datasets in order to extract the frequent pattern and rulesets of thousands of records of data. The most common frequent patterns and data mining methods are APRIORI and Frequent pattern growth (FP-Growth) techniques. APRIORI method is very simple in implementation and straight forward. However, FP-Growth method is faster in performance [5-6]. Fig. 1 depicts the logic flow of APRIORI method. And Fig. 2 charts the logical flow of FP-Growth method. In order to describe the logic of each method, an example is given below to demonstrate numerically the working principles of each method as shown in Table 9. It shows example of four transactions of HRES systems. Each row represents one transaction. Each column represents one item of transaction. Item can be system component, reliability determination method, or economical optimization technique. By using the APRIORI method, it firstly calculates the support value of each item which represents the frequency of appearance of the item throughout all transactions. It then calculates in permutable way all possible item sets which represent the combination sets of items. Then it selects or discards item sets based on its support value. The APRIORI technique produces the following rulesets:

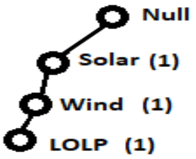
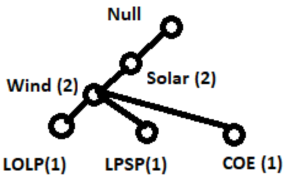
- 100% of sets of HRES that include Solar PV, also include Wind.
- 50% of sets of Solar PV and Wind use the loss of power supply probability LPSP method.
- 50% of sets of Solar PV and Wind use the loss of load probability LOLP method.
- 50% of sets of solar PV and wind use the cost of energy COE method.

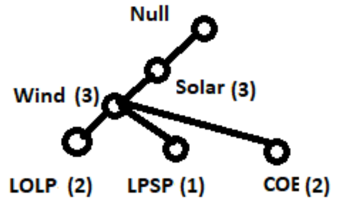
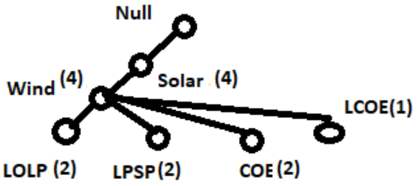
Table 9. Example of transactions

TID	**HRES components**		**Reliability method**	**Economic cost**
1	Solar PV	Wind	LOLP	-
2	Solar PV	Wind	LPSP	COE
3	Solar PV	Wind	LOLP	COE
4	Solar PV	Wind	LPSP	LCOE

Now moving to the FP-Growth method, Table 10. describes the FP tree showing updates that are occurred after each transaction. It depicts the updates in the right column, and describes it as comment in the left column:

Table 10. FP- Growth step by step.

TID	**FP Tree updates**
After transaction 1, all three new nodes are created and initialized by 1.	
After transaction 2, the counters of the repeated nodes have been incremented and the new nodes are created and initialized to 1	

After transaction 3, all old nodes incremented their counters and the new nodes are created and initialized to 1	
After transaction 4, supports of all items have been determined and rulesets can be collected like in Apriori method.	

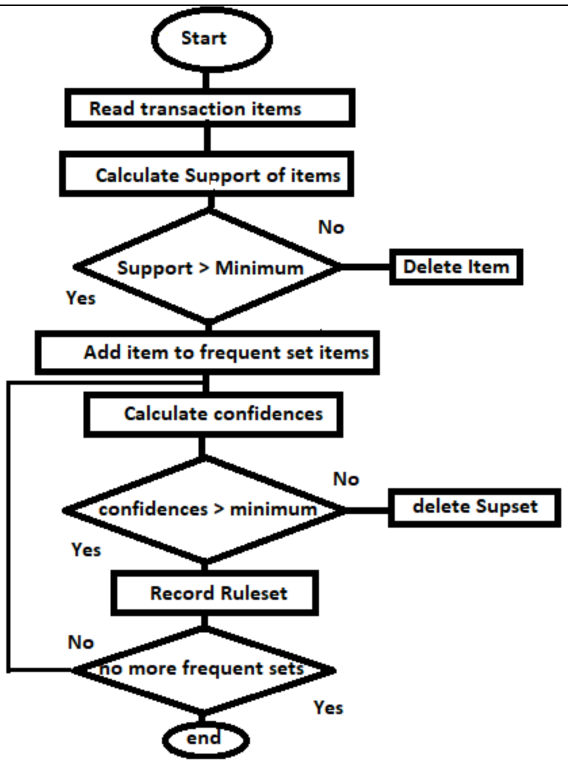


Fig. 1. Flowchart of Apriori Algorithm

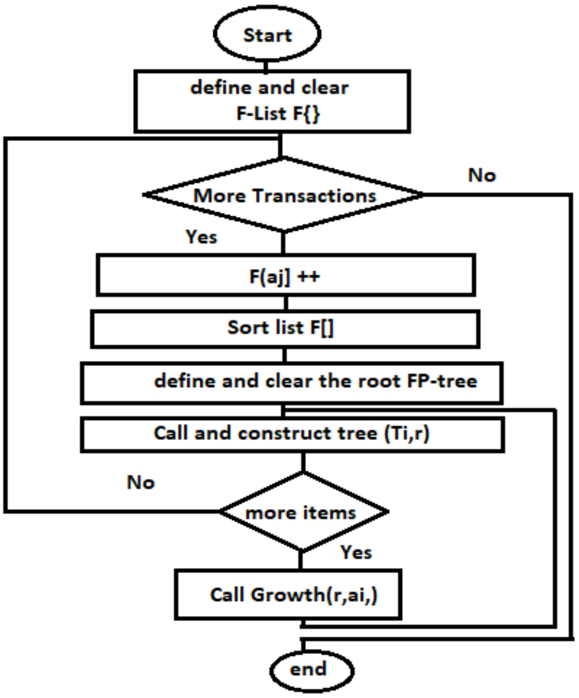


Fig. 2. FP-Growth flowchart

3. Results and Discussion

3.1 Introduction

This paper produces two databases, one from the conducted survey. And the second is comprises the statistical results and the obtained frequent pattern rulesets. In the next sub sections, the results of the survey are tabulated and discussed. In addition, the statistical results and rulesets are presented and discussed in form of charts and numbers.

3.2 *Results of the conducted survey*

Table 11. tabulates the results of reviewing hundreds of the most recent research papers on HRES. Each row represents one research of HRES system including all aspects like system components, topologies, methods and techniques of sizing and optimization of HRES systems in three angles: economical, reliability, and environmental aspects. In addition, it includes the optimization algorithms, software packages and tools that have been used in the surveyed research. The results of statistical and data mining analyses are presented and discussed in the next subsection.

Table 11. Results of the survey

REF.	HRES COMPONENTS	TOPOLOGY	N	ENV.	ECONOMICAL	RELIABILITY	OPT. ALGORITHM	SOFTWARE TOOLS
7	PV WIND DIESEL HYDROGEN TANK BATTERY	SA	5					HOMER HOGA HYBRID 2
8	PV DIESEL BATTERY FC	SA	4				GA	HOMER
9	WIND PV BATTERY	GC	3		STC COE COSE NPC	LPSP LOLP UL		MATLAB
10	PV BATTERY PV WIND BATTERY PV WIND DIESEL BATTERY		2 3 4				GA	HOMER
11	PV WIND BIOMASS BATTERY PV WIND FC HYDROGEN TANK	SA GC	4 3	CO2	LCOE NPC	LPSP	PROBABILISTIC ITERATIVE GA ICA	MATLAB
12	PV WIND DIESEL BATTERY	SA	4	CO2	ASC		GC PROBABILISTIC ANALYTICAL ITERATIVE IFO	HOMER HOGA RETSCREEN HYBRIDS TRNSYS
13	PV WIND BATTERY	SA	3		TC		GA PSO ACO MOA ITERATIVE ANALYTICAL PROBABILISTIC GC	HOMER HOGA RET SCREEN HYBRIDS TRNSYS
14	PV WIND DIESEL BATTERY FC	SA	5		LCC	LPSP LOLP UL	GC PROBABILISTIC ITERATIVE MOO	HOMER
15	PV WIND DIESEL BATTERY	SA	4		LCC	SPL LOLH LPSP	EBI	MATLAB
16	PV WIND DIESEL BATTERY	SA	4		LCC NPC	LPSP	GA EBI	MATLAB
17	PV WIND DIESEL BATTERY	SA	4		COE LCC	LPSP	GA EBI	MATLAB
18	PV WIND FC DIESEL BATTERY	SA	5		LCC TC	LPSP	GC EBI DA	HOMER
19	PV WIND DIESEL BATTERY	SA	4		LCC	LPSP	GC EBI	HOMER
20	PV WIND DIESEL BATTERY	SA	4		LCC	LPSP	ITERATIVE PROBABILISTIC LP	MATLAB
21	PV WIND DIESEL BATTERY	SA	4		LCC	LPSP	TO EBI	MATLAB
22	WIND PV DIESEL BATTERY	SA	4		COE	LPSP	GA PSO SA ACO BBO LP	MATLAB

REF.	**HRES COMPONENTS**	**TOPOLOGY**	**N**	**ENV.**	**ECONOMICAL**	**RELIABILITY**	**OPT. ALGORITHM**	**SOFTWARE TOOLS**
23	PV WIND BATTERY	SA	3		COE	LPSP	LP	MATLAB
24	PV WIND FC HYDROGEN TANK	SA	4	CO2	TAC NPC	LPSP	BIA DHS ABS ICA	MATLAB
25	PV WIND FC HYDROGEN TANK	SA GC	4	CO2	TAC NPC	LPSP	ABS ICA BBO	MATLAB
26	PV WIND FC HYDROGEN TANK	SA	4	CO2	NPC	LPSP	GSA ICA TS	MATLAB
27	PV WIND FC HYDROGEN TANK	SA GC	4	CO2	NPC TC	LPSP	ICA HOT DA	HOMER MATLAB
28	PV WIND FC HYDROGEN TANK BATTERY	SA GC	5	CO2	NPC TC	LPSP	GA PSO ICA CS	MATLAB
29	WIND PV BIOMASS DIESEL HYDROGEN BATTERY	SA GC	6	CO2	NPC TAC	LPSP UL	PSO GA MOEA ICA DHS	MATLAB
30	PV DEISEAL BATTERY FC HYDRO WIND	SA GC	6	CO2	NPC LCOE TAC TC	LPSP	GA ICA DHS A-STRONG	HOMER MATAB
31	BIO DIESEL BATTERY PV WIND HYDRO HYDROGEN TANK FC	SA GC	7	CO2	COE NPC	LPSP	ICA	HOMER MATLAB
32	PV BATTERY DIESEL WIND FC HYDROGEN TANK	SA GC	6	CO2	COE NPC	LPSP	ICA	HOMER MATLAB
33	PV WIND HYDRO DIESEL BATTERY		5		NPC CLOE			HOMER
34	PV DIESEL WIND		3		COE			HOMER
35	WIND DIESEL PV BATTERY	SA	4	CO2	COE NPC TAC		DHS	HOMER MATLAB
36	PV WIND FC HYDROGEN TANK BATTERY	SA	5		COE	LOLE	ITERATIVE	MATLAB HOMER
37	PV MICRO HYDRO LPG GENERATOR BATTERY		4	NPC				HOMER
38	WIND PV BATTERY DIESEL		4	CO2	LCOE		FL-GWO	MATLAB
39	WIND PV BATTERY DIESEL FC		5	CO2	COE		PSO	
40	WIND PV BATTERY		3		NPC			HOMER MATLAB
42	WIND PV BATTERY ULTRACAPACITOR FC DIESEL GAS TURBINE		6	CO2 NOX SO2	COE	LPSP	DP MCS	
43	PV BATTERY DIESEL		3		LCOE	LPSP	FL CS	MATLAB
44	PV WIND FC BATTERY		4	CO2 NOX SO2	COE		FL PSO	MATLAB
45	PV WIND DIESEL BATTERY	SA	4	CO2	ASC NPC		IFO	MATLAB HOMER
46	PV WIND BATTERY	AC						
47	PV WIND FC HYDROGEN TANK BATTERY	SA HYBRID	5		COE	LOLE	ITERATIVE	MATLAB

REF.	HRES COMPONENTS	TOPOLOGY	N	ENV.	ECONOMICAL	RELIABILITY	OPT. ALGORITHM	SOFTWARE TOOLS
49	PV WIND DIESEL BATTERY	SA	4		TC		A STRONG CS	MATLAB HOGA HOMER
50	PV WIND DIESEL BATTERY	SA	4		TC	LPSP	A STRONG	HOMER MATLAB
51	PV WIND BATTERY	SA				LOLP		HOMER
52	PV WIND MICRO HYDRO DIESEL	SA	4			LOLP LOEE		HOMER
53	PV WIND BATTERY					DPSP UL	SA TS	HOMER
54	PV WIND FC HYDROGEN TANK BATTERY	SA	5		COE CC	LOLE LPSP EENS	ITERATIVE	MATLAB
55	PV BATTERY					EIR		HOMER
56	PV WIND FC HYDROGEN TANK	SA	4		TAC	LPSP ELF	ABSO	MATLAB
57	PV WIND					D		HOMER
58	PV WIND DIESEL BATTERY	SA	4	CO2	ASC	TED	IFO	MATLAB HOMER
59	PV WIND	SA	2			WRE		HOMER
60	WIND DIESEL BATTERY	SA	3			REP		HOMER
61	PV WIND BATTERY					FEE		HOMER
62	PV WIND DIESEL BATTERY	SA	4	EE CO2	TAC	LEP KL LPSP R H	DHS	HOMER
63	PV WIND DIESEL BATTERY	SA	4		COE TIC NPC		BBO	MATLAB HOMER
64	PV WIND	SA	2		LCC		ACO	HOMER
65	PV WIND DIESEL	SA	3		LCOE TAC CS			HOMER
66	PV WIND	SA	2	CO2				HOMER
67	PV WIND BIOMASS BATTERY	SA	4	EE	TC LCA		ABC	MATLAB HOMER
68	PV WIND DIESEL BATTERY	SA	4	CO2	LCC D		GA	MATLAB
69	PV WIND HYDRO BIOMASS BIOGAS BATTERY	SA	6		NPC COE	LOLP	GA	MATLAB
70	PV WIND BATTERY	SA	3		TC	DPSP	GA	MATLAB
71	PV WIND BATTERY	SA	3		TIC	EENS	GA	MATLAB
72	PV WIND DIESEL BATTERY	SA	4	CO2 EE	ASC LCC	LPSP	PICEA GA	MATLAB
73	PV WIND FC HYDROGEN TANK	SA	4		TAC	LPSP	MBA PSO	MATLAB
74	PV WIND BATTERY	SA	3		LCC	LPSP	PSO	MATLAB
75	PV WIND BATTERY	SA	3		LCOE	R	PSO	MATLAB
76	PV WIND BATTERY DIESEL	SA GC	3		TIC		PSO	MATLAB
77	PV WIND FC HYDROGEN TANK	SA	4		TAC	LOLE LOEE	PSO	MATLAB
78	PV WIND DIESEL BATTERY	SA	4	GHG	TAC		PSO	MATLAB
79	PV WIND DIESEL BATTERY	SA	4		TAC		MLCA	MATLAB

REF.	**HRES COMPONENTS**	**TOPOLOGY**	**N**	**ENV.**	**ECONOMICAL**	**RELIABILITY**	**OPT. ALGORITHM**	**SOFTWARE TOOLS**
80	PV WIND BATTERY	SA	3		TC		ACO	MATLAB
81	PV WIND DIESEL BATTERY	SA	4	CO2	ASC	LPSP	PICEA	MATLAB
82	PV WIND DIESEL BATTERY	SA	4	CO2	ASC COE		IFO BBO	MATLAB
83	PV WIND DIESEL BATTERY	SA	4		COE		BBO	MATLAB
84	PV WIND DIESEL BATTERY	SA	4		COE		BBO	MATLAB
85	PV WIND FC HYDROGEN TANK	SA GC	4	CO2	NPC	LPSP	ICA	MATLAB
86	PV WIND DIESEL BATTERY FC HYDROGEN TANK	SA	6		TC CC	LPSP	A-STRONG ITERATIVE	MATLAB
87	PV WIND DIESEL BATTERY	SA	4		TC		A STRONG	MATLAB
88	PV WIND FC HYDROGEN TANK BATTERY	SA	5		COE CC	LOLE LPSP	ITERATIVE	MATLAB
89	PV WIND FC HYDROGEN TANK BATTERY	SA	5		COE	LOLE	ITERATIVE	MATLAB
90	PV WIND FC HYDROGEN TANK BATTERY	SA	5		COE	LOLE	ITERATIVE	MATLAB
91	PV WIND FC HYDROGEN TANK BATTERY	SA	5		COE	LOLE	ITERATIVE	MATLAB
92	PV WIND BATTERY	SA	3		TC	LPSP	LP	MATLAB
93	PV WIND BATTERY	SA	3		TC	LPSP	LP	MATLAB
94	PV WIND BATTERY	SA	3		CC		MILP	MATLAB
95	PV WIND DIESEL BATTERY	SA	4		TC		GUI	MATLAB
96	PV WIND	SA	2		TC		ANALYTICAL	MATLAB
97	PV WIND BATTERY	SA	3		NPC	ENS	BBBC	MATLAB
98	PV WIND DIESEL BATTERY	SA	4		TAC	LPSP	TLBO	MATLAB
99	PV WIND BATTERY	SA	3		TC		GA ES	MATLAB
100	PV WIND BATTERY	SA	2		TC	EENS D EIR	FL ITERATIVE	MATLAB
101	PV WIND BATTERY	SA	2		TAC	LPSP	MESCA	HOMER
102	PV WIND DIESEL BATTERY	SA	4		NPC		MOEA GA	MATLAB
103	PV WIND DIESEL BATTERY	SA	4		NPC	ENS	GA ANN MCS	MATLAB
104	PV WIND DIESEL BATTERY FC BIO DIESEL	SA	6		COE		SA TS	MATLAB
105	PV WIND DIESEL	SA	3	CO2	TC	LOLP	MARKOV GA	MATLAB
106	PV WIND BATTERY	SA	3		TAC		HS CS SA	MATLAB
107	PV WIND BATTERY	SA	3		LCC	LPSP	HS CS	MATLAB

REF.	HRES COMPONENTS	TOPOLOGY	N	ENV.	ECONOMICAL	RELIABILITY	OPT. ALGORITHM	SOFTWARE TOOLS
108	PV WIND BATTERY	SA	3		TC		ITERATIVE GA	MATLAB
109	WIND	GC	1				PSO FL	MATLAB
110	PV	SA	1					MATLAB
111	PV	GC	1					MATLAB
112	PV	SA	1					MATLAB
113	PV WIND	GC	2					MATLAB
114	WIND PV HYDRO	SA	3				MILP	MATLAB

3.3 *Data preparation*

In order to run the statistical and frequent patterns and data mining analyses, the collected data of the conducted survey, have been converted into numerical data type format to make the statistical analysis and data mining processing simpler and faster than processing a character string data type format. Table 12. lists sample of some records of the converted data into numerical format. Each row represents one research transaction. Each transaction consists of items represented by the table columns. For example, the first row represents one transaction of items {1,2,6,9,10,15,5,120,122,124}. The numerical conversion has been done thanks to the codes included in the ID columns of Tables 1-8. Like the sample of records listed in Table 12. all data in Table 11. have been converted into numerical format in order to run the statistical analysis and frequent pattern mining algorithm. The next subsection presents and discusses the results obtained from the statistical, and data mining analyses.

3.4. *Results of statistical and data mining analyses*

After converting the collected dataset into numerical format, a statistical analysis and frequent pattern data mining have been performed by using linear regression and APRIORI algorithm respectively.

Table 12. Sample records of the numerical conversion of the collected data

REF	HRES COMPONENTS ID	TOPOLOGY ID	N	ENVIRONMENTAL OPT. METHOD ID	ECONOMICAL OPT. METHOD ID	RELIABILITY DETERMINATION METHOD ID	OPTIMIZATION ALGORITHM ID	SOFTWARE PACKAGES AND TOOLS
7	1,2,6,9,10	15	5					120,122,124
8	1,3,9,10,	15	4				74	120
9	2,1,10	16	3		35,36,42,	50,60,64		138
10	1,10		2				74	120
	1,2,10		3					
	1,2,9,10,		4					
11	1,2,6,10,	15	4	25	41	50	84,139	138
	1,2,3,6,	16	3		42		74,98	

3.4.1 *Statistical analysis results*

Table 13. lists the frequency of appearance of combined components of HRES in the surveyed papers. Each column represents the frequency of appearance of specific combination of HRES. For example, the first column shows the frequency of appearance of HRES comprising PV, Wind, and Battery bank. It shows that, the HRES component combination of {PV, Wind, and Battery} is the most frequently appeared in the survey. Then the combination of PV and Wind comes next and all other combinations are listed with their frequencies of appearance. Also, Fig. 3. depicts the repetition rate of HRES component combinations. It shows the combination of PV, Wind, and Battery is the most frequently appeared in the survey with percentage of 29%.

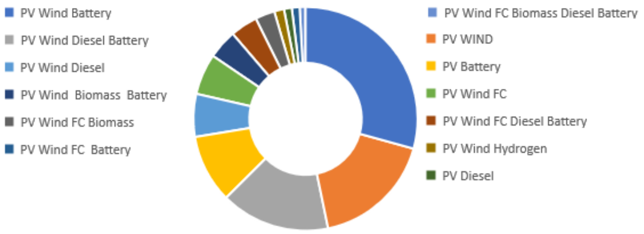


Fig. 3. Percentages of HRES components

Table 13. Frequency of Combined HRES Component

HRES Components	**PV Wind Battery**	**PV WIND**	**PV Wind Diesel Battery**	**PV Battery**	**PV Wind Diesel**	**PV Wind FC**	**PV Wind Biomass Battery**	**PV Wind FC Diesel Battery**	**PV Wind FC Biomass**	**PV Wind Hydrogen**	**PV Wind FC Battery**	**PV Diesel**	**PV Wind FC Biomass Diesel Battery**
Frequency	104	62	56	35	22	21	15	14	10	5	4	4	3

Table 14. lists the frequency of appearance of HRES topologies according to the conducted survey. Each column represents the frequency of appearance of one topology. In addition, Fig. 4. shows the pie chart of the percentages of their frequent appearance in the survey. They show that, the most frequently appeared topologies are the stand alone and the DC Bus system.

Table 14. Frequency of topologies

Topology	**SA**	**GC**	**AC Bus**	**DC Bus**	**AC DC**	**SA GC**	**SA AC**	**SA AC DC**	**SA AC DC bus**
Frequency	354	6	7	11	2	13	1	1	2

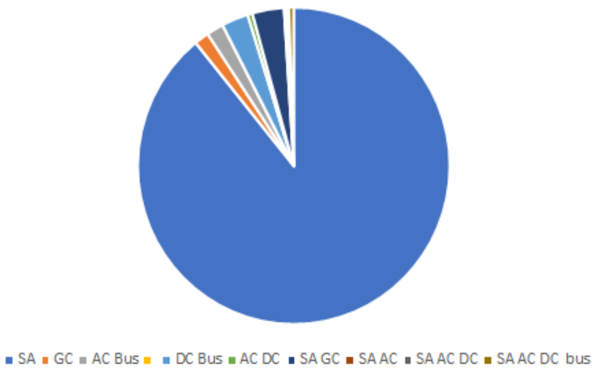


Fig. 4. Frequency of topologies

Table 15. lists the frequency of presence of environmental optimization method throughout the conducted survey. Each column represents the frequency of appearance of one method. For example, the first column represents the number of researches that have used CO2 method. In addition, Fig. 5. charts the percentages of their appearance throughout the survey. They show that CO2 is the most frequently appeared in the surveyed papers.

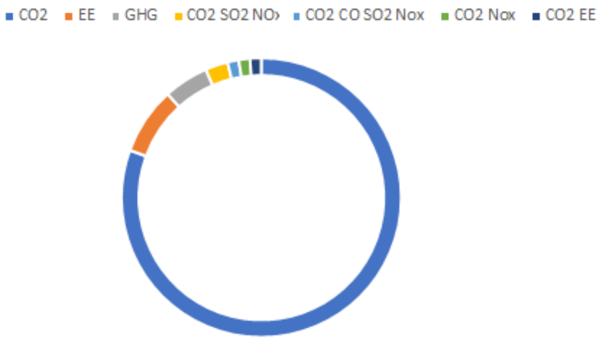


Fig. 5. Frequency of emission optimization

Table 15. Frequency of environmental optimization

Environmental optimization Method	**CO2**	**EE**	**GHG**	**CO2 SO2 NOx**	**CO2 CO SO2 Nox**	**CO2 Nox**	**CO2 EE**
Frequency	62	6	4	2	1	1	1

Table 16. lists the frequency of appearance of economical optimization methods throughout the surveyed researches. Each column represents the number of researches that used specific method of economical optimization. For instance, the first column represents the frequency of appearance of the ACS method. Furthermore, Fig. 6. charts the percentages of their frequency of appearance in the survey. They show that Annual cost technique is the most frequently used method. Furthermore, the other methods come next in descending order.

Fig. 6. Economical optimization methods

Table 16. Economical optimization methods

Economical optimization Method	ACS	TC	COE	COE NPC	LCE	NPV	LCC	TAC	TC LCE	CC	TC NPC	STC	LCE NPV	COE TC NPV	TIC	TAC NPV
frequency	45	35	32	31	30	29	28	14	13	12	8	7	6	3	3	3

Table 17. lists the frequency of appearance of the reliability methods in the surveyed researches. Each column represents the frequency of using specific method of reliability optimization in the survey. For example, the first column represents the number of researches that have used the LPSP method throughout the survey. In addition, Fig. 7. charts the percentages of their frequency of appearance throughout the survey. They show that, the loss of power probability is the most frequently used method. Then the loss of load probability comes next. And the other methods are rarely appeared in the survey.

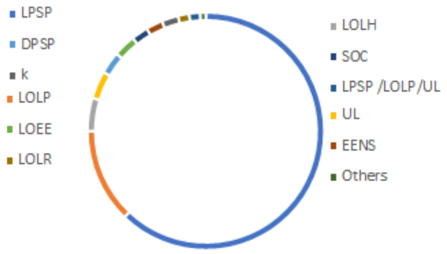


Fig. 7. Reliability optimization methods

Table 17. Reliability optimization methods

Reliability optimization Method	**LPSP**	**LOLP**	**LOLH**	**UL**	**DPSP**	**LOEE**	**SOC**	**EENS**	**k**	**LOLR**	**LPSP LOLP UL**	**Others**
frequency	82	17	6	5	4	4	3	3	3	2	2	1

Table 18. lists the frequency of appearance of the optimization algorithms in the conducted surveyed researches. Each column represents the number of researches that used specific optimization algorithm in the survey. For example, the first column represents the frequency of appearance of the GA method. in addition, Fig. 8. charts the percentages of their presence in the survey. They show that the genetic algorithm is the most frequently used algorithm. Then other algorithms come next in descending order as shown and listed in Fig. 8. and Table 18, respectively.

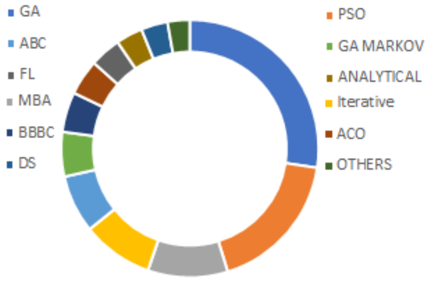


Fig. 8. Optimization algorithms

Table 18. Optimization algorithms

Optimization Algorithm Method	**GA**	**PSO**	**MBA**	**Iterative**	**ABC**	**GA MARKOV**	**BBBC**	**ACO**	**FL**	**ANALYTICAL**	**DS**	**OTHERS**
frequency	49	32	18	16	13	10	9	8	7	6	6	5

Table 19. lists the frequency of appearance of the tools and software packages in the surveyed researches. Each column represents the number of researches that used specific optimization software. For example, the first column represents the frequency of using MATLAB package throughout the survey. In addition, Fig. 9. charts the percentages of their frequency of appearance throughout the survey. They show that the MATLAB package is the most frequently used software. Then HOMER Software comes next. After that, other tools and software packages come next in descending order.

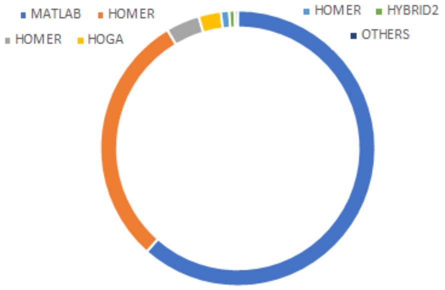


Fig. 9. Tools and software packages

Table 19. Optimization tools and software packages

Optimization tool	**MATLAB**	**HOMER**	**HOMER MATLAB**	**HOGA**	**HOMER HOGA**	**HYBRID2 HOGA**	**OTHERS**
Frequency	187	91	12	8	3	2	1

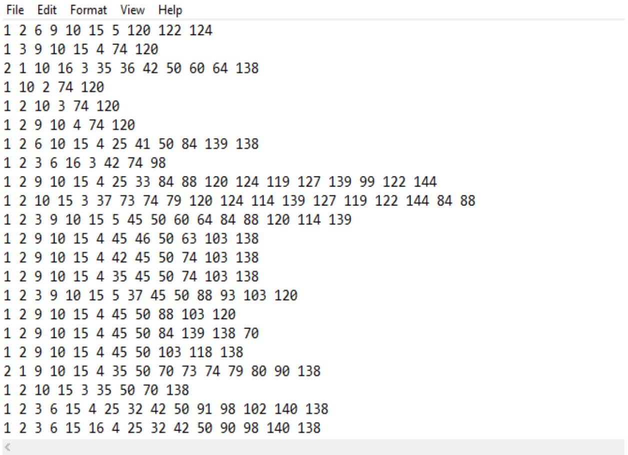
3.4.2 *Data mining and frequent pattern results*

After preparing the data transactions in numerical format, APRIORI frequent pattern Algorithm has been applied on the transactions having the minimum support equal to 0.1 or 10%. This means that, if the total transactions are 1000 transactions, then the pattern with frequency less than 100 (10%) would not be considered and those with frequency greater than or equal to 100 (10%) would be considered. Fig. 10. shows a list of some input transactions in numerical format. For example, the first record transaction is "1 2 6 9 10 15 5 120 122 124". According to codes in Tables 1-8, this transaction represents an HRES system which is comprised of PV, Win, Biomass, Diesel, Battery, and Hydrogen Tank. In addition, its topology is SA; it has been optimized by HOMER, HYBRID, and HOGAN software packages. Table 20. lists the results of running the Apriori Algorithm with minimum support of 10%. It reported that, the processing time was 100 ms as in the fourth row and the memory usage was 75.53 MB as in the third row. Moreover, it stated that, there were 368 of candidates or items as in the first row while there are 239 frequent item sets as in the second row. Furthermore, the frequent pattern results are presented starting from the seventh row. The first column shows the itemset which is the combination of the HRES components represented in numerical format while the second column represents the itemset in character format. The third column represents the support of the corresponding itemset. The results showed that, Wind is the most frequently appeared as HRES component; The most frequent patterns are PV, Wind, and battery as HRES components, stand alone as HRES topology, MATLAB and HOMER as an optimization software package, Net present value as an economical optimization method, and Genetic algorithm as an optimization algorithm.

Table 20. Results of APRIORI frequent pattern

Candidates count	368	
Frequent item sets count	239	
Maximum memory usage	75.53770446777344 mb	
Total time	100 ms	
Itemset (Numerical format)	**Itemset (character format)**	**Support**
2	Wind	461
1, 2, 10	PV Wind Battery	220
1,2,10,15,	PV Wind Battery SA	201
1,2,10,138,	PV Wind Battery MATLAB	106
1,2,10,15,138,	PV Wind Battery SA MATLAB	103
1,2,10,42,	PV Wind Battery NPV	58
1,2,10,120,	PV Wind Battery HOMER	58
1,2,10,50,	PV Wind Battery LPSP,	57

1,2,10,15,50,	PV Wind Battery SA LPSP,	56
1,2,10,35,	PV Wind Battery COE	55
1,2,10,15,42,	PV Wind Battery SA NPV	53
1,2,10,15,35,	PV Wind Battery SA COE	48
1,2,10,15,120,	PV Wind Battery SA HOMER	45
1,2,10,74,	PV Wind Battery GA	44
1,2,10,25,	PV Wind Battery CO2	43
1,2,10,37,	PV Wind Battery TC	43



```
1 2 6 9 10 15 5 120 122 124
1 3 9 10 15 4 74 120
2 1 10 16 3 35 36 42 50 60 64 138
1 10 2 74 120
1 2 10 3 74 120
1 2 9 10 4 74 120
1 2 6 10 15 4 25 41 50 84 139 138
1 2 3 6 16 3 42 74 98
1 2 9 10 15 4 25 33 84 88 120 124 119 127 139 99 122 144
1 2 10 15 3 37 73 74 79 120 124 114 139 127 119 122 144 84 88
1 2 3 9 10 15 5 45 50 60 64 84 88 120 114 139
1 2 9 10 15 4 45 46 50 63 103 138
1 2 9 10 15 4 42 45 50 74 103 138
1 2 9 10 15 4 35 45 50 74 103 138
1 2 3 9 10 15 5 37 45 50 88 93 103 120
1 2 9 10 15 4 45 50 88 103 120
1 2 9 10 15 4 45 50 84 139 138 70
1 2 9 10 15 4 45 50 103 118 138
2 1 9 10 15 4 35 50 70 73 74 79 80 90 138
1 2 10 15 3 35 50 70 138
1 2 3 6 15 4 25 32 42 50 91 98 102 140 138
1 2 3 6 15 16 4 25 32 42 50 90 98 140 138
```

Fig. 10. Sample records of converted transactions into numerical format

5. Conclusions

This paper initially investigated the most recent and reputable international reports regarding RES. It concluded in language of numbers and charts that, RES have been growing up from year to year in the last decade and became the second largest source of electricity. In addition, it is found that, combining two or more RES which have a complementary nature like solar and wind in hybrid topology is very viable to overcome the intermittent nature of RES. Consequently, this paper presented a novel technique to determine the key parameters of developing the sizing and optimizing HRES systems in three dimensions of interest which are economics, environmental impacts, and system reliability. The new technique is based on statistical calculations and frequent pattern datamining analysis on the statistics of the previous researches on HRES. It firstly conducted a comprehensive review of hundreds of recent research papers on HRES systems. The survey included HRES components, Size and capacity, topology , economical and environmental optimization, system reliability, optimization algorithms, and tools and software packages. Secondly, it performed statistical and data mining analyses on the big dataset which is obtained from the conducted survey. The statistical results and the obtained frequent patterns rulesets are validated with each other in order to verify the accuracy and correctness of the results. The overall results proved that, the statistical results and the obtained rulesets showed typical results. By reviewing hundreds of papers and running statistical calculations and data mining analysis, this paper produced two big databases. The first one can be considered as a great database that can guide researchers to find all needed information regarding HRES systems of different combinations, topologies, economical and environmental optimization methods, system reliability methods, optimization algorithms, optimization and simulation tools and software packages. Furthermore, the second obtained database of the frequent pattern rulesets and statistical results can help researchers immensely in predicting the most suitable optimization methods for increasing system reliability, minimizing system total cost, and reducing the environmental impacts and hence developing HRES system. It will be also easy to update such databases to support the development of more reliable and efficient renewable energy systems.

References

[1] Renewables 2018 Global status report http://www.ren21.net/

[2] International electricity agency report 2017 http://www.iea.org

[3] Philip E. Bett , Hazel E. Thornton, "The climatological relationships between wind and solar energy supply in Britain" Renewable Energy 87 (2016) 96-110.

[4] ZDZISLAW HELLWIG, Linear Regression and its Application to Economics, Pergamon, 1963,Pages 1-51,ISBN9781483200736,https://doi.org/10.1016/B978-1-4832-0073-6.50004-4.

[5] Y. Venkata Raghavarao,L. S. S Reddy,A. Govardhan Map Reducing Stream Based Apriori in Distributed Big Data Mining Volume 4, Issue 7,July 2014 ISSN: 2277 128X International Journal of Advanced Research in Computer Science and Software Engineering

[6] Totad, S. G., Geeta, R. B., Prasanna, C. R., Santhosh, N. K., & Reddy, P. V.. Scaling data mining algorithms to large and distributed datasets. Intl J Database Manag Syst 2010, 2, 26-35

[7] Rodolfo Dufo-Lopez, José L. Bernal-Agustín, Multi-objective design of PV–wind–diesel–hydrogen–battery systems, Renewable Energy, Volume 33, Issue 12, December 2008, pp. 2559-2572.

[8] Karakoulidis K, Mavridis K, Bandekas D, Adoniadis P, Potolias C, Vordos N." Techno-economic analysis of a stand-alone hybrid photovoltaic-diesele battery-fuel cell power system". Renew Energy 011;36: pp. 2238- 2244.

[9] Akbar Maleki , Marc A. Rosen, Fathollah Pourfayaz,Optimal Operation of a Grid-Connected Hybrid Renewable Energy System for Residential Applications, Sustainability 2017, 9, 1314; doi:10.3390/su9081314

[10] Yashwant swale, s. c. Gupta , Aashish Kumar Bohre, function for a long-term district heat demand ,Optimal sizing of standalone PV/Wind/Biomass hybrid energy system using GA and PSO optimization technique, 1st International Conference on Power Engineering, Computing and CONtrol,

PECCON-2017, 2- 4 March 2017, VIT University, Chennai Campus

[11] Singh S, Singh M, Kaushik SC. Feasibility study of an islanded microgrid in rural area consisting of PV, wind, biomass and battery energy storage system. Energy Convers Manage 2016;128:178–90.

[12] Dufo-López R, Cristóbal-Monreal IR, Yusta JM. Optimisation of PV-winddiesel-battery stand-alone systems to minimise cost and maximise human development index and job creation. Renewable Energy 2016;94:280–93.

[13] Mahesh A, Sandhu KS. Hybrid wind/photovoltaic energy system developments: Critical review and findings. Renew Sustain Energy Rev 2015;52:1135–47.

[14] Zahboune H, Zouggar S, Krajacic G, Varbanov PS, Elhafyani M, Ziani E. Optimal hybrid renewable energy design in autonomous system using Modified Electric System Cascade Analysis and Homer software. Energy Convers Manage 2016;126:909–22

[15] Tito SR, Lie TT, Anderson TN. Optimal sizing of a wind-photovoltaic-battery hybrid renewable energy system considering socio-demographic factors. Sol Energy 2016;136:525–32.

[16] Kamjoo A, Maheri A, Dizqah AM, Putrus GA. Multi-objective design under uncertainties of hybrid renewable energy system using NSGA-II and chance constrained programming. Int J Electr Power Energy Syst 2016;74:187–94.

[17] Cho J-H, Chun M-G, Hong W-P. Structure optimization of stand-alone renewable power systems based on multi object function. Energies 2016;9:649.

[18] Baghaee HR, Mirsalim M, Gharehpetian GB, Talebi HA. Reliability/cost-based multi-objective Pareto optimal design of stand-alone wind/PV/FC generation microgrid system. Energy 2016;115:1022–41.

[19] Margaret Amutha W, Rajini V. Techno-economic evaluation of various hybrid power systems for rural telecom. Renew Sustain Energy Rev 2015;43:553–61

[20] Ma G, Xu G, Chen Y, Ju R. Multi-objective optimal configuration method for a standalone wind-solar-battery hybrid power system. IET Renew Power Gener 2016.

[21] Maleki A, Khajeh MG, Ameri M. Optimal sizing of a grid independent hybrid renewable energy system incorporating resource uncertainty, and load uncertainty. Int J Electr Power Energy Syst 2016;83:514–24.

[22] Malheiro A, Castro PM, Lima RM, Estanqueiro A. Integrated sizing and scheduling of wind/PV/diesel/battery isolated systems. Renewable Energy 2015;83:646–57.

[23] Bhuiyan FA, Yazdani A, Primak SL. Optimal sizing approach for islanded microgrids. IET Renew Power Gener 2015;9:166–75.

[24] Sanajaoba S, Fernandez E. Maiden application of Cuckoo Search algorithm for optimal sizing of a remote hybrid renewable energy System. Renewable Energy 2016;96:1–10.

[25] Hosseinalizadeh R, Shakouri H, Mohsen G, Amalnick S, Taghipour P. Economic sizing of a hybrid (PV–WT–FC) renewable energy system (HRES) for standalone usages by an optimization-simulation model: Case study of Iran. Renew Sustain Energy Rev 2016;54:139–50.

[26] Hassan A, Kandil M, Saadawi M, Saeed M. Modified particle swarm optimisation technique for optimal design of small renewable energy system supplying a specific load at Mansoura University. IET Renew Power Gener 2015;9:474–83.

[27] Gharavi H, Ardehali MM, Ghanbari-Tichi S. Imperial competitive algorithm optimization of fuzzy multi-objective design of a hybrid green power system with considerations for economics, reliability, and environmental emissions. Renewable Energy 2015;78:427–37.

[28] Fathy A. A reliable methodology based on mine blast optimization algorithm for optimal sizing of hybrid PV-wind-FC system for remote area in Egypt. Renewable Energy 2016;95:367–80.

[29] Ahmadi S, Abdi S. Application of the Hybrid Big Bang-Big Crunch algorithm for optimal sizing of a stand-alone hybrid PV/wind/battery system. Sol Energy 2016;134:366–74.

[30] Ogunjuyigbe ASO, Ayodele TR, Akinola OA. Optimal allocation and sizing of PV/Wind/Split-diesel/Battery hybrid energy system for minimizing life cycle cost, carbon emission and dump energy of remote residential building. Appl Energy 2016;171:153–71.

[31] Shezan SA, Julai S, Kibria MA, Ullah KR, Saidur R, Chong WT, et al. Performance analysis of an off-grid wind-PV (photovoltaic)-diesel-battery hybrid energy system feasible for remote areas. J Clean Prod 2016;125:121–32

[32] Kalinci Y, Hepbasli A, Dincer I. Techno-economic analysis of a stand-alone hybrid renewable energy system with hydrogen production and storage options. Int J Hydrogen Energy 2015;40:7652–64.

[33] Das HS, Dey A, Wei TC, Yatim AHM. Feasibility analysis of standalone PV/ wind/battery hybrid energy system for Rural Bangladesh. Int J Renew Energy Res 2016;6:403–12.

[34] Haghighat Mamaghani A, Avella Escandon SA, Najafi B, Shirazi A, Rinaldi F. Techno-economic feasibility of photovoltaic, wind, diesel and hybrid electrification systems for off-grid rural electrification in Colombia. Renewable Energy 2016;97:293–305

[35] Askarzadeh A, dos Santos Coelho L. A novel framework for optimization of a grid independent hybrid renewable energy system: A case study of Iran. Sol Energy 2015;112:383–96.

[36] Maleki A, Pourfayaz F. Optimal sizing of autonomous hybrid photovoltaic/ wind/battery power system with LPSP technology by using evolutionary algorithms. Sol Energy 2015;115:471–83.

[37] Fadaeenejad M, Radzi MAM, AbKadir MZA, Hizam H. Assessment of hybrid renewable power sources for rural electrification in Malaysia. Renew Sustain Energy Rev 2014;30:299–305.

[38] Ma T, Yang H, Lu L. A feasibility study of a stand-alone hybrid solar–wind– battery system for a remote island. Appl Energy 2014;121:149–58

[39] Maleki A, Askarzadeh A. Artificial bee swarm optimization for optimum sizing of a stand-alone PV/WT/FC hybrid system considering LPSP concept. Sol Energy 2014;107:227–35.

[40] Zhou T, Sun W. Optimization of battery-supercapacitor hybrid energy storage station in wind/solar generation system. IEEE Trans Sustain Energy 2014;5:408–15.

[41] [41] Chauhan A, Saini RP. Techno-economic feasibility study on Integrated Renewable Energy System for an isolated community of India. Renew Sustain Energy Rev 2016;59:388–405.

[42] Sanchez VM, Chavez-Ramirez AU, Duron-Torres SM, Hernandez J, Arriaga LG, Ramirez JM. Techno-economical optimization based on swarm intelligence algorithm for a stand-alone wind-photovoltaic-hydrogen power system at south-east region of Mexico. Int J Hydrogen Energy 2014;39:16646–55.

[43] Smaoui M, Abdelkafi A, Krichen L. Optimal sizing of stand-alone photovoltaic/ wind/hydrogen hybrid system supplying a desalination unit. Sol Energy 2015;120:263–76.

[44] Rajanna S, Saini RP. Development of optimal integrated renewable energy model with battery storage for a remote Indian area. Energy 2016;111:803–17.

[45] Baneshi M, Hadianfard F. Techno-economic feasibility of hybrid diesel/PV/ wind/battery electricity generation systems for non-residential large electricity consumers under southern Iran climate conditions. Energy Convers Manage 2016;127:233–44.

[46] Belfkira R, Zhang L, Barakat G. Optimal sizing study of hybrid wind/PV/diesel power generation unit. Sol Energy 2011;85:100–10.

[47] Shi Z, Wang R, Zhang T. Multi-objective optimal design of HRES using preference-inspired coevolutionary approach. Sol Energy 2015;118:96–106.

[48] Suhane P, Rangnekar S, Khare A, Mittal A. Sizing and performance analysis of standalone wind-photovoltaic based hybrid energy system using ant colony optimisation. IET Renew Power Gener 2016;10:964–72.

[49] Zhao J, Yuan X. Multi-objective optimization of stand-alone hybrid PV-winddiesel-battery system using improved fruit fly optimization algorithm. Soft Comput 2015;20:2841–53.

[50] Shi Z, Wang R, Zhang T. Multi-objective optimal design of HRES using preference-inspired coevolutionary approach. Sol Energy 2015;118:96–106.

[51] Fazelpour F, Soltani N, Rosen MA. Economic analysis of standalone hybrid energy systems for application in Tehran, Iran. Int J Hydrogen Energy 2016;41:7732–43.

[52] Khan MRB, Jidin R, Pasupuleti J, Shaaya SA. Optimal combination of solar, wind, micro-hydro and diesel systems based on actual seasonal load profiles for a resort island in the South China Sea. Energy 2015;82:80–97.

[53] Katsigiannis YA, Georgilakis PS, Karapidakis ES. Hybrid Simulated Annealing Tabu Search Method For Optimal Sizing Of Autonomous Power Systems With Renewables. IEEE Trans Sustain Energy 2012;3

[54] Gupta RA, Kumar R, Bansal AK. BBO-based small autonomous hybrid power system optimization incorporating wind speed and solar radiation forecasting. Renew Sustain Energy Rev 2015;41:1366–75.

[55] Nogueira CEC, Vidotto ML, Niedzialkoski RK, de Souza SNM, Chaves LI, Edwiges T, et al. Sizing and simulation of a photovoltaic-wind energy system using batteries, applied for a small rural property located in the south of Brazil. Renew Sustain Energy Rev 2014;29:151–7.

[56] Khatod DK, Pant V, Sharma J. Analytical approach for well-being assessment of small autonomous power systems with solar and wind energy sources. IEEE Trans Energy Convers 2010;25:535–45.

[57] Chen H-C. Optimum capacity determination of stand-alone hybrid generation system considering cost and reliability. Appl Energy 2013;103:155–64

[58] Kaabeche A, Ibtiouen R. Techno-economic optimization of hybrid photovoltaic/wind/diesel/battery generation in a stand-alone power system. Sol Energy 2014;103:171–82.

[59] Ferrer-Martí L, Domenech B, García-Villoria A, Pastor R. A MILP model to design hybrid wind–photovoltaic isolated rural electrification projects in developing countries. Eur J Oper Res 2013;226:293–300.

[60] Gan LK, Shek JKH, Mueller MA. Optimised operation of an off-grid hybrid wind-diesel-battery system using genetic algorithm. Energy Convers Manage 2016;126:446–62.

[61] Sheng W, Liu K-Y, Meng X, Ye X, Liu Y. Research and practice on typical modes and optimal allocation method for PV-Wind-ES in Microgrid. Electr Power Syst Res 2015;120:242–55.

[62] Abbes D, Martinez A, Champenois G. Life cycle cost, embodied energy and loss of power supply probability for the optimal design of hybrid power systems. Math Comput Simul 2014;98:46–62.

[63] Paliwal P, Patidar NP, Nema RK. Determination of reliability constrained optimal resource mix for an autonomous hybrid power system using Particle Swarm Optimization. Renewable Energy 2014;63:194–204.

[64] Fetanat A, Khorasaninejad E. Size optimization for hybrid photovoltaic–wind energy system using ant

colony optimization for continuous domains based integer programming. Appl Soft Comput 2015;31:196–209.

[65] Maleki A, Askarzadeh A. Optimal sizing of a PV/wind/diesel system with battery storage for electrification to an off-grid remote region: A case study of Rafsanjan, Iran. Sustain Energy Technol Assess 2014;7:147–53.

[66] Chang K-H, Lin G. Optimal design of HRES using simulation optimization. Simul Model Pract Theory 2015;52:40–51.

[67] Mukhtaruddin RNSR, Rahman HA, Hassan MY, Jamian JJ. Optimal hybrid renewable energy design in autonomous system using Iterative-Pareto-Fuzzy technique. Int J Electr Power Energy Syst 2015;64:242–9.

[68] Lujano-Rojas JM, Dufo-López R, Bernal-Agustín JL. Probabilistic modelling and analysis of stand-alone hybrid power systems. Energy 2013;63:19–27.

[69] Hong Y-Y, Lian R-C. Optimal sizing of hybridwind/PV/diesel generation in a stand-alone power system using markov-based genetic algorithm. IEEE Trans Power Delivery 2012;27:640–7.

[70] Askarzadeh A. A discrete chaotic harmony search-based simulated annealing algorithm for optimum design of PV/wind hybrid system. Sol Energy 2013;97:93–101.

[71] Maleki A, Khajeh MG, Rosen MA. Weather forecasting for optimization of a hybrid solar-wind–powered reverse osmosis water desalination system using a novel optimizer approach. Energy 2016;114:1120–34.

[72] Khatib T, Mohamed A, Sopian K. Optimization of a PV/wind micro-grid for rural housing electrification using a hybrid iterative/genetic algorithm: Case study of Kuala Terengganu, Malaysia. Energy Build 2012;47:321–31.

[73] Tahani M, Babayan N, Pouyaei A. Optimization of PV/Wind/Battery standalone system, using hybrid FPA/SA algorithm and CFD simulation, case study: Tehran. Energy Convers Manage 2015;106:644–59.

[74] Baghdadi F, Mohammedi K, Diaf S, Behar O. Feasibility study and energy conversion analysis of stand-alone hybrid renewable energy system. Energy Convers Manage 2015;105:471–9.

[75] Olatomiwa L, Mekhilef S, Ohunakin OS. Hybrid renewable power supply for rural health clinics (RHC) in six geo-political zones of Nigeria. Sustain Energy Technol Assess 2016;13:1–12.

[76] Maatallah T, Ghodhbane N, Ben Nasrallah S. Assessment viability for hybrid energy system (PV/wind/diesel) with storage in the northernmost city in Africa, Bizerte, Tunisia. Renew Sustain Energy Rev 2016;59:1639–52.

[77] Bentouba S, Bourouis M. Feasibility study of a wind–photovoltaic hybrid power generation system for a remote area in the extreme south of Algeria. Appl Therm Eng 2016;99:713–9.

[78] Dufo-López R, Bernal-Agustín JL, Yusta-Loyo JM, Domínguez-Navarro JA, Ramírez-Rosado IJ, Lujano J, et al. Multi-objective optimization minimizing cost and life cycle emissions of stand-alone PV–wind–diesel systems with batteries storage. Appl Energy 2011;88:4033–41.

[79] Perera ATD, Attalage RA, Perera KKCK, Dassanayake VPC. A hybrid tool to combine multi-objective optimization and multi-criterion decision making in designing standalone hybrid energy systems. Appl Energy 2013;107:412–25.

[80] Bahramara S, Moghaddam MP, Haghifam MR. Optimal planning of HRES using HOMER: A review. Renew Sustain Energy Rev 2016;62:609–20

[81] Khatib T, Mohamed A, Sopian K, Mahmoud M. Optimal sizing of hybrid pv/ wind systems for Malaysia using loss of load probability. Energy Sour, Part A: Recovery, Utiliz, Environ Effects 2015;37:687–95.

[82] Dufo-López R, Cristóbal-Monreal IR, Yusta JM. Stochastic-heuristic methodology for the optimisation of components and control variables of PV-wind-diesel-battery stand-alone systems. Renewable Energy 2016;99:919–35.

[83] Mokheimer EMA, Sahin AZ, Al-Sharafi A, Ali AI. Modeling and optimization of hybrid wind–solar-powered reverse osmosis water desalination system in Saudi Arabia. Energy Convers Manage 2013;75:86–97.

[84] Maheri A. Multi-objective design optimisation of standalone hybrid wind-PVdiesel systems under uncertainties. Renewable Energy 2014;66:650–61.

[85] Adaramola MS, Agelin-Chaab M, Paul SS. Analysis of hybrid energy systems for application in southern Ghana. Energy Convers Manage 2014;88: 284–95.

[86] Sharafi M, Elmekkawy TY. Multi-objective optimal design of HRES using PSO-simulation based approach. Renewable Energy 2014;68:67–79.

[87] Perera ATD, Attalage RA, Perera KKCK, Dassanayake VPC. Designing standalone hybrid energy systems minimizing initial investment, life cycle cost and pollutant emission. Energy 2013;54:220–30.

[88] Ma T, Yang H, Lu L, Peng J. Technical feasibility study on a standalone hybrid solar-wind system with pumped hydro storage for a remote island in Hong Kong. Renewable Energy 2014;69:7–15.

[89] Rajkumar RK, Ramachandaramurthy VK, Yong BL, Chia DB. Technoeconomical optimization of hybrid pv/wind/battery system using NeuroFuzzy. Energy 2011;36:5148–53.

[90] Abbes D, Martinez A, Champenois G. Eco-design optimisation of an autonomous hybrid wind–photovoltaic system with battery storage. IET Renew Power Gener 2012;6:358–71

[91] Vergara PP, Rey JM, Silva LCPd, Ordóñez G. Comparative analysis of design criteria for hybrid PV/wind/battery systems. IET Renew Power Gener 2016.

[92] Gan LK, Shek JKH, Mueller MA. Hybrid wind–photovoltaic–diesel–battery system sizing tool development using empirical approach, life-cycle cost and performance analysis: A case study in

Scotland. Energy Convers Manage 2015;106:479–94.

[93] Zhao B, Zhang X, Li P, Wang K, Xue M, Wang C. Optimal sizing, operating strategy and operational experience of a stand-alone microgrid on Dongfushan Island. Appl Energy 2014;113:1656–66.

[94] Givler T, Lilienthal P. Using HOMER software, NREL's micro power optimization model, to explore the role of gen-sets in small solar power systems case study: Sri Lanka. Technical Report NREL/TP-710-36774. Available from: http:// www.osti.gov/bridge; 2005.

[95] Hafez O, Bhattacharya K. Optimal planning and design of a renewable energy based supply system for microgrids. Renewable Energy 2012;45:7e15.

[96] Lau KY, Yousof MFM, Arshad SNM, Anwari M, Yatim AHM. Performance analysis of hybrid photovoltaic/diesel energy system under Malaysian conditions. Energy 2010;35(8):3245e55.

[97] Himri Y, Stambouli AB, Draoui B, Himri S. Techno-economical study of hybrid power system for a remote village in Algeria. Energy 2008;33(7):1128e36.

[98] Nandi S, Ghosh HR. Prospect of wind-PV-battery hybrid system as an alternative to grid extension in Bangladesh. Energy 2010;35(7):3040e7.

[99] Bekele G, Palm B. Feasibility study for a sustainable solar-wind-based hybrid energy system for application in Ethiopia. Applied Energy 2010;87(2):487e 95.

[100] Rohit Sen, Subhes C. Bhattacharyya , Off-grid electricity generation with renewable energy technologies in India: An application of HOMER, Renewable Energy 62 (2014) 388-398, . http://dx.doi.org/10.1016/j.renene.2013.07.02

[101] Moghaddam AA, Seifi A, Niknam T, Pahlavani MRA. Multi-objective operation management of a renewable MG (micro-grid) with back-up micro-turbine/fuel cell/ battery hybrid power source. Energy 2011;36:6490–507.

[102] Shuai Z, Fang J, Ning F, Shen ZJ. Hierarchical structure and bus voltage control of DC microgrid. Renew Sustain Energy Rev 2018;82:3670–82.

[103] Zaibi M, Champenois G, Roboam X, Belhadj J, Sareni B. Smart power management of a hybrid photovoltaic/wind stand-alone system coupling battery storage and hydraulic network. Math Comput Simul 2016. 2016/09/24/.

[104] Al-Falahi MDA, Nimma KS, Jayasinghe SDG, Enshaei H. Sizing and modeling of a standalone hybrid renewable energy system. In: 2016 IEEE 2nd annual southern power electronics conference (SPEC); 2016. p. 1–6.

[105] Morais H, Kádár P, Faria P, Vale ZA, Khodr HM. Optimal scheduling of a renewable micro-grid in an isolated load area using mixed-integer linear programming. Renew Energy 2010;35:151–6.

[106] Moradi H, Esfahanian M, Abtahi A, Zilouchian A. Optimization and energy management of a standalone hybrid microgrid in the presence of battery storage system. Energy 2018;147:226–38. 2018/03/15/.

[107] Berrazouane S, Mohammedi K. Parameter optimization via cuckoo optimization algorithm of fuzzy controller for energy management of a hybrid power system. Energy Convers Manage 2014;78:652–60.

[108] Kutaiba S. El-Bidairi, Hung Duc Nguyen , S.D.G. Jayasinghe , Thair S. Mahmoud , Irene Penesis, A hybrid energy management and battery size optimization for standalone microgrids: A case study for Flinders Island, Australia, Energy Conversion and Management 175 (2018) 192–21

[109] M A Hannan, K Parvin, Yoon Khay Kit, Ker Pin Jern, M M Hoque, Particle Swarm Optimization based Fuzzy Logic MPPT Inverter Controller for Grid Connected Wind Turbine, IJRER, Vol 9, No 1 (2019) ,PP 164-174

[110] Balaji Veerasamy, Amruth Ramesh Thelkar , Ganesan Ramu , Takaharu Takeshita , Efficient MPPT control for fast irradiation changes and partial shading conditions on PV systems, 2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA)

[111] Jeremy Every , Li Li , Youguang G. Guo , David G. Dorrell , Maximizing investment value of small-scale PV in a smart grid environment, 2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA)

[112] Md Tofael Ahmed , Teresa Gonçalves , Mouhaydine Tlemcani , Single diode model parameters analysis of photovoltaic cell, 2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA)

[113] Ram Shankar Yallamilli , Mahesh K. Mishra , Power management of grid connected hybrid microgrid with dual voltage source inverter, 2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA)

[114] Surachai Waiwong , Parnjit Damrongkulkamjorn , Optimal sizing for stand alone power generating system with wind-PV-hydro storage by mixed-integer linear programming , 2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA)