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AN APPLLICATION OF MULTIPLE RENEWABLE ENERGY SYSTEMS WITH PLURAL GOAL OPTIMIZATION

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Abstract

The Proposed System is a mixed system with features of renewable nature and hybrid nature. It consists of panels which are photovoltaic in nature (photo voltaic cells), turbines which operates with wind (wind turbines), and also it will have non- stop production of hydrogen through green energy route using reformers. Genetic algorithm is applied for optimization and is validated. In the hypothecated system the storage of hydrogen the annualized cost for storing the hydrogen is minimized and the energy wastage is reduced by 65%. A detailed sensitivity analysis conducted on the effect of cost variation, impact of different kinds of storage, and various capacities on system performance. the issues related to green criteria as environment sustainability has become the need of the hour optimization of cost, and green criteria are taken as objectives in the paper Multi-objective formulation is done, and a suitable metaheuristic is applied to solve the problem.

Key words: photo voltaic cell, green hydrogen, renewable systems

1. Introduction

The continuous exploitation of conventional energy resources and their negative impact on environment led to the development of systems utilizing non fossil fuels like solar energy and wind energy and these two energies have many environmental friendly features but also some negative aspects like their sudden non availability which is beyond the control of system designers. [1,2]. For these reasons the reliability of these systems bound to be low.

The development of power systems which are plural in existence like combination of wind and solar energy in nature, it is absolutely important to see that build systems have large life of reliable working which is associated with minimal costs and reasonable profit. Such systems have to be optimized considering aspects based on cost economics, system reliability etc. It is also important to achieve the above objectives it is absolutely important to search and develop advanced optimization methods. Baghaee, et al., [3] developed a new procedure for optimizing the yearly expenditure, the predicted energy loss, and energy load loss, relating to a micro size grid system which stores hydrogen. photo voltaic cell, wind, and fuel cells the production of hydrogen in hybrid renewable energy system (Hybres) by separating water into elements of Hydrogen and Oxygen through use of conventional electrolysis process, it is noted that Hydrogen generation in Hybres is often produced by deploying electrolysis technique for storing energy which is excess. They are also cases of developing hydrogen from bio masses but such cases are not taken up for optimization purpose. They are many instances of combining the storing of produced hydrogen in the battery but it invariably demanded the presence of electrolyser. The maximizing the process of Hybres is a complicated one due to variance of different sources of energies which are renewable in nature and it is also difficulty arises due to plural technologies, and attempting multi goal optimization consisting of economic type, environmental type and also social type.

This paper attempts mainly on storing the hydrogen through usage of electrolysers. This work incorporates the uninterrupted generation of hydrogen using reformers with enhanced reliability and improved efficiency.

This approach attempts storing of hydrogen through multiple sources and also taken up combining of hydrogen storage in hybrid manner and generation. It also maximizes the important parameters like size and configuration for variable situations. It also attempts to maximize the utilization of multiple storage of hydrogen along with its generation under different conditions.

This paper uses the meta heuristic genetic algorithm and the results are validated by exhaustive sensitivity analysis which concentrates on variation of cost, different types of storage, and capacities with respect to performance of system

2. Literature Review

Ansari [4] implemented an MCDM method by combining AHP and TOPSIS. He also executed a sensitivity analysis while addressing the fuel cost and storage cost. Ma, et al., [5] first time used a specialized Hybrid Genetic algorithm for the purpose of configuration of Hybres and its efficiency measurement is carried out with Pareto optimization methods like multi objective. Techniques. The works that propose first time a Pareto-based multi-objective maximization techniques for Hybres was studied in [6-8]. The utilization of hydrogen in Hybres, as source which is as well as an energy which is renewable in nature and as well as used as storage tool. And this trend is slowly increasing because of its environmental friendly nature along with its sustainability nature according to Modu etc. [9].

The one of the output of electrolysis of water the Hydrogen is stored in two different types of systems one exclusively in liquid form or gaseous form another through usage of battery.

Samy, et al., [10] introduced firs time combining of hybrid systems: photo voltaic cell/fuel cell, photo voltaic cell/wind turbine/fuel cell, and wind turbine/fuel cell. In the above study the results of FPA and the results of the PSO algorithm with SFL Algorithm techniques are compared.

Ceylan and Devrim [11] while applying Hybres to greenhouse while delivering the power and heat to a greenhouse have optimized system efficiency using a software which makes use of MATLAB.

The storage of hydrogen such as in batteries, in Hybres has attracted scientific community very much according to [12].

Sharafi and ElMekkawy [13] a novice method for the design of a Hybres consisting of photo voltaic cell, wind turbines, DG, batteries, and hydrogen storage, while minimizing the entire cost, load which is not supported, and the emissions of fuel system.

Athamnah [14] has executed the management of size and energy for maximizing to a grid-independent Hybres consisting of wind turbine and photo voltaic cell in combination with battery and hydrogen backup systems. According to [15] have designed the best design of a Hybres along with wind turbines, photo voltaic cell systems, for a domestic load, while involving all parameters which are technical, and non-technical.

Bryan, et al., [16] designed an Hybres involving thermal and hydrogen storage which are components like nuclear energy, wind, and solar energy to address needs fully developed metropolitan city in USA. Guo and Niu [17.] designed an optimal method that combines single and multi-goal optimal process for individual Hybres.

Li, et al., [18] developed an integrated the energy systems and storage system to improve the sustainability and minimization of cost.

The PMS maximizes the flow of energy y efficient management of the hydrogen and battery storage at diverse atmospheric situations using only one type of renewable energy system will be always likely to be drawback for the energy production as there is dynamic change in weather, working environment and seasons.

Literature gap identified in the area related to optimization of integration of various green hydrogen techniques is one of the areas to be explored

3. Methodology

The basic design of the grid operating with power from Wind source and power generated from solar source for the stable generation of hydrogen is done while taking the fluctuations in wind energy and solar energy entire day period.

Table-1: Data of renewable sources

	Aggregate	average	Maximum	Minimum	Standard deviation
City 1 data (m/s) relating to wind speed	—	4.412	19.483	0.04564	2.456
City 2 data (m/s) relating to wind speed	—	4.393	10.032	0.00452	2.915
City 3 data (m/s) relating to wind speed	—	3.765	9.965	0.0000	1.964
City 1 data (kWh/m^2) relating to solar radiation	1531.17	0.173	—	—	0263
City 2 data (kWh/m^2) relating to solar radiation	1853.90	0.211	—	—	0.302
City 3 solar radiation data (kWh/m^2 data (kWh/m^2) relating to solar radiation)	1697.01	0.194	—	—	0.281
City 1 data (°C) relating to temperature	—	15.253	26.162	4.795	7.821
City 2 data (°C) relating to temperature	—	17.783	25.344	11.092	5.194
City 3 data (°C) relating to temperature	—	11.824	24.484	–0.472	8.864

3.1 PHOTO VOLTAIC CELL

The design of system which produces the hydrogen generation while taking care of variation of availability of both solar and wind energies should be carefully planned. The equation for generation of power from a photo voltaic cell is presented in Eq. (1)

$$P_{pv} = P_{pv\_rated} \times \frac{R}{R_{stc}} \times (1 + T_{co} \times (T - T_{ref})) \tag{1}$$

In Eq. (1) above, $P_{photo\ voltaic\ cell\_rated}$ denotes the power, R indicates the radiation of sun light(W/m^2), and R_{stc} states the radiation of sunlight all are considered under standard test conditions. T_{ref} is related to the temperature of photo voltaic cell and T_{co} is the factor considers temperature of coefficient. The cell temperature *is denoted by T* and is determined by the ambient temperature (T_{ort}) and R, as computed with Eq. (2)

$$T = T_{ort} + Ri \times 0.026 \tag{2}$$

3.2 Wind turbines

By using the wind turbine energy which is nominal $(P_{wt_{rated}})$, wind turbine hub high heat transfer speed ($V_{hub}(t)$), inlet wind speed of turbine (V_{cin}), rated wind speed (V_{rated}), and speed noticed at exit end of turbine (V_{cout}), and a parameter k *which is having fixed value,* the power produced per hour by the wind turbine ($P_{Wind\ turbine}(t)$) is calculated as follows

$$P_{wt}(t) = \begin{cases} 0 & 0 \le V_{hub} \le V_{cin} \text{ and } V_{hub} > V_{cout} \\ \dfrac{V_{hub}(t)^k - V_{cin}{}^k}{V_{rated}{}^k - V_{cin}{}^k} \times P_{wt_{rated}} & V_{cin} \le V_{hub} < V_{rated} \\ P_{wt_{rated}} & V_{rated} \le V_{hub} < V_{cout} \end{cases} \tag{3}$$

To calculate $V_{hub}(ti)$ at the hub high heat transfer ((h_{hubi}), annual wind speed data measured hourly ($V_{ref}(t)$i) at a reference high heat transfer (hi_{ref}) of 10 m is used:

$$V_{hub}(t) = V_{ref}(t) \times \frac{\ln(h_{hub} / l_{sr})}{\ln(h_{ref} / l_{sr})} \tag{4}$$

where l_{sr} is denoted for the length of the surface roughness (m) which is determined using the relevant PMS algorithm in case of wind turbine.

3.3 Battery

The PMS algorithm is used to protect safe route of battery use and it also safe guard the length of life of battery and it decides the quantity of energy absorbed by the battery as well as energy discharged by the battery also. In case the energy absorbed by the battery exceeds its maximum capacity then extra energy absorbed by battery will be discharged as waste energy. Same procedure is adopted in case battery receives less than the minimum energy it is supposed to receive. In case still energy is not enough, same is taken care by the fuel cell by utilizing hydrogen available by heat transfer and is provided by the reformer.

$p_{exc_{pvwt}}$, is defined as the power produced in time t, which is the deviation in the power generated by photo voltaic cell ($P_{photo\ voltaic\ cell}$) and wind turbines ($P_{Wind\ turbine}$) and the power demanded by the load (P_{load}). It is computed by using Eq.(5). P_{exc} is the deviation between the load requirement and the power made available by the system and is computed. The battery input energy and output energy status (P_{bat_ex}) at t time is computed as indicated in the Eq. (7) and Eq. (8),

$$P_{exc_{pvwt}} = P_{pv} + P_{wt} - P_{load} / e_{conv} \quad (5)$$

$$P_{exc} = P_{load} / e_{conv} - (P_{photo\ volatic\ cell} + P_{Wind\ turbine} + P_{rfr}) \quad (6)$$

$$P_{bat\_ex} = P_{bat(t-1)} + P_{exc_{pvwt}} \times e_{bat\_ch} \quad (7)$$

$$P_{bat\_ex} = \mathrm{P_{bat}}(t-1) - p_{exc} / e_{bat\_dch} \quad (8)$$

e_{bat_ex} and e_{bat_dch} indicate the battery efficiencies of charging and discharging, respectively. the self-release rate of energy of battery is not considered whereas charging and discharging currents are considered

DOFD denotes the maximum power which can be released the battery and is set at 90%. In this study, the maximum recovered energy and the minimum recovered energy from the batteries. The energy stored in the battery should be always be in between above stated minimum and maximum energies.

$$P_{bat\_max} = P_{bat\text{-}r} \times n_{bar} \quad (9)$$

$$P_{bar\_min} = P_{bar\_max} \times (1 - dod) \quad (10)$$

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$$P_{bat\_min} \le P_{bat}(t) < P_{bat\_max} \quad (11)$$

3.4 Electrolyzer

When the power generated by the wind turbine and photo voltaic cell generators crosses the demand asked by power consumer, the surplus energy is passed to the system executing the electrolysis process for the production of hydrogen which is diverted to the fuel cell for storaging. Utilizing the excess power generated from the wind turbines and photo voltaic cells ($P_{exc\_photo\ volatic\ cellWind\ turbine}$), the electrolyzer efficiency (e_{ELC}) and max hydrogen heating value (HHV_{H_2} of 39.42 kWh/kg), the quantity of hydrogen generated (in kg) within the time interval t ($P_{ELC}(t)$)

$$P_{ELC}(t) = \begin{cases} \dfrac{P_{exc_{pvwt}}(t) \times e_{ELC}}{HHV_{H_2}} & \text{if } P_{exc_{pvwt}}(t) \le P_{ELC_{rated}} \times n_{ELC} \\ \dfrac{P_{ELC_{rated}} \times e_{ELC}}{HHV_{H_2}} & \text{if } P_{exc_{pvwt}}(t) \ge P_{ELC_{rated}} \times n_{ELC} \end{cases} \quad (12)$$

where, $P_{ELC_{rated}}$ denotes the maximum power generated by the electrolyzer, and n_{ELC}, denotes the number of electrolyzers, the value of e_{ELC} is taken to be 0.85 in this work.

3.5 Hydrogen tank

To evaluate the quantity of hydrogen stored in the tank generated through water electrolysis / reformer within interval step t (1 h),

$$E_{tank}(t) = E_{tank}(t-1) + P_{elc\_tank}(t) - \frac{P_{tank\text{-}fc}(t)}{e_{tank}} \tag{13}$$

Here E_{tank} denotes the present capacity (kg) of the heat transfer, P_{elc_tank} indicates the hydrogen amount (kg), P_{tank_fc} is the quantity of hydrogen (kg) catered for the storage in the fuel cell, and e_{tank} is the efficiency of the heat transfer and assumed 0.95

3.6 Fuel cell

The hydrogen usage by the fuel cell ($Cons_{H_2}$) during time interval t is computed using the equation stated below.

$$Cons_{H_2} = \frac{P_{tank_{fc}}(t)}{e_{tank}} = \begin{cases} fcic \times P_{fc\_r} \times i + fcs \times P_{fc}(t) & \text{if } P_{def}(t) \le P_{fc_r} \times i \quad (i \le n) \\ fcic \times P_{fc\_r} \times i + fcs \times P_{fc}\_r & \text{if } P_{def}(t) > P_{fc_r} \times i \quad (i \le n) \end{cases} \tag{14}$$

where $fcic$ denotes the intercept value of the fuel cell (kg/hr/ kW_{rated}), fcs is the slope constant (kg/hr/kW) value of the fuel cell, P_{fc_r} denotes the output power generated by the fuel cell (kW), $P_{fc}(t)$ represents the power generated by the fuel cell for the time with interval t (kW), P_{dcf} denotes the power in shortage ,n represents fuel cells considered in this case and i denotes the working fuel cells during time t., the values of $fcic$ and fcs are set at 0.075 kg/h/kW and 0.245 kg/h/kW.

If $i < n$, then required fuel cells which are necessary only will be activated to fulfil load needs.

The hydrogen utilized is proportional to their rated power, the PMS maximizes the hydrogen utilization of the fuel cells,

Heating value of hydrogen (LHV_{H_2} = 33.33 kWh/kg), the fuel cell efficiency (η_{fc})

$$\eta_{fc}(\%) = \frac{P_{fc}}{LHV_{H_2} \times Cons_{H_2}} \times 100 \tag{15}$$

3.7 Reformer

The hydrogen generated from biogas is sent to the fuel cell for transforming into electrical power. The maximum hydrogen output of the reformer (P_{H_2}),

$$W(\text{kg}) = \frac{P_{H_2}(\text{kg})}{0,0454} \tag{16}$$

The power generated by the fuel cell in t h hour *t*, s:

$$P_{fc\_rfr}(t) = (Cons_{H_2^{\cdot}}(t) - fcic \times P_{fc\_r}) / fcs \tag{17}$$

4. Multi-goal Maximization

To face the challenges described above the following objective function with necessary constraints have been formed. The fundamental aim of this paper is to calculate the best design of Hybres components to reduce annualised cost as much as possible, and PEW. steps of GA are depicted in Fig.3. The objective function is

$$\min F_{x.y} = \{F_{AC}, F, F_{PEW}\} \tag{18}$$

$x = (i_{photo\ voltaic\ cell}, i_{wind\ turbine}, i_{FC}\ i_{ELC}, i_{heat\ transfer}, i_{RFR})$

$y = (n_{photo\ voltaic\ cell}, n_{wind\ turbine}, n_{FC}, n_{ELC}, n_{heat\ transfer})$

subject to

$0 \le i_{photo\ voltaic\ cell}, i_{wind\ turbine}, i_{FC}\ i_{ELC}, i_{heat\ transfer}, i_{RFR} \le S_{\max}$

$1 \le n_{photo\ voltaic\ cell}, n_{wind\ turbine}, n_{FC}, n_{ELC}, n_{heat\ transfer} \le N_{\max}$

$0 \le \le {}_{\max}$

$0 \le PEW \le PEW_{\max}$

Here, F_{AC}, $_{\max}$ and $PEW_{\max}$ represent the ultimate allowed values for AC and *PEW*, which are designed to have at 5% and reliability losses are to be maintained within tolerable limits. Additionally,

$N_{\max}$ represents the total number of each system component which are allowed.

$S_{\max}$ denotes the optimum value for each component permitted.

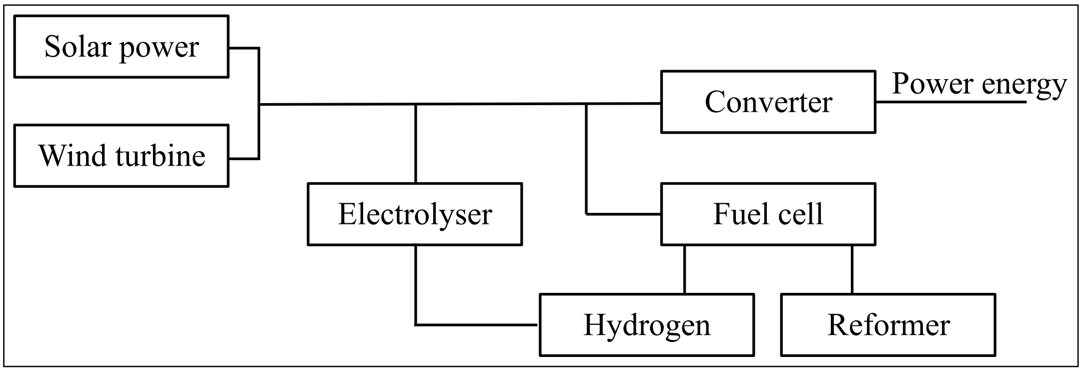

Fig. 1: Scheme considered

Table-2: System components data

Component of the System	Size Options	Options allowed
Photo voltaic cell	0 to 6 kilowatts in steps of 1 kilowatt	One to fifteen
Wind turbine		
Fuel cell		
Heat transfer	0 to 4 kg in steps of 0.5 kgs	
Reformer	0 to 8 kg in steps of 0.5 kgs	—
Electrolyzer	0 to 6 kilowatts in steps of 1 kilowatt	One to sixteen
Battery		

The system comprises of nominal output power, photo voltaic cell's temperature coefficient, efficiency coefficient relating to the fuel cell, and the inlet and outlet of the wind turbine. From the above Table-2 the algorithm randomly selects the value for each parameter.

4.1 Objective function

In the annualised cost design, the nominal interest rate ($ir_{nominal}$) is assumed as 0.05 and the rate of inflation for twelve months (*fr*) is taken as 0.04.

Table-3: Parameters for GA

Parameters	Values
Size of Population	60
Maximum generations	80
Rate of Crossover	0.8
Rate of Mutation	0.25
Probability of Mutation	0.025

Table-4: Parameters used in multi objective

Parameters	Values
Permitted iterations	80
Size of population	80
Size of repository	40
Inertia weight transfer	0.4
transfer damping rate of Inertia weight	0.89
Coefficient of personal learning	0.9
Coefficient of global learning	3
No. of grids per dimension	7
Rate of inflation	0.1
selection pressure of leader	2
selection pressure of deletion	2
Rate of mutation	0.1

Table-5: Objective functions applied in GA

Objectives	Equations
The economic objective	$ACS\left(\frac{\$}{\text{year}}\right)=\sum_{i=1}^{n} N_i \times [(CC_i + RC_i \times F_i(ir, Li, yi)) \times CRF(ir,R) + OMC_i]$ $ir = \frac{ir_{no\min al} - fr}{1+fr}$ $CRF[ir,R] = \frac{ir[1+ir]^R}{[1+ir]^R - 1}$ $F = \sum_{n=1}^{Y_i} \frac{1}{[1+ir]^{L_i \times n}}$ If R is divisible by L; $Y = \frac{R}{L} - 1$ else or $Y = \frac{R}{L}$ $PEW = \frac{\sum_{t=1}^{8760} P_{exc_{pvwt}}(t) - P_{ren\_elc}(t)]}{\sum_{t=1}^{8760} P_{syst}(t)}$ $P_{syst}(t) = P_{photo\ voltaic\ cell}(t) + P_{Wind\ turbine}(t) + P_{rfr}(t)$
The efficiency objective rrenewable energy fraction	REF(x) ′ = REF(x) − REF(xmin) /REF(x max) − REF(xmin)

Abbreviations

n	:	The system elements considered
N	:	The component number taken i

CC_i : The component *I* capital cost ($/kW)

OMC_i : The yearly O&M costs

ir : The actual rate interest

$ir_{nominal}$: The Nominal rate of interest

fr : The yearly inflation rate

CRF : The retrieval factor of the capital

R : The project life span

L_i : Residual useful life span of component i

Y_i : Frequency of component *I is replaced*

$P_{load}(t)$: Per hour demand

$P_{siest}(t)$: Output delivered from the hybrid system per hour

$P_{bealr}(t)$: Battery's energy at time

e_{ceolnv} : The efficiency of the converter

$P_{renle\_elc}(t)$: The extra power transferred from photo voltaic cells and wind turbines to electrolyzers

$P_{rene\text{-}bat}(t)$: Extra power diverted from photo voltaic cells, wind turbines to batteries

R : The working period of the project is taken as 25 years.

Here design of the system is such that hydrogen will be available as backup energy and as a direct energy to keep it in such a manner an uninterrupted hydrogen generation is made possible. the size of fuel cell and reformer is to be kept as same size. Any excess hydrogen produced is transferred to fuel cell.

Table-6: Decision variables

Elements	Notation
Photo voltaic cell type (kW)	$i_{photo\ voltaic\ cell}$
Wind turbine type (kW)	$i_{wind\ turbine}$
Fuel cell (kW)	i_{FC}
Electrolyzer (kW)	i_{ELC}
Battery type (kW)	i_{BAT}
Heat transfer type-1 (kg)	$i_{H;T}$
Heat transfer type-2 (kg)	$i_{R;FR}$
Photo voltaic cell type number	$n_{photo\ voltaic\ cell}$
Wind turbine number	$n_{wind\ turbine}$
Fuel cell number	n_{FC}
Electrolyzer number	n_{ELC}
Battery number	n_{BAT}
Heat transfer number	$n_{heat\ transfer}$

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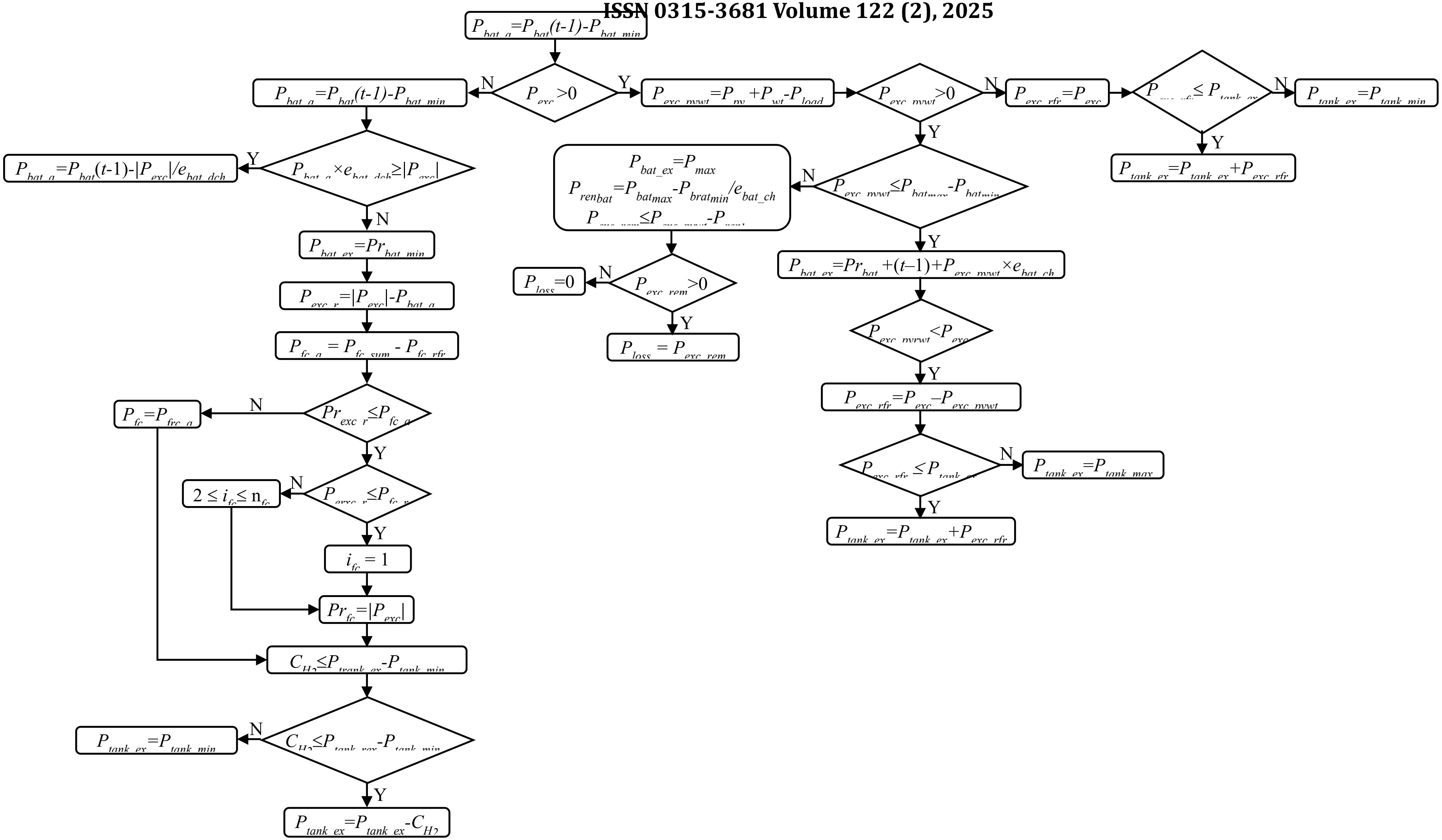

Fig. 2: Parameters

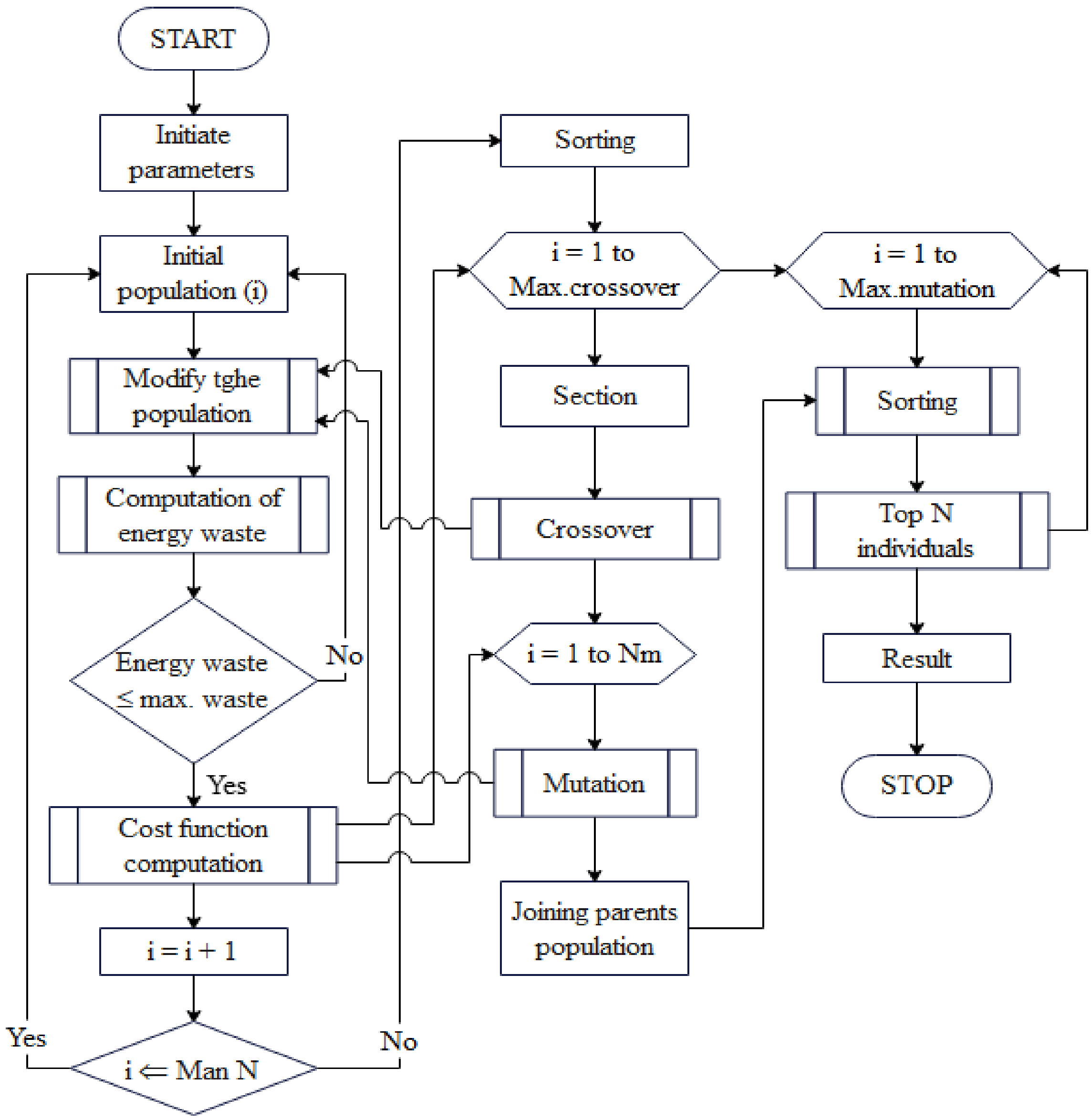

Fig. 3: GA

5. Results

5.1 Multi-objective optimization results

The Pareto solutions obtained presented below.

Table-7: results for City 1

		$i_{photo\ voltaic\ cell}$	$n_{photo\ voltaic\ cell}$	$i_{wind\ turbine}$	$n_{wind\ turbine}$	i_{PC}	n_{PC}	i_{ELC}	n_{ELC}	$i_{heat\ transfer}$	$n_{heat\ transfer}$	i_{RFR}	Annualised cost		PEW
		(kW)		(kW)		(kW)		(kW)		(kW)		(kg)	($/y)	(%)	(%)
1	Least annualised cost result	4	1	1	4	3	1	0	–	1,5	3	0.8	5129.25	4.66	1.72
2	Lowest PEW result	3	1	4	1	2	2	3	1	4	15	0.8	10566.14	4.79	0.12

Table-8: Results for City 2

		i_{photo} voltaic cell	n_{photo} voltaic cell	i_{wind} turbine	n_{wind} turbine	i_{PC}	n_{PC}	i_{ELC}	n_{ELC}	i_{heat} transfer	n_{heat} transfer	i_{RFR}	Annualised cost		PEW
		(kW)		(kW)		(kW)		(kW)		(kW)		(kg)	($/y)	(%)	(%)
1	Least annualised cost result	3	1	1	3	3	1	1	2	1,5	2	0.8	5127.30	4.60	1.27
2	Least PEW result	0	–	1	4	3	2	2	1	4	15	0.8	10586.06	4.06	0.06

The outcomes of objective function (annualised cost and PEW) are shown in Table-10 for three cities: City 1, City 2 and City 3.

Table-9: Results for City 3

		i_{photo} voltaic cell	n_{photo} voltaic cell	i_{wind} turbine	n_{wind} turbine	i_{PC}	n_{PC}	i_{ELC}	n_{ELC}	i_{heat} transfer	n_{heat} transfer	i_{RFR}	Annualised cost		PEW
		(kW)		(kW)		(kW)		(kW)		(kW)		(kg)	(rs/y)	(%)	(%)
1	Least annualised cost result	2	2	1	5	3	1	0	–	3,5	2	0.8	562500.62	4.61	3.56
2	Least PEW result	2	1	1	4	3	2	2	2	4	15	0.8	1059600.09	4.67	0.60

Table-10: Intermittent solutions

		i_{photo} voltaic cell	n_{photo} voltaic cell	i_{wind} turbine	n_{wind} turbine	i_{PC}	n_{PC}	i_{ELC}	n_{ELC}	i_{heat} transfer	n_{heat} transfer	i_{RFR}	Annualised cost		PEW
		(kW)		(kW)		(kW)		(kW)		(kW)		(kg)	($/y)	(%)	(%)
City 1	Autumn day	3	1	4	2	2	2	1	5	4	15	0.8	1170100.65	1.56	2.22
City 2	Winter day	1	1	1	4	3	2	1	2	3	10	0.8	926200.86	1.57	1.89
City 3	Summer day	3	1	2	4	2	2	3	5	4	6	0.8	1143500.52	2.98	2.96

5.3 Sensitivity analysis

Sensitivity analysis is conducted to explore the effect of various factors on the cost and positive side possibilities of the designed Hybrid system. It is presented in Fig.4.

5.3.1 The influence of components system considered on the variations of cost per twelve months

The results of the Pareto method with the maximum annualised cost values in City 1 are proved as best among others. The evaluation of the individual system component on annualised cost, on all other parameters are presented graphically in the Fig. 4.

Fig. 4 demonstrates the impact of variations in cost for all system components for City 1. It depicts annualised cost is more effective for variations in fuel cell and heat transfer costs. There is a drop of 45% in fuel cell costs which results in a 16% drop in annualised cost, heat transfer costs lead to a 14.5% decrease. photo voltaic cell costs have a minimal impact, decreasing of 0.52% in case of annualised cost, wind turbine, the impact of costs for electrolyzer and reformer having reasonably less effects, and it results in reduction of 5.85%, 8.91%, and 3.65%, annualised cost by respectively.

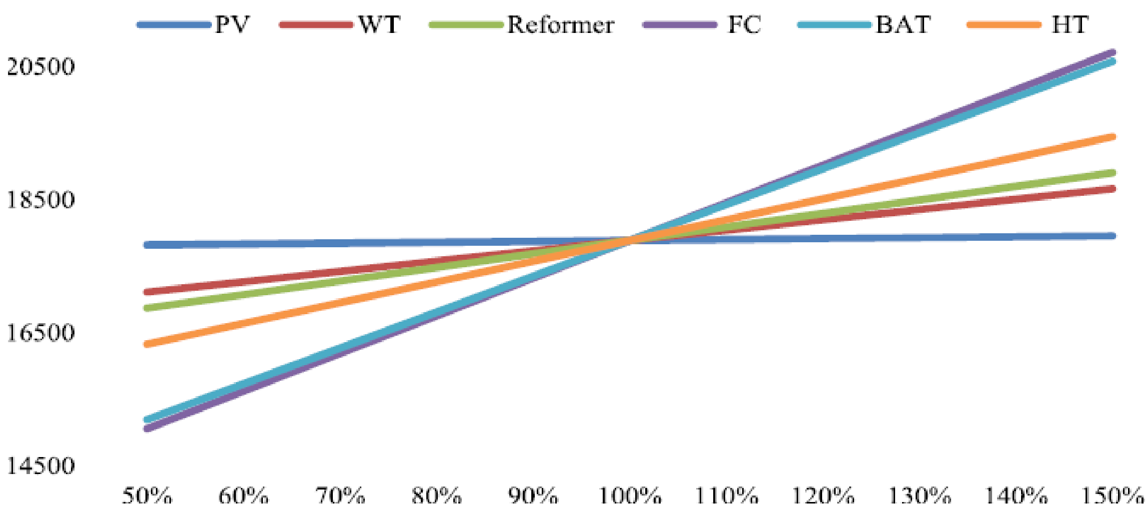

Fig. 4: Sensitivity analysis

Table-11: Variation of Pareto solutions

	Photo voltaic cell	Fuel cell	Electrolyzer	PEW (%)	Annualised cost (RS)	Reformer (kg)	Heat transfer (kg)	Wind turbine
GAmin annualised cost Solution	4 (4 kW*l)	3 (3kW*l)	0	1.89	512900.25	0.8	4.5 (1.5 kW*3)	3 (1 kW*3)
Multi objective min annualised cost Solution	4	3	0	2.33	567400.	0.8	8	2
GAmin Solution	3 (3 kW*l)	6 (3kW*2)	5 (1 kW*5)	4.47	1120000.	0.8	60 (4 kW*15)	6 (1 kW*6)
Multi objective min Solution	4	3	5	4.45	1002500.46	0.8	60	9.5
GAmin PEW	3 (3 kW*l)	6 (3kW*2)	3 (3 kW*1)	0.10	1048000.24	0.8	60 (4 kW*15)	4 (4 kW*1)
Multi objective min PEW	4	3	5	0.61	875600.57	0.6	60	4

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