Chapter 4

Optimal sizing of the Hybrid Renewable Energy System (HRES)

4.1 Introduction

This chapter first presents the design optimization of a hybrid PV Hydro based renewable energy system. The mathematical model for the system's optimal sizing is discussed. The overview of the selected study area's load profile along with the assessment of relevant data required for the system model is also presented. This is followed by the design optimization for the hybrid system using the same approach as reported in chapter 3 for comparison of 23 optimization algorithms.

4.2 Developing an effective mathematical model for PV Hydro Hybrid Renewable Energy System(HRES)

This study utilizes the findings of research [181] on the hydrology model to estimate the flow rate for the region throughout several seasons. The hydraulic, mechanical power and total energy generated given by [64, 166]:

$$P_{H,h} = \rho \times g \times H \times Q(t) \tag{4.1}$$

$$P_{H,m} = P_{H,h} \times \eta_{tb} \tag{4.2}$$

$$E_H = P_{H,h} \times T_{Turbine} \tag{4.3}$$

Where, $P_{H,h}$ = hydraulic power at the turbine shaft, W
ρ = density of water, g/m^3
g = gravitational acceleration, m/sec^2
H = gross head of the turbine, m
Q (t) = water discharge through turbine, m^3/sec
$P_{H,m}$ = mechanical power output, W
η_{tb} = conversion efficiency of turbine
E_H = energy generated from the turbine, Wh
$T_{Turbine}$ = time period for which turbine is active, h.

The output power and energy of a PV system is calculated using the methodologies reported in the literature [222, 243]:

$$P_{PV,e} = \eta_{PV,m} \times A \times G_T \times (1 - 0.005 \times (t_a - 25)) \tag{4.4}$$

$$E_{PV} = P_{PV,e} \times T_{Sun} \tag{4.5}$$

Where, $P_{PV,e}$ = electrical power output from the PV system, W,
A = surface area of the PV system, m^2,
G_T = incident global radiation, W/m^2,
t_a = outside air temperature, $^\circ C$,
$\eta_{PV,m}$ = conversion efficiency of the solar module.
E_{PV} = energy output from the PV system, Wh
T_{Sun} = time period for which sunlight is falling on PV system, h.

The HRES consisting of the PV and Hydro system components are modeled mathematically for the optimal sizing problem. Solar irradiance and average temperature are the key parameters needed to design the PV system, and these values are exacted from National Renewable Energy (NREL)[198] over the span of 15 years while the rainfall data has been collected from India Meteorological Department (IMD)[92]. The modeling of the hydro-system requires data for run off and effective elevation which are taken from the work of Pandey [181].

The Levelized Cost of Energy (LCOE) function serves as an objective function for determining the cost associated with supplying a single unit of energy. The capital cost, operation and maintenance costs, salvage value, and lifetime of both the hydro and PV systems are obtained from renewable energy tariff orders prepared by India's Central Electricity Regulatory Commission, which is part of the Ministry of Power's Electricity Regulatory Commission [31]. The LCOE is computed using the method and equations described in this literature. The system's maximum guaranteed energy output is obtained by maximizing $E_{g,HRES}$ with the help of the following equations [123],

$$E_{g,HRES} = (P_{PV} \times T_{g,PV}) + (P_H \times T_{g,H}) \tag{4.6}$$

$$T_{g,PV} = P(R_{e,PV}) \times T_{h,PV} \tag{4.7}$$

$$T_{g,H} = P(R_{e,H}) \times T_{h,H} \tag{4.8}$$

Where, $E_{g,HRES}$ = guaranteed energy output per year, Wh
P_{PV} = output power from the PV system, W
P_H = output power from the hydro system, W
$T_{g,PV}$ = guaranteed time for which radiation to be exceeded, h
$T_{g,H}$ = guaranteed time for which runoff to be exceeded, h
$P(R_{e,PV})$ = probability of radiation to be exceeded,
$P(R_{e,H})$ = probability of runoff to be exceeded,
$T_{h,PV}$ = total sunshine duration over year, h .
$T_{h,H}$ = total hours in a year, h
The capacity of the HRES is bounded by a number of constraints. The constraints for the hydro system are as follows:

$$Q(t)_{min} < Q(t) < Q(t)_{max} \tag{4.9}$$

$$0 < H \leq H_{max} \tag{4.10}$$

$$C_H = D_{max} \tag{4.11}$$

The PV system constraints are given as:

$$0 < A_{PV} \leq A_{PV,max} \tag{4.12}$$

$$0 < R_D \leq R_{D,max} \tag{4.13}$$

$$0 < P_{PV,peak} \leq (m \times C_H) \tag{4.14}$$

Where, Q(t) = discharge of turbine, m^3/sec,
H = head of the turbine of the hydro system, m
C_H = capacity of the hydro system, W
D_{max} = maximum demand, W
A_{PV} = area of the PV system, m^2

R_D = radiation used for sizing of PV system, W/m^2
$P_{PV,peak}$ = power output from PV system at peak radiation, W
m = a factor which depends on capacity of hydro system and number of units in hydro system, m < 1 .
The LCOE is calculated as given by[123]:

$$LCOE = \left(\frac{ALC}{\sum_{t=1}^{8760} E_L(t)} \right) \tag{4.15}$$

$$ALC = A_{CC} + A_{O\&M} - A_{Sal} \tag{4.16}$$

$$\begin{aligned} A_{CC} = [P_{PV} \times (C_{PV,C} + C_{PV,e} + C_{PV,m}) \\ +P_H \times (C_{H,C} + C_{H,e} + C_{H,m}) \\ +N_{BAT} \times (C_{BAT,C} + C_{BAT,e})] \times CRF \end{aligned} \tag{4.17}$$

$$\begin{aligned} A_{O\&M} = P_{PV} \times C_{PV,O\&M} + \\ P_H \times C_{H,O\&M} + N_{BAT} \times C_{BAT,O\&M} \end{aligned} \tag{4.18}$$

$$A_{Sal} = [P_{PV} \times C_{PV,Sal} \times l + P_H \times C_{H,Sal} \times l] \times CRF \tag{4.19}$$

$$l = \frac{1}{(1 + i_d)^n} \tag{4.20}$$

$$CRF = \frac{i_d \times (1 + i_d)^n}{(1 + i_d)^n - 1} \tag{4.21}$$

$$i_d = \frac{i_{nom} - i_{inf}}{1 + i_{inf}} \tag{4.22}$$

Where, LCOE = levelized cost of energy, Rs/kWh
ALC = annual levelized cost, Rs
$E_L(t)$ = energy supplied, kWh
A_{CC} = annual capital cost of HRES, Rs
$A_{O\&M}$ = annual operation and maintenance cost of HRES, Rs.
A_{Sal} = annual salvage value of HRES, Rs
P_{PV}&P_H = capacity of PV system and Hydro system respectively, kW
N_{BAT} = number of batteries
$C_{PV,C}, C_{H,C}, C_{BAT,C}$ =capital cost of PV and hydro system, and batteries respectively, Rs.
$C_{PV,e}, C_{H,e}, C_{BAT,e}$ =erection cost of PV and hydro system, and batteries respectively Rs.
$C_{PV,m}, C_{H,m}$ = mechanical cost of PV and hydro system, Rs.

$C_{PV,O\&M}, C_{H,O\&M}, C_{BAT,O\&M}$ = operation and maintenance cost of PV and hydro system, and batteries respectively, Rs.
$C_{PV,Sal}, C_{H,Sal}$ = salvage value of PV and hydro system, Rs.
CRF = capital recovery factor
i_d= discount factor
i_{nom} = nominal interest rate
i_{inf} = inflation rate.
The number of batteries can be decided according to requirement of backup. It is derived as:

$$C_{A,h} = \frac{E_L \times D_A}{V_B \times DoD \times \eta_B} \tag{4.23}$$

$$N_{BAT} = \frac{C_{A,h}}{C_{A,h1}} \tag{4.24}$$

Where, $C_{A,h}$ = Capacity of Battery, Ah
N_{BAT} = number of battery required,
E_L = Daily energy consumption, Wh
D_A = Days of Autonomy
V_B = Voltage of Battery, volts
DoD = Depth of Discharge
η_B = Efficiency of Battery,
$C_{A,h1}$ = Capacity of single Battery, Ah.

The literature clearly demonstrates that the cost of the hybrid system has been carefully considered while defining the optimization problem or objective function. However, in the majority of studies, the Capital Cost of a hydro-power project is disregarded. The present analysis incorporates the capital expenditure of the hydro-power project, encompassing the expenses related to civil construction and electromechanical equipment, given by [31,144,178].

$$C_{CW} = 89322 \times p^{0.1141} \times H^{-0.2566} \tag{4.25}$$

The cost of the electromechanical equipment in (INR/kW),

$$C_{EW} = 181680 \times p^{0.1719} \times H^{-0.5401} \tag{4.26}$$

4.2.1 Study Area and Load Profile

As per the economic survey report (2019-2020) by the Nagaland government [169], the state satisfies its power requirements by generating 24 MW of electricity inter-

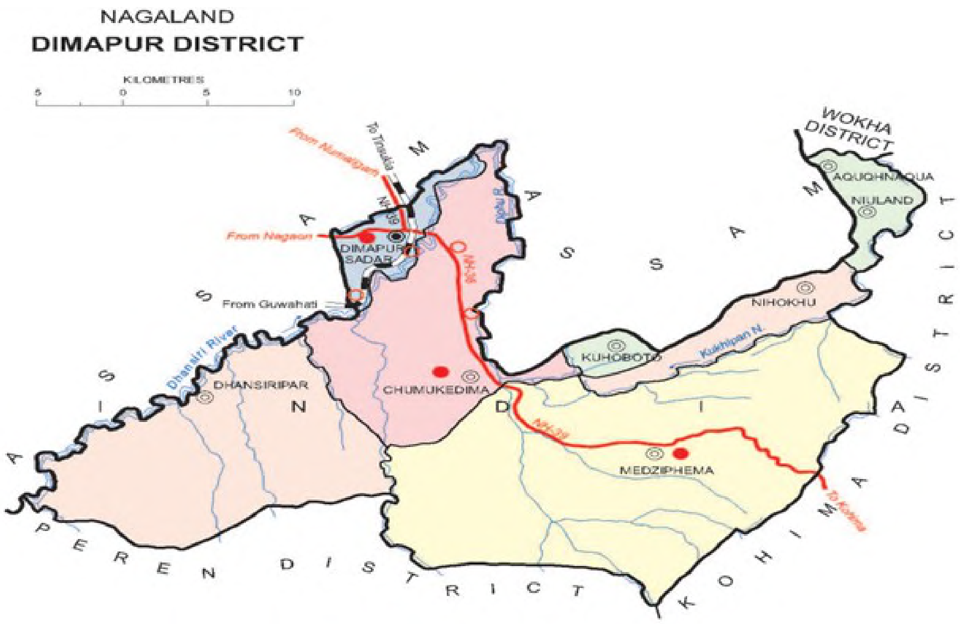

Figure. 4.1: Map of Dimapur District

nally and obtaining 155 MW from various central government initiatives like the National Hydroelectric Power Corporation (NHPC), North Eastern Electric Power Corporation Limited (NEEPCO), National Thermal Power Corporation (NTPC), and Oil and Natural Gas Commission (ONGC) Tripura Power Company Limited (OTPC). Nagaland frequently experiences load shedding and power disruptions during periods of low hydro output, since the peak season demand amounts to around 160 MW, with hydro power serving as a significant power source. The remote geographical position also poses challenges in expanding the grid. According to the study published by Power Finance Limited [200] about the performance of state utilities, the average aggregate technical and commercial (AT&C) loss in India for the fiscal year 2019-20 is stated to be 22.01%. However, due to the aforementioned constraints, the AT&C loss in Nagaland is approximately twice the national figure, amounting to 52%.

According to this report, Nagaland is included in the category of states that saw a decline in financial performance for the financial year 2018-2019 compared to the preceding financial year, 2017-2018. HRES can have a substantial impact in this scenario. Hence, the chosen location for the present study is Hazadisa village, situated inside the Dhansiripar subdivision of Dimapur district, Nagaland. Located near the basin of the Dhansiri River, the Latitude and Longitude of the location are 25.69 °N, 93.54 °E, and 32 Km south of the district headquarters. According to the 2011 population census data [247], the region's village comprises a total of 93 homes, consisting of 232 men and 226 females.

4.2.2 Load Assessment

A load assessment was carried out while keeping a locality's basic requirements in mind and as reported in literature [124, 181, 192]. When calculating electricity demand, the following factors were considered: domestic load, commercial load, agricultural load and community load. Due to their rural location, the selected community has a limited need for electrical power. The load demand considered in this study encompasses home appliances including lighting, fans, television and set-top boxes. Commercial loads includes lighting and fans for the shops, while agricultural loads are primarily for water pumping. Furthermore, the community loads such as street lighting, fans and lights in schools, halls and cooperative societies are considered in this study.

The load profile estimated for the current research area is displayed in Figure 4.2 which shows a daily hourly load profile for three seasons, namely summer considered for the period March-May, rainy seasons from June-October and winter period which is considered between the months of November-February. The maximum daily demand (in kWh) for summer, winter and rainy are respectively 332.6, 173.6, 268.3. Peak load (in kW) for each season, namely summer, rainy and winter has been obtained as 24.61, 11.1, 17.4 respectively and the base demand for the site is 4.8 kW.

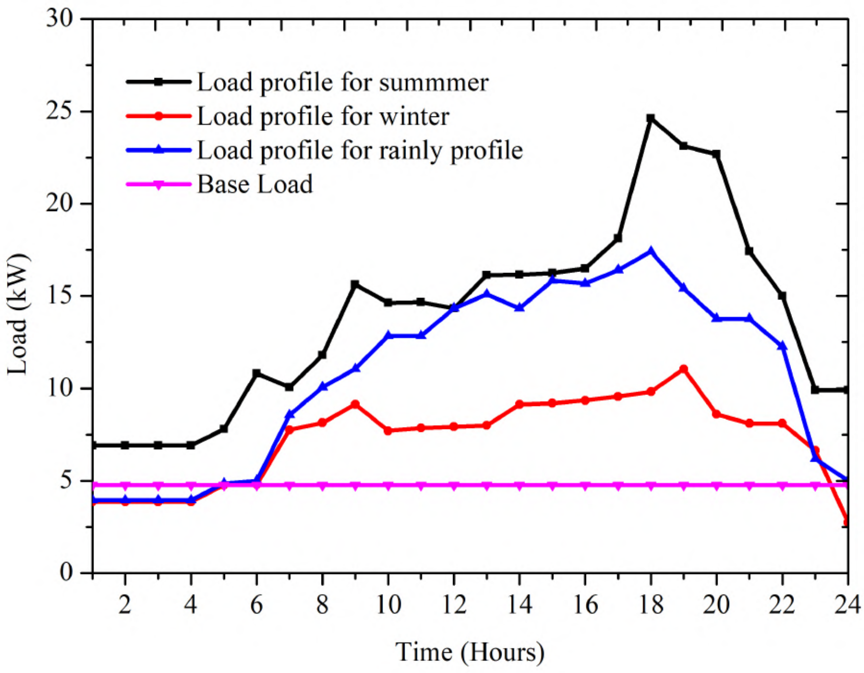

Figure. 4.2: Load variation in study area for different seasons [181]

4.2.3 Assessment of study's area Meteorological data

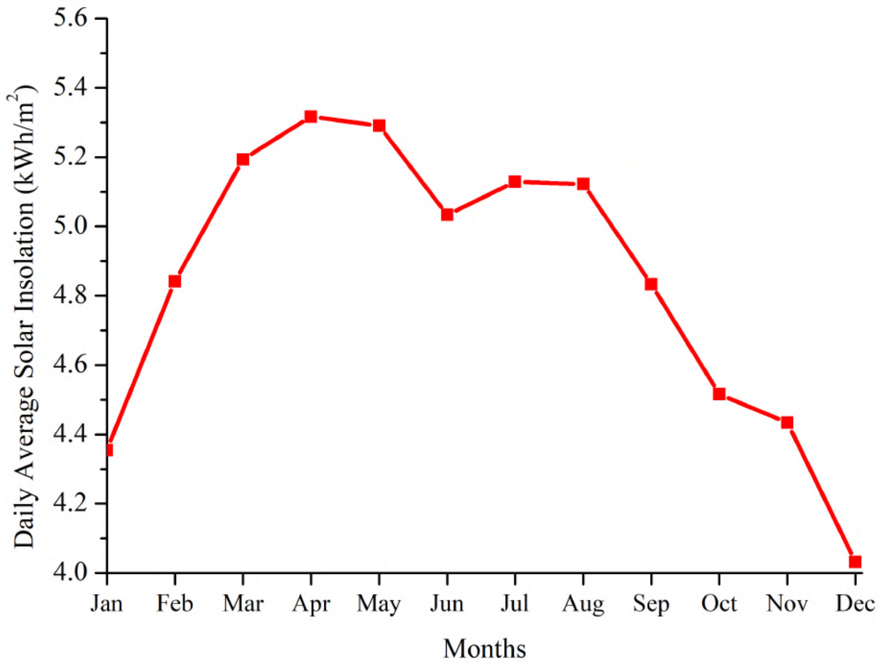

Figure. 4.3: Daily average solar insolation data for the study area (2000 to 2014)

The meteorological data of study area consists of raw data in the form of solar irradiance, rainfall, temperature for the span of (2000-2014) as reported also in [181]. Solar irradiance and temperature are taken from National Renewable Energy Laboratory (NREL) [198] and precipitation data has been recovered from Indian Meteorological Department (IMD) [92]. From figure 4.3 we have observed that maximum average solar irradiance has been found in the month of April that is 5.32 kW/m^2/day and minimum in the month of December that is 4.03 kW/m^2/day.

Availability of rainfall is one of key meteorological parameter for consideration of hydro power plant. The higher the accuracy in the available data, the more reliable the designing of system would be. Rain fall data has been extracted from IMD over the span of 15 years for the selected reference area. From figure 4.4 it is observed that the monthly average of rain fall in June is found as maximum while the minimum is observed for the month of December that is 225.7 mm and 28 mm respectively.

Temperature is another key parameter used to design the solar system and relevant data is extracted from the NREL over the span of 15 years for better and

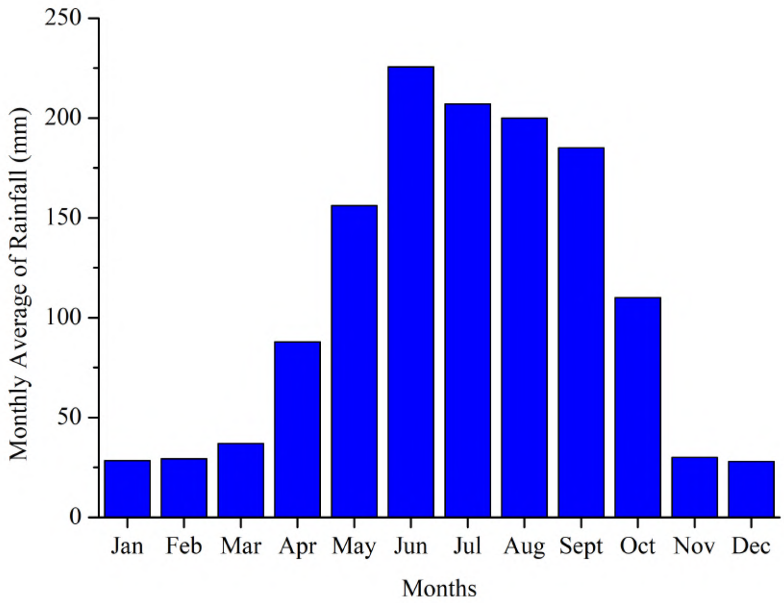

Figure. 4.4: Monthly Rainfall duration over a year (2000 to 2014)

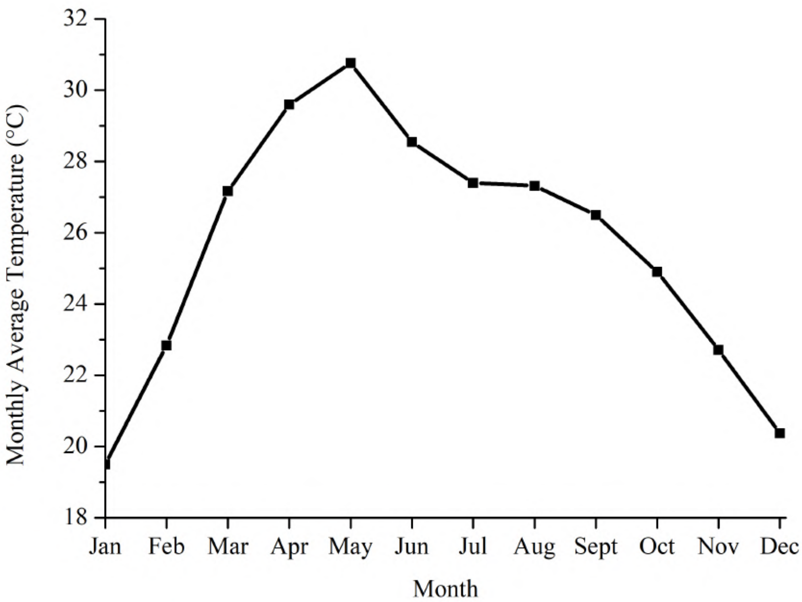

Figure. 4.5: Monthly average temperature for the study area (2000 to 2014)

reliable design of the solar PV system. Recognizing that solar systems cannot function at night, in order to guarantee dependable and steady operation and to closely resemble an actual system, temperature values are extracted from 6 am to 4 pm. From the figure 4.5 we have observed that the minimum average temperature for the region has been obtained from the month of January and maximum is for the month of May that is 19.5° and 30.8 ° Celsius respectively. Average monthly temperature of study area increases gradually from January till May and decreases thereafter.

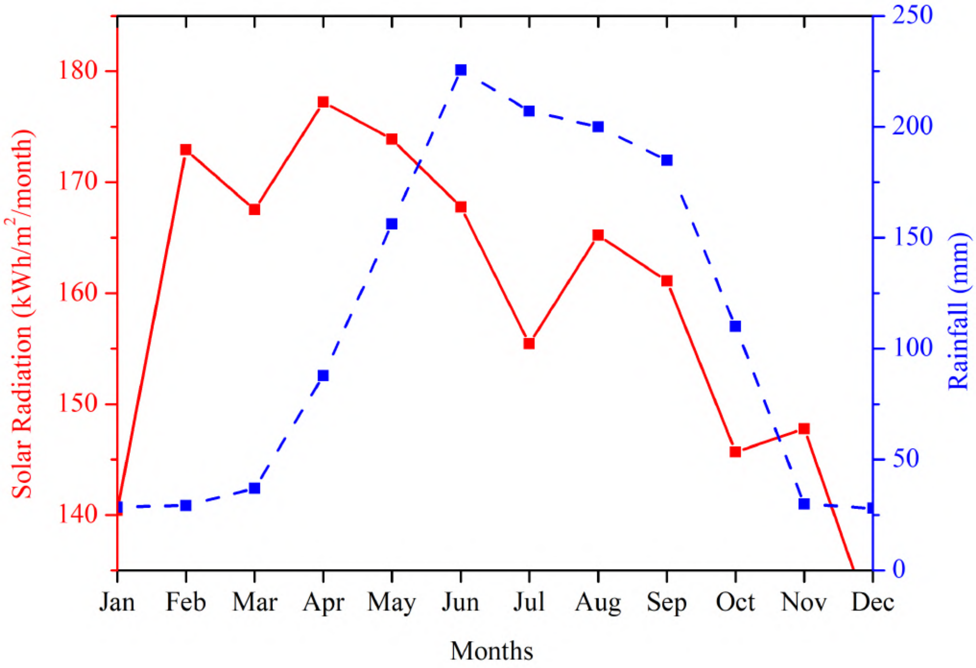

Figure. 4.6: Availability of solar radiation and rainfall for a year (2000 - 2014)

After plotting monthly average for both rainfall and solar irradiance it is observed (figure 4.6) that for most of time, there is near complimentary behavior in nature in reference to each other. It is clearly seen that from the months of May to October when there is continuous decrement in solar radiation the rainfall is relatively high for that period. Similarly, from February to April when rainfall is low solar radiation is high but for the month of January, November and December, this characteristic of complementary nature is not always evident, therefore a battery backup is added in efforts to make the system reliable.

From the work in [181] and as shown in Figure 4.7 the maximum and minimum elevation of the study region, which has been observed to be 189.85 meters, and 177.11 meters respectively, with an effective elevation variation of 12.74 meters. The evaluation of the required hydro head is necessary in order to determine the optimum hydro size for the hydroelectric system.

Runoff calculated from the SCS-CN number method [181] is shown in the figure 4.8 and its observed that the maximum runoff obtained from the calculation is 6.34 (m^3/sec) for the month of June and the minimum has been observed for

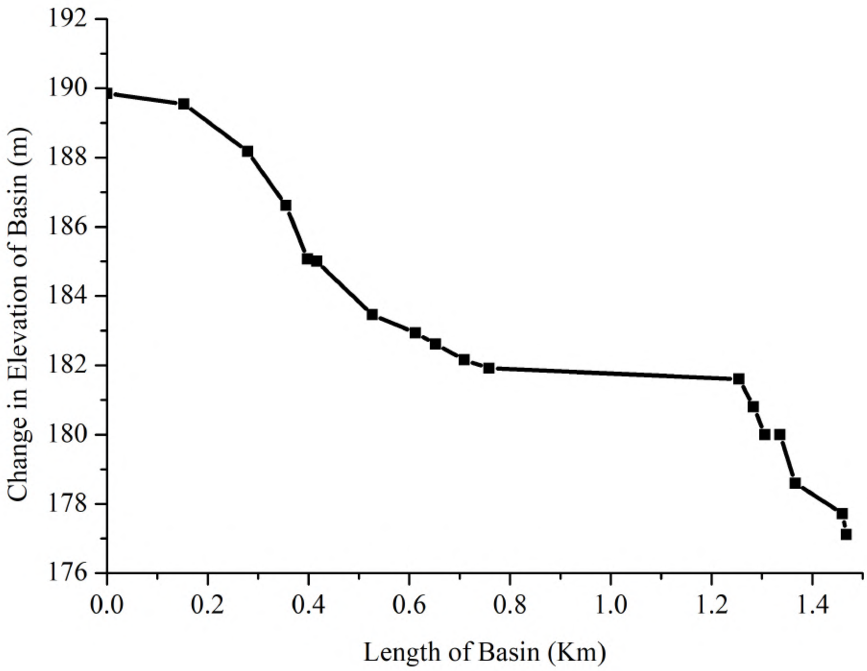

Figure. 4.7: Variation in the elevation w.r.t length of the basin [181]

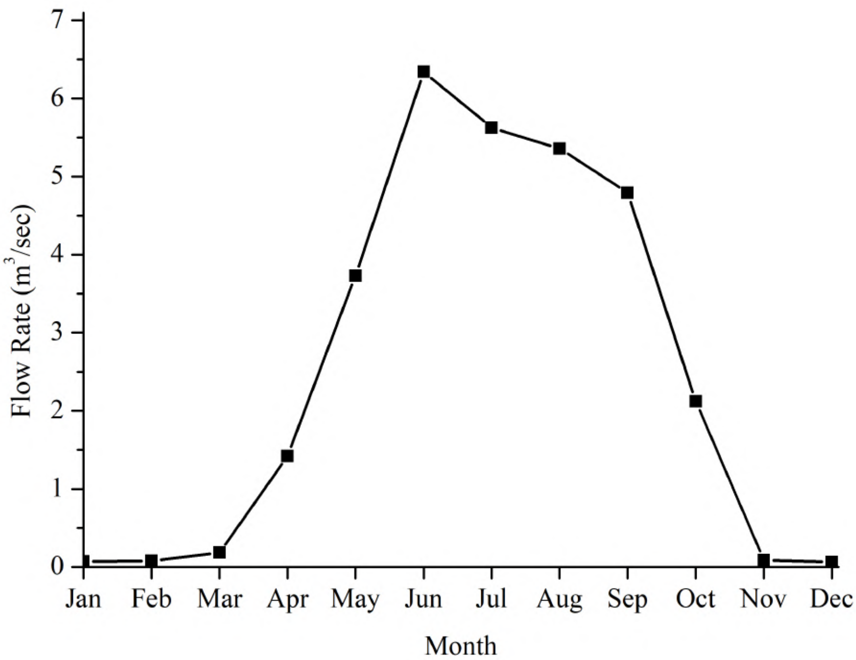

Figure. 4.8: Monthly Runoff rate for study area [181]

the month of December that is 0.06 (m^3/sec). If we refer the figure 4.8 due to the high rainfall for June month flow rate is high.

4.3 Optimal Sizing of Hybrid PV Hydro Renewable Energy System using Metaheuristic Algorithms

All the data sets utilized in the present investigation were sourced from the research conducted by Pandey [181]. After gathering all essential data for solar radiation, temperature, runoff rate and elevation, the hybrid system has been designed for optimal operating condition such that it can fulfill the load demand efficiently. All 23 algorithms have been implemented in order to address the optimization problem. Overall workflow of HRES system design optimization using the metaheuristics algorithms is shown in figure 4.9.

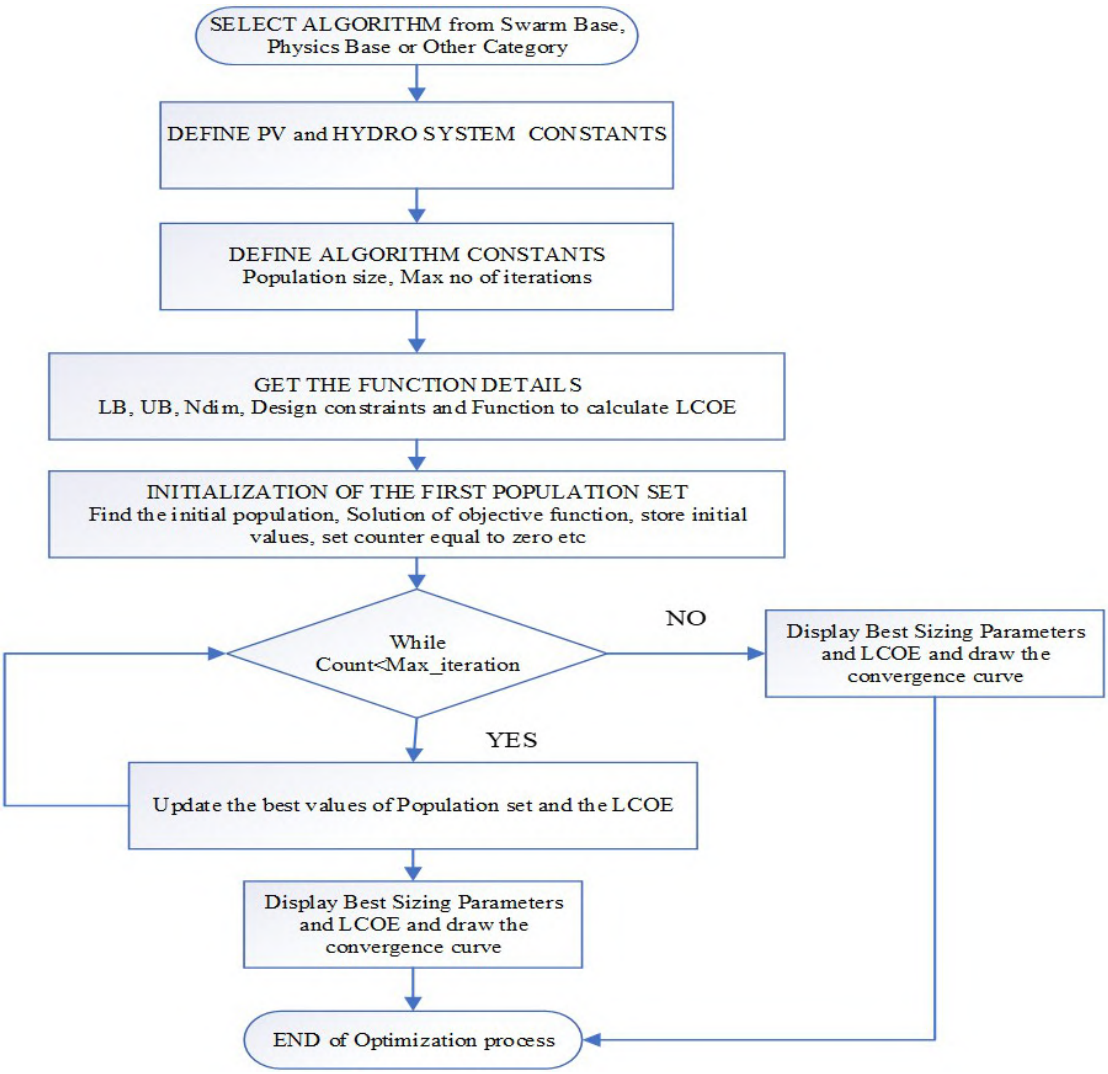

Figure. 4.9: Flowchart of the design optimization of HRES system using the Metaheuristic Algorithms

The optimization algorithms' control settings are taken from Table 3.1 in chapter 3, section 3.4. For each method, we used the optimal parameter combinations recommended in the primary paper in this study to guarantee peak performance. The algorithms' population size is set at 30, while there can be a maximum of 100 iterations. Due to their heuristic nature, all of these algorithms have a random start and as such the recorded best values over 100 iterations have to be considered to ascertain their performance over a number of trials. To acquire statistical findings, each algorithm in the current study is therefore run for 100 times, and for each technique, the optimum fitness function value is selected, which is the LCOE in our case. The findings are tabulated in table 4.1.

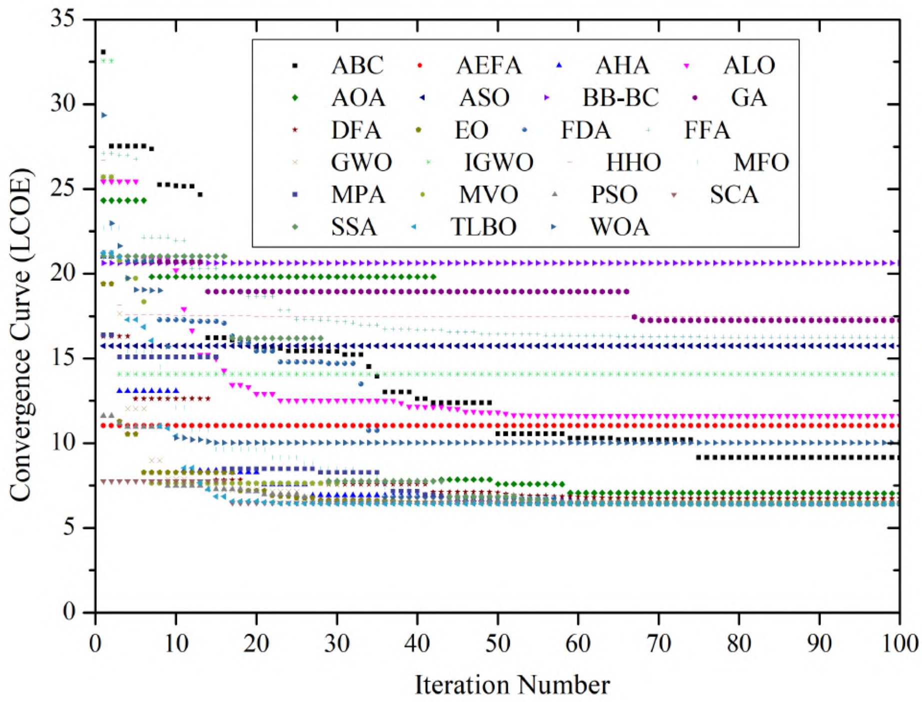

Figure. 4.10: Convergence characteristics of all the Metaheuristic Algorithms

The results and convergence plot of the assessed algorithm used to minimize the LCOE for the optimal size of a hybrid photovoltaic (PV) and hydro system is presented in figure 4.10 and table 4.1. In figure 4.10, we observe that the convergence characteristics of all the algorithms do not reach the best optimal results. It is observed that for majority of the algorithms the fitness value of function, i.e. LCOE in our case starts far away from the final value ranging from 7.5 to 38 (INR/kW), which is evidence of the randomness of the algorithms. The best optimal values are reached around the 20^{th} iteration for the fastest converging algorithms. The convergence characteristics show similar trends in most

Table 4.1: Statistical parameters for the optimal design of the Hybrid PV-Hydro based HRES for LCOE in INR/kW

Optimization Algorithm	Best	Mean Value	Worst Value	Standard Deviation	Iteration time (sec)
ABC	6.48	9.78	16.65	2.19	7.48
AHA	6.41	6.51	6.97	0.113	3.62
ALO	6.408	7.67	14.97	1.636	3.71
DFA	6.408	7.077	11.04	0.914	5.22
FFA	6.760	10.20	19.81	2.747	3.18
GWO	6.408	6.409	6.437	0.006	4.80
IGWO	7.616	14.60	28.31	4.53	7.22
HHO	6.496	11.76	17.80	2.727	4.79
MFO	6.408	6.409	6.441	0.005	4.51
MPA	6.408	6.409	6.434	0.003	7.33
PSO	6.412	6.488	7.570	0.124	4.70
SCA	6.435	6.746	7.288	0.21	2.84
SSA	6.408	6.840	11.148	0.933	3.98
WOA	6.506	10.371	18.636	3.360	2.81
AEFA	9.110	21.560	52.747	7.582	2.77
ASO	7.829	23.463	40.332	7.160	2.83
BB-BC	9.266	23.510	44.551	7.294	7.31
EO	6.408	6.410	6.422	0.002	4.52
FDA	6.408	6.509	8.798	0.323	8.00
MVO	6.410	6.437	6.813	0.043	4.83
AOA	6.464	6.987	7.450	0.178	4.74
GA	6.540	8.506	17.062	2.138	3.02
TLBO	6.408	6.419	6.44	0.007	8.32

of the algorithms except for the AEFA, ASO and BBBC algorithms, where the algorithms fail to get the optimal value of LCOE indicating that they are not suitable for application to the optimization of the HRES problem. It is evident that SCA and MVO starts very close to the final value as compared to the rest of the algorithms and in contrast to the majority of other algorithms, the number of iterations required is comparatively fewer to reach the final value. While the convergence curves are a good indicator of the overall performance to attain the best solution of the fitness value, however they are not the absolute indicators for the same. Due to inherent randomness in the metaheuristic algorithms, it is essential to carry out a statistical assessment to ascertain the overall performance of algorithms to solve an optimization problem.

From table 4.1 it is evident that the iteration time of the best algorithms across the three categories are SCA and WOA, AEFA and ASO and GA respectively. However, upon closer reflection on the statistical parameters and figure 4.10 it is seen that the GWO, EO, PSO, MVO, SCA and TLBO produce the

Table 4.2: Optimal parameters for the design sizing of PV-Hydro based hybrid system

Algorithm	LCOE (INR/kWh)	Hydro plant size(kW)	Optimal flow rate(m^3/sec)	Effective Head (m)	PV plant size(kW)	Area for PV plant (m^2)	Total size of Hybrid system (kW)
ABC	6.48	15.74	0.210	9	16.62	98.58	32.36
AHA	6.41	15.78	0.211	9	16.17	95.87	31.95
ALO	6.408	15.74	0.210	9	16.128	95.62	31.87
DFA	6.408	15.76	0.210	9.011	16.12	95.58	31.88
FFA	6.76	16.10	0.210	9.195	18.00	106.67	34.10
GWO	6.40845	15.74	0.210	9	16.12	95.58	31.86
IGWO	7.61608	15.88	0.211	9.02	16.50	97.85	32.38
HHO	6.49698	15.74	0.210	9	16.29	96.55	32.03
MFO	6.40845	15.74	0.210	9	16.12	95.58	31.86
MPA	6.40845	15.74	0.210	9	16.12	95.58	31.86
PSO	6.41175	15.74	0.210	9	16.135	95.67	31.88
SCA	6.4353	15.74	0.210	9	16.17	95.87	31.91
SSA	6.40845	16.10	0.210	9.205	16.12	95.58	32.22
WOA	6.50642	15.74	0.210	9	16.12	95.58	31.86
AEFA	9.10915	22.46	0.299	9.032	7.96	47.22	30.42
ASO	7.82906	21.5	0.287	9.004	17	100.85	38.50
BB-BC	9.26614	21.94	0.292	9.012	17.41	103.24	39.35
EO	6.40845	15.74	0.210	9	16.12	95.58	31.86
FDA	6.40845	15.74	0.210	9	16.12	95.58	31.86
MVO	6.41006	16.08	0.210	9.195	16.12	95.58	32.20
AOA	6.46445	15.74	0.210	9	16.12	95.58	31.86
GA	6.53977	15.74	0.210	9	16.17	95.87	31.91
TLBO	6.408	15.74	0.210	9	16.12	95.58	31.86

better results in terms convergence characteristics. The SCA and TLBO perform better than any other swarm intelligence-based algorithms when measured against the convergence curve. However if we consider the statistical indicators like the minimum cost function value and standard deviation, then we find that the GWO, MFO, MPA, EO, FDA and TLBO have greater performance compared to the rest of the algorithms. Within the swarm intelligence category GWO, MFO and MPA have similar indicators with respect to best cost function values (the smallest LCOE value), mean values, and standard deviation, demonstrating its superiority in the swarm intelligence category of algorithms. If we take into account Physics-Based algorithms, EO and FDA are the best algorithms while TLBO gives the best performance against GA and AOA.

From the table 4.2 there is a clear indication that the best optimal size of HRES comes up to 31.86 (kW) in which hydro contributes 15.74 (kW) and PV contributes 16.12 (kW) respectively and optimal head is found to be 9 (m) with a flow rate of 0.21 m^3/sec and the optimized area for the PV plant has been found to be 95.58 (m^2). This result is obtained in the case of the swarm intelligence based algorithms for the GWO, MFO and MPA algorithms. In the physics based category, the best results are attained by the EO and FDA while TLBO attains this result as well in comparison to GA and AOA.

Table 4.3: Specification of Optimized Hydro System

Parameter	Specification
Optimum Size (kW)	15.74
Optimum Flow rate (m^3/sec)	0.21
Effective Head (m)	9.0
No of Units	3
Flow rate of each Unit (m^3/sec)	0.07
Turbine Type	Cross Flow @ 85% of Full load

Table 4.4: Specification of Optimized PV System

Parameter	Specification
Optimum Size (kW)	16.12
Total Area (m^2)	95.58
Efficiency (%)	16.94
No of Modules	43
Size of Each Module (Wp)	325
Type of module	Canadian Solar Max Power CS6X-325 Poly-crystalline

If we see our load profile the peak load in summer is 24.66 kW during 6 pm to 7 pm but our maximum installed capacity of hydro power plant is 17.26 kW, so at that time the peak load demand cannot be met with the HRES. Similarly we observe that during winters, for the peak hours between 5 pm to 9 pm even there is not sufficient generation from the solar system and due to less runoff, all units of hydro are not possible to run with only one unit operational in winters. A lithium-ion ($LiFePO_4$) type battery with minimal maintenance expenses has been taken into account in order to fulfill the load requirements during periods of high demand. A set consisting of 46 batteries and a 30 kW inverter has been incorporated to ensure the stability of the system and provide uninterrupted power supply to the load. The rating of battery has been considered as 24 volts, 36 Amp with 90 % efficiency and 70% Depth of Discharge. Table 4.3 and 4.4 present the optimized design parameters of the Hydro and PV system respectively.

4.4 Discussion

This study examines the impact of search performance exhibited by 23 metaheuristic algorithms namely ALO, ABC, AHA, DFA, FFA, GWO, IGWO, HHO, MPA, PSO, WOA, SCA, SSA, ASO, AEFA, BBBC, FDA, EO, MVO and GA, TLBO and AOA in addressing the challenge of size optimization of a HRES at minimized LCOE.

It is evident that in-terms of iteration time, the FFA, SCA, WOA and GA are highly competitive. TLBO has the fastest convergence followed closely by the performance of the SCA and MVO. Although the computational time required by TLBO and FDA is higher, they are able to achieve the optimal solutions. AEFA, ASO and BBBC algorithms stand out as the algorithms that produce the poorest results. From the analysis, it is clearly seen that no single algorithms is able to perform equally as the best in all of the above mentioned categories, however the GWO algorithm emerges as the most successful method that performs satisfactorily and evidently better when compared with other algorithms across all the performance parameters.

4.5 Summary

This chapter presents the mathematical model of the HRES consisting of the combination of PV and Hydro Power as the main sources of energy. Formulation of the power generated from PV and Hydro sources is presented along with the load profile for the selected study area, i.e. rural location of Hazadisa village in Dimapur, Nagaland India is presented taking into account the seasonal variation in the demand. The optimal design sizing problem is formulated with radiation data, temperature profile and rainfall data acting as inputs for calculation of LCOE of the hybrid system which acts as the objective function. The size optimization process also takes into account the capacity based constraints for the PV and Hydro system to arrive at the optimal design. The 23 algorithms are implemented to optimize the size of the HRES and their performance comparison is discussed.

The overall size of the optimized hybrid system was found to be 31.86 kW for the considered load profile, in which the share of PV and Hydro was 16.12 kW and 15.74 kW respectively with an area for the PV system equal to 95.58 m^2, a flow rate of 0.21 m^3/sec. and effective head of hydro equal to 9.0 meter. The optimal value of LOCE was found to be 6.408 INR/kWh.

Comparison between all the implemented algorithms show that the GWO algorithm, within the category of swarm intelligence techniques, outperforms other algorithms in terms of achieving optimal values of the objective function, statistically significant results and fast convergence characteristics.

The originality of this study lies in three key aspects: first, the development of a specific design optimization algorithm tailored to determine the optimal sizing for the PV-Hydro system, ensuring suitability for the task at hand. Second, we conducted a preliminary investigation into the feasibility of implementing a PV-Hydro arrangement in a grid-isolated hamlet with unique load demands, demonstrating that such a system is indeed complementary under the given resource conditions. Finally, this study establishes a reference framework for similar investigations in regions with comparable atmospheric conditions and hydro potential, serving as a standard for future applications, particularly in remote areas like Hazadisa Village in Nagaland and other similar regions of NE India.