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Optimal Design and Economicanalysis of an Off-Grid Pv/Wind/Battery/Biomass System for Kunak City, Malaysia

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Abstract:

This work proposes a design of a hybrid power system including photovoltaic (PV) module, wind turbine, battery and biomass for Kunak city, Sabah in Malaysia. An optimum design of the stand-alone hybrid power system based on minimization of the total system cost during the project lifetime is obtained using Imperialist Competitive Algorithm (ICA) by considering the power supply to the load. In order to carry out this investigationfor a 10-year period (from 2004 to 2013), the cost function of PV, wind, battery and biomass are derived by deliberating local power demand, solar radiation, wind speed and site temperature data. The optimal system in this case study regarding to the outcome in 2013 is the combination of 73.8% PV module, 13.2% wind turbine, 13% battery and extra 24% biomass for unmet load with a total cost of USD $50,958,946 for 20 years and with 15 years and 4 months payback period. To show the functionality of the implemented method, a comparison between the results obtained using ICA, Gravitational Search Algorithm (GSA) and Hybrid Optimization Model for Electric Renewable (HOMER) software, is also made.

Keywords: *Optimization, Renewable Energy, Stand-alone Hybrid Power System, Imperialist Competitive Algorithm, Gravitational Search Algorithm*

I. INTRODUCTION

Across the globe, some of the most important problems nowadays are global warming, air pollution and lack of sufficient fossil fuel for generating electricity. Oil, gas and coal reservoirs are predicted to finish in the next 40, 60 and 200 years respectively [1]. Furthermore, diesel electricity supply as a conventional technology solution not only has expensive fuel and maintenance cost, but also emits large amount of greenhouse gases to the environment [2]; the more the fossil fuel usage, the more carbon dioxide in the atmosphere increasing the earth's temperature [3, 4]. Electricity demand has also increased recently [5]. For this reason, the alternatives, Renewable Energy Sources (RESs) includes wind, solar, biogas and tidal are introduced to generate electricity [6, 7]. Compared to fossil fuels, RESs do not produce any pollution but there are some challenges about their implementation methods. Hybrid Power Systems (HPSs) containing various combination of RES such as PV and wind are introduced to address the main problems and these sources could be applied to supply load continuously.

The first step leading to cost-effective system is HPS design, where metrological data such as wind speed, irradiance, temperature and the overall cost of the components needs to be considered in determining the optimal number of components. Optimization is a mathematical procedure which guarantees system effectiveness and functionality [8]. The main key in lower cost and increased efficiency is proper system design. Thus, the problem of determining the optimal number of components and sizing is required in the optimization process. In [9], deterministic algorithm is used to define the optimum number and type of units in stand-alone hybrid wind-PV-diesel energy

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system based on minimizing the total system cost by considering supply to the load. Strength Pareto Evolutionary Algorithm (SPEA) for stand-alone hybrid PV-wind-diesel-battery is implemented in [10] for reducing the levelized cost of energy (LCOE) and CO2 life cost emission (LCE). According to this work, the most effective source of generating electricity for Spain and southern Europe off-grid systems based oneconomical and environmental aspect is PV system.

Optimization of components combination through Multi-objective Evolutionary Algorithm (MOEA) and Genetic Algorithm (GA) based on minimizing total system cost, greenhouse emission and unmet load was done in [11]. A new numerical method is introduced in [12] to determine the optimal number and tilt angle of PV stand-alone system in Oman by considering loss of load probability (LLP). A sizing technique is developed for PV-diesel system in Malaysia as proposed in [13] for zero load rejection. In [14] hybrid PV-wind-diesel-battery system is optimized by a discrete version of Harmony Search (HS).The results including total cost of the system and environmental emission are compared with a stand-alone diesel generating system.

Many other methods are known for optimization such as Particle Swarm Optimization (PSO), Simulated Annealing (SA) and Bee Algorithm (BA) [15-17]. In [18-20] comparative investigation is carried out between Imperial Competitive Algorithm (ICA), GA, PSO and BA.It is found that ICA optimization is more efficient in finding the best combination of renewable energy resources with lower price. Therefore for this research, ICA optimization is selected as one proposed optimization method. This method is derived from process of imperialism and its procedure, and is used as an optimization technique to minimize the total cost of proposed hybrid power system in this study.

Combination of off-grid power generation with renewable energy is conducted for Kunak city, Sabah in Malaysia with great potential of biomass energy to find the optimum number of components (PV module, wind turbine and battery bank) and biomass generator fuel consumption during a period of 20-years. Although several research work has been carried out for hybrid power system, minimalinvestigation is carried out for this area. For this purpose, average hourly data (solar radiation, wind speed, ambient temperature, and load demand), yearly component price and interest rate within 10 years are considered. Calculating financial indices and cost forecasting for next 2 years is the another premise of this research.In this work, firstly, the mathematical model of the proposed hybrid power system components are presented after a brief introduction about ICA optimization, then system operation strategy is introduced. Definition of the objective function and system constraints is the following issues, and finally the simulation work, result and discussion are presented.

II. SYSTEM METHODOLOGY

A. *Proposed Hybrid Power System Configuration*

Hybrid power system studied in this work is shown in Fig. 1 constituting a PV module, wind turbine, battery bank and biomass generator. Since PV module and wind turbine output power depends on the climate condition, battery bank is provided as an energy storage system. The excess power of PV module and wind turbine will be stored in battery bank. Once power deficit is experienced, the system will discharge power form the battery to meet the load demand. Biomass generator is used when PV module and wind turbine cannot supply the load and battery bank is depleted.

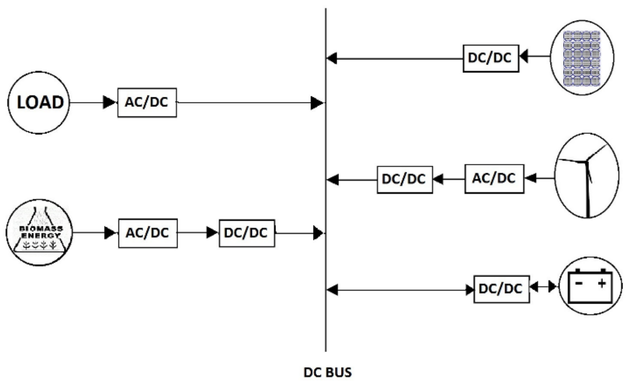

Figure 1: Proposed hybrid power system block diagram

B. *PV Module*

The power generated by PV module should be varied by level of irradiance and temperature of the region. This power can be calculated by [21]

$$P_{Module} = \left(\frac{\frac{V_{OC}}{\frac{n_{mpp}\ KT}{q}} - ln\left(\frac{V_{OC}}{\frac{n_{mpp}\ KT}{q}} + 0.72\right)}{1 + \frac{V_{OC}}{\frac{n_{mpp}\ KT}{q}}} \right) * \left(1 - \frac{R_S}{\frac{V_{OC}}{I_{SC}}}\right) * I_{SCO}\left(\frac{G}{G_0}\right)^{\alpha} * \frac{V_{OCO}}{1+\beta\ ln\left(\frac{G_0}{G}\right)} * \left(\frac{T_0}{T}\right)^{\gamma}$$

(Eq.1)

where nMPP is the ideality factor at the maximum power point (1 <nMPP< 2), K is the Boltzmann constant (1.38×10-23 J/K), T is the PV module temperature (°K), q is the magnitude of the electron charge (1.6×10-19 C), Rs is the series resistance (Ω), G and G0 are different solar irradiation impinging the cell (W/m2), α is factor responsible for all the nonlinear effects that the photocurrent depends on, β is PV module technology specific-related dimensionless coefficient and γ is factor considering all the nonlinear temperature–voltage effects.

α, β, γ, Rs, nMPP parameters can be calculated by available data listed in Table 1.

TABLE 1: DETAILED DATA REQUIREMENTS FOR PARAMETER ESTIMATION [34]

	G_0	G_1
T_0	I_{SC}, V_{OC}, I_{MPP}, V_{MPP}	I_{SC}, V_{OC}, I_{MPP}, V_{MPP}
T_1	Null	V_{OC}

As can be seen from Eq. 1, PV output power has reverse relationship with PV cell temperature. Therefore, in order to increase the efficiency, cooling process should be considered [22]. There are other factors such as PV derating factor which causes reduction of output power in real operating conditions, such as dust on the module, wiring losses and shading [23]. Ground reflectance (Albedo) is the next factor affecting the performance of the output power by the reflectance of solar radiation from the ground. Albedo for grass-covered area is considered 20% [24]. Thus, the maximum output power of the PV system can be calculated by Eq. 2.

$$P_{PV} = N_P \times N_S \times P_{Module} \times \eta_{MPP} \times \eta_{oth} \text{ (Eq. 2)}$$

where ηMPP is the efficiency of the maximum power point tracking, although it is variable according to different working conditions, a constant value of 95% is assumed to simplify the calculations. ηoth is the factor representing the other losses. NP is the number of PV cell in parallel which optimized by ICA algorithm and NS is the number of PV cell in series. Table 2 shows the PV module specification in this study.

TABLE 2: PV MODULE SPECIFICATION

Brand	Kyocera- KC200GT
V_{OC} (V)	32.9
I_{SC} (A)	8.21
V_{max} (V)	26.3
I_{max}(A)	7.61
NCOT (ºC)	47
$T_{C,ref}$ (ºC)	25
G_{ref} (W/m^2)	1000
Number of cell per Module	54
Lifetime (year)	20

C. *Wind Turbine*

Each turbine model has a specific power curve determining the wind speed and power which is a function of wind speed. Typically, the wind speed in the range of 4-25 m/s is capable of generating power. Daily variable wind speed may cause variation in daily generated power. Illustrated in Fig. 2, the output power increases when wind speed is between 3.5 m/s until 11 m/s, and then it remains constant for wind speed which is between 11 m/s and 24 m/s, after that it reduces suddenly to zero [25]. Thus, relationship between wind turbine output power (PWT) and wind speed (V) can be found using [26] as shown in Eq. 3.

$$P_{WT}(t) = \begin{cases} \frac{V-V_{ei}}{V_r-V_{eo}} P_R & V_{ei} < V < V_r \\ P_R & V_r < V < V_{eo} \\ 0 & otherwise \end{cases} \text{ (Eq. 3)}$$

where V is sampling wind speed, Vei is cut in wind speed, Veo is cut out wind speed, Vr is rated wind speed and Pr is rated wind turbine power.

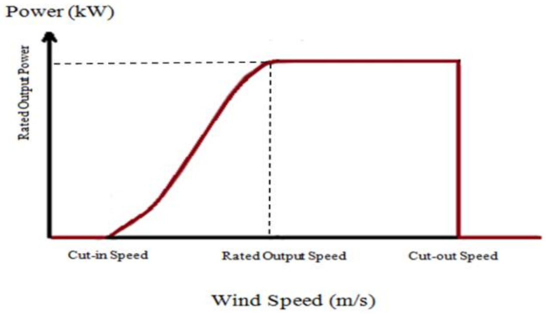

Figure 2 Typical wind turbine power curve [25]

There are some factors which have the significant effect on the output power of the wind turbine, such as Weibull shape factor showing the windy trend of a location and wind speed distribution over one year, autocorrelation factor illustrating the wind strength in one hour, diurnal pattern strength, peak hour, site height above the sea level and anemometer height showing the height of measured wind speed above the ground. Eq. 4 shows the relationship between the wind speed at

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reference height and the velocity at specific height of the hub

$$V(t) = V_r(t)(\frac{h}{h_r})^{\gamma} \quad \text{(Eq. 4)}$$

where hr is the reference height and h is specific height [9]. Table 3 shows the wind turbine specifications used in this work.

TABLE 3: WIND TURBINE SPECIFICATIONS

Brand	Hummer- H8.0
Rated Power (W)	10000
V_r (m/s)	10
V_{ci} (m/s)	3
V_{co} (m/s)	20
Height of hub (m)	12
Lifetime (year)	25

D. Battery Bank

The amount of charging and discharging in the battery can be calculated using

$$SOC(t + \Delta t) = SOC(t) + \eta_{bat}\left(\frac{P_B(t)}{V_{bus}}\right)\Delta t \quad \text{(Eq. 5)}$$

where SOC is the state of charge, ηbat is equal to round-trip efficiency of battery in charging process which is considered here 80% and in discharging process is equal to 100%, Vbus is DC bus voltage (V) and Δt is time step which is equal to 1 hour in this research.

SOCmax which is equal to nominal capacity of the battery bank depending on the number of batteries in series and usually is considered 1, and SOCmin should be defined for preventing over and under charging sequentially. Thus, the lower limit of the discharging can be defined using

$$SOC_{min} = (1 - DOD)SOC_{max} \quad \text{(Eq. 6)}$$

The number of batteries in series is calculated using Eq. 6. Optimization for series-connected batteries is not required. However, the number of batteries in parallel is calculated using ICA [9] as follows,

$$N_{bat,s} = \frac{V_{bus}}{V_{bat,nom}} \quad \text{(Eq. 7)}$$

Table 4 shows battery bank, with 10 batteries 24 volt and 200 Ah in series, specification for this research.

TABLE 4: BATTERY BANK SPECIFICATION

Brand	ZD- 24V200 lead acid battery
Nominal Capacity (Ah)	200
Voltage (V)	240
DOD (%)	80
Efficiency (%)	90
Lifetime (year)	3

E. Biomass Generator

Energy from sunlight is stored in the plants in the form of chemical, biomass renewable energy is extracted from these kinds of plants [27]. Palm oil waste and wood waste are high due to agricultural activities makes Malaysia a great source of biomass renewable energy. Current statistics illustrates 16% of energy consumption in the country made up by biomass fuel which consists of 51% palm oil, 22% wood waste and 27% other biomass resources; Fig. 3 shows the biomass resources in Malaysia [28].

The principle categories of biomass conversion to electricity technologies are gasification and direct-fired which is used the most. High-pressure steam is prepared by burning biomass fuel in a boiler then it is driven to the generator. The boiler efficiency is calculated by percentage of converted steam energy over usage fuel energy which is usually between 65% and 85% [29, 30].

Fig. 4 shows the consumption of 1MW biomass generator fuel for generating electricity which varies hourly by different output power. The generator fuel consumption can be calculated by

$$F = F_0 Y_{bgen} + F_1 P_{bgen} \quad \text{(Eq. 8)}$$

where, F_0 is the generator fuel curve intercept coefficient which is 0.1835 kg/h/kw here, F_1 is the generator fuel curve slope which is 1.429 kg/h/kw here, Ybgen is the related capacity of the generator and P^{bgen} is the generator output. Table 5 illustrates biomass generator specification in this work.

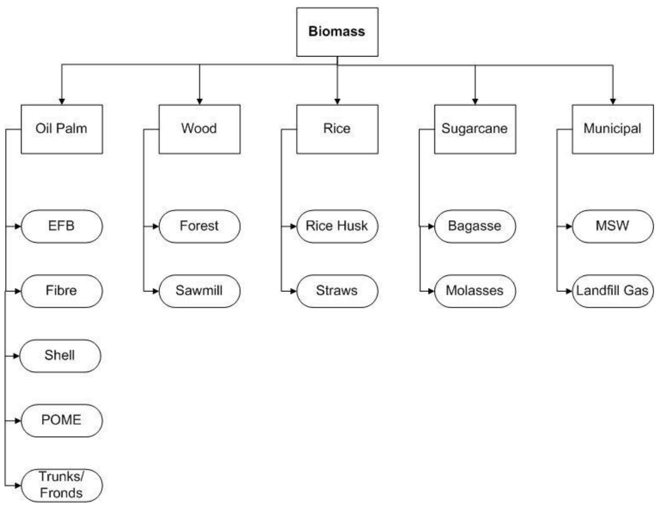

Figure 3: Malaysia biomass resources

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TABLE 5 BIOMASS GENERATOR SPECIFICATION

Brand	CUMMINS 1000kW
Rated Power	1000 kW/ 1250 kVA
Standby Power	1100 kW/ 1375 kVA
Rotation Speed	1500 rpm
Voltage	230 V/ 400 V
Lifetime (hour)	15000

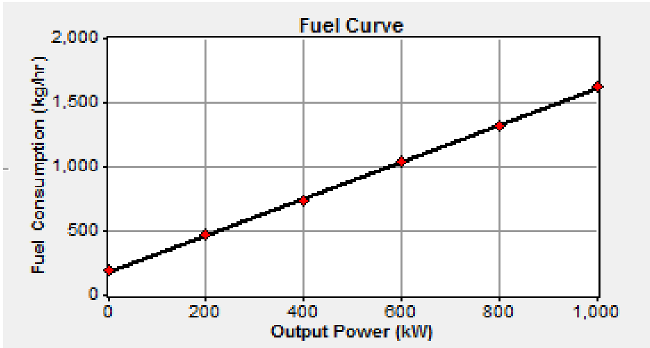

Figure 4: Biomass generator fuel curve

III. OPTIMIZATION ALGORITHM

A. *Imperialist Competitive Algorithm*

Imperialist Competitive Algorithm (ICA) was developed by Atashpaz-Gargari et al. in 2007. The algorithm starts by initial population (countries), then some of the best ones are chosen as empire and colonies are divided among them. Power of empire has a reverse relationship with cost. This means that low cost empire is the strongest one. The next step after dividing colonies between empires is moving colonies to their empire. Power of the new empire is the summation of the empire power and the mean percentage of colonies. After that, competition between emperors will begin and in each step empire with lower colonies will collapse and stronger ones which increase the number of colonies or other empire which prevents decreasing colonies will remain. This competition will continue until one emperor remains in the world and other countries will become the colonies of it. Fig. 5, shows the related flowchart [31].

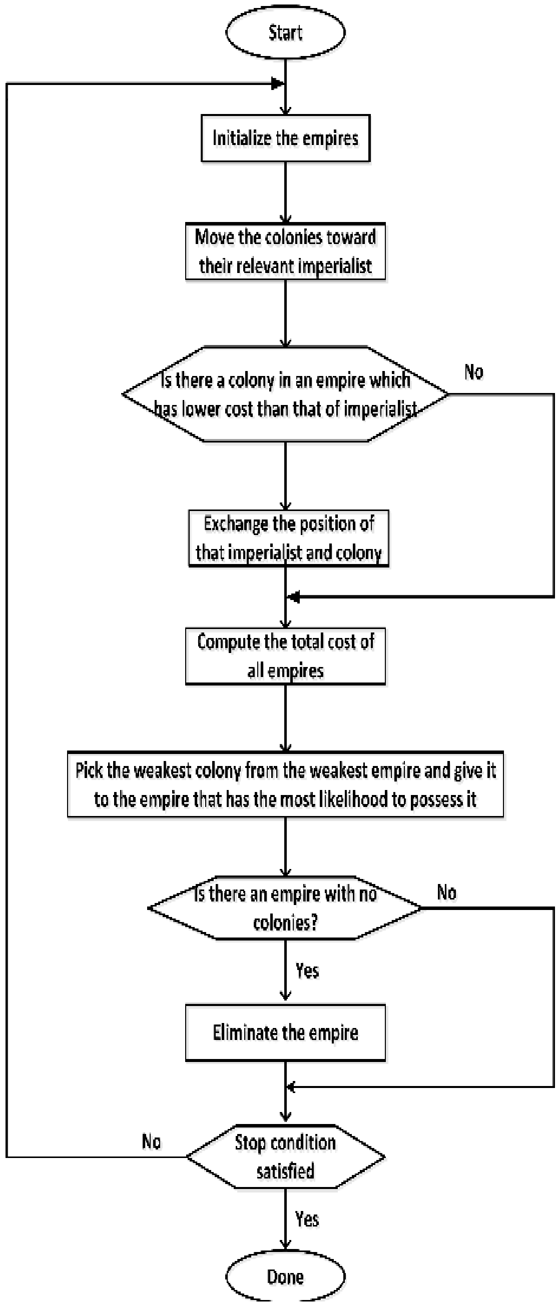

Figure 5: Imperialist Competitive Algorithm optimization flowchart

Optimization variable are formed in a row array with the number of variables, which is named country and the cost can be calculated by function f in Eq.9,

$$country = [p_1, p_2, p_3, \dots, p_{N_{var}}] \text{(Eq. 9)}$$

$$cos\,t = f(country) = f(p_1, p_2, p_3, \dots, p_{N_{var}}] \quad \text{(Eq. 10)}$$

The total power of each empiresare affected by the power of imperialist with define percentage of colonies. It can be calculated by Eq. 11, where T.Cn is total cost of nth empire and ξ is a positive number less than 1.

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$$T.C_n = \text{cost}(imperialist_n) + \zeta mean\{\text{cost}(colonies\ of\ impire_n)\} \quad \text{(Eq. 11)}$$

B. Gravitational Search Algorithm

Gravitational Search Algorithm (GSA) was introduced by Rashedi et al. in 2009 is an optimization algorithm derived from the law of gravity and mass interaction based on the Newtonian gravity and the laws of motion. Computational procedure of this algorithm consists of generating initial population, mass (agent) fitness evaluation, gravitational constant (G) updating, calculation of different direction total force, acceleration and velocity and updating agent position [32].

C. System Operation Strategy

The power generation from hybrid system and its battery bank storage depends on the time as shown by

$$\Delta P = P_{re}(i) - P_l(i) \quad \text{(Eq. 12)}$$

where P_{re} is summation of generated renewable energy and P_l can be calculated by

$$P_l(i) = \frac{P_{load}}{\eta_{inv}} \quad \text{(Eq. 13)}$$

where Pload is load power demand and ηinv is DC to AC conversion efficiency. By considering Eq. 12, three scenarios are as follows:

1) If ΔP > 0, i.e. when load supplied, demand have been met and remaining power will be stored to the battery bank. If the batteries are completely charged, surplus power will dump.

2) If ΔP < 0, i.e. when hybrid system is not able to meet the load demand. The remaining power will be obtained from the battery bank. If battery bank could not support the load demand, biomass generator will be turned on. However, during this time, batteries neither be charged, nor be discharged.

3) If ΔP = 0, the hybrid system will supply the load demand. During this time battery bank will neither be charged, nor be discharged.

D. Objective Function and System Constraints

The objective function of the proposed hybrid system and annual cost is obtained using

$$\text{cost} = \sum_i (C_{acap} + C_{arep} + C_{o\&m} + C_{abiomass}) \quad \text{(Eq. 14)}$$

where i is number of units for wind, solar, battery and generator, C_{acap} is annual capital cost of the system, C_{arep} is annual replacement cost of the system, $C_{o\&m}$is the annual operation and maintenance of the system and $C_{abiomass}$ is the annual cost of biomass for generator. The net present cost (NPC) of system can be defined by

$$NPC = N \times (\text{capital cost} + \text{replacement cost} \times k + o\&m \times \frac{1}{CRF(i_r, R)}) \text{(Eq. 15)}$$

where, N is the number of components, R is the lifetime of the project which is 20 years based on this investigation, $i_r$is the real interest rate, CRF is capital recovery factor and K is single payment which can be defined by (16), (17) and (18) respectively.

$$i_r = \frac{i' - f}{1 + f} \text{(Eq. 16)}$$

$$CRF(i_r, r) = \frac{i_r(1+i_r)^R}{(1+i_r)^R - 1} \text{(Eq. 17)}$$

$$K(i_r, L, y) = \sum_{n=1}^{y} \frac{1}{(1+i_r)^{n \times L}} \text{(Eq. 18)}$$

TABLE 7 OPTIMIZATION RESULTS

Year	No. PV	No. Wind turbine	No. Battery	No. Converter	No. Biomass Generator for 24% exceed load demand	Fuel Consumption (Tone/h)	Cost	Cost with Biomass
2004	18692	39	65	30	1	1.0818	21051769	38545769
	19000	0	108				21756897	39250897
2005	20409	12	97	32	1	1.1515	23823276	42574276
	19987	0	146				24167992	42918992
2006	20000	13	241	34	1	1.2251	26580124	46510124
	21920	0	130				26254841	46184841
2007	21945	13	220	35	1	1.294	27770326	49219326
	23917	0	115				27679197	49128197
2008	24000	29	233	38	1	1.3969	27229148	51378148
	26554	0	91				26197360	50346360

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2009	25000	49	294	39	1	1.5054	23550426	48003426
	28583	0	97				20765425	45218425
2010	26000	51	401	40	2	1.5842	20764591	50728591
	33158	0	67				14872285	44836285
2011	28000	182	400	41	2	1.7101	20708440	50696440
	34785	0	86				12956179	42944179
2012	30000	215	535	42	2	1.8316	22006209	52124209
	36880	0	93				11866005	41984005
2013	33000	218	395	43	2	1.9589	18854946	50958946
	39898	0	97				11290114	43394114

where i’ is nominal interest rate, f is annual inflation rate, L is useful lifetime of the components and y is the number of replacements. For the optimum size, there are some constraints for the mentioned objective function due to reliability issues and limitation in size and number of installed units. The constraints which are considered for the above objective function are given as follows:

The hybrid power system is designed to cover the annual load demand. The main constraint for purposed hybrid power system is defined in (19).

$$P_p(i) > P_l(i) \quad \text{(Eq. 19)}$$

where $P_p = P_{RE} + P_b$ and P_{RE} is equal to generated energy by wind and PV. The following constraint is related to battery state of charge due to preventing of overcharging and under discharging.

$$SOC_{min} \leq SOC \leq SOC_{max} \quad \text{(Eq. 20)}$$

Some constraints are due to limitation of construction, purchase or also policy of applying different renewable resources. These limitations are modeled as constraints on number of selected units from each renewable resource as

$$0 \leq N_{PV,P} \leq N_{PV,P_{\max}} \quad \text{(Eq. 21)}$$
$$0 \leq N_{WT} \leq N_{WT_{\max}} \quad \text{(Eq. 22)}$$
$$0 \leq N_{Bat,P} \leq N_{Bat,P_{\max}} \quad \text{(Eq. 23)}$$
$$0 \leq N_{bgen} \leq N_{bgen_{\max}} \quad \text{(Eq. 24)}$$

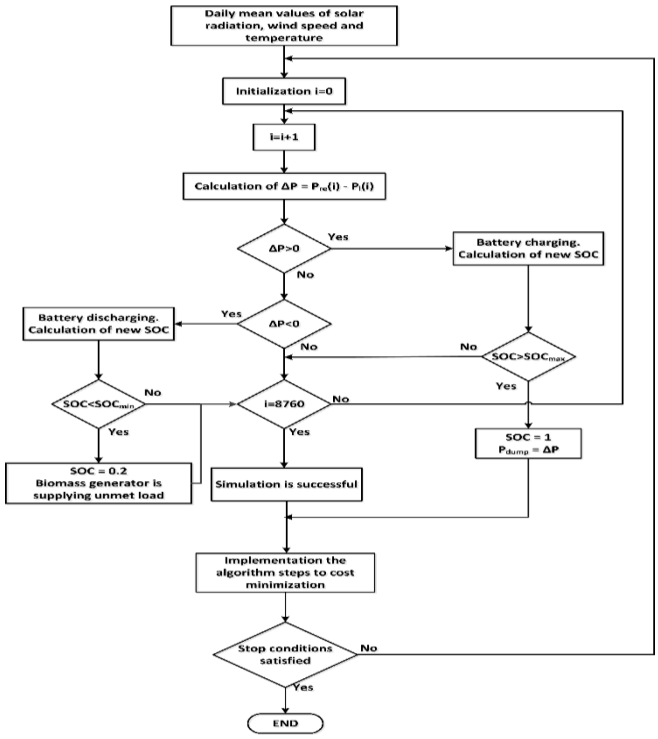

Figure 6: System operation strategy flowchart

E. Simulation Framework

In the first step, variable matrix array should be formed, and subsequnelty ICA os initialized. In this work, the variables to be optimized are number of PVs, number of wind turbines, number of batteries and number of biomass generators for unmet load. The dimension of each array of the matrix is 1×5 and it is formed as [NPV, NWind, NBat, Nbgen, Ncon]. This array is generated based on the number of colonies which is fixed at 200. Once the objective function
is calculated for all 200 arrays, the best cost (minimum cost) are treated as imperials. The remaining countries are divided to them based on their power. At this stage, optimization process will start, and the colonies move to relative empire by

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changing the number of units. The procedure will continue until one colony remains. The amount of this array component is the optimized based on the number of renewable units which can meet the demand, unmet load and constraints simultaneously and also the cost is the least with these numbers of units.

Fig. 6 shows the modelling flowchart of the proposed algorithm. As it is mentioned before, one of the three possible cases (over generation, overload and equal position) will occur. Initially this should be investigated, and optimization of the Res size will be carried out. This trend will continue until the end hour of year (8760 hours). All optimum sizes should meet the designed constraints. At the end, the optimal size of the components with the minimum cost which covers the constraints are obtained.

IV. RESULTS AND DISCUSSION

In this work, a stand-alone hybrid power system consisting of PV module, wind turbine, battery bank and biomass generator is taken into consideration. The case study is based on a 10 years metrological data in Kunak, a small city in Sabah, Malaysia. The sizing optimization is done in MATLAB software by using ICA algorithm with 100 countries and 200 iterations. The system sizing is optimized via the best cost, which is the minimum cost with respect to all the constraints. The monthly load demand, ambient temperature, daily solar radiation and wind speed of 2013 are given in Figs. 7-10 respectively. The summaries of economical information are mentioned in Table 6. All data are obtained from an electrical utility company in Sabah, Malaysia. By considering the input data, optimization of hybrid system for 2004 until 2013 by using ICA is shown in Table 7.

TABLE 6 COMPONENT COST PER PIECE

2013	PV	Wind Turbine	Battery	Biomass Generator	Converter
Capital Cost ($)	200	8420	3870	145000	1450
Replacement Cost ($)	200	6000	3870	70000	1450
O&M ($/year) ($/h)	2	112	116	4	10
Malaysia Interest Rate				3%	

The hourly load demand and 20% increasing each year can be estimated according to publication from the electrical utility company in Sabah, Malaysia.The electricity tariff is assigned according to maximum demand. In simple words, the electricity tariff for unmet load which is 24% of load demand is considered more, it means that any household consuming more than considered peak load will be charged more. The total system cost according to Table 7 is at its peak on 2008 because of the high amount of inflation rate in Malaysia in this year. Moreover, from 2010 which the price of PV module has a downward trend the total cost of only PV module system has been lower amount rather than PV and wind. It can be clarified that the strength of solar radiation for generating electricity comparatively to wind speed at Kunak area is higher. Fig. 7 shows the difference of generated power by renewable energy and load demand. The positive amount shows during the year of 2013, load demand can be supplied without any shortages.

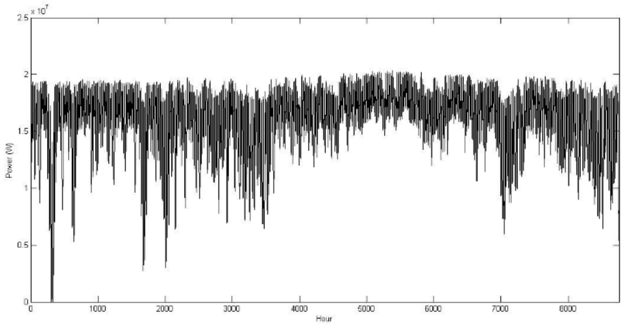

Figure 7: Renewable generated power and load demand difference

A. Forecasting

The total cost of system for the following years can be predicted by considering Table 7, components price trend, load growth, inflation rate and environmental changing. Figs. 12 and 13 show the estimation results for two-years of 2014 and 2015.

B. Financial Indices

The economic indexes in term of Net Present Value (NPV), summation of the present values of incoming and outgoing cash flows over a period of time, Internal Rate of Return (IRR), Benefit Cost Ratio (B/C), Return on Investment (ROI) and Payback Period, length of time required to recover the investment, point out the benefits of this proposed hybrid power system. To calculate the financial indices of this system, the results are compared to a diesel generator system as reference [33]. Table 8 summarizes the results.

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TABLE 8 FINANCIAL INDICES

Economic Index	Proposed Hybrid Power System	Diesel Based
NPV ($)	739,124.125	10,360,679.55
IRR (%)	3.106	8
Payback Period (year)	15.346	10.579
ROI ($)	29.311	21.19
B/C	1.29	1.21

Positive NPV and B/C bigger than 1 shows that both systems have benefits. However, payback period and IRR resultshows that diesel system recovers the investment earlier than proposed hybrid power system. In addition, bigger amount of ROI for proposed hybrid power system shows regardless of time and economic inflation, total benefit of hybrid power system is more compared to the diesel system.

C. Changing PV module temperature

Fig. 8 shows the increase of system cost due to daily increase in temperature by 5°C and 10°C. Increasing ambient air temperature has a direct relationship with system cost. Therefore, in a hot area, number of PV modules in proposed hybrid system will increase and this in turn will lead to an increase in system cost.

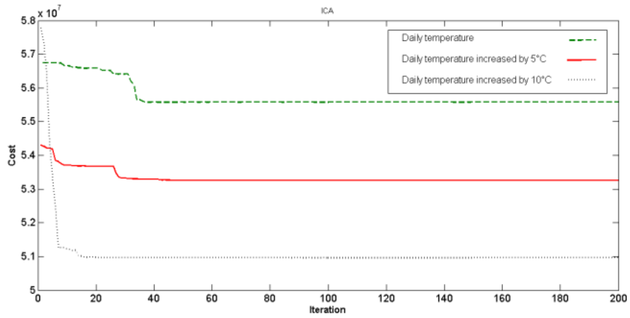

Figure 8: System cost by different temperature

D. Changing Initial Number of Countries in ICA Algorithm

Fig. 9 illustrates the cost of proposed hybrid power system by changing initial number of countries is one of the most important factors in this algorithm. Increase in the number of countries leads the algorithm to obtain a better combination of hybrid system with lower price. This is because the increase in number of countries will allow a larger search space for the optimization algorithm and this leads to the increase of probability to find a better answer for optimization problem. However, this leads to a significant increase in computation time of the program, which varies from 791.36s for 20 countries until 3520s for 100 countries.

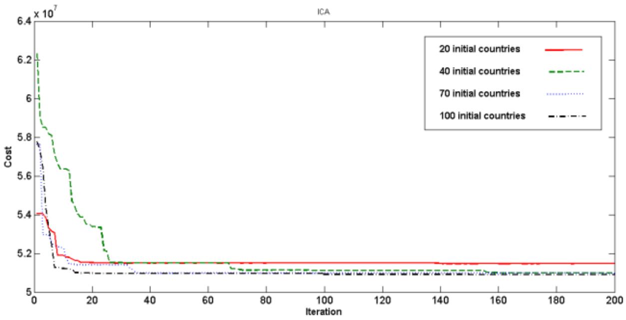

Figure 9: Total system cost by different initial number of countries

E. Changing β parameter in ICA Algorithm

The second most important factor in ICA algorithm which can influence the output result is β parameter. It is defined between 1 and 6 in moving colonies towards imperialists. Eq. 25 shows its relationship in regard to the number of populations,

TABLE 9: COMPARISON RESULTS BETWEEN ICA, HOMER AND GSA

Year	No. PV	No. Wind turbine	No. Battery	No. Converter	No. Biomass Generator for 24% exceed load demand	Fuel Consumption (Tone/h)	Cost	Cost with Biomass	Time
HOMER	40000	500	500	30	2	2.27	23541866	52922992	300
GSA	33000	223	412	43	2	1.9589	21789545	53908762	3520
ICA	33000	218	395	43	2	1.9589	18854946	50958946	4341

$x = U(0, \beta \times d)$ (Eq. 25)

where x is random with uniform or any proper distribution, d the distance between colonies and imperialist, and U theuniform distribution function [31]. As it can be seen from Fig. 10an illustration of different amount of β for different initial number of countries is shown. High amount of β is required for less initial number of countries in order to increase the possibility seeking better solution in the search space.

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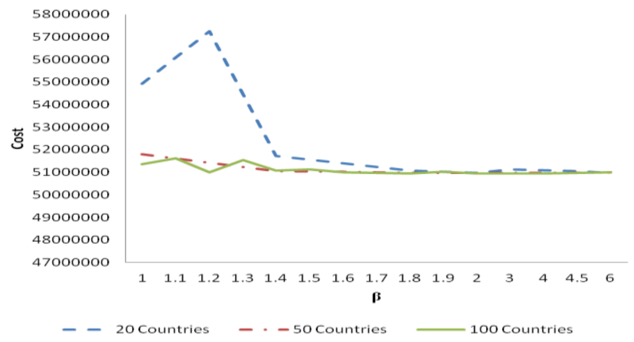

Figure 10: Total cost of system by different value of β

F. *Comparison between ICA, HOMER and GSA*

Table 9 indicates optimum number of components for proposed hybrid power system using HOMER software and GSA. As it is apparent, total cost of the system by ICA optimization is lower than other 2 methods. Fig. 11highlights this difference.

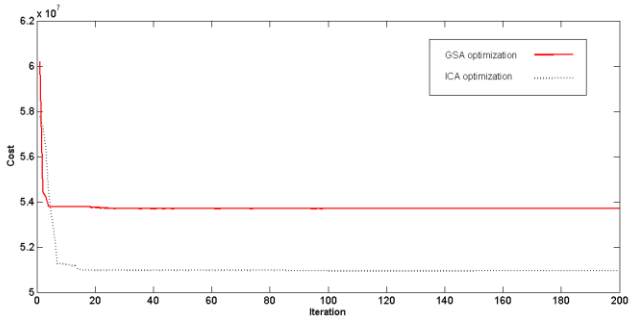

Figure 17: ICA and GSA comparison

V. CONCLUSION

In this work, a new optimization algorithm, Imperialist Competitive Algorithm (ICA) which is based on social and human behaviour,has been successfully implementedto find optimum number of proposed hybrid system components with minimum possible cost. The proposed hybrid system consists of PV module, wind turbine, battery and biomass for unmet load. Mathematical model for renewable resources were successfully introduced in this work, expressing their application validity based on different scenarios. Battery state of charge (SOC) plays a great role in optimization process to control the optimum number of proposed hybrid system components by considering two limitations including overcharging and undercharging. An estimation of total system cost for following years and economical index such as payback period were also successfully determined. Increasing ambient air temperature is discussed in this paper and it is shown that clearly it has a direct relationship to system cost. Also increasing initial number of countries and high amount of β for few numbers of countries leads to increase in probability of finding better answer. Results shows that ICA performs better compared to GSA and HOMER software.

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