

A Novel Hybrid Algorithm for Power Flow Control of Grid-Connected Hybrid Renewable Energy System

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Abstract: This paper depicts a stout voltage control of grid connected of Renewable Energy System (RES) consists of Solar Energy, Wind Energy and Fuel Cell Technology. A smart controller is suggested to alleviate the power fluctuations. Here, the suggested controller achieves the mixture of Bat Search algorithm and artificial neural network (BSNN). In order to correct the constancy of HRES, error gathering of the system is to be reduced. Here, the bat search algorithm is recycled in the optimization reason to diminution the system error and accomplish the optimal power flow by legitimate tuning of PI parameters. Within the corresponding input time intervals of a day dataset, the ANN is trained using the target capacity. The performance of proposed technique is invoked in MATLAB/Simulink platform.

Keywords: Hybrid Renewable energy Systems (HRES), Bat search neural network (BSNN), PV Array, Wind energy, Fuel cell.

I. INTRODUCTION

The spiralling cost and improper nature of fossil fuel, and the flagging global awareness in renewable energy sources, growth of fossil fuel possessions and the occasion of lessening CO₂ emissions, grid connected renewable power systems have acquired unresolved interest [1-3] that has widened the energy feasting. For the improvement of a country, energy is measured as a relevant mechanism, but its amount is increased and there is deficiency in its consumption. Small and long-term energy storage apparatuses such as batteries and hydrogen storage tanks are utilized [3-6] for further development of

Renewable Energy System performance for gathering varying load. In order to analyst [6-8] the objectionable fluctuations in real and reactive power making caused by the intermittency of RES, the performance management and power flow control of hybrid RES (HRES) is joined with the storage require development and proper design of refined controllers with multi-inputs and outputs capabilities.

The power is not always procurable every time it is needed by the renewable energy which is the main issue. To control active/reactive power, frequency, and to fulcrum grid voltage during faults and voltage sag, power electronic inverters are used and utility integration has been refined and invoked with the increase of power production of renewable resources. Energy storage device is essential at the dc link [8-10] since the availability of renewable energies is variable and unpredictable. The power balance at the dc link is retained by this device which results in a smooth power dispatch. Because of instantaneous fluctuation of solar irradiation and wind speed, both the solar and the wind energy are unpredictable even though, they complement each other in most of the cases. Using doubly fed induction generators [11-13] many large wind turbines will operate at variable speed for reasons of improved efficiency of energy transfer from the wind and reduced mechanical stresses. To match that of the wind turbine system based on small PV, wind, hydro and storage devices, the required generator terminal voltage or power factor, and the control of the generator torque are maintained.[14-15]

II. POWER FLOW MANAGEMENT OF GRID CONNECTED HRES

With tenacious operating constraints, an electrical storage element engenders expensive investment and operation costs in the power flow management. Generally, battery storage systems and advanced energy management systems are not required for grid-connected renewable systems.

For the cited case Utilization of grid connected hybrid renewable energy systems (HRESs) as a DG source could degrade the stress on the grid caused by simultaneous charging of numerous vehicles and also in comparison with stand-alone systems, covers the uncertainties caused by the discontinuous

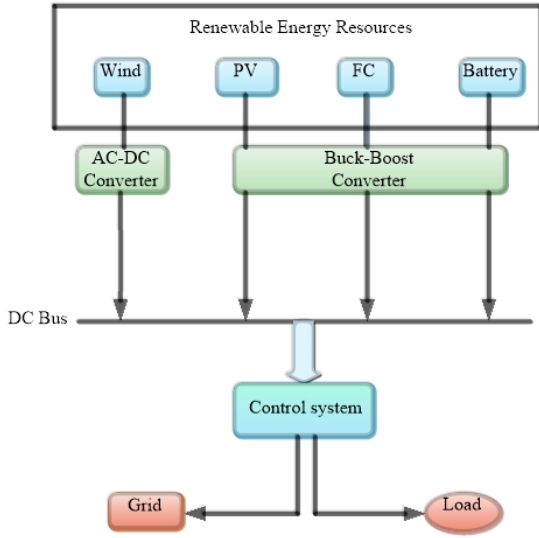


Figure 1: Structure of grid connected hybrid renewable energy sources

III. Mathematical Model of Renewable Energy Sources

a) The model of the WT

Depending upon its power coefficient for a given wind velocity, the wind turbine captures the mechanical power and it is represented as,

$$P_m = \frac{1}{2} (C_p \rho \pi R^2 v^3) \quad (1)$$

Where, P_m represents the mechanical power, v represents the velocity of wind, ρ and R represents the density of air and the radius of the turbine propeller respectively.

nature of renewable energies. Consequently, reductions in the following items would be feasible like,

- Severe voltage sag and swell
- Suboptimal generation dispatch.
- Likelihood of blackouts due to network overloads.

To investigate a range of different placement and sizing of decentralized electricity systems (not the components), several studies are proclaimed in the literature on optimal positioning to attain reduction in power losses or to provide steady-state voltage profile through the grid, via utilizing classical optimization, meta-heuristics approaches and analytical methods.

b) The model of the PV

PV can be described as the following equation,

$$I = I_{pv} - I_o \left[\exp \left(\frac{V + R_s \times I}{V_t \times a} \right) - 1 \right] - \frac{V + R_s \times I}{R_p} \quad (2)$$

Where, I , I_{pv} and I_o represents the output current, photovoltaic and saturation current respectively. V_t represents the thermal voltage of the PV panel, R_s and R_p represents the equivalent series and parallel resistance of the PV panel.

c) The model of the FC

The mathematical model of the fuel cell (FC) can be shown as follows,

$$C_{FC} = C_{nl} \times \left(\sum P_{FC} \Delta t / \eta_f L \right) \quad (3)$$

Where, C_{FC} is the gas consumption cost of the FC, P_{FC} is the output power of the FC during the calculation period Δt in kW, η_f is the efficiency of the FC, L is the net thermal value of gas and C_{nl} is the price of the gas.

d) The model of the BS

The ratio of the residual energy to the rated energy refers to the state of charge (SOC) of the battery. For controlling the charging and discharging process, it is very important to

predict the SOC of the battery accurately and the system economic dispatching. The battery's SOC during the charging process is given by the relation,

$$SOC_t = SOC_{(t-1)}(1-\delta) - (P_c \Delta t \mu_c / E_c) \quad (4)$$

Where, P_c represents the charging power which is positive, μ_c is the charging efficiency, E_c is the total capacity of the BS during the time Δt in KW. SOC_t is the SOC of the BS in period t, and SOC_{t-1} is the SOC of the BS in period t-1. The battery's SOC during the discharging process is given by the reaction,

$$SOC_t = SOC_{(t-1)}(1-\delta) - (P_d \Delta t / E_c \mu_d) \quad (5)$$

Where, P_d represents the discharging power which is positive, μ_d is the discharging efficiency and δ is the self-discharge rate of storage in percentage per hour.

IV. Proposed Technique for Power Flow Management

During this section, for controlling the power flow management of HRES the proposed controller is utilized. The utility integration has been refined and invoked with the proposed controller based HRES and to control active/reactive power, frequency, and to support grid voltage during faults and voltage sag, power electronic inverters are used. Energy storage device is crucial at the dc link because the availability of HRES is variable and unpredictable. In order to generate the power demanded by the grid, the proposed methodology takes responsibility in controlling the energy sources using optimally both renewable energy sources and energy storage devices. Figure 2, illustrates the structure of proposed controller with HRES for power flow management in which arrows represent directions of power flows in the hybrid system.

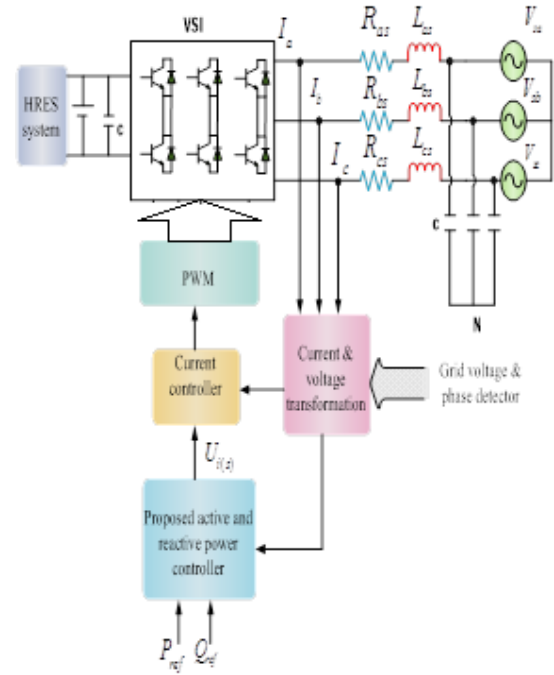


Figure 2: Structure of proposed control strategy

V. HRES PROCESS

The power electronic inverters are required to realize the power conversion in the HRES, connected with the grid which is illustrated in figure 2. The grid-connected PWM VSIs are widely applied in PV and wind power systems where HRES process is scrutinized. Since the output voltage of the PV modules varies with temperature, irradiance, and the effect of MPPT, in the PV part of scrutiny, the dc-bus voltage of the inverter should be fixed to a specific value. Then, by converting the dc current into a sinusoidal waveform synchronized with the utility grid, the energy should be fed from the PV modules into the utility grid. The conversion power quality including the high power factor, and fast dynamic response, largely depends on the control strategy adopted by the grid-connected inverters which is obvious for the inverter-based PV system.

The load demand is directly fed by the output power of the renewable systems. The surplus power will be stored into the battery bank, if the demand is less than the renewable output. The deficit of power will be supplied by the battery or the grid, if the load power requirement is larger than the renewable output. Depending on the price of electricity in the considered time interval, the grid plays a

preponderant role in the hybrid system for charging the battery and directly supplying the load demand. Either to the load or to the grid to save electricity cost, the battery can be charged by the grid in the off-peak period, and then discharged in the peak period. When the load cannot be entirely met by the renewable sources and the battery storage system, the grid provides electricity directly.

VI. PERFORMANCE SCRUTINY OF BS ALGORITHM

For solving hard optimization tasks, Bat Algorithm is recently proposed using bio-inspired meta-heuristics method. The behaviour of bats hunting for their prey is proved by the algorithm. Yang in 2010 [112] introduced the algorithm. Based on population of bats, the Bat Algorithm explores in order to find interesting areas, by flying through solution search space. One solution in n-dimensional search space is portrayed by each single bat. By providing fit function, solutions are evaluated in terms of their fit value. Linking with the objective function, some features of the echolocation are chosen in optimization problem which makes it possible to formulate a smart, bat algorithm. From nearby objects, they hear back the echo that comes by emitting loud sound. They rely on the frequency of the echo reaching to their ears, to resolve the location and size of their prey. In hunting their prey, the BA is formulated idealizing bats characteristics. By idealizing the echolocation behaviour of bats at first, the bat algorithm is formulated which includes the behaviour of micro bats and Acoustics of Echolocation. Following describes the step procedure of the bat search algorithm.

Step procedure of BSA:

Step 1: Initialization

At the beginning, the input of the algorithm is the real and reactive power values and the random generation of PI parameters like K_p and K_i values are initialized. The bat population is initiated as position (δ_k) and velocity as (w_k). A possible solution of the given optimization problem is represented by the position of a bat. The position of the food source found by the bat can be expressed as

$$A_i = \{A_1, A_i, \dots, A_N\} \quad (6)$$

Where, $i = 1, 2, 3, \dots, N$

To initialize the echolocation parameters like pulse frequency (F_i), the pulse rate (ρ_i) and the loudness parameters (B_i). Here the pulse frequency is selected in the range of $F_i \in [F_{\min}, F_{\max}]$.

Step 2: Fitness function

In this step, an optimization problem, the objective function is represented by minimization of error value which is examined by use of equation (7),

$$Obj F_j = Min E(v) \quad (7)$$

The objective function active and reactive power management is expressed as,

$$E(v) = P_{ref}^*(t) - P^I(t) \quad (8)$$

$$E(v) = Q_{ref}^*(t) - Q^I(t) \quad (9)$$

Where, $E(x)$ represents the error function of the system. Once the minimum objective function is attained and the corresponding K_p and K_i parameters are tuned, the process gets optimized.

Step 3: Generation of new solutions

In the third step, by adjusting the pulse frequency and keeping wavelength as constant new solutions may be generated. During the optimization process, the position (A_i) and velocity (w_i) of each bat should be defined and updated. The new solutions A_i^t

and velocity A_i^t at time step t are performed by the following equations,

$$F_i = F_{Min} + \phi(F_{Max} - F_{Min}) \quad (10)$$

$$w_i^t = w_i^{t-1} + (A_{ik}^{t-1} - A^*) \times F_i \quad (11)$$

$$A_i^t = A_i^{t-1} + w_k^t \quad (12)$$

Where ϕ is denoted as the range of $[0, 1]$ is a random drawn from a uniform distribution.

Then, the A^* is expound as the best location in search space after comparing solutions of all then number of bats. The product of F_i and θ_i represents the velocity increment. The velocity increment can be adjusted by changing one and keeping fixed another according to a problem. Basically, depends on the domain size of the problem of interest, the frequency is assigned to $F_{Min,Max} \in (0,100)$.

Step 4: Local search

Once the finest current solution is selected among the available solutions, then a new solution is generated by using local random walk and assigned to each bat as portrayed in below equation,

$$A_{new} = A_{old} + \sigma \times B^t \quad (13)$$

Where, $\sigma \in [-1,1]$ represents a random number range and $B^t = \langle B_i^t \rangle$ is the average value of loudness of all initiated n bats at time t. If the process of local search is improved the crossover and mutation is investigated under the section.

Step 5: Bat flying and generation of a new solutions

As the number of iteration increases, the loudness B_i and the rate of pulse ρ_i emission have to be updated. As a micro-bat reaches to its target or prey the rate of pulse emission increases while the loudness should be diminishing. Habitually select the loudness is $[B_{Min}, B_{Max}] = [1, 0]$.

Assuming the minimum loudness means that a bat has just found the prey and temporarily stop emitting any sound. Thus, the loudness and the rate of pulse emission is updated as

$$B_i^{t+1} = \alpha B_i^t \quad (14)$$

$$\rho_{ik}^{t+1} = \rho_i^0 [1 - \exp(-\mu)] \quad (15)$$

Where, α and μ are represents the adaptation parameters of the loudness and pulse rate. Here, α is similar to the cooling factor of a cooling schedule in the simulated annealing and the range of these constants is as $0 < \alpha < 1$ and $0 < \mu$.

Step 6: find best solution

In this step process, find the best micro-bats, which satisfies the objective function

Step 7: Stop the process

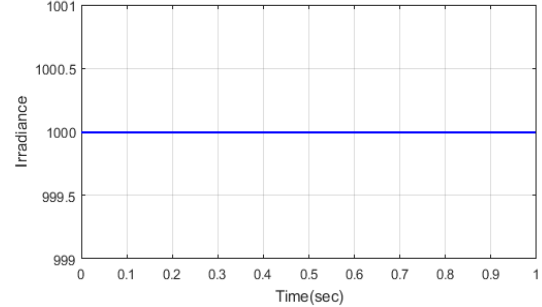
If the maximum count of iterations is reached as a stopping criterion is satisfied, then the process of computation is terminated. The output of the algorithm is formed as the dataset to trained the ANN. Otherwise, go to steps 4 and 6 to repeat the process.

VII RESULTS AND DISCUSSION

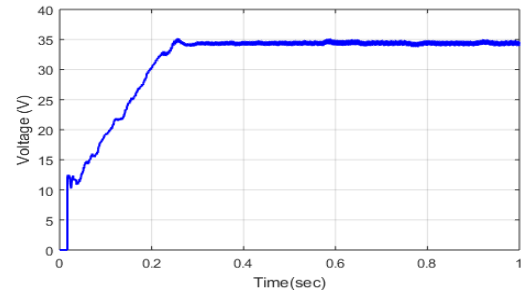
The below segment sketch the three cases of analysis. The existing methods, PSO, GA and PI controller are also invoked, in order to scrutinise the proposed control technique.

Case 1: Balanced supply with unbalanced load condition

At the range of 1000 with in $t = 0$ to 1 sec, the irradiance under PV runs at constant level. The performance of the DC bus voltage, where the voltage starts at zero range is illustrated in the waveforms). The output of the bus voltage is performed in constant level at time $t = 0.25$ sec.

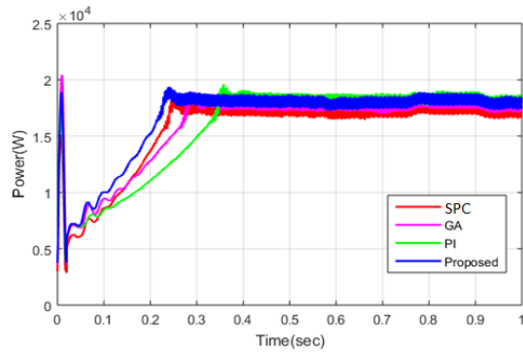


(a)

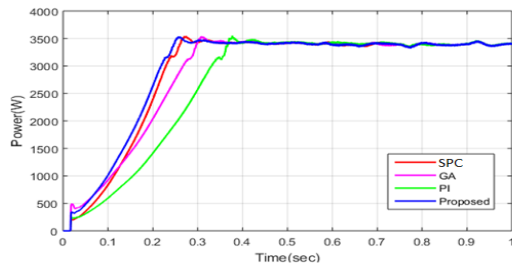


(b)

Figure 3: Scrutiny of (a) PV irradiance and (b) DC bus voltage



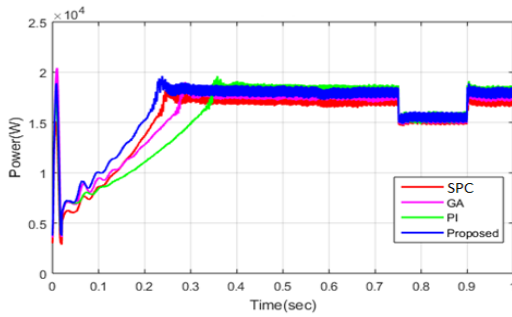
(a)



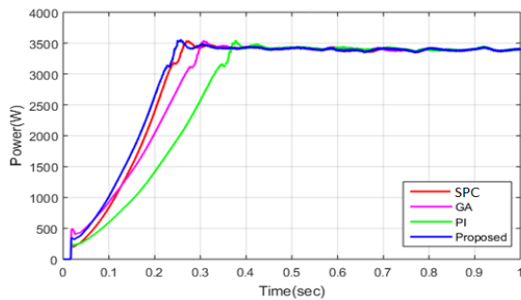
(b)

Figure 4: Comparison Scrutiny of (a) Total power and (b) Battery power

Case 2: Scrutiny of step response in PV system



(a)

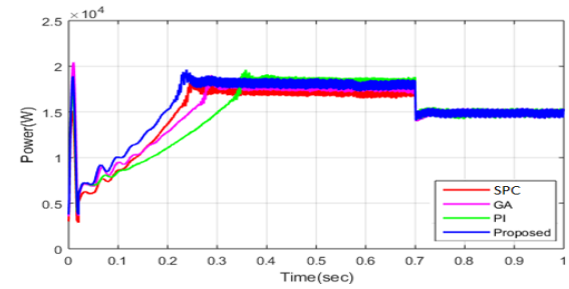


(b)

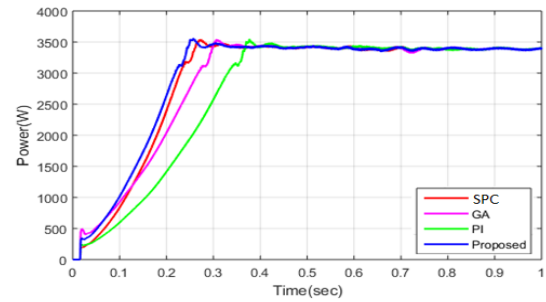
Figure 5: Scrutiny of (a) Total power and (b) Battery power in unbalanced condition

Rising time and settling time of the proposed method is $t_r = 0.02$ sec and $t_s = 0.28$ sec respectively from the comparison scrutiny shown in figure 6. In addition, the proposed method gives zero value for its peak overshoot time. Moreover settling time of existing methods like PSO is $t_s = 0.32$ sec, GA is $t_s = 0.38$ sec and PI is $t_s = 0.44$ sec.

Case 3: Scrutiny of Zero response in PV system

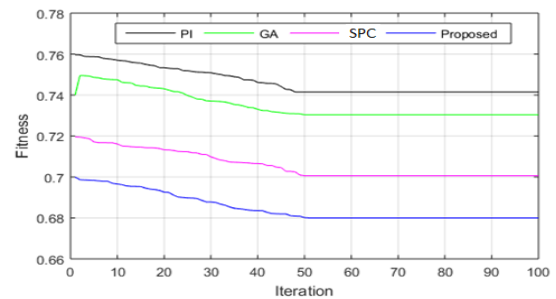


(a)



(b)

Figure 6: Comparison Scrutiny of (a) total power and (b) Battery power



(a)

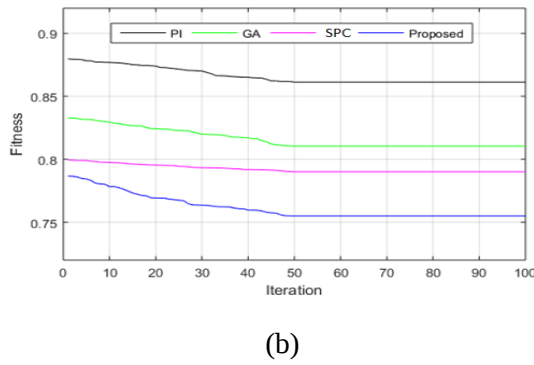


Figure 7: Comparison Scrutiny of Convergence Graph in Case 2 (a) Real power and (b) Reactive power

Solution techniques		Mean	Median	Standard Deviation
BSNN method	Case 1	0.8854	0.8883	0.0655
	Case 2 (Condition- A)	0.9028	0.8926	0.0526
	Case 2 (Condition-B)	0.8402	0.8334	0.0869

Table 1: First Order Statistical Scrutiny for 100 Iterations (Active power)

VIII. CONCLUSION

To improve the power flow control of Hybrid Renewable Energy System of bat search neural network algorithm used to improving the performance of power converter and energy sources. The HRES consists of a Photovoltaic (PV), Wind Turbine (WT), Fuel Cell (FC), and Battery. To stabilize the power fluctuation happened in the integrated power system, an intelligent controller is proposed. The paper introduces is performed on the combination of Bat Search algorithm and artificial neural network (BSNN). Utilizing the bat search algorithm for optimization purpose in order to reduce the system error and hence achieve the optimal power flow by proper tuning of PI parameters. The fairness and unfairness restraints are defined for examining of the power flow management.

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