

# Hybrid harmony search algorithm & fuzzy logic for solving unit commitment problem with wind power uncertainty

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## Abstract

This work spotlights on fuzzy logic and hybrid harmony search algorithm based framework for solving the unit commitment problem in any electric utility. Here, the selection of fuzzy logic is because of its qualitative representation ability with respect to input attributes, cost-effective operating agenda and all the calculations of feasible schedules. A three-unit system is assumed here, to compute the above-mentioned aspects. In recent days, the meta-heuristic optimization algorithms are constructed because of its zero utilization and storage for making the search procedure as effective. Hybrid harmony search algorithm searches whether the load demand is met or not. If it is not satisfied an error is developed. The error and change in error is fed input to fuzzy logic unit. The output of fuzzy logic unit is given to a breaker. The breaker will cut off the system if the power output is more and if the power output is less than the required value additional power is fed to the system. Constant output power is thus maintained. To test and prove that the proposed HHS-FL results a superior optimization, performance by analyzing the wind speed in Coimbatore region. The experimental results demonstrated that the proposed model is efficient even if the wind gets changed and all simulations were performed with MATLAB.

**Keywords:** Contingency-Constrained; Computational Modeling; Unit Commitment; Transmission Contingency; Wind Generation.

## 1. Introduction

In recent days, the reliable and cost-effective processes of energy frameworks are developed with the plentifulness of the proximity wind and sun power. The process completely depends upon the ability of streamline strategies to adequately deal with their vulnerability. Pandian and Duraiswamy (2004) stated that the most significant process that faces this test is the unit commitment (UC) issue [1], which plans to produce limits for the upcoming day and prepares the power framework for possibly strong changes in the accessibility of discontinuous sustainable assets.

The major goal of energy framework operation and control is to preserve a nonstop balance between power generation and a continually shifting power demand while keeping up framework frequency, voltage levels, security and this must be accomplished at the very least cost. Financial power dispatch is a major prerequisite for control framework operation and control. The traditional numerical programming approaches ensure convergence and ordinarily have no problem-specific parameters to indicate. In any case, it can neglect to take care of issues adequately within the sight of discontinuities and non-convexities. The conventional methods like linear programming and Lambda iteration methods are sensitive to the starting point.

Numerous researchers focused on advancement of optimization under uncertainty have been created for the UC issue. Two primary kinds of strategies are stochastic programming and robust optimization. Normally, the stochastic programming system is flexible to display the unverifiable parameters. It is significant for different computational challenges for complex issues and it is hard to tem-

poral and spatial relationships. Similarly, the robust optimization dependent upon the uncertainty set concept, specifically, realizations of an uncertain deterministic set of parameters, which directs to basic models and enhanced computational tractability. Yu et al., (2015) stated that the reliability is the important aspect [2].

Indhumathi et al., (2004) applied the fuzzy logic for UC problem [3]. The fuzzy logic usage has obtained greater attention in the last decades as its effectiveness in the multipart mathematical models. It utilizes linguistic terms with the fundamental relationship among input and output attributes. Therefore, the method builds it simpler to influence and crack numerous problems. Finally, the process is completely formulated even at known or unknown mathematical models. It endeavors to evaluate etymological terms so the factors can be treated with constant as opposed to discrete. Additionally, fuzzy is a strategy, which approximates reasoning, while at the same time enabling choices to be made proficiently.

Reddy et al., (2016) researched about the uncertain wind energy and its problems [4]. Wind power is very indeterminate in nature as it relies upon the climatic conditions, area, wind speeds and so forth. It is completely based on the wind turbine setup has been charged. The aggregate cost of the framework gets very much influenced because of the uncertain idea of wind power accordingly it must be consolidated into the framework. Wind power accessible from a wind turbine is given in condition (1) as:

$$\text{Windpower} = \frac{\text{Air density} \times \text{area of the blades} \times \text{speed of wind}}{2} \quad (1)$$

$$P_w = \rho A V^3 / 2$$

Where, air density ( $\rho$ ) represented in  $\text{kg/m}^3$ , the area ( $A$ ) of the blades has the unit of  $\text{m}^2$  and speed of wind ( $V$ ) blowing in the area is represented in  $\text{m/s}$ . The remaining part of this research is summarized as follows: Section II describes the UC problem and its formulation. Section III described about the fuzzy logic formulation. Section IV stated recent case study for UC problem with presence and absence of wind units. Section V represents the key steps for the hybrid module and its detailed description framed in section VI. The fuzzy logic controller is implemented in section VII. Finally, numerical results are included in section VIII followed by conclusion in section IX.

## 2. UC problem formulation

### 2.1. Objective function

Chakraborty et al., (2011) stated that the objective function of UC problem is to reduce the overall production cost while fulfilling the following constraints as given in equation (2).

$$\text{Min TC} = \sum_{t=1}^N \sum_{i=1}^T [F(P_{i,t} + S_{c_i}(1 - I_{i,t-1}))] I_{i,t} \quad (2)$$

From equation 2, the  $F(P_{i,t})$  is represented by,  $F(P_{i,t}) = a + b.P_{i,t} + c.P_{i,t}^2$ . Where, expansion of  $F(P_{i,t})$  denotes the quadratic fuel cost function of  $P_{i,t}$  which is the thermal power output of unit  $I$  at hour  $t$ ,  $I_{i,t}$  is the status of  $i^{\text{th}}$  unit at hour ' $t$ ',  $N$  and  $T$  are the number of production units and time horizon, respectively.

### 2.2. Constraints

- i) Generation limit: The generating unit output power must be maintained within a range as stated in the following equation (3).

$$P_{i,\text{min}} \leq P_{i,t} \leq P_{i,\text{max}} \quad (3)$$

Where,  $P_{i,\text{min}}$  is the minimum power output limit for the unit  $I$  and  $P_{i,\text{max}}$  is the maximum power output limit for the unit  $I$ .

- ii) System spinning reserve requirements: The system spinning reserve requirement is considered here to maintain the reliability. It is expressed as represented in equation (4)

$$\sum_{i,t} I_{i,t} P_{i,t,\text{max}} - 1 \geq D_t + SR_t \quad (4)$$

Where,  $SR_t$  is the required spinning reserve for hour ( $t$ ).

- iii) Unit minimum up/downtime: If a unit is committed/decommitted after a generation process, it should be kept as stable for a meanwhile before a transition. It is listed as shown in equation (5)

$$T_{\text{on},i} \leq X_{\text{on},i}, T_{\text{off},i} \leq X_{\text{off},i} \quad (5)$$

- iv) Emission constraint: The contaminated gases must be restricted by the following equation (6)

$$E = H_i(P_{i,t}) \leq E_{\text{limit}} \quad (6)$$

Where,  $H_i(P_{i,t})$  is a quadratic function associated with several emission types and  $E_{\text{limit}}$  is the emission limit.

## 3. Fuzzy logic formulation

Change in the demand can be treated with as fuzzy requirements rather than crisp limitations. The accompanying subsections depict the fuzzy limitations with related enrollment capacities. Fuzzy membership function is shown in Figure 1. Mamdani model is utilized in this proposed work.

$$f(x; a, b, c) = \max\left(\min\left(\frac{x-a}{b-a}, \frac{c-x}{c-b}\right), 0\right) \quad (7)$$

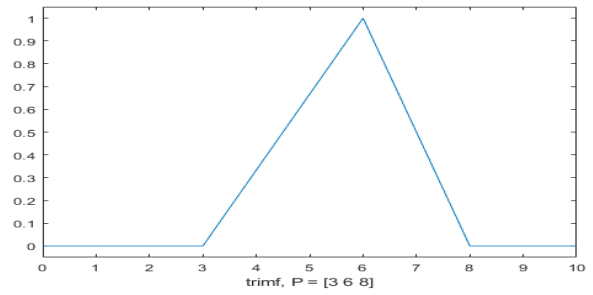


Fig. 1: Representation of Fuzzy Membership Function.

The predicted load demand may get varied and results in inaccurate data. Thus, the exact representation is carried out with the help of fuzzified load. The load which is forecasted is deviated ( $\Delta d$ ) with the original factor varies from  $\pm 2\%$  to  $\pm 5\%$ . Formulating the load is done with Mamdani's method invented by Mamdani and Assilian (1993) [6]. The membership function for fuzzy load percentage ( $\Delta d_{\text{vs}} \mu_{\text{LD}}$ ) error. Here, the triangular-shaped membership function is studied and considered for implementation. The expression for trimf membership function is represented in the equation (7). The block diagram for fuzzy system is represented in Figure 2.

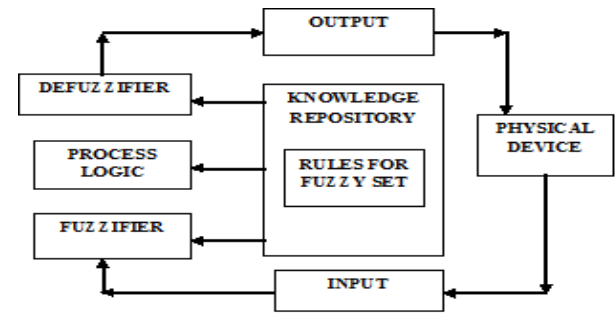


Fig. 2: Block Diagram for Fuzzy System.

## 4. Case study

The proposed algorithm is tested with the three-bus systems to find out the optimal intervals of wind power uncertainty. It must consider with respect to the economic directories and its reliability. The experimental results are carried out with the help of MATLAB stimulation tool. The experimental results were compared with the optimal intervals. These processes were carried throughout on a personal computer with an Intel Core i5 2.60 GHz and 8 GB of memory. The simulation attributes are listed in table 1.

Table 1: Simulation Attributes

Sl. No	Attributes	Value
1	Scheduling period	24Hours
2	Optimality gap	$1e^{-6}$
3	The generating unit's cost curve	4- piecewise linear segments

Table 2: Representation of Transmission Line Data

From	To	MVA	R(pu)	X(pu)
1	2	100	0.040	0.0200
1	3	100	0.030	0.0100
2	3	100	0.025	0.0125

Table 3: Representation of Generator/Wind Data

BUS	V (kv)	P (pu)	Q (pu)
1	33	2.163	0
3	33	2.0	0.4

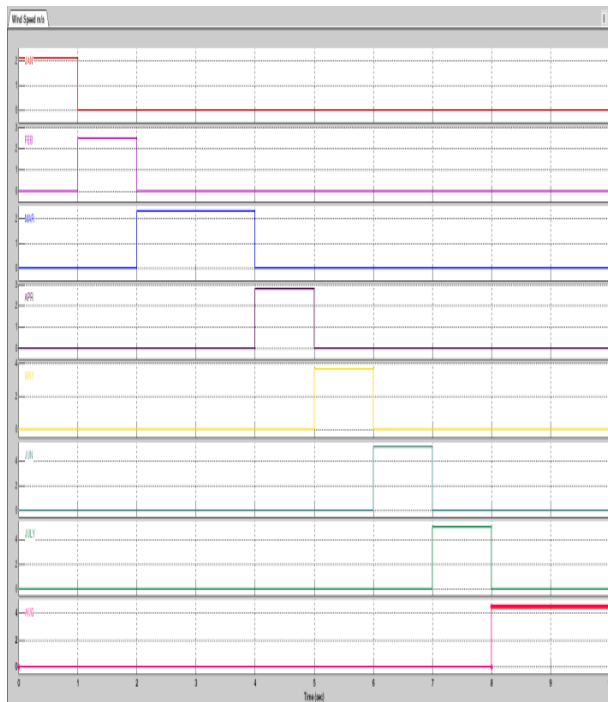
Table 4: Representation of Load Data

BUS	Type	P (MW)	Q (Mvar)
1	PV	0	0
2	PQ	100	1
3	PV	0	0

**Table 5:** Analysis of Wind Speed January 2017-August 2017 in Coimbatore

Month	KM/Hr	M/Sec
Jan	7.7	2.13
Feb	8.9	2.47
Mar	8.2	2.27
Apr	10.0	2.78
May	13.1	3.64
Jun	18.5	5.14
July	18.1	5.03
Aug	16.2	4.5

The effects of various uncertainty levels on the dependability of energy frameworks are precarious. [5], [11]. The analysis of wind speed from January to August 2017 in Coimbatore is demonstrated in Table IV. It proposes a co-optimized model for wind power as shown in figure 3. The proposed model helps to minimize the costs of operation.

**Fig. 3:** Representation of Wind Speed in Coimbatore Region.

## 5. Key steps of hybrid algorithm

Geem et al., (2001) presented the Harmony Search (HS) algorithm by the procedure of music creation. This optimization method has just been effectively executed in different applications, for issues from various logical fields. Harmony search algorithm checks whether the load demand is satisfied at every instant or not. The time period is between 0-10 seconds. Since the nature of wind is varying there may be some instants at which the load demand is not satisfied. In that case we have some error. The error can be positive, zero or negative depending on the output or in other words, the best demand. If an error occurs fuzzy logic controller becomes active.

The fuzzy logic controller works on the basis of rule table. Here Mamdani rule model is utilized. Based on the output 4 rules are possible. Based on error and difference of error conditions can be expressed linguistically as very low error, low error, medium error and high error. The compensation breaker will be active based on the output of the fuzzy logic controller. That is load demand compensation will start working. Deficiency in power will be fed to the load side.

Initialize 'N' with a random process as the HM starts with respect to the equation (8)

$$X_{i,j} = l_j + \text{rand}().(u_j - l_j) \quad (8)$$

Where,  $x_{i,j}$  is the dimension  $j$  of HM  $i$ ;  $u_j$  and  $l_j$  are the minimum and maximum limits of dimension  $j$ ;  $\text{rand}()$  produces random numbers that lies between zero and one. The algorithmic flow of HS computation is described as follows:

Initialize Hybrid Search

Randomly initialize  $x_{ij}$  in HM

Creation and assessment of new solution candidate 'x'.

If (random value (0, 1) is less than the HMCR)

Then

Select the  $x_j$  in  $X$  with the dimension of HM member.

If (rand (0, 1) is less than the PAR

Perform the pitch adjustment between to mutate  $x_j$ ;

$X_j = x_j + \text{rand} (0, 1) \times bw$

Find out the fitness of  $X.F(x)$

Terminate the construction and appraisal of new solution candidate

Update the HMS value

If ( $f(x)$  is better than the fitness of the worst HHS member)

Replace the worst HHS member with  $X$ .

Terminate the updating factor

Until a pre-set termination criterion is met.

In the improvement issues concerning power frameworks namely cost minimization. Kadam et al., (2007) framed a hybrid HS algorithm [16] to deal with non-curved monetary load dispatch of true power frameworks. Kayalvizhi et al., (2015) encircled a monetary load dispatch and the mix of economic and stack dispatch issues [17] that can be changed over into the minimization of the cost work. Lorca et al., (2017) consolidate the HS with consecutive quadratic programming and GA to tackle the ideal power stream issues [18]. The target capacity to be enhanced is the aggregate generator fuel costs in the whole framework.

## 6. Improved hybrid harmony search algorithm

Harmony search algorithm was obtained by accepting the prevailing meta-heuristic algorithms concepts are found in the standard of natural phenomena. Mahto and Mukherjee (2015) presented the algorithm that was newly constructed with an improvisation method [19, 20], where music players manage the pitches of their instruments to attain enhanced harmony. The pitch of every musical instrument establishes the aesthetic quality, just like the function value objective is resolute by the set of values allocated to every decision variable. In improved harmony search algorithm fuzzy logic is also utilized. Optimization steps procedure of HHSA are as follows:

- 1) Initiate the optimization crisis and algorithm factors.
- 2) Initiate the harmony memory accepting (HMR).
- 3) Enhance a novel harmony from the HM.
- 4) Revise the HM.
- 5) Continue the process 3 & 4 until the termination standard is identified.

As well, the population diversity is directly derived from the scaling factor (F) and crossover probability factor (CR). It has a tendency to develop premature convergence and also enhance the nearby searching capacity. The proper parameters would straightforwardly impact the consequences of the calculation. Test outcomes have demonstrated that the calculation will get better outcomes when F and CR are changing in a linear fashion. The dynamic F and CR are set up in a linear relation as in equation (9) and (10):

$$F_t = F_{\max} - (F_{\max} - F_{\min}) \cdot t / T_{\max} \quad (9)$$

$$CR_t = C_{\min} + (C_{\max} - C_{\min}) \cdot T / T_{\max} \quad (10)$$

Where,  $C$  is the current iteration and  $T_{\max}$  is the maximum number of iterations.

The flow diagram is shown in Figure 4

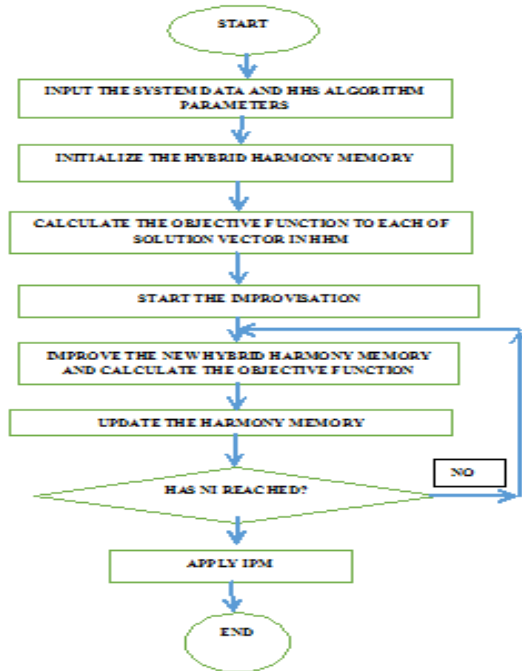


Fig. 4: Flow Diagram of the Proposed Hybrid Harmony Search Algorithm.

In general, a constrained enhancement issue is depicted as follows. Find  $\vec{x}^* = (x_1, x_2, \dots, x_n)$  to minimize  $f(\vec{x}^*)$ , subject to  $g_i(\vec{x}^*) \leq 0$ ,  $i = 1, 2, \dots, M$ , and  $h_j(\vec{x}^*) = 0$ ,  $j = 1, 2, \dots, N$ , where  $f(\vec{x}^*)$  is the objective function and  $g_i(\vec{x}^*)$  and  $h_j(\vec{x}^*)$  are the inequality and equality constraint functions, respectively. The equality constraint functions can be transformed into the inequality constraint functions, with a small enough tolerance parameter ( $\epsilon$ ) as shown in equation (11):

$$|h_j(\vec{x}^*)| - \epsilon \leq 0, \quad (11)$$

The inequality constraints [20] can be described as follows:

- 1) Load bus voltage constraints:
- 2) Thermal limits:
- 3) Generation output limits:

After completion of HM ranking, the worst HM ( $\vec{x}^{\#}$ ) member can be chosen and compared with the novel solution aspirant  $\vec{x}^*$ . The  $\vec{x}^*$  does not need to be feasible. When  $\vec{x}^{\#}$  is compared with  $\vec{x}^*$ ,  $\vec{x}^*$  will replace  $\vec{x}^{\#}$ , only if the following conditions are satisfied.

- 1) Initially,  $\vec{x}^*$  is feasible, and  $\vec{x}^{\#}$  is infeasible,
- 2) Secondly, both  $\vec{x}^*$  and  $\vec{x}^{\#}$  are feasible, and  $f(\vec{x}^*) < f(\vec{x}^{\#})$ ,
- 3) Finally, both  $\vec{x}^*$  and  $\vec{x}^{\#}$  are infeasible, and  $\vec{x}^*$  dominates  $\vec{x}^{\#}$ .

To assess the constrained optimization capabilities of these two HS methods, the Number of Constraint Evaluations (NCEs) is used as the performance criterion here. Similarly, the smaller the NCEs optimization technique is more proficient. The evolution procedures of the two HS approaches [20] are completed, when a predetermined optimization plan goal is met, and the NCEs utilized are in contrast with each other.

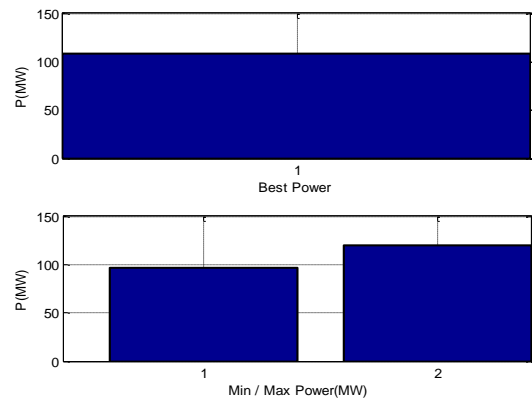


Fig. 5: Best Power Outcome Based on HHS and FL Controller.

The Hybrid HS method [23] makes use of less NCE than the novel HS for attaining the similar optimal design objective. Best power outcome is depicted in Figure 6.

- Adaptive global pitch modification is intended to improve the misuse capacity of arrangement space.
- Opposition-based learning procedure is mixed to expand the assorted variety of arrangement.
- Competition determination component is built up to enhance arrangement accuracy and improve the capacity of getting away nearby optima.

The above process completely depends upon the harmony memory are also examined.

## 7. Fuzzy logic controller

In this investigation, the fuzzy rationale controller is offered to follow the greatest power from the wind with respect to the rotor speed. Fuzzy logic [24] is the best controller to track the most extreme power point. The contributions of the fuzzy logic controller are the blunder between the actual rotor speed and the assessed rotor speed. Using mamdani model fuzzy rules are formulated.

- Error (Very Low error, Low error, Medium error and High error.)
- Difference of Error

In systems, the reactive power, active power, capacitor voltage and terminal voltage of the line are essential to be sustained [26]. So as to manage these factors, they are compared and sensed with the reference values. To accomplish this, the fuzzy controller membership functions is provided below in equation (12)

$$U = - [Ae + (1-\alpha)*C] \quad (12)$$

From the equation 12, the self-adjustable factor ( $\alpha$ ) determines and regulates the whole operation. The de-fuzzification is performed that converts the fuzzified value into de-fuzzified value [27]. It provides the optimal output value. The de-fuzzification is shown in Table VI. Which is the representation of rule table for Fuzzy controller. Based on the error the output is adjusted with the help of compensation breaker. The output is maintained at 100MW.

Table 6: Rule Table for Fuzzy Controller

E/dE	VLE	LE	ME	HE
VLE	HE	HE	LE	ME
LE	HE	ME	VLE	ME
ME	ME	ME	LE	VLE
HE	HE	ME	VLE	VLE

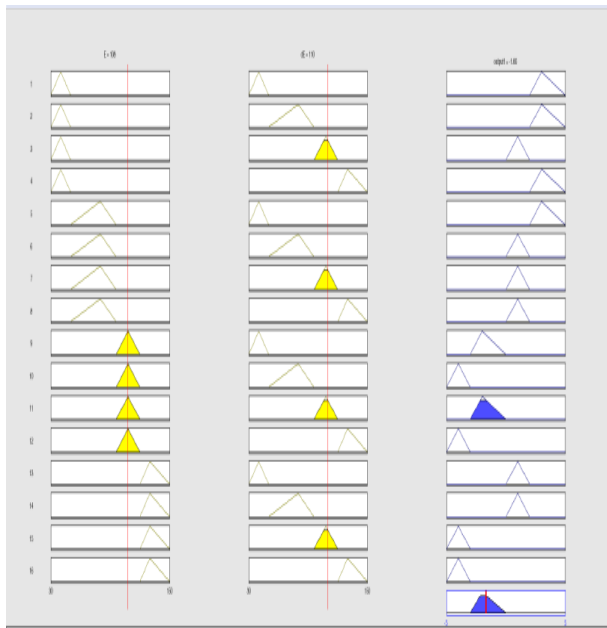


Fig. 6: Representation of Rule Table for Fuzzy Controller.

The following characteristics defines the fuzzy controller logic

- The Fuzzyfication boundary will transfers its input data into appropriate linguistic values.
- The Knowledge Base is comprises of a data base with the essential linguistic descriptions and control rule set [26].
- A Decision Making Logic will, replicates a human decision procedure, and bound the fuzzy control action from the control rules knowledge and the linguistic variable definitions.
- De-fuzzyfication interface provides non-fuzzy control action from a conditional fuzzy control action.

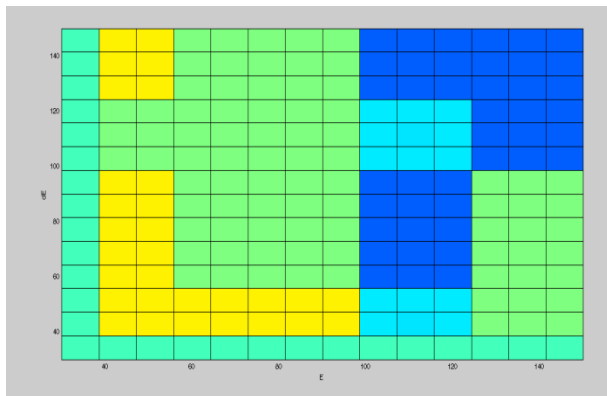


Fig. 7: Schematic Representation of Pseudo Colour.

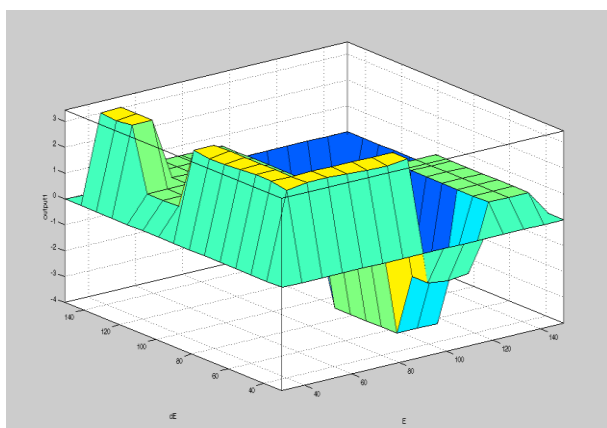


Fig. 8: Surface Representation.

The results are demonstrated in Figure 6, 7, 8 based on the rule table, pseudo colour and surface structure. The power output is

shown in Figure 9. Flow diagram for estimation of best power is shown in Figure 11. The power injected in a distribution system is represented at  $i^{th}$  bus can be represented as shown in the equation (13), (14), (15) and (16)

$$P_{inj,i} = V_i \sum V_j [ G_{ij}(\cos \delta_i - \delta_j) + B_{ij} \sin (\delta_i - \delta_j)] \quad (13)$$

$$Q_{inj,i} = V_i \sum V_j [ G_{ij}(\cos \delta_i - \delta_j) - B_{ij} \sin (\delta_i - \delta_j)] \quad (14)$$

The real power and reactive power flow from bus  $i$  to  $j$  can be depicted as

$$P_{ij} = V_i V_j (-G_{ij} \delta_i - \delta_j) + B_{ij} \sin (\delta_i - \delta_j) + V_i^2 G_{ij} \quad (15)$$

$$G_{ij} = V_i V_j (-G_{ij} \delta_i - \delta_j) - B_{ij} \sin (\delta_i - \delta_j) + V_i^2 G_{ij} \quad (16)$$

The line conductance ( $G$ ) and susceptance ( $B$ ) of the distribution system is represented with the voltage magnitude ( $V_i$ ) of  $i^{th}$  bus and the voltage angle ( $\delta_i$ ) of  $i^{th}$  bus.

a) Equality attributes

The equality attributes  $C(x)$  is defined with the zero injection buses in (17) & (18)

$$P_{gi} - PD_i - V_i \sum V_j [ G_{ij} (\cos \delta_i - \delta_j) + B_{ij} \sin (\delta_i - \delta_j)] = 0 \quad (17)$$

$$Q_{gi} - QD_i - V_i \sum V_j [ G_{ij} (\cos \delta_i - \delta_j) + B_{ij} \sin (\delta_i - \delta_j)] = 0 \quad (18)$$

From the equation 17, the real load is represented as  $PD_i$  and reactive load as  $QD_i$  demands at  $i^{th}$  bus. Similarly, the real power ( $PG_i$ ) and reactive power ( $QG_i$ ) injections are displayed at  $i^{th}$  bus with the total number of buses ( $n$ ) in a network.

b) Performance metrics

The following performance metrics are considered for evaluating the proposed algorithm.

Mean square error (MSE)

$$MSE = \sum I = 1/n (x_i - x_{est})^2 \quad (19)$$

From equation 19, the true ( $x_i$ ) and the estimated value ( $x_{est}$ ) of the  $i^{th}$  measurement quantity is defined with the number of variables ( $n$ ). The Power framework transient strength is the ability of a power framework to come back to a stable working point after the event of an unsettling influence that changes its topology. Occasions of topology changes of a power framework are

- Generator or a line tripping,
- A sudden variation of a load, as well as a load trip,
- Fault occurrence, which is a short circuit.

To evaluate the transient stability performance of the system, the easiest and extensively utilized test scheme is accepted and a closed loop fault is replicated on one line among Buses.

c) During the fault

In case of fault instant, owing to short circuit, the DFIG generator voltage terminal drops thus obtained numerous outcomes. Generator rotor and stator flux reduction results in generator demagnetizing method. The subsequent outcome is the electromagnetic torque reduction and active generator power. Due to mechanical rotor frequency decouple control from the grid frequency through power electronic converters, as a segment of stored potential energy in the rotating mass of the DFIG wind turbine shaft cannot be abounding to the method [27].

It leads to exciting oscillations in the rotating mass of the shaft, which is harsh with greater time constant and superior damping time. Figure 7 represents the best power outcome.

d) Fault completion

If there is any occurrence of fault to be corrected, the voltage may not recover absolutely right away, as rotor-side converter can't supply fundamental responsive power [30] to the generator for its charge advancement. The generator requires retaining grids responsive power and this postpones the improving strategy for the framework voltage [31]. The voltage recovers absolutely, the voltages and the generator streams start to join to their pre-fault es-

teems, and the RSC keeps up its control over the dynamic and responsive power. Comparison of proposed method with existing methods is shown in Table VI.

### 8. Results and discussion

The performance of the proposed algorithm has been evaluated for obtaining the optimal result with the use of hybrid system parameters. Figure 10 represents the voltage and current of IEEE Bus 1, Bus 2 and Bus 3 with respect to time in seconds correspondingly.

a) Three-Bus system

The concept of the three-bus system is displayed in figure 9. Bus 1 is a synchronous generator. Bus 2 is a wind generator. Bus 3 is load bus. Load is assumed to be 100 MW.

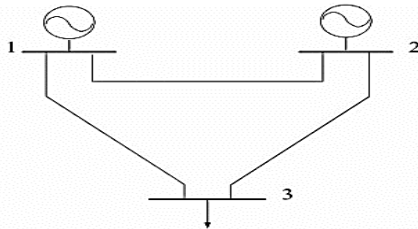


Fig. 9: Three Bus System.

The value of R with respect to pu are 0.040, 0.030, 0.025, as well The value of X with respect to pu are 0.0200, 0.0100, 0.0125 respectively, based on IEEE data. It is noticed that the utilization of new solutions to forecast uncertainty. TABLE II, III and IV shows the schematic representation of Transmission Line data, Generator/Wind Data, and Load data respectively. With 33kV, bus 1 and 3 provides P (pu) of 2.163, 2.0 and load data for bus 1 and 3 is 0 and bus 2 is 100 MW and 1 M<sub>var</sub> respectively.

MATLAB code is utilized to execute and to code the proposed for the fuzzy logic technique and the Hybrid Harmony search algorithm algorithm. For the three bus system, the inputs are fed to obtain the output. It is found that, the use of fuzzy logic technique the computation time is much lesser. The unit commitment crisis has been solved with the three bus units and the generating power units. Thus, the outcome has been compared with the existing algorithms.

The number of numerical tests on the proposed HHS has been carried out to find the most appropriate parameters. The parameters are discussed below.

Table 7: Comparison of Existing Algorithm with the Proposed HHS

FACTORS	Simple HS [35]	FHS1 [35]	FHS2 [35]	FHS3 [35]	HHS
Harmonics	4 to 40	4 to 40	4 to 40	4 to 40	4 to 40
Iterations	1000	1000	1000	1000	1000
HMR	0.95	Dynamic	0.95	Dynamic	0.96
PA rate	0.7	0.7	Dynamic	Dynamic	0.8

Tables VI presents the Harmonics, Iteration, HMR and PA rate for using Simple HS, FHS1, FHS2, FHS3 and HHS. From table VI it is clear that the HHS algorithm Pitch Adjustment rate and Harmony Memory accepting are considerably efficient and probability of convergence is also more for both the units. The number of iterations set for each algorithm is 1000. The computation is made based on the above steps.

The PA rate of HHS is about 0.8 whereas HMR rate is about 0.96 for the proposed work. Similarly, The PA rate and HMR of the existing work is considerably lower when compared to the current work as in figure 10.

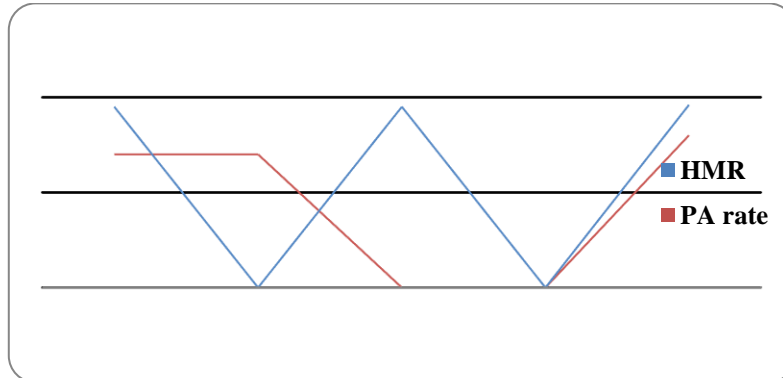


Fig. 10: Graphical Representation of the Comparison of Proposed Algorithm with the Existing Algorithm.

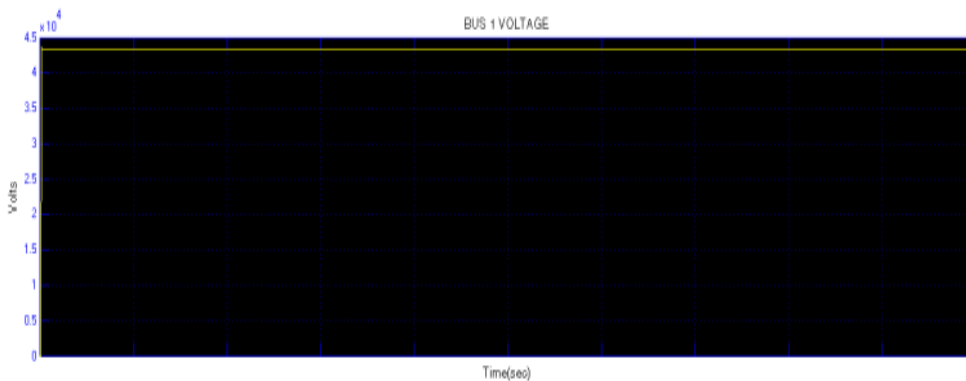




Fig. 11: Best Power Outcome.

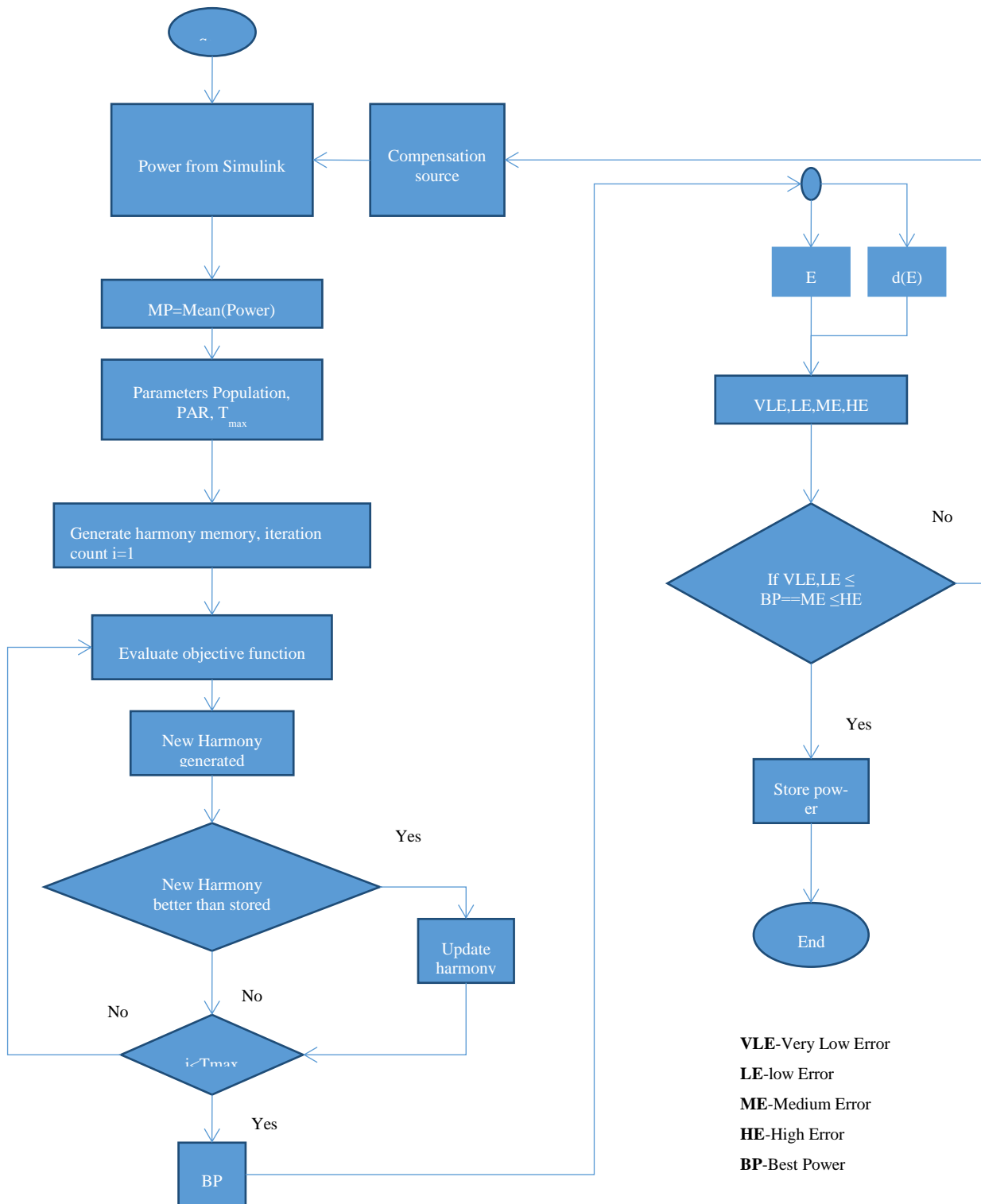


Fig. 12: Flow Diagram for the Estimation of Best Power.

The best power convergence with the generator units are elaborated using the above flow diagram in figure 12. It is seen that the solution provides best power as an outcome, in which the simulation has been carried out based on evaluating the parameters such as very low error, low error, medium error, high error respectively.

### 9. Conclusion

This work highlights the theory and applications of the HHS method and fuzzy logic controller. The basics of the HHS are initially introduced. Subsequently, both the fundamental HHS algorithm and certain distinctive variants are discussed in detail. The HHS method application in a few applications fields, like power systems, optimization, processing, are also presented. Ow-

ing to the Pareto-dominance ranking of Hybrid HM members, the provided constraints can be openly handled in this novel Hybrid HS method. The optimal wind generator design crisis has been utilized to authenticate its effectiveness. The fuzzy controller is better than many types of controllers. The analysis of wind speed has been examined from January to august in Coimbatore region and the obtained results are 2.13, 2.47, 2.27, 2.78, 3.64, 5.14, 5.03, and 4.5 respectively. This study helps to find out accurate simulation results for predicting out best power with low error, smooth, dependable and continuous operation of energy systems.

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