MVO-PS Optimized Hybrid FOFPID Controller for Load Frequency Control of an AC Micro-Grid System

P.C. Nayak, S. Patel, R.C. Prusty, S. Panda

Abstract: This paper proposes a new approach for load frequency control in a multi micro grid system by using hybrid multi verse with pattern search (hMVO-PS) algorithm based Fractional Order Fuzzy PID controller. A multi micro grid system may be moulded by some of the renewable resources (RESs) like photovoltaic (PVs), wind (WTGs), energy storage system (ESSs) and loads. The fractional order fuzzy PID (FOFPID) controller parameters are optimized by novel hybrid Multi verse with pattern search (hMVO-PS) technique. The flexibility and robustness of proposed FOFPID controller is inspected under different disturbance like stochastic variations. The superiority of FOFPID structure over conventional Fuzzy PID/PID and hMVO-PS technique over multi verse optimization (MVO), particle swarm optimization (PSO) and genetic algorithm (GA) has been manifested.

Index Terms: Multi-micro grid, load frequency control, hybrid multi verse with pattern search (hMVO-PS) algorithm, Fractional Order Fuzzy PID (FOFPID) Controller.

1. INTRODUCTION

To overcome several environmental issues due to conventional energy sources, non-conventional sources like Solar PV, Wind energy system, tidal sources etc. are integrated in power system now-a-days. Engineers mostly prefer these renewable resources due to several benefits like no greenhouse gas emission, cost effective and reduce air pollution [1-3]. The distributed energy resources like PVs, WTGs and energy storage systems play a main role in multi micro-grid systems [4]. Micro grid can be operated in 2 modes. During dynamic loading conditions, it may be operates in connected to grid mode and it can be operated in islanded mode during blackout period [5]. Renewable sources (RESs) like photovoltaic (PV) and wind are not considered as secondary control [6-7] because they are intermittent in nature. Now-a-days, demands of consumers fluctuate rapidly. Hence, it is essential to balance supply and load demand [8-11]. Frequency fluctuations are directly related to power stability. Many approaches are used by researchers in micro grid to compensate the unstable operation. For compensation, co-ordination of renewable sources with some of the energy storage elements is highly needed [12]. In this paper, our main aim is to design a robust controller in micro grid by using secondary control loop [13]. Two fundamental structure (i.e. centralized and decentralized structure) are considered for secondary control [14-15]. Micro grid controller centre (MGCC) is worked for centralized structure and decentralized structure allows coordination of various units inside micro grid. Centralized approach is preferred for the islanded micro grid and decentralized structures are preferred for the grid connected micro grid [16]. Centralized approach is considered for this paper. A variety of robust controllers are explained in literatures [17,18]. Researchers are preferred fractional order structure to improve system performance [19,20]. Micro grids having electric vehicle (EVs) and RESs are used FOFPID controller [21]. Inspired from this, here FOFPID controller is proposed. Mirjali suggested a innovative partial search technique i.e., multi verse optimization (MVO) [22]. Motivated from this, here hMVO-PS technique is proposed. In this paper, hMVO-PS technique is employed to optimize the parameters of FOFPID controller. In this research work, FOFOID is a well-defined hybrid controller which can able to control the unwanted disturbances as well as control the system frequency and random variations in tie line power.

Contributions:
The main deposition of this research work is given below:

- The multi-micro grid system consists of various non-conventional energy sources, energy storage system, synchronous alternators and energy consuming devices.
- The projected FOFPID controller is designed for minimize system frequency and changes in tie line power of this two area multi micro grid system.
- To inspect the superiority of projected FOFPID controller, comparisons carried out with Fuzzy based PID and conventional PID controller.
- The proposed FOFPID controller parameters are tuned by novel hybrid Multi verse with pattern search (hMVO-PS) technique.
- The proposed hybrid Multi verse with pattern search (hMVO-PS) technique is compared with multi verse optimisation (MVO), particle swarm optimisation (PSO) and genetic algorithm (GA).
- The proposed controller is examined under various stochastic variations to measure the flexibility and ruggedness of the controller.

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II. SYSTEM MODELLING

The proposed model of transfer function type i.e. multi micro grid system [23] has been demonstrated in Fig 1. Area-1 as well as Area-2 comprise of wind, solar, synchronous generator, energy storage system (i.e. FESS and BESS). Here, FESS and BESS are used for store the backup power and communication links are used for bi directional communications. The whole system under account is divided into two areas integrated through tie lines. The individual single area is a power pool which is a hybrid of synchronous generators (SG), photovoltaic (PV), wind turbine (WT) and storage systems like BESS and FESS. The output of the energy storing element such as BESS and FESS are recorded by observing frequency deviation. This requires the formation of a controller to control each of the storing elements in the feedback path.

III. OBJECTIVE FUNCTION

The main aim of a controller is to minimize steady state error, overshoot and settling time. Four types of performance criterions are taken while designing a controller. These are integral of time multiplied squared error (ITSE), integral of square error (ISE), Integral of absolute error (IAE), and integral of time multiplied absolute error (ITAE).

ITAE is chosen as objective function in this paper which represents as:

\[
ITAE = \int_{0}^{T_f} (|\Delta f_1| + |\Delta f_2| + |\Delta P_{f1}|) \, dt
\]  

where \(T_f\) is final simulation time.

IV. CONTROLLER DESCRIPTION

Popular traditional PID controller is still chosen by many control engineers because of its certain benefits like good reliability, cost effective etc. PID structure is extended to fractional order PID (FOPID) structure due to its several advantages like high degree of freedom and reliability. High degree of freedom is obtained by two additional parameters i.e., integral order (\(I\)) and differential order (\(D\)) whose values lie in between 0 to 1. FOPID controller having transfer function as follows:

\[
M(s) = k_p + \frac{k_i}{s} + k_d s^m
\]  

Here \(k_i\), \(k_d\), \(k_p\) are integral, differential and proportional gain respectively, \(I\) and \(m\) are integral and differential order, respectively. Again FOPID is extended to fuzzy FOPID due to its several benefits. Fuzzy FOPID structure is painted in Fig. 2. Fuzzy can build non-linear relation among input scaling factor(\(k1\)) and output scaling factor(\(k2\)) which enhance its reliability and robustness as compare to FOPID.

![Fig. 1 Transfer function model of multi micro grid system](image)

![Fig. 2 Fractional Order Fuzzy controller](image)

Table 1. Fuzzy rule

<table>
<thead>
<tr>
<th>ACE/ΔACE</th>
<th>NL</th>
<th>NM</th>
<th>NS</th>
<th>Z</th>
<th>PS</th>
<th>PM</th>
<th>PL</th>
</tr>
</thead>
<tbody>
<tr>
<td>NL</td>
<td>NL</td>
<td>NL</td>
<td>NL</td>
<td>NL</td>
<td>NL</td>
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<td>Z</td>
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<td>Z</td>
<td>NL</td>
<td>NM</td>
<td>NS</td>
<td>Z</td>
<td>PS</td>
<td>PM</td>
<td>PL</td>
</tr>
</tbody>
</table>

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To regulate the tie line power as well as frequency deviations, the fuzzy rules are taken which consist of 7 membership functions stated in Table 1. The linguistic variables like NS (negative small), NL (negative large), Z (zero), NM (negative medium), PL (positive large), PS (positive small), PM (positive medium), are taken for this fuzzy structure. The membership function range are shown in Fig. 3.

![Fuzzy membership functions of inputs (error, change in error) and output](image)

**Fig. 3. Fuzzy membership functions of inputs (error, change in error) and output**

### V. HYBRID MULTI VERSE OPTIMIZATION AND PATTERN SEARCH (hMVO-PS) ALGORITHM

#### A. The Multi Verse Optimization (MVO)

MVO algorithm follows the multi verse theory. This algorithm deals with the interaction among multiple universes through worm hole, white hole and black hole. Stochastic optimization is done by this algorithm. White hole and black hole explore the phase of optimization [24] however, warm hole assists to achieve the target towards the search space.

#### B. Pattern Search Algorithm

Pattern search algorithm is a novel algorithm. Number of non-linear optimizations can be solved by this algorithm. Researchers mostly prefer this algorithm due to its several advantages like easy operation, easy concept and computationally more effective. The operator related to this algorithm is flexible which enhance in global search and increase the capability to fine tuning the local search. The initial point $X_0$ is taken from MVO algorithm which is the starting point of Pattern search. Then, we add multiple scalar quantities with a group of current vector quantities for pattern formation. Now, this will be the initial point for next iteration. During first iteration, the pattern vectors or the direction vectors are organized in a manner like $[0 \ 1], [1 \ 0], [-1 \ 0]$ and $[0 \ -1]$. In PS process, the mesh size is recognized as iteration counter. In the subsequent step, mesh point is expressed by totaling the pattern vectors to the starting point $X_n$. This point is treated as the starting point for subsequent iteration. Then, the current mesh is multiplied by 2 called as an expansion factor. Therefore, at the end of second iteration, the mesh points turn out to be: $X_1 + 2 \times [0 \ 1], X_1 + 2 \times [1 \ 0], X_1 + 2 \times [-1 \ 0]$ and $X_1 + 2 \times [0 \ -1]$, and this process is proceeded till the terminating criteria is achieved. The measurement of objective function is done at $t=120$ second.

<table>
<thead>
<tr>
<th>PS</th>
<th>NS</th>
<th>NS</th>
<th>Z</th>
<th>PS</th>
<th>PL</th>
<th>PM</th>
<th>PL</th>
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</thead>
<tbody>
<tr>
<td>PM</td>
<td>NS</td>
<td>Z</td>
<td>PS</td>
<td>PM</td>
<td>PM</td>
<td>Z</td>
<td>PL</td>
</tr>
<tr>
<td>PL</td>
<td>Z</td>
<td>PL</td>
<td>PL</td>
<td>PL</td>
<td>PL</td>
<td>PL</td>
<td>PL</td>
</tr>
</tbody>
</table>

### VI. RESULT AND ANALYSIS

This part of the paper represents the superiority of the projected hMVO-PS algorithm optimized FOFPID controller to minimize the system frequency and changes on tie-line power. The proposed hMVO-PS technique is compared over MVO/PSO/GA to prove its efficiency. Number of search agent/population/swarm size is taken as 20 and maximum number of iterations is taken as 100 for all the algorithms. To confer the efficacy of proposed FOFPID controller, it is compared with Fuzzy PID and conventional PID controller in this paper. To check the robustness of the proposed controller, stochastic variation in RESs and load are also added during controller design. Here, same tuned controller parameters are taken for both un stochastic and stochastic variations which enhance the robustness of controllers. The gain of controller parameters lie in between 0 to 4 [25]. Here, simulation time ($T$) is taken as 120 sec. In this paper, two different case studies have been taken. Case1: without stochastic variations, Case2: With stochastic variations.

#### A. Case 1

The variation of load condition at both the load and source side, the step variations as listed in Table 2 are considered. The variable step signal for photovoltaic, wind turbine and load are shown in Fig. 4. The efficiency of the controller is studied through the detailed comparison of MVO-PS optimized PID and fuzzy PID controller. The tuned controller parameters and minimum ITAE values of designed controllers are provided in Table 3. To show superiority of MVO-PS technique, the results are compared with GA and PSO algorithm as shown in Table 3.

**Table 2. The parameters for step variation for loads and sources**

<table>
<thead>
<tr>
<th>Disturbance at</th>
<th>Range: Magnitude</th>
</tr>
</thead>
</table>
| Load in MG1   | 0 < t < 80: Load=1 p.u.  
|                | 80 < t < 120: Load=1.16 p.u. |
| Load in MG2   | 0 < t < 80: Load=0.8 p.u.  
|                | 80 < t < 120: Load=0.96 p.u. |
| Wind turbine  | 0 < t < 40: Load=0.4 p.u.  
|                | 40 < t < 120: Load=0.2 p.u. |
| Sun irradiance| 0 < t < 40: Load=0.3 p.u.  
|                | 40 < t < 120: Load=0.15 p.u. |

The proposed FOFPID controller is compared with hMVO-PS optimized Fuzzy PID/PID controller to prove its efficiency. To study the supremacy of hMVO-PS technique, it is compared with MVO/PSO and GA algorithm which is stated in Table 2. The optimized controller parameters and minimum ITAE values are stated in Table 2. In Table 2, subscripts 1 and 2 represents Area1, Area2, respectively.

It is very clear from Table 2 that, by taking PID controller structure, hMVO-PS is having minimum ITAE value (ITAE=1.9687) as compare to MVO (ITAE=2.3269), PSO (ITAE=2.6944) and GA (ITAE=2.9716).
Hence, it is concluded that, the performance of hMVO-PS algorithm is superior as compare to MVO/PSO/GA. From Table 2, it is also manifested that ITAE value is further decreased to 0.8574 in Fuzzy PID structure (ITAE=0.8574) and least in proposed FOFPID structure (ITAE=0.736). The transient response of above cases is stated in Fig. 5-6.

![Graphs showing performance comparison](image)

**Fig. 4.** Step variations of PVs, Wind and load

**Fig. 5.** Different algorithm comparison in Area1

<table>
<thead>
<tr>
<th>Controller Parameters / Fitness value</th>
<th>GA:PID</th>
<th>PSO:PID</th>
<th>MVO:PID</th>
<th>hMVO-PS:PID</th>
<th>hMVO-PS: Fuzzy PID</th>
<th>hMVO-PS: Fuzzy FOPID</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k_P$</td>
<td>2.5</td>
<td>3.98</td>
<td>3.96</td>
<td>4</td>
<td>2.9892</td>
<td>2.9892</td>
</tr>
<tr>
<td>$k_I$</td>
<td>3.54</td>
<td>3.89</td>
<td>3.54</td>
<td>4</td>
<td>3.9</td>
<td>3.9000</td>
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<tr>
<td>$k_D$</td>
<td>1.023</td>
<td>1.30</td>
<td>2.44</td>
<td>2.3510</td>
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<td>3.0913</td>
</tr>
<tr>
<td>$k_1$</td>
<td>………</td>
<td>………</td>
<td>………</td>
<td>………</td>
<td>3.9950</td>
<td>………</td>
</tr>
<tr>
<td>$k_2$</td>
<td>………</td>
<td>………</td>
<td>………</td>
<td>………</td>
<td>1.9003</td>
<td>3.9002</td>
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</table>


<table>
<thead>
<tr>
<th>l_1</th>
<th>m_1</th>
<th>k_p1</th>
<th>k_i1</th>
<th>k_d1</th>
<th>m_2</th>
<th>ITAE (un stochastic)</th>
<th>ITAE (stochastic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.98</td>
<td>0.99</td>
<td>2.43</td>
<td>3.02</td>
<td>3.12</td>
<td>3.189</td>
<td>2.4464</td>
<td>2.8970</td>
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<tr>
<td>3.760</td>
<td>2.0913</td>
<td>1.9943</td>
<td>1.9943</td>
<td>2.23</td>
<td>2.22</td>
<td>1.9943</td>
<td>2.0913</td>
</tr>
<tr>
<td>2.8970</td>
<td>1.2891</td>
<td>1.2891</td>
<td>1.2891</td>
<td>2.43</td>
<td>2.4464</td>
<td>1.9943</td>
<td>2.0913</td>
</tr>
<tr>
<td>0.964</td>
<td>1.3007</td>
<td>1.3007</td>
<td>1.3007</td>
<td>1.9687</td>
<td>1.9687</td>
<td>0.8574</td>
<td>0.736</td>
</tr>
</tbody>
</table>

(a) frequency variation in Area1

(b) frequency variation in Area2

**Fig. 6. Comparative dynamic performances for un-stochastic variations**

### B. Case 2

To make a realistic study, stochastic variations in non-conventional energy sources such as Solar PV, wind and the load are considered. The equation for the generated output powers are of the form [24]:

\[ P = (\phi \theta \sqrt{\alpha} (1 - G(s)) + \alpha) / \alpha) \chi = \sigma \chi \]  (3)

\( \phi \) denotes the stochastic component of the uncontrolled generated power, \( \theta \) denotes the normalization constant, \( \alpha \) denotes the mean value, \( \chi \) denotes the fluctuation level of the generated power to a specific point at a specific time. The nominal parameter values used for loads, solar and wind power in this scenario is listed in Table 5.

The below equation represents the stochastic variations at PV, wind and load. The appropriate curves for the stochastic variations are depicted in the Fig. 7.

\[ \chi_{l_1} = 0.05F(t) + [1.1F(t) - 0.15F(t - 60) + 0.3F(t - 90)](1 / \sigma) \]  (4)

\[ \chi_{l_2} = 0.05F(t) + [0.65F(t) - 0.10F(t - 60) + 0.16F(t - 90)](1 / \sigma) \]  (5)

\[ \chi_{WT_1} = \chi_{WT_2} = 0.45F(t) - 0.2F(t - 30) \]  (6)

\[ \chi_{PV_1} = \chi_{PV_2} = 0.2F(t) - 0.1F(t - 30) \]  (7)

where \( F(t) \) is the Heaviside step function. To this scenario MVO algorithm is applied to find the optimized gain parameters of PID controller, fuzzy PID – LQG controller and the proposed best controller fuzzy FOPID LQG to satisfy the objective function minimum integral time absolute error.

Stochastic variations in RESs i.e. PV, Wind and load are taken in real world. The equations for output power for each case are taken from [23] and curves are shown in Fig. 8.
Fig 7. Stochastic variations at load and source

Table 5. Parameters for stochastic disturbance at loads and sources

<table>
<thead>
<tr>
<th>Disturbance at</th>
<th>( \phi )</th>
<th>( \theta )</th>
<th>( \alpha )</th>
<th>( G(s) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load In MG1</td>
<td>U(-1,1)</td>
<td>0.8</td>
<td>10</td>
<td>( \frac{300}{300s+1} + \frac{1}{1800s+1} )</td>
</tr>
<tr>
<td>Load in MG2</td>
<td>U(-1,1)</td>
<td>0.8</td>
<td>10</td>
<td>( \frac{300}{300s+1} + \frac{1}{1800s+1} )</td>
</tr>
<tr>
<td>Wind turbine</td>
<td>U(-1,1)</td>
<td>0.8</td>
<td>10</td>
<td>( \frac{1}{10^4s+1} )</td>
</tr>
<tr>
<td>Sun irradiance</td>
<td>U(-1,1)</td>
<td>0.7</td>
<td>1</td>
<td>( \frac{1}{10^4s+1} )</td>
</tr>
</tbody>
</table>
The optimized controller parameters for PID/Fuzzy PID /FOFPID controller are taken in Table 2. From Table 2, minimum ITAE of 7.0133 is obtained for PID structure (ITAE=0.133). The ITAE value is further decreased to 1.3007 when PID is replaced by Fuzzy PID controller (ITAE=1.3007). Least ITAE value is obtained in our proposed FOFPID controller (ITAE=1.2891) which shows its superiority over Fuzzy PID/PID controller. The transient behavior of above discussion is presented on Fig 8.

VII. CONCLUSION

In this paper, hMVO-PS technique is implemented to optimize the parameters of PID, Fuzzy PID and Fractional order fuzzy PID controller. A two area interconnected multi micro grid system is considered here which consist of RESs like PV, Wind, synchronous generator, load along with energy storage elements (FESS and BESS). Here, the main focus is to minimize frequency as well as tie line power deviations by considering the hybrid multi verse with pattern search (hMVO-PS) algorithm based Fractional Order Fuzzy PID (FOFPID) controller. Simulation results shows that proposed FOFPID controller gives better results than conventional controller like PID/Fuzzy PID controller. To check the robustness of proposed controller, stochastic variations are also considered in this paper. Here, same tuned controller parameters are taken for both un-stochastic and stochastic variations which enhance the robustness of controller. The superiority of hMVO-PS technique over MVO/PSO/GA are also being checked.

APPENDIX

The nominal values for MMG:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nominal Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R_a )</td>
<td>0.05 (p.u.)</td>
</tr>
<tr>
<td>( R_b )</td>
<td>0.04 (p.u.)</td>
</tr>
<tr>
<td>Frequency bias constants: ( B_a = 10 ) (p.u.), ( B_b = 12.5 ) (p.u.)</td>
<td></td>
</tr>
<tr>
<td>Time constants of turbine: ( T_{ma} = 0.4 ) (s), ( T_{mb} = 0.4 ) (s)</td>
<td></td>
</tr>
<tr>
<td>Speed governor time constants: ( T_{ga} = 0.1 ) (s), ( T_{gb} = 0.1 ) (s)</td>
<td></td>
</tr>
<tr>
<td>Time constants of WT : ( T_{WTa} = 0.5 ) (s), ( T_{WTb} = 0.5 ) (s)</td>
<td></td>
</tr>
<tr>
<td>Time constants of PV : ( T_{PVa} = 1.5 ) (s), ( T_{PVb} = 1.5 ) (s)</td>
<td></td>
</tr>
</tbody>
</table>

FESS: \( K_{FESS} = -1.5 \) (p.u.), \( K_{FESS} = -2 \) (p.u.), Gain constant of WT: \( K_{WTa} = 1 \) (p.u.), \( K_{WTb} = 1 \) (p.u.), Gain constants of PV: \( K_{PVa} = 1 \) (p.u.), \( K_{PVb} = 1 \) (p.u.), Inertia constants: \( M_a = 8 \) (p.u.), \( M_b = 8 \) (p.u.), Damping constants: \( D_a = 1 \) (p.u.), \( D_b = 1 \) (p.u.), Synchronizing coefficient: \( \delta_{12} = 1.4 \)

In above data: subscripts \( a, b \) denote nominal values for Area1 and Area2 respectively.

REFERENCES


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