# Integration of distributed power sources to hydro-hydro power system subjected to load frequency stabilization

**Chandan Kumar Shiva, B. Vedik, Ritesh Kumar**

***Abstract – It is well known that the renewable integration to the power system plays important roles to enhance system dynamic responses. To take the account of this effect, the influences of renewable energy source after addition to the power system is studied in this work. The work done here is to integrate wind turbine generator (WTG) to the studied hydro-hydro test power system to stabilize load frequency subjected to load penetration. The two degree of freedom (2DOF) based proportional-integral-derivative (PID) controller is employed as the primary control task. The studied 2DOF PID controller gains are tuned by moth-flame optimization algorithm. Following to integration of WTG, the impacts on load frequency control is also presented. The simulation results showed that dynamic responses get improved with the addition of WTG.***

***Keywords - Grid frequency stabilization; hydro power system, optimization; wind turbine generation.***

## 1. INTRODUCTION

The grid frequency stabilization after load perturbation is an essential criterion for reliable power generation [1]. This issue is also of rising interests when it is concerning to study of hydro power systems. The study becomes more difficult when renewable energy sources (RESs) is incorporated to the system dynamics. It is due to the stochastic behaviour of RES [2]. The previous study shows that an important feature of RES units is the possibility of their fast active power injection to support frequency regulation. This study is apprehensive on the large penetration of wind power generation to the system dynamics. The impacts of RESs on system dynamics following to power imbalance is shown in [3].

### Literature review

The utilization of more and more electrical equipment and regularly changing structure of the power system entail for the new system with modified control techniques. In the load frequency control (LFC) study, it is needed to design the improved dynamic system which is supplemented with the modified LFC approach [4]. Under these circumstances, the addition of wind power to the grid may provide solution to suppress the load frequency oscillations. The action of high penetrated wind farm comes in power shortage. The active power generated by wind turbine may be used as the recovery of system frequency and support primary frequency support [4]. In the added work, the contribution of wind power subjected to load frequency stabilization has been included in [5, 6]. In this work, the functioning of wind power generation with change in load demands has been shown. The utilization of rotating kinetic energy of the wind power in system frequency regulation have been studied in [7].

The previous work done suggested that wind turbine generators (WTGs) have the impact on frequency regulation and control. Thereby, this work is on focused to (LFC) study of hydro power systems.

### Motivation of the present work

A number of difficulties may be pointed out while designing the controller gains using different methods. It may be due to improper selections of boundary condition, local optima and difficult to design optimal derivative gain [8]. The fuzzy based PI controller shows somewhat acceptable dynamic responses. Later, concerned to the fuzzy based proportional-integral-derivative (PID) controller, it produces even better dynamic responses. Here, the problem is the implementation of fuzzy PID controller because of its three-dimensional rule base [9, 10].

Optimization techniques are one of the primary concerns to the solution of power system problems [11-14]. However premature convergence, the reduction in search capability and local minima solutions need to be solved while dealing with optimization method [15]. Here, our concerned is with the moth flame optimization (MFO) algorithm. The details and effectiveness of MFO algorithm is shown in [16]. In response to this, the work done here is to design the degree of freedom (2DOF) PID controllers using MFO algorithm for the LFC action.

After this portion, the work is performed as followed. The subsequent section details the studied test system. The constraint optimization task is revealed in Section 3. The explanation of the optimization tool is obtainable in Section 4. The simulation results are showing in Section 5. The conclusion are presented in Section 6.

## 2. DYNAMIC POWER SYSTEM MODEL

### WTG: basic concept

The power output of WTG depends on the wind speed . The wind model chosen for the simulation is a four component sub-system and may be defined in (1) [17].

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**Chandan Kumar Shiva,** Department of Electrical and Electronics Engineering, S R Engineering College, Ananthsagar, Hasanparthy, Warangal, Telangana, India (dr.ck_shiva@srecwarangal.ac.in)

**B. Vedik,** Department of Electrical and Electronics Engineering, S R Engineering College, Ananthsagar, Hasanparthy, Warangal, Telangana, India (b.vedik@gmail.com)

**Ritesh Kumar,** Department of Electrical and Electronics Engineering, S R Engineering College, Ananthsagar, Hasanparthy, Warangal, Telangana, India (ritesh_kumar@srecwarangal.ac.in)

$$V_W = V_{WB} + V_{WG} + V_{WR} + V_{WN} \quad (1)$$

In (2), is the base wind speed, is the gust wind speed, is the ramp wind speed and is the background noise.

The simplified model of WTG as first order may be expressed in (2) [17].

$$G_{WTG}(s) = \frac{K_{WTG}}{1 + sT_{WTG}} \quad (2)$$

### Design of PID controller

A 2DOF PID controller is used as a feedback mechanism. It makes sure that response of the system may be improved with almost zero steady state error [18]. The comparative performance of 2DOF based control system with the conventional one is shown in [18]. The designing aspect of a 2DOF PID controller is displayed in Fig. 1.

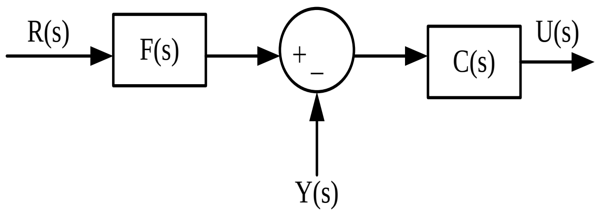


**Fig. 1. Configuration of 2DOF PID controller.**

In Fig. 1, R(s) is the reference signal, Y(s) is the feedback signal and U(s) is the output signal. For a 2DOF PID controller, C(s) and F(s) may be stated by (3) and (4), respectively.

$$C(s) = \frac{(K_p + K_D N)s^2 + (K_p N + K_I s)s + K_I N}{s(S+N)} \quad (3)$$

$$F(s) = \frac{(bK_p + cK_D N)s^2 + (bK_p N + K_I)s + K_I N}{(K_p + K_D N)s^2 + (K_p N + K_I)s + K_I N} \quad (4)$$

where, and are the proportional, integral and derivative gain respectively, b and c are the proportional and derivative set point weights respectively and N is the derivative filter coefficient. The complete structure of 2DOF PID controller is shown in Fig. 2 [14].

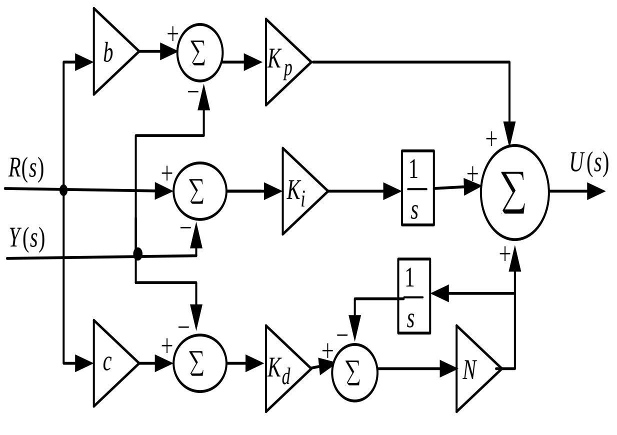


**Fig. 2. Studied structure of 2DOF PID controller**

### Studied hydro-hydro power system

The basic model of two-area hydro power system, equipped with hydraulic governor , hydro-turbine as well as load and machine is shown in Fig. 3.

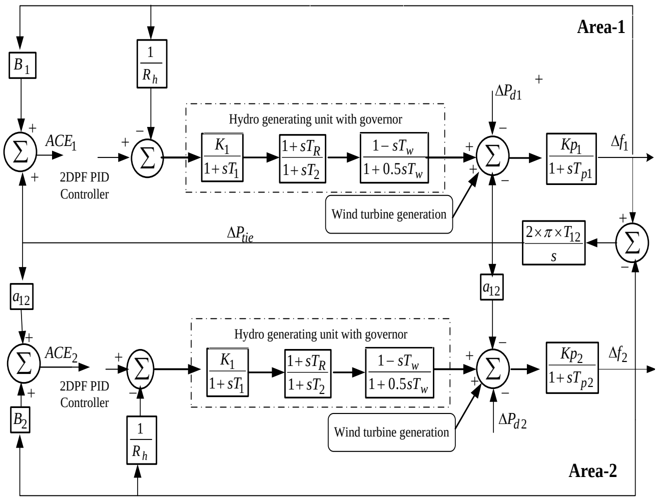


**Fig. 3. Studied configuration of hydro-hydro power system model**

The transfer function model for the same may be expressed in (5) - (7), in order.

$$G_g(s) = \frac{K_1}{1+sT_1}\,\frac{1+ST_R}{1+sT_2} \quad (5)$$

$$G_t(s) = \frac{1 - sT_w}{1 + s\,0.5T_w} \quad (6)$$

$$G_{ps}(s) = \frac{K_p}{1 + sT_p} \quad (7)$$

The open loop transfer function without drooping may be stated in (8).

$$P(s) = G_g(s)G_t(s)G_{ps}(s)$$

$$= \frac{K_1}{1+sT_1}\,\frac{1+ST_R}{1+sT_2}\,\frac{1-sT_w}{1+s\,0.5T_w}\,\frac{K_p}{1+sT_p} \quad (8)$$

The value for may be voiced by (9) [19].

$$B_i = \frac{1}{R_i} + D_i \quad (9)$$

where and are the regulation constant and the damping ratio of the i-th area, respectively. The system parameters are depicted in Appendix Section.

## 3. MATHEMATICAL PROBLEM FORMULATION

Integral of square error (ISE) is picked up as the objective function. The expression of ISE may be stated in (10)

$$ISE = \int_0^{t_s} (ACE_i^2)\,dt \quad (10)$$

where $t_s$ is the simulation time.



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In the present LFC work, the constraints are the 2DOF PID controller parameters and may be formulated in (11).

$$\left.\begin{array}{l} K_{pi}^{\min} \le K_{pi} \le K_{pi}^{\max} \\ K_{ii}^{\min} \le K_{ii} \le K_{ii}^{\max} \\ K_{di}^{\min} \le K_{di} \le K_{di}^{\max} \\ N^{\min} \le N \le N^{\max} \\ a_{ii}^{\min} \le a_{ii} \le a_{ii}^{\max} \\ b_{di}^{\min} \le b_{di} \le b_{di}^{\max} \end{array}\right\} \quad (11)$$

The minimum values for $K_p$, $K_i$, $K_d$, $N$, $a_i$ and $b_i$ are set as 0.001 whereas the maximum values for the same are set as 1, 1, 1, 300, 1 and 1, respectively, in the optimization process.

The performance indices like integral of time absolute error (ITAE), integral of absolute error (IAE) and integral of time square error (ITSE) are also determined for the computational efficiency of the algorithm. The expressions for the same may be stated in (12), (13) and (14), respectively.

$$ITAE = \int_0^{t_s} |ACE_i| t dt \quad (12)$$

$$IAE = \int_0^{t_s} |ACE_i| dt \quad (13)$$

$$ITSE = \int_0^{t_s} (ACE_i^2) t dt \quad (14)$$

## 4. MFO ALGORITHM

### MFO: basic concept

Moth is a class of insects comparable to families of butterflies. The moths have a special navigation in night and retaining a fixed angle as reference to the moon. This helps in travelling a long distance. However, owing to artificial lights, it may be stuck to a spiral path. This mathematical concept is being used in [16] to design the MFO algorithm. The algorithmic steps of the MFO are shown in the Appendix section. The flowchart for the same is shown in Fig. 4.

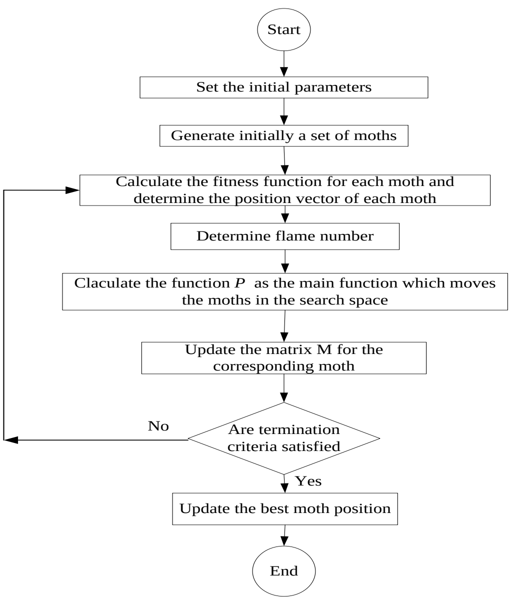


**Fig. 4. Flowchart of the MFO algorithm.**

## 5. SIMULATED RESULTS AND DISCUSSION

The LFC response of hydro-hydro test system model is studied with the impact of WTG. The MFO algorithm is applied to tune the gains of 2DOF PID controller's gains.

### Studied hydro-hydro power system model

The transfer function based configuration of studied hydro-hydro power system model is presented in Fig. 3. The parametric values for the studied test system are depicted in [20] (refer Appendix section). The step load perturbation (SLP) applied to area-1 is 0.01 p.u.MW. Subjected to this, the LFC response with the effect of WTG is investigated.

The MFO based optimized controller gains are shown in Table 1. The LFC responses with and without WTG are shown in Fig. 5. A close look of the obtained simulation results divulges that the system dynamic performance is improved with WTG. The dynamic responses may further be justified by observing the Table 2. This table shows the tuning efficiency of the MFO algorithm in terms of ISE, IAE, ITSE and ITAE. It may be noted that an improvement in FOD, IAE, ITSE and ISE values is observed with the addition of WTG to the power system dynamics.

**Table 1 MFO based optimized 2DOF PID controller gains subjected to 1% SLP**

| Control area | Optimized controller gains | | | | | |
|---|---|---|---|---|---|---|
| | $K_p$ (-ve) | $K_i$ (-ve) | $K_d$ (-ve) | $N$ | $b_i$ | $c_i$ |
| | For SLP without WTG | | | | | |
| Area-1 | 0.1965 | 0.0010 | 0.3335 | 300 | 0.0010 | 0.4215 |
| Area-2 | 0.0010 | 0.0010 | 0.9948 | 283.97 | 0.2280 | 1.0000 |
| | For SLP with WTG | | | | | |
| Area-1 | 1.0000 | 0.0032 | 0.0010 | 197.93 | 0.3047 | 0.8871 |
| Area-2 | 0.1267 | 0.0010 | 1.0000 | 135.3189 | 0.5553 | 1.0000 |

**Table 2 Comparative FOD and studied performance indices subjected to MFO based optimized 2DOF PID controller**

| Studied system types | Objective function | Performance indices | | |
|---|---|---|---|---|
| | ISE | IAE | ITSE | ITAE |
| With WTG | **0.0113** | **0.8807** | **0.1187** | **24.3780** |
| Without WTG | 0.0621 | 1.7605 | 0.4017 | 32.9009 |


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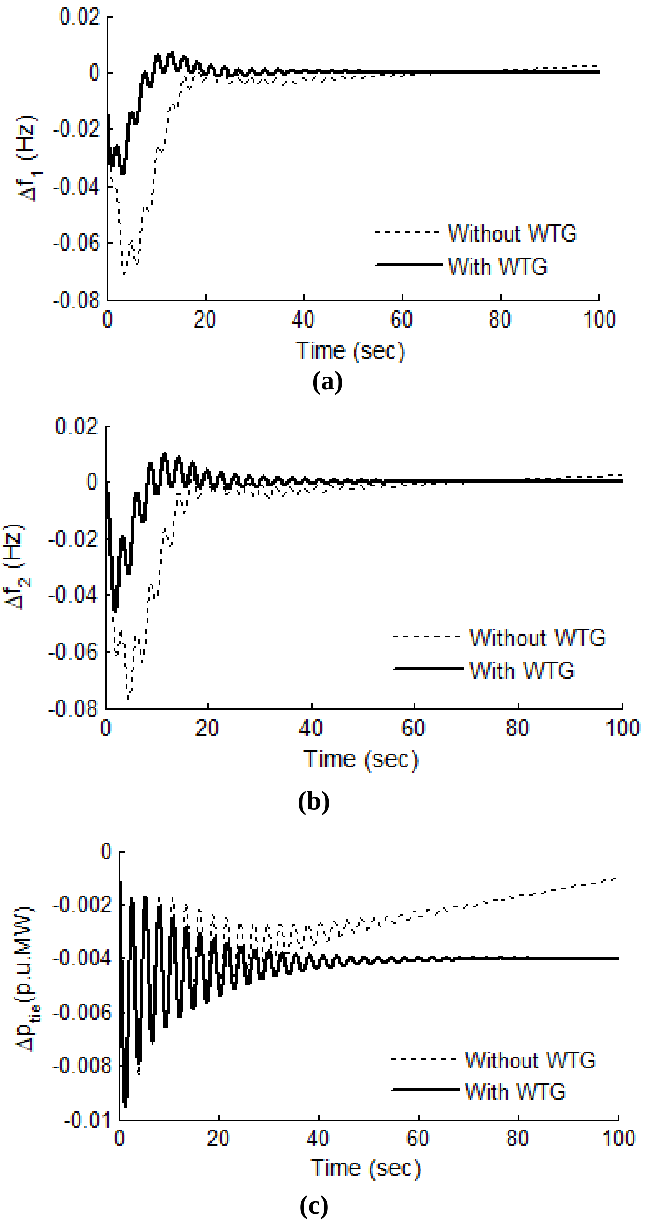


**Fig. 5. Comparative dynamic responses offered by the MFO based 2DOF-PID controller: (a), (b) and (c)**

## 6. CONCLUSION

The present study is focused on LFC study of hydro-hydro power system with WTG. The study is concerned on to control the large overshoots due to water inertia of the hydro turbine with the effect of WTG and 2DOF-PID controller. The observation said that the MFO based 2DOF PID controller offers better dynamic responses and converge to quality solutions. Thereby, the MFO algorithm is an effective tool for LFC problem of hydro power system.

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**Appendix**

*Rated parameters of hydro power system [20]*

$f$ = 50 Hz, $B_1, B_2 = 0.425$ p.u.MW/Hz, $R_1 = 2.4$ Hz/p.u, $R_2 = 2.4$ Hz/p.u, $K_p = 100$ Hz/p.u.MW, $T_p = 20$ sec, $K_1 = 1.0$, $T_w = 1.0$ sec, $T_2 = 0.513$ sec, $T_R = 5.0$ sec, $T_{12} = 0.0707$ p.u.MW/rad.

*Algorithm details of the MFO algorithm*

**Algorithm 1:** structure of the MFO algorithm [16]

$M = I(\ );$
***while*** $T(M)$ *is equal to false*
    $M = P(M);$
***end***

**Algorithm 2:** Step of objective function [16]

***for*** $i = 1 : n$
  ***for*** $j = 1 : d$
    $M(i, j) = (ub(i) - lb(i)) * rand(\ ) + lb(i);$
***end***
***end***
$OM = FitnessFunction(M)$

**Algorithm 3:** General steps of function $P$ [16]

*Update flame number using*
$OM = FitnessFunction(M)$
***If*** $iteration == 1$
  $F = sort(M);$
  $OF = sort(OM);$
***else***
  $F = sort(M_{t-1}, M_t);$
  $OF = sort(M_{t-1}, M_t);$
***end***
***for*** $i = 1 : n$
  ***for*** $j = 1 : d$
    *Update* $r$ *and* $t$
    *Calculate* $D$ *with respect to the corresponding moth*
    *Update* $M(i, j)$ *with respect to the corresponding moth*
  ***end***
***end***


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