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IMC-DE-FOPID BASED LOAD FREQUENCY CONTROL OF SINGLE-AREA POWER SYSTEMS

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Abstract

The present research paper discusses differential evolution optimization based modified control configuration for the aim of load frequency control of single-area non-reheated thermal power system. The load frequency control can be achieved by proposed scheme which contains an internal model control (IMC) controller in the internal loop and a FOPID controller in the external loop. Designed of the IMC controller is assembled by low pass filters and a predictive model (PM) which is derivative from the system model using the Routh approximation method. The tuning parameters of low pass filters and exterior loop controller are enhanced by using Differential evolution (DE) optimization. The projected method can sustain faster rejection of external load disturbances and offers better robustness under parameter uncertainty.

Keywords – DE-Differential FOPID-Fractional Order proportional integral derivative, IMC Two degree of freedom-internal model control, load frequency control, model reduction, differential evolution, robustness.

I. INTRODUCTION

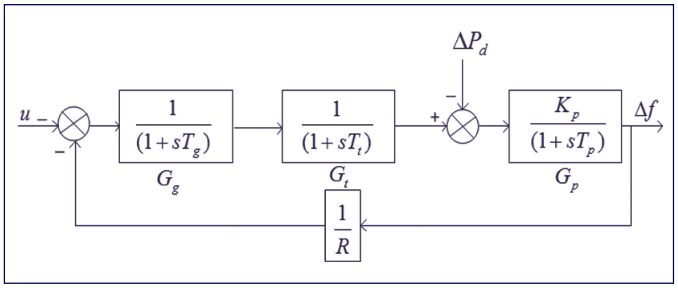
Few decades ago, various approaches [1] using different controltechniquese have been presented for load frequency control (LFC) of SİNGLE AREA POWER SYSTEMS (SAPS) to maintain the system frequency and tie-line power exchange within specified limits [2, 3]. During operation of a power system it has been found that it is one of the major issues which needs to be tackled properly. Since it has been observed that IMC and model reduction (MR) are being used quite frequently for LFC of SAPS and multi-area power systems (MAPS). To tackle LFC issue a self-tuning based controller, [4] model reduction (MR) based controller [5, 6] were presented. In the continuation of this Tan [7, 8] presented use of PID controller using two-degree-of-freedom (TDF) IMC for SAPS and MAPS. Later, Tan also proposed a IMC based PID for decentralized multi-area power system (MAPS) in [9]. Thenafter, Saxena and Hote [10] presented another TDF-IMC based technique for LFC of single-area non-reheated thermal power system (NRTPS). The various structures of TDF-IMC for eliminating load disturbance and its applications can be referred from [11]. Furthermore, a robust controller is proposed for LFC of MAPS in [12] by bearing in mind the parametric suspicions. A modified TDF-IMC scheme for LFC of a non-reheated TPS using stability equation method is presented in [13] and another MR based TDF-IMC is presented in [14] using Routh, Padè and second-order plus- dead-time approximations. Furthermore, Kasireddy et al. [15] presented integer and non-integer type IMC based controller using a decoupling approach for AGC of MAPS. Some other variants of PID controller are also presented in recent years such as a PID controller based on Laurent series expansion for LFC of MAPS in [16], a PID controller based on direct synthesis approach for SAPS and MAPS using frequency response matching in [17] and a PID controller based on linear matrix inequality (LMI) is designed for LFC of MAPS in [18]. It is observed that there is a large scope of improvement in LFC techniques. Therefore, in this paper, a DE based TDF-IMC scheme is developed for LFC of SAPS. DE [19] is one of the popular optimization algorithms; therefore, it is use for tuning of the controller parameters in the proposed approach. For designing the PM, a popular MOR approach [20] is used which approximates the system model. It has been observed that the performed method minimizes the frequency deviations and oscillations. Further, the proposed controller provides better robustness under parametric uncertainties and also removes the external load disturbance (ELD) during operation [22]. A novel dual loop-internal model control approach for LFC of single and multi-area power systems. scheme utilizes a predictive model which is obtained by model reduction and conventional IMC scheme. In order to establish the superiority of the proposed scheme, the results are compared with existing techniques[23]. A modified two degree of freedom-internal model control structure is proposed with dual feedback loop configuration for load frequency control problem of the single area and two area non- reheated power systems to achieve better transient and steady state performance. Predictive model of the proposed configuration is derived through Routh, Padé and SOPDT approximations[24]. A differential evolution optimization based modified control configuration for load frequency control of single-area non-reheated thermal power system. The proposed scheme contains an internal model control (IMC) controller in the internal loop and a PID controller in the external loop. The IMC controller is designed by using low pass filters and a predictive model (PM) which is derived from the system model using the Routh approximation method. The tuning parameters of low pass filters and external loop controller are optimized by using Differential evolution (DE) [25].

II. BACKGROUND

A. System model

The single area NRTPS [1-2] is considered for the validation of proposed approach as shown in Fig. 1

Figure 1. Single area power system.



where $G_g(s)$ is transfer function (TF) of governor, $G_p(s)$ is the TF of load and machine, $G_t(s)$ is the TF of turbine, K_p is the gain of load and machine, T_p is the time constant of electric system in sec., T_t is the time constant of non-reheated turbine in sec., T_g is the time constant of governor in sec., R is the speed regulation obtained by governor in Hz/p.u. MW, ΔP_d is the ELD in p.u. MW, and Δf is deviation in the frequency. The system model G(s) is with respect to reference input is obtained as

$$G(s)= G_p(s)\, G_g(s)\, G_t(s) / (1+ G_p(s)\, G_g(s)\, G_t(s)/R) \qquad (1)$$

The feedback controller $u(s) = -G_c(s)\,\Delta f(s)$ is used to control the LFC of SAPS for removing the ELD ΔP_d.

B. Differential Evolution (DE)

DE [19] is one of the optimization techniques which are a competitive form of evolutionary algorithms for global optimization. It maximizes or minimizes the fitness function under the specified selection rules to obtain the best solution from the evolution operators i.e. reproduction, crossover and mutation. It is initialized with a population consisting of randomly generated individuals which can be expressed by real vectors equal to the number of design parameters/ control variables. DE is used for obtaining the values of the controller parameters of the proposed approach. The flow chart of DE is shown in Fig. 2 which clearly explains the operation of DE.

This section presents a MOR and DE based approach for LFC of single area non-reheated TPS. The Routh approximation is used to derive the PM which is further used to design the modified TDF-IMC controller. The parameters of modified TDF-IMC controller and FOPID gains are obtained by using DE algorithm. The proposed control scheme is based on [12] as shown in Fig. 3

C. Fractional Order proportional integral derivative (FOPID)

The fractional order PID (FOPID) controller is the expansion of the conventional PID controller based on. fractional calculus. For many decades, proportional - integral - derivative (PID) controllers have been very popular in industries for process control applications [24] in Fig 2.

Figure 1. Flow chart of DE algorithm

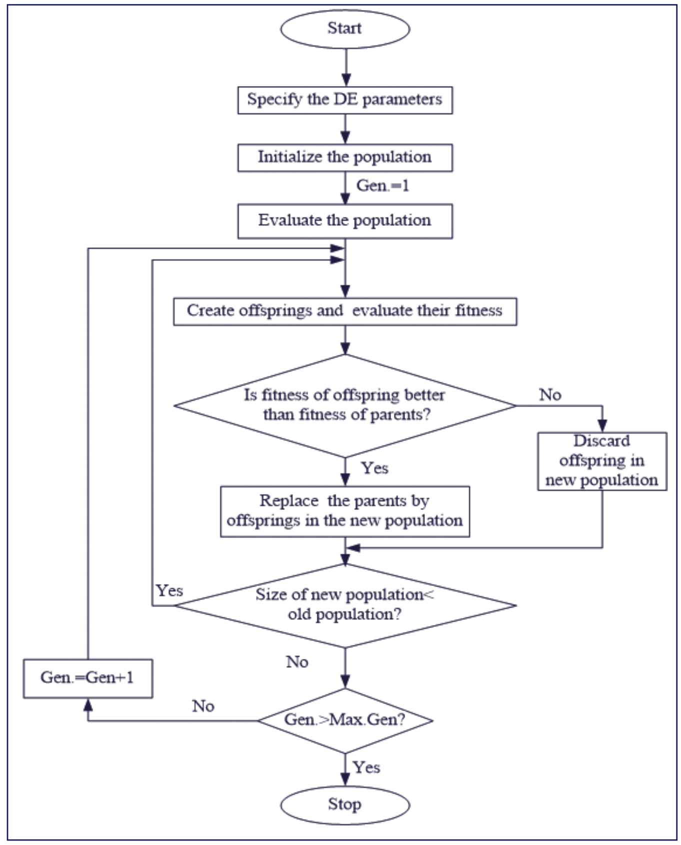
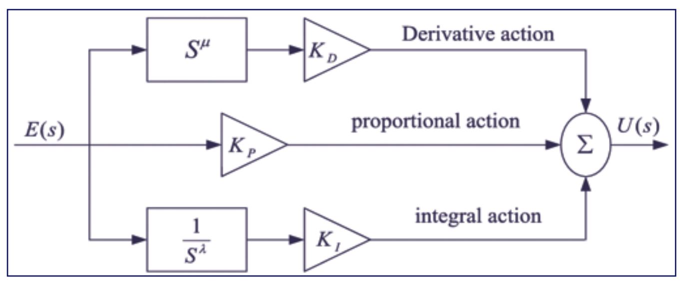
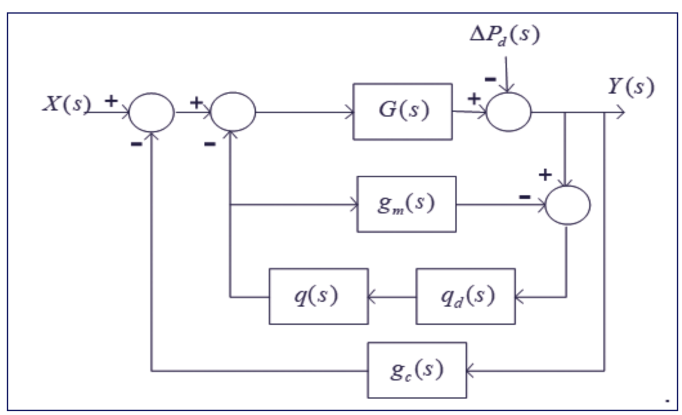


Figure 2. FOPID



Proposed method

Figure 1. Control scheme



Where G(s) is the system model of SAPS, $g_m(s)$ is the PM, $q_d(s)$ and q(s) are the internal loop controllers and $g_c(s)$ is the external loop controller. It may be noted that [7, 16] doesn't involve internal and external loops configuration. The proposed technique is discussed as follows:

Firstly, the PM is obtained by using Routh approximation [20] in following steps:

• The reciprocal transformation is applied on $G(s)$ to obtain

$$G'(s) = \frac{1}{s} G\left(\frac{1}{s}\right) \quad (2)$$

$$= \frac{c_1 s + c_0}{d_0 s^3 + d_1 s^2 + d_2 s^1 + d_3} \quad (2a)$$

- Find

$$P_2'(s) = \lambda_2 + k_2 \lambda_1 s \quad (2b)$$

and

$$Q_2'(s) = 1 + k_2 s + k_2 k_1 s^2 \quad (2c)$$

Where

$K_1 = d_0/d_1$, $k_2 = d_1/(d_2 - k_1 d_3)$, $\lambda_1 = c_0/d_1$ and $\lambda_2 = c_1/(d_2 - k_1 d_3)$,

- Then, the PM is obtained as

$$g_m(s) = (1/s)\, g'm(1/s) \quad (2d)$$

where $g'_m(s) = P'_2(s)/Q'_2(s)$.

Now, $q(s)$ and $q_d(s)$ are obtained as

$$q(s) = 1/(g_{m}\text{-}(s)(1+\sigma s)^n) \quad (3)$$

$$q_d(s) = (\tau_2 s^2 + \tau_1 s + 1)/(\sigma_d s + 1)^n \quad (4)$$

where σ and σ_d are tuned by using DE and n is the order of controller which depends on the order of PM that is obtained in Eq. (4). Further, the coefficients τ_1 and τ_2 of $q_d(s)$ and gains of $g_c(s)$ are obtained by using DE. The objective function is considered as integral time of absolute error (ITAE) which is given by

$$\text{ITAE} = \int_0^{\infty} t|e(t)|dt \quad (5)$$

After optimization, the FOPID controller is obtained as

$$g_c(s) = K_P + K_I/s^{\lambda} + K_D s^{\mu} \quad (6)$$

where K_P is the proportional gain, K_I is the integral gain, and K_D is the derivative gain.

III. SIMULATION AND DISCUSSION

In this section, the system parameters of SAPS [7-8] with non-reheated turbine are considered as

$K_P=120$, $T_P=20$, $T_t=0.3$, $T_g=0.08$, $R=2.4$.

After substituting the above parameters in Eq. (1), the system model G(s) with respect to input reference is obtained as

$$G(s) = 250/(s^3+15.88s^2+42.46s+106.20) \quad (7)$$

From the proposed technique as discussed in Section III, the PM $g_m(s)$ is derived as

$$g_m(s) = 18.68/(s^2+3.174s+7.94) \quad (8)$$

Figure 2. Plot of system model and predictive model.

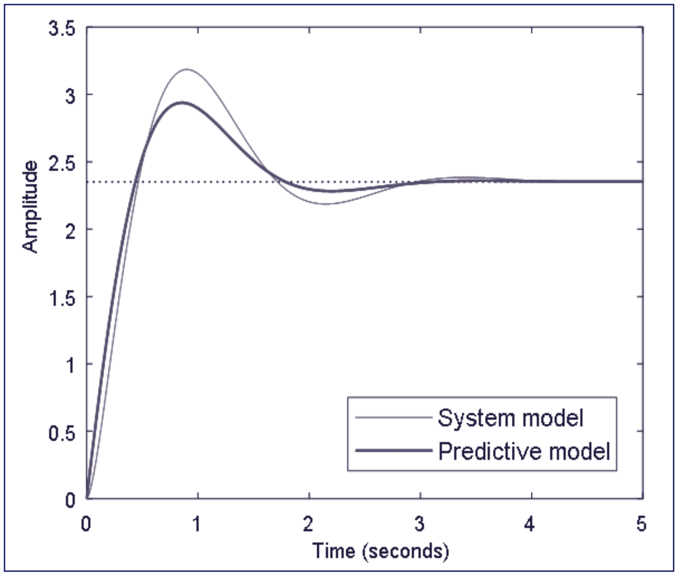


Figure 3. Values of tuning parameters

TDF-IMC parameter	τ_2	τ_1	σ	σ_d	ITAE
Values	0.0799	0.3307	0.01	0.1	0.7133
DE-FOPID parameters	K_P	K_I	K_D	λ	μ
Values	17.028	38.148	1.707	0.946	1.203

The step responses of $g_m(s)$ and G(s) are compared as shown in Fig. 3 and it is observed from the figure that the designed PM gives a good approximation of system model.

After substituting, n=2 in Eq. (3) and (4), the parameters of q(s) and $q_d(s)$ are obtained by DE which are shown in Table I and the q(s) and $q_d(s)$ are

$$q(s) = (s^2+3.173s+7.94)/(0.001868s^2+0.373s+18.68) \quad (9)$$

and

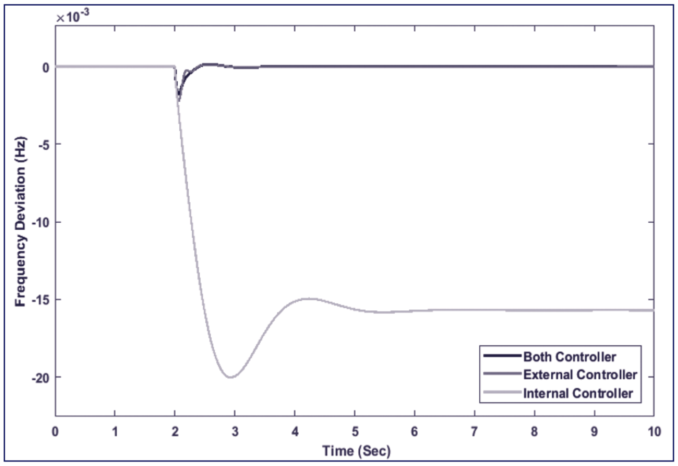
$$q_d(s) = (0.0799s^2+0.3307s+1)/(0.01s^2+0.2s+1) \quad (10)$$

Further, the parameters of $g_c(s)$ are obtained by DE as discussed in Section III which are shown in Table 1.

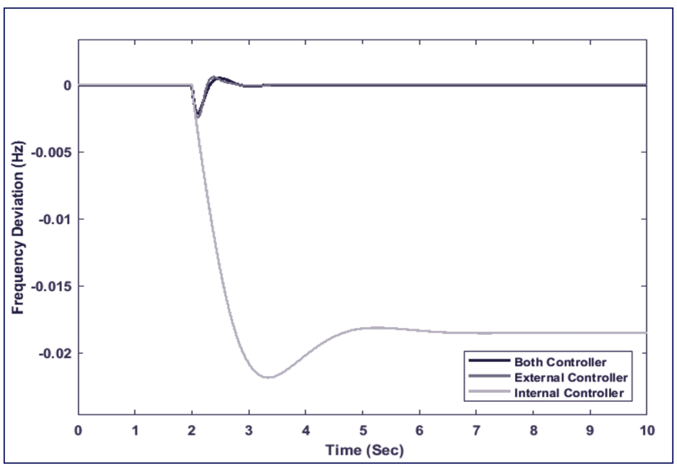
The proposed technique is implemented for controlling the frequency deviations of single area NRTPS due to ELD and parametric uncertainties. The performance of the proposed technique is demonstrated during the ELD $\Delta P_d(t) = -0.01$ at t=2 sec in Fig. 5. It is from the figure that the proposed dual loop structure performs well during frequency deviation. Further, the robustness of proposed approach is analysed by inserting ±50% variation in the parameters of system. Therefore, the parameters of single area NRTPS can now be expressed as

K_p/T_p € [4,12], $1/T_p$ € [0.033, 1], $1/T_t$ € [2.564, 4.762], $1/T_g$ € [9.615, 17.857] and $1/RT_g$ € [3.081, 10.639].

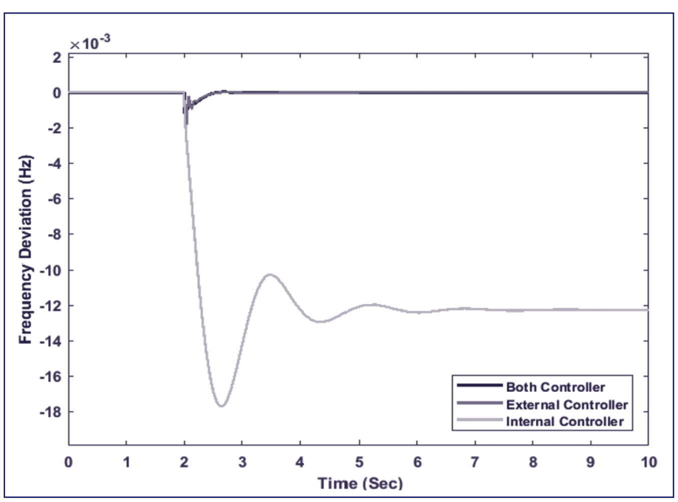
The performance of proposed internal and external loop controllers are shown in Fig. 5a, 5b and 5c with the nominal values (NV), lower bounds (LB) and upper bounds (UB) of the system parameters. From the responses, we can conclude that the external loop controller removes ELD with some oscillations in the system. The internal controller decreases total gain with less oscillation during ELD but it does not achieve zero steady-state error. However, the combinations of proposed internal and external loop controllers remove the ELD at a faster rate with less oscillation.



(a)

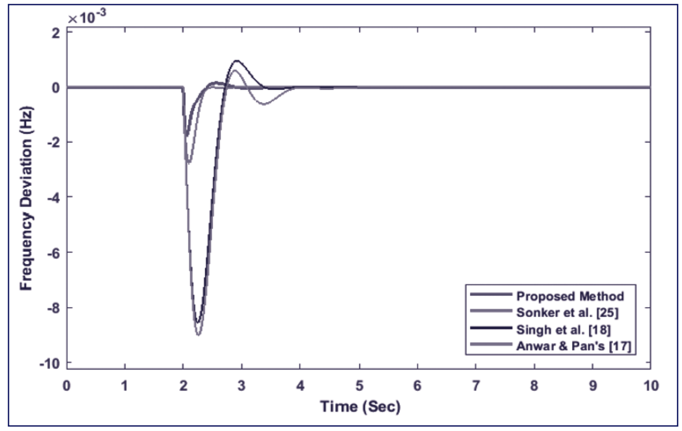


(b)

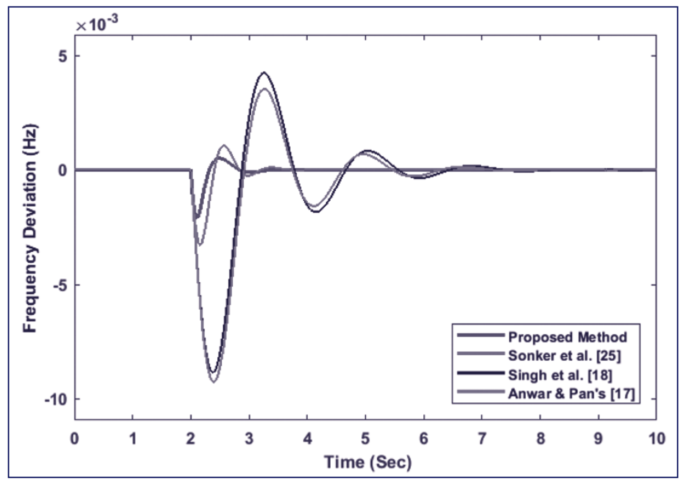


(c)

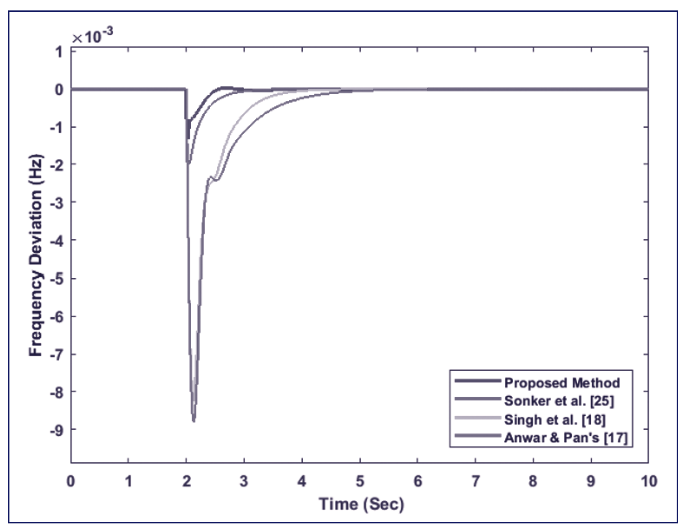
Figure 4. Plot of responses of proposed internal loop controller and external loop controller for (a) NV (b) LB (c) UB.



(a)



(b)



(c)

Figure 5. Responses for (a) NV (b) LB (c) UB.

The simulation results for nominal value are shown in Fig. 6a, and it is observed that the proposed technique gives a very smooth and fast disturbance rejection than the existing approaches [17, 18-25]. Similarly, Figs. 6b and 6c show that the proposed technique gives better results for ±50% parametric uncertainties which are plotted by considering lower and upper bounds of the interval bounds. It is clear from the responses that the proposed approach results responses with lower overshoot, undershoot and also settles faster than [8, 16-18]. The performance of proposed controllers is also analyzed by computing integral square error (ISE), integral absolute error (IAE) and integral time absolute error (ITAE) with nominal parameters and ±٪٥٠ variation in system parameters. The expressions of the performance indices are given as

(a) ISE = $\int_0^{\infty} |e(t)|^2 dt$

(b) IAE = $\int_0^{\infty} |e(t)| dt$

(c) ITAE= $\int_0^{\infty} t|e(t)| dt$

It is clear from the Tables 2, 3 and 4 that the error indices are significantly lower than the existing approaches [17, 18-25].

Table I. Performance Indices For Nominal Values

	ISE	IAE	ITAE
Proposed Method	3.456×10^{-7}	0.0003901	0.002903
Sonker et al. [25]	1.127×10^{-6}	0.0005813	0.004551
Singh et al. [18]	2.28×10^{-5}	0.003841	0.02931
Anwar [17]	$10^{-5}\times2.591$	0.00423	0.03202

Table II. Performance Indices For Lower Bound

	ISE	IAE	ITAE
Proposed Method	6.914×10^{-7}	0.0006153	0.004621
Sonker et al. [25]	2.239×10^{-6}	0.001157	0.008847
Singh et al. [18]	4.273×10^{-5}	0.008973	0.06163
Anwar [17]	$10^{-5}\times4.387$	0.008516	0.0595

Table III. Performance Indices For Upper Bound

	ISE	IAE	ITAE
Proposed method	1.79×10^{-7}	0.0003086	0.002266
Sonker et al. [25]	6.018×10^{-7}	0.0005757	0.00444
Singh et al. [18]	1.345×10^{-5}	0.003175	0.02409
Anwar [17]	$10^{-5}\times1.617$	0.004	0.02963

IV. CONCLUSION

In the present article, a TDF-IMC and Differential evolution (DE) FOPID based technique is proposed for LFC of single area thermal power system consisting of a non-reheated turbine. A dual loop control structure is developed which contains an internal loop with modified TDF-IMC controller and an external loop with a (DE)FOPID controller. The parameters of modified TDF-IMC and FOPID controllers are tuned using DE and the predictive model of internal loop is obtained by utilizing Routh approximation. The proposed method gives a better disturbance rejection, less oscillation and better robustness during the parametric uncertainties than the existing approaches [17, 18-25]. The performance of the proposed technique is analyzed by with nominal parameters and ±٪٥٠ parametric uncertainties. It is clear from the performance indices table that the proposed technique provides lower values of error indices than the existing techniques.

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