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System Dynamics and Frequency Regulation of a Multi-Area Power System Using an Optimal Controller

Anab Rashid[1], Satish Saini[2], Sheikh Safiullah[3], and Zahid Farooq[4]

[1,2,3] M. Tech Scholar, Department of Electrical Engineering, RIMT University, Gobindgarh, 140406, Punjab, India.
[2] Assistant Professor, Department of Electrical Engineering, NIT Srinagar, 190006, J&K, India

Correspondence should be addressed to Anab Rashid; anabrashid39@gmail.com.

ABSTRACT- For system frequency control, the current work proposes a multi-area power system integrating various renewable sources. An effective controller with intrinsic superior capabilities of restricting peak deviation, steady state errors, and oscillatory behavior of a dynamic system is an apparent alternative for autonomous generation control of interconnected power systems. The most difficult part of using a controller is figuring out how to get the most out of it. Because of its space complexity, the trial and error method of determining the benefit by indirect optimization with an acceptable performance index appears to be insufficient. As a result, it appears that using an effective algorithm technique to find the maximum gains for the controllers is the best option. The gains of the controllers are addressed in this work and thus are optimized using a meta-heuristic technique in this study.

KEYWORDS- Power system, Optimal Controller, Thermal solar, Thermal wind

I. INTRODUCTION

Automatic generation control is a mechanism for managing the power output of several generators at non-identical power plants in response to load fluctuations (AGC). Since a power grid demands that generation and load be closely balanced at all times, generator output must be adjusted on a regular basis. The balance can be assessed by measuring the system frequency, which can be used to keep the frequency of each field within reasonable bounds and the tie-line power flow within a certain range of resilience [1-2]. Frequency control is an indispensable stability criterion in power system. To corroborate stability of the power system, active power equilibrium and continual frequency are indispensable. Frequency relay on active power balance and if some discrepancy transpires in active power, frequency cannot be hold in its set value and oscillations are exaggerated in the two i.e. power and frequency. Therefore, the system is subjected to severe uncertainty complications with genuine design of load frequency control (LFC) systems, solidity of power system chain is ameliorated. The objective of LFC is to maintain a real power balance in the power system over supervising the system frequency. AGC keeps track on the system frequency and tie-line flows, evaluates the alteration in the generation needed. Just as to the swap in demand and switch the set position of the generators inside the area so as to manage the time average of the ACE at a little worth. ACE is customarily considered as restrained output of AGC. As the ACE is fixed to zero by AGC, the duo i.e. frequency and tie-line power glitches will become zero [3-4-5-6-7]. It is the LFC's job to guarantee that the system response falls to “0” as quickly as feasible while staying inside the permissible degree of overreach and under reach. Several academics have successfully implemented clever techniques in adjusting controller settings. For example, consider the LFC issue [8]. Many academics have proposed numerous control techniques for load frequency management. Traditional procedures such as conventional control [9]and optimum control [10] are among the proposals. Various intelligence methods, such as the Genetic Algorithm. Different intelligent approaches like Genetic Algorithm [GA] [11], Particle Swarm Optimization [PSO] [12], Bacteria Foraging Optimization Algorithm [BFOA] [13], Differential Evolution [14], Fuzzy Logic Controller [15], Artificial Neural Network [ANN] [16] etc. has been proposed in literature survey for frequency control and it is discovered that LFC scheme is determined by the optimization method used, design of controller and achievement basis selected. Consequently, new approaches with innovation are consistently welcome to clear up the real-world complexity or snag. Just be aware of an optimization strategy known as the Firefly Algorithm (FA) devised by Xin-She Yang and was inspired by the flaring properties of fire files [17-18]. The Firefly Algorithm (FA) because the non-identical fireflies act separately and pile more securely throughout the zenith values, it outperforms the standard PSO algorithm. The FA is also capable of simultaneously locating global and local optima. Novel investigation determines the FA is very efficient and generally provides superior results then optimization techniques like ABC, PSO, BFOA [19-20].

II. SYSTEM BACKGROUND

As shown in Figure 1, the system analysis is achieved on a two-area (Thermal-solar & Thermal-wind) interconnected power system. This model of a power system is widely used. LFC analysis is being carried out by researchers. To further approximate the functional method, a GRC is applied to this model. The Generation Rate Constraint is being used to keep plant's generation percentage under control. For thermal power plants, the usual GRC value is 3% p.u. MW/min.

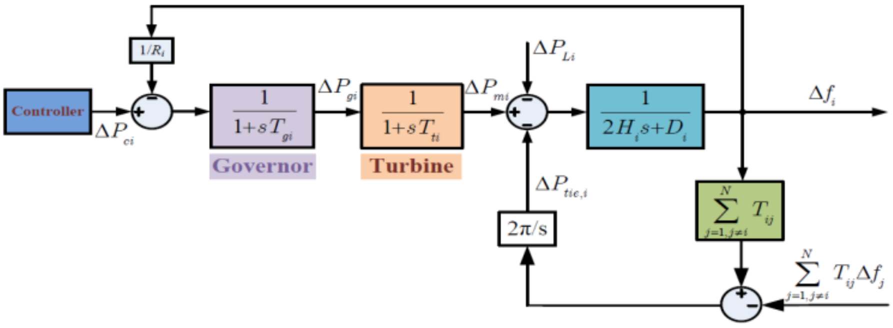

Figure 1: LFC model in an n-area power system [21]

The AGC's area control error (ACE) signal is a crucial part. The frequency deviation (Δf) and tie line power deviation are also included in the ACE value (ΔP_{tie}). There will be an ACE for each field. When a perturbation arises in any domain, the controller function is triggered.

$$ACE_1 = \Delta P_{tie1-2} + B_1\Delta f_1 \quad (1)$$

$$ACE_2 = \Delta P_{tie2-1} + B_2\Delta f_2 \quad (2)$$

Based on the area control error signal, the settings were fine-tuned. ($ACE_{i,\ i=1,2\ldots.}$) are the proportional gain (K_P), integral time constant (T_i), and derivative time constant (T_d). The result of the controller, u_n (n=1,2….), is written as follows.

$$u_n = K_{pn}(ACE_n + \frac{ACE_n}{sT_{in}} + sT_{dn}ACE_n)$$

III. FIREFLY ALGORITHM

The firefly algorithm (FA) created by xin-she yang in mathematical optimization is a meta heuristic optimization method inspired by the actions of fire flies in nature. The above-mentioned firefly algorithm makes use of fireflies as nature's communicators. The glazing character is equal to the attractiveness, and both contract as the distance between them increases. As a result, if there are two blinking fireflies, the one that is lesser light will shift against the one that is glistening. If there isn't another firefly that is dazzling than it, it will pass at arbitrary. The following procedures are performed to construct the algorithm.

- Since fireflies are unisex, they are alluring to one another
- The fireflies' attractiveness is equal to their brilliance and as a result, the fireflies are drawn to higher levels of light and travel in that direction. The luminance varies inversely with distance.
- The brightness level is used to express the objective function's value. The attraction of the firefly (β) as a relation of span or gap (r) is defined as.

$$\beta(r)=\beta_0 e^{-\Upsilon r2} (4)$$

where β_0 is the attractiveness at r = 0
Υ is fixed luminescence absorption factor
Gap in the middle of each fireflies (r_{ij}) found on Euclidean distance is given by:

$$r_{ij=} \|x_i - x_j\| = \sqrt{\sum_{k=1}^{d}(x_{i,k} - x_{j,k})}^{\,2} (5)$$

Where,
The two Fireflies are denoted as x_i, x_j and their motion is described as:

$$x_{i\,=}\, x_i + \beta_{0^2}{-}\Upsilon r^2{}_{ij}\left(x_j - x_i\right) + \alpha(rand - 0.5) * scale \quad (6)$$

α =randomization parameter

The value of the scale, which is the interval between both minimum and maximum values, is utilized as the scaling parameter, and rand is randomly generated number (0,1). Values that are commonly used in this study: β_0 =1, Υ =1 and α =0.8

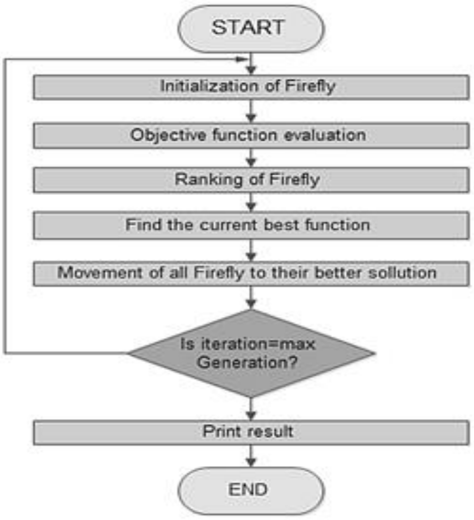

Figure 2: Shows firefly algorithm.

IV. OBJECTIVE FUNCTION

The suggested I, ID, PID, FO-PID controllers are designed using ISE as the objective feature in this work. Equation gives the interpretation for the integral square error (ISE) target function.

$$J = ISE = \int_0^{t_{sim}} e^2 . t . dt \qquad (7)$$

The design hindrance can be expressed as the optimization problem below.

Minimize **J** (8)

Subject to

$$K_{pmin} \le k_p \le k_{pmax}, k_{imin} \le k_i \le k_{imax}, k_{dmin} \le y_d \le k_{dmax} \qquad (9)$$

The lowest and highest values of controller specifications are elected as [0 2] respectively. The frequency aberration response of the system and circuit power under three distinct scenarios are researched in evaluating the efficiency of the controller. FO-PID is a device that grant you to manage the flow of FA-FOPID (optimized based on FA) and is correlated to the I, ID, and PID controller in the traditional sense.

V. RESULT AND ANALYSIS

The capabilities and endurance of the firefly method, a fractional order PID (FOPID) optimization tool, against I, ID, PID controllers are compared in this paper using non-identical circumstances. The frequency and tie line power using the above-mentioned controllers are shown in figures 3, 4 & 5. The FO-PID controller is capable of settling the frequency with the least amount of over reach & settling time associated to I, ID, and PID controller. In addition, the FO-PID reduces oscillations, eliminates steady-state error, provides stability against plant gain fluctuations, and provides excellent disturbance rejection. As a result, the FO-PID controller is ideal for LFC applications.

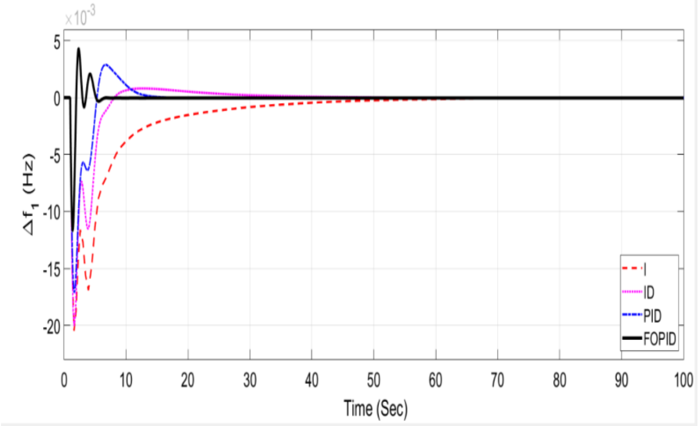

Figure 3: Area 1's frequency deviation step response (Red line: I, Pink line ID, Blue line PID, Black line FO-PID)

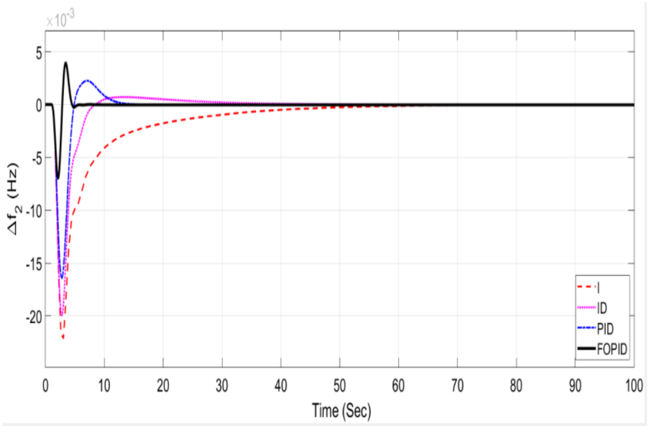

Figure 4: Area 2’s frequency deviation step response (Red line I, Pink line ID, Blue line PID, Black line FO-PID)

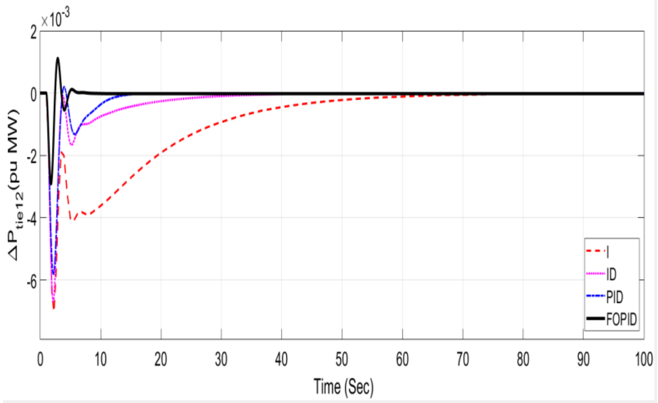

Figure 5: Tie line power deviation (Red line I, Pink line ID, Blue line PID, Black line FO-PID)

These different conditions are examined in a similar way to monitor the firefly algorithm's efficiency and stability. The good gains of all the controllers are listed in table 1 for each scenario. The frequency and tie-line power practiced by different controllers are shown in figs. 1, 2 and 3. When compared to alternative controllers, the FO-PID controller can settle the frequency with a nominal settling time and overshoot. In addition, the FO-PID controller curtails the number of oscillations in the system. In table 2 ISE values of different controllers are mentioned.

Table 1: Good gains of all the controllers are listed in fo r each scenario

Controllers	**Kp1**	**Kp2**	**Ki1**	**Ki2**	**Kd1**	**Kd2**	**Kn1**	**Kn2**
I	-	-	0.2399	0.5977	-	-	-	-
ID	-	-	0.9295	0.4095	3.4146	0.5409	20.7731	21.9284
PID	0.0836	0.1206	1.5692	1.8249	0.5268	1.5542	49.6826	84.6213
FO-PID	0.8506	0.2257	11.9544	14.9532	1.6879	4.2623		

Table 2: ISE values of different controllers are mentioned

Scenario	**Controllers**	**ISE**
1	I	0.001597
2	ID	0.0013103
3	PID	0.00075517
4	FO-PID	0.00015928

VI. SENSITIVITY ANALYSIS

Sensitivity analysis has been accomplished to examine the stability of optimum gains of FO-PID controller attained at nominal loading situations and nominal SLP to wide changes in system loading conditions, the size of SLP, and the inertia constant H. The loading is replaced to ± 25%. Like-wise the SLP is replaced in step of 1% and H is replaced to ±25%. In each changed condition K_P, K_I, K_D are optimized using firefly algorithm and system dynamic responses analogous to optimum gain at each changed condition are attained critical scrutinization of the dynamic responses, it is openly examined that the feedbacks are more or less look-alike and displaying a well-being tolerance limit with corresponding to immense adjustments in system conditions and specifications. Thus, the gains of FO-PID controller attained at nominal conditions and specifications are strong and not required to be reset for large changes in system conditions and specifications.

VII. SOLAR VARIATION

A. *Real Time vs. Offline*

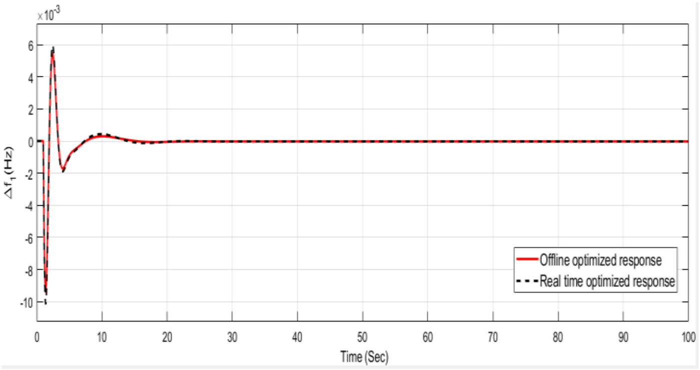

Figure 6: Real time & offline optimized response of Δf_1.

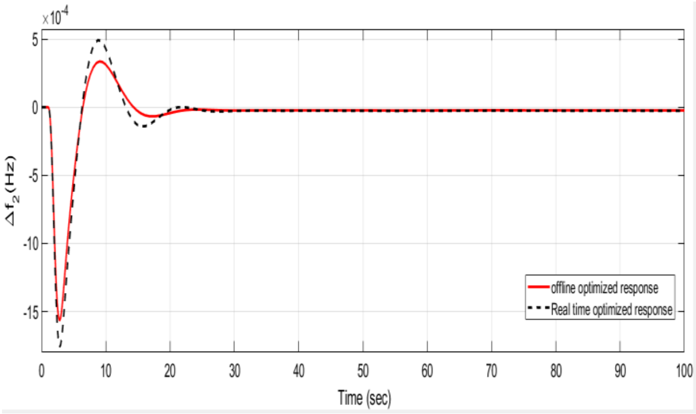

Figure 7: Real time & offline optimized response of Δf_2.

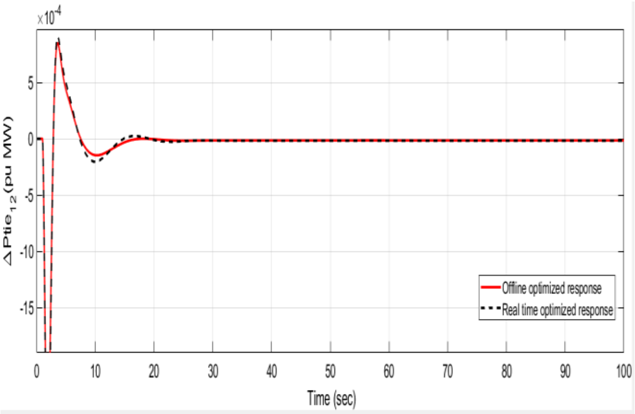

Figure 8: Real time & offline optimized response of ΔP_{tie}

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B. *H (Inertia Constant) VARIATION*

At -25%

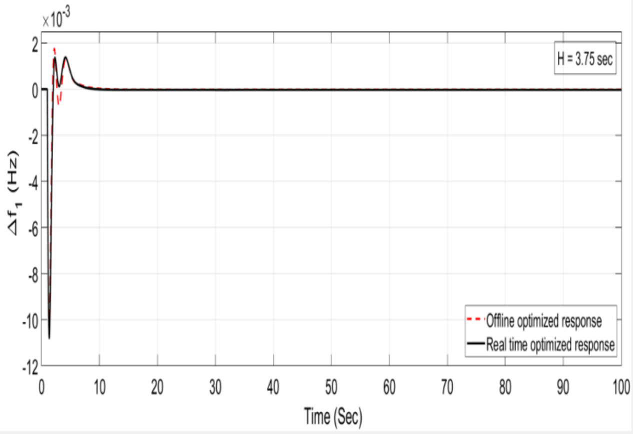

Figure 9: Real time & offline frequency deviation step response with H variation at -25%.

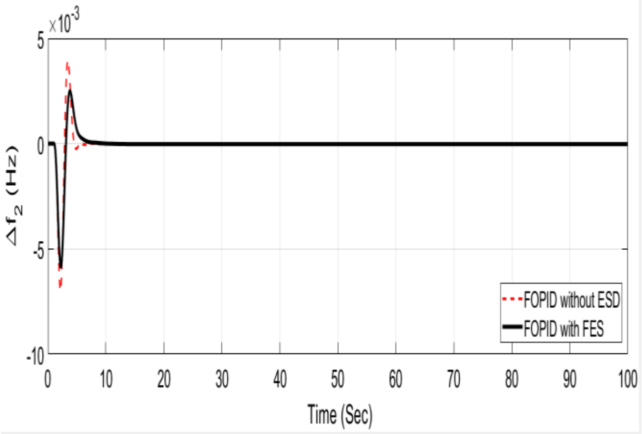

Figure 10: Frequency deviation step response of FOPID without ESD & FOPID with FES

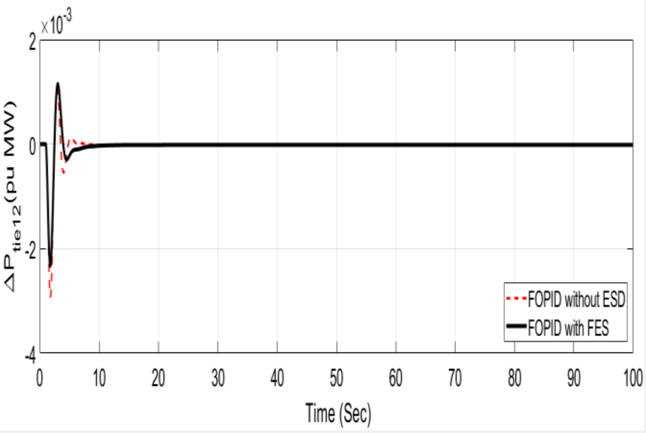

Figure 11: Tie-line power of FO-PID without ESD & FOPID with FES

At +25%

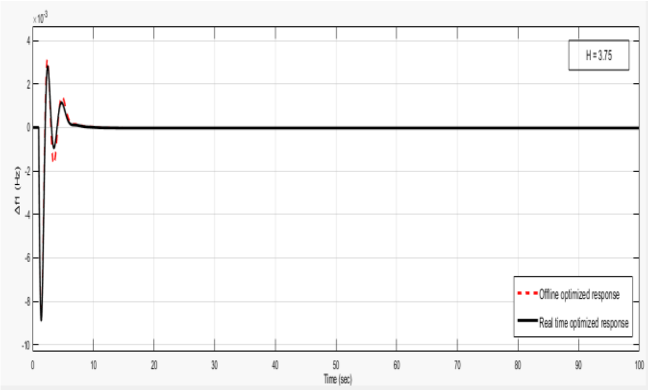

Figure 12: Real time & offline frequency deviation step response with H variation at -25%

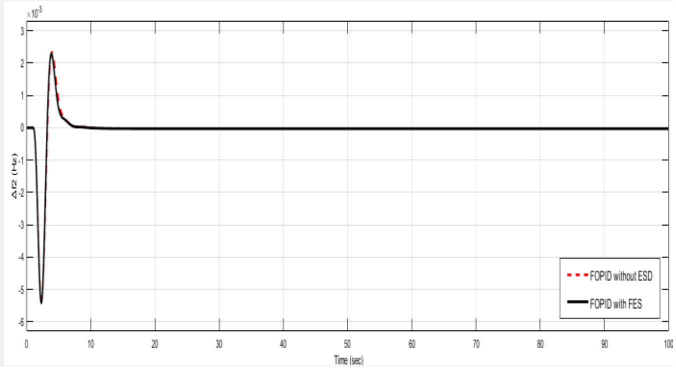

Figure 13: Frequency deviation step response of FOPID without ESD & FOPID with FES

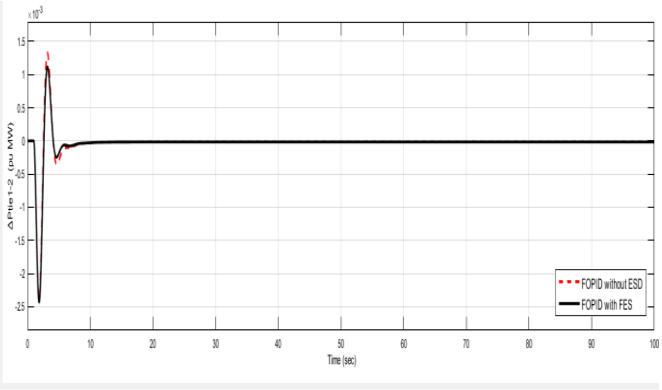

Figure 14: Tie-line power of FOPID without ESD & FOPID with FES

V. CONCLUSION

This study examines the rationale behind the FO-PID controller's normalized approach. The FA-based FO-PID controller is employed in a two-area (Thermal-Solar & Thermal Wind) power system with GRC. The system's weaknesses will be exacerbated by the GRC, which is an indiscriminate component. As a result, in order to overcome these system constraints, the controller's tuning approach must be resilient. As a real-valued function, the ISE selection criteria are utilized to change the gains of the FO-PID controller. In the same way, the FO-PID controller is compared to the I, ID, PID controller. The frequency fluctuation step response and tie line power are analyzed to evaluate the correlative achievement of all the controllers, and FO-PID outperforms them all. This is owing to FA's meta-heuristic approach's advantages.

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