# Automatic ɢeneration control based whale optimization αlgorithm

**Wisam Najm Al-Din Abed[1], Omar A. Imran[2], Ibrahim S. Fatah[3]**
[1,3]Department of Electriconic Engineering, College of Engineering, University of Diyala, Iraq
[2]Department of Chemical Engineering, College of Engineering, University of Diyala, Iraq

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**ABSTRACT**

In the designing and operation of interconnected power systems, automatic-generation-control (AGC) represent an important topic. AGC is responsible for maintaining the balance between generation side and load side via controlling the frequency and active power interchange. A new metaheuristic strategy is proposed in this work for optimal controller tuning in AGC system. Whale Optimization Algorithm (WOA) is proposed for optimal tuning of reset integral controller. T he proposed strategy is used for optimal AGC in two-areas interconnected-power system. The proposed tuning strategy is compared with other new metaheuristic optimization strategy termed as Harmony Search (HS). The two-area interconnected power system are simulated based MATLAB-toolbox. From results obtained, it is obvious that, the system transient and steady-state behavior are enhanced greatly under the same conditions. This is due to the use of the proposed optimization technique. The proposed technique has an advanced and superior feature like, local optimum avoiding, fast convergence ability, and lower search agents and iteration are required. All mentioned features, make this strategy optimal for various optimization problems.



***Corresponding Author:***

Wisam Najm Al-Din Abed,
Departement of Electronic, College of Engineering
University of Diyala,
Baqubah, Iraq.
Email: wisam_alobaidee@yahoo.com

## 1. INTRODUCTION

Inter-connected multi-area power-plants is divided into various control-areas. Tie lines are connect these areas for load-sharing [1, 2]. The control-area generators are supposed coherently grouping. Normally, any power plant is subjected to load variations. Power system frequency should be constantly maintained (frequency deviation should be maintained as small as possible) for proper operation. The system active power and frequency are related because the frequency affected by active-power balancing [1]. The AGC is responsible for maintaining the balance between generation area and load side at lower cost. It plays an important role for frequency control, economic dispatch, and active power interchange [3]. Nowdays, Multiobjective Evolutionary techniqes are used to solve different optimization problems [4-6].

Recently, many researchers give great deal of attentaion on serving different meta-heuristic optimization algorithms. Thes algorithms are used for traditional controllers tuning in AGC as illustrated in literature survey. Genetic Algorithm was proposed by Vikrram et al., [7] in (2012). Omar et al., [8] introduce ACO technique (2013). Sarroj et al., [9] introduce different meta-heuristic optimization methods in (2014) like, Fire Fly (FA), (GA), Particle Swarm Optimization (PSO), … etc. in (2015) Rabindra et al., [10] introduce a hybrid Firefly optimization technique as well introduce Pattern Search (hFA–PS). BFOA, GA and ZN are used for comparison. Lakshmi et al., [11] introduce in (2016) the algorithm of Flower-Pollination. Mushtaq et al., [12] introduce (PSO) and (HS) techniques in (2017).

The major problems that faces the AGC control system, is the presence of a prominent frequency deviation. This deviation is presented due to the changing in the system load. Integral reset-controller is proposed in this work to solve this issue. This controller has the ability to settle the system deviation to zero due to its integral action which increase the system type by 1.

The second problem in the AGC control design is the choosing of appropriate optimization strategy for controller tuning. In this work, new nature inspired optimization algorithm (NIOA) called Whale Optimization Algorithm (WOA) is proposed for controller tuning. WOA has the characteristic of good balance between the exploration and exploitation phases over other metaheuristics algorithms. This characteristic makes WOA explore the search space effectively with fast convergence as well as avoiding entrapping in local optima. The results of the proposed tuning techniques are compared with other optimization technique called Harmony Search (HS) to prove the superiority features of the proposed strategy.

## 2. MODEL OF SYSTEM

Figure 1 illustrate the transfere function model for the two-area power plant. The individual areas include governor, turbine and generator. The input signal to controller ($\Delta P_{ref}$), power error of tie-line ($\Delta P_{12}$) and load disturbance ($\Delta P_L$) represent individual area inputs. While the frequency of area ($\Delta\omega$) and the area control error (ACE) represent individual area output [9]. For each area ACE represent the controller input and it should be reduced to zero [12]. ACE given by,

$$ACE = B.(\Delta\omega) - \Delta P_{12} = e(t) \quad (1)$$

Where: B, $\Delta P_m$, $\Delta P_v$, $T_T$ , $T_g$, D and H represents frequency-bias parameters, mechanical output power of turbine, governor output power, time constant of turbine, time constant of governor, damping parameter and constant of inertia respectively [9].

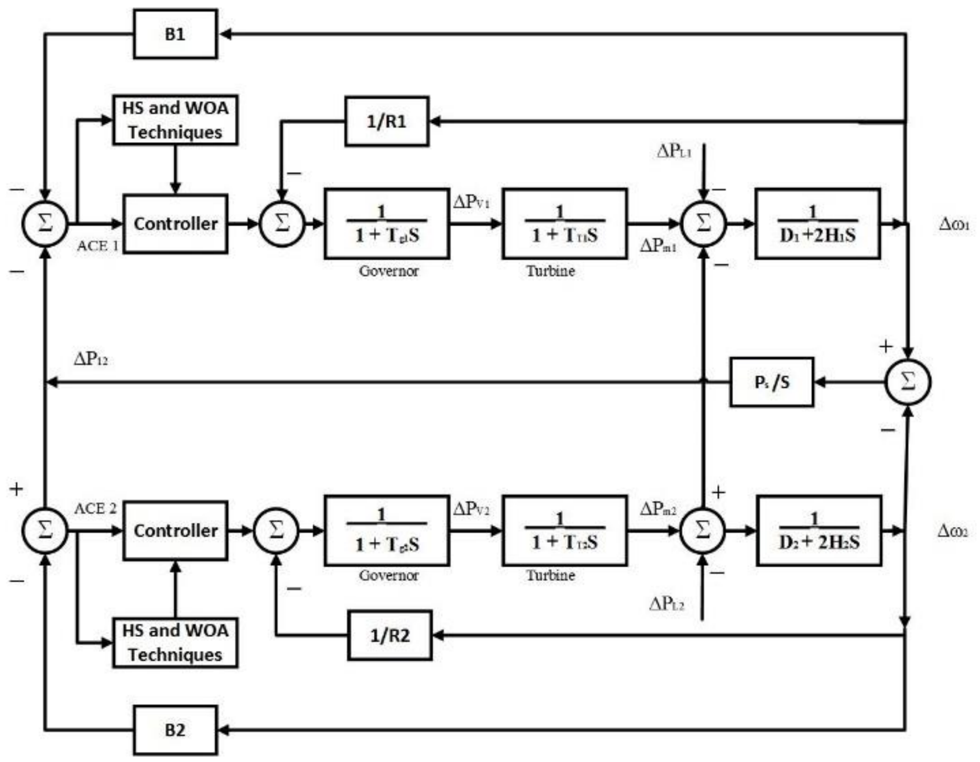



Figure 1. Two-area complete model with AGC

## 3. WOA OVERVIEW

WOA imitate the hunting process to the prey of humpback whales. The hunting process incuding encircling, searching and attaching the prey. It is a novel meta-heuristic optimization algorithm used to solve optimization problems. It was introduced recently in 2016 by Lewis and Mirjalili [13]. A mong other various bio-inspired optimization techniques, WOA have different superior own features. It required low number of parameters and have fast convergence ability [14]. Also, this strategy can attain global optimum solution and avoide entrapping in local optimum. All mentioned features make this strategy can be applied effectively in different optimization area [15].

Krill school and small-fishes near to the surface represent the preferred prey to humpback whales. The hunt process start by creating a special path of bubbles like 9 shape or along a circle. These bubbles can be distinguish by humpback whales only as illustrate in Figure 2 [16]. WOA consists of two distinct phases; the first phase is the exploitation phase and the second is the exploration phase. The exploitation phase consists of prey encirclement and then bubble net attack. While the exploration phase represent searching the prey randomly [17].

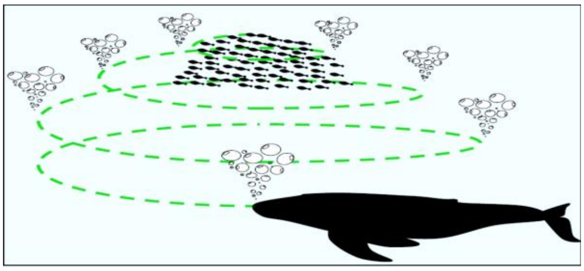


Figure 2. Humpback bubble-net attack [18]

### 3.1. Exploitation-phase

#### 3.1.1. Encircling prey

This step starts by recognize the prey position and encircling the prey. Then the whale's location is modified towards best agent. This process illustrates mathematically as:

$$\vec{D} = \left|\vec{C}.\overrightarrow{X^*}(t) - \vec{X}(t)\right| \quad (2)$$

$$\vec{X}(t+1) = \overrightarrow{X^*}(t) - \vec{A}.\vec{D} \quad (3)$$

$t$ = current-iter. $X^*$ = vector for best position solution. $\vec{X}$ = position vector. $\vec{r}$ = random vector between [0,1]. C $^{\rightarrow}$ & A $^{\rightarrow}$ represent vectors of coefficient and obtained as follows,

$$\vec{A} = 2\vec{a}.\vec{r}.\vec{a} \quad (4)$$

$$\vec{C} = 2.\vec{r} \quad (5)$$

#### 3.1.2. Bubble-net attack behaviour:

This strategy of the hump-back whales is expressed as:

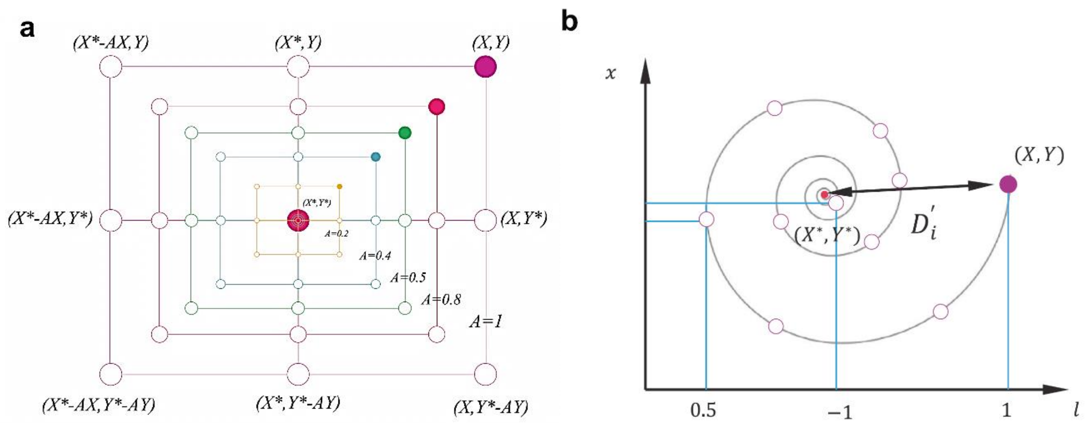
1. *Shrinking-encircling-technique*; over the course of iteration, the vector $\vec{a}$ is decrased linearly from 2 to 0 for both phases of WOA for attaining this behavior refer (4). By setting the vector $\vec{A}$ values randomly in range [-1, 1], the new location of discovering agents in anyplace can be determined. This position can be specified in between the original agent position of current best agent.
2. *Spiral-updating position*: The helical-shaped movement of the hump-back whales towards prey can be expressed mathematically by the spiral equation as,

$$\vec{X}(t+1) = \overrightarrow{D'}.e^{bT}.\cos(2\pi l) + \overrightarrow{X^*}(t) \quad (6)$$

Hump-back whales swim encircling the prey and alternates instantinously along a spiral-shaped path and within a shrinking circle. This sudden behavior can be modeled by choosing 50% probability for mechanism of shrinking encircling and spiral model, this can be expressed mathematically as,

$$\vec{X}(t+1) = \begin{cases} \overrightarrow{X^*}(t) - A^{\rightarrow}.D^{\rightarrow} \text{ if } p < 0.5 \\ \overrightarrow{D'}.e^{bT}.\cos(2\pi l) + \overrightarrow{X^*}(t) \text{ if } p \geq 0.5 \end{cases} \tag{7}$$

The best solution obtained can be represents by the $ith$ whale distance to the prey. This specifies by $\overrightarrow{D'} = \left|\overrightarrow{X^*}(t) - \vec{X}(t)\right|.b$ = constant of logarithmic spiral-shape. $l$ = multiplication of element by element which represent a random number between $[-1,1]$ [13, 17, 19]. Encircling strategy is simulated by first part of (7) while bubble-net attack mechanism is represented by the second part of the same equation. The variable p alternates with an equal probability between these two modes. The search agents possible locations (X, Y) based (7) are modified towards best current best position (X*, Y*). The bubble net strategy are explained in Figure 3.




(a) (b)

Figure 3. Bubble-net attack (or searching) strategy. (a) shrinking-encircling (b) spiral updating position

### 3.2. Exploration phase (prey searching)

This phase based on $\vec{A}$ vector variation randomly. To ensure the search whales move away from the positioning whale, the vector values must be more than 1 or below$-1$. This is due to the fact that the randomly prey searching of the humpback whale's dends on the location of each other. This is expressed as,

$$\vec{\mathrm{D}} = |\vec{C}.\overrightarrow{\chi_{random}} - \vec{\chi}| \tag{8}$$

$$\vec{\chi}(t+1) = \overrightarrow{\chi_{random}} - \vec{\mathrm{A}}.\vec{\mathrm{D}} \tag{9}$$

$\overrightarrow{\chi_{random}}$ = location vector chosed randomly [15, 13, 17, 19]. Figure 4 illustrate WOA pseudo code.

```
Initialize search agents  X_i , i = 1,2, ..., n
Initialize coefficient vectors  C⃗ , A⃗, and a⃗
Evaluate cost function calculation for each search agent
Start WOA, (search agents, C⃗, a, A⃗,  Max -iter., ..., etc)
    t = 1,
        while t ≤ Max iter. do
            for each search agent do
                if|A| ≤ 1 then
                    Update current location of each search agent by equ(3)
                else if|A| ≥ 1 then
                    Select search agent randomly X_r by equ(9)
                    Updating current search agent by equ(6)
                endif
            endfor
            updating coefficient vectors
            if a better solution is found then update X*
            t = t + 1
        endwhile
        return X*
end
```

Figure 4. WOA pseudo code

## 4. RESULTS AND DISCUSSION

### 4.1. Proposed work design

MATLAB-SIMULINK toolbox is used to simulate and design the under-study model of AGC. The proposed WOA tuning strategy is based on mfile coding. The under-study model is done based different operating conditions. The integral rest controller is proposed as controller for each area in the under-study system. The proposed controller is tuned based WOA for controlling the tie line power and frequency deviation optimally. The results that obtained from the proposed new strategy (WOA) are compared with other good new metaheuristic optimization algorithm termed as Harmony Search (HS). The comparison of results between the two optimization techniques, is to prove the superiority advanced features of the proposed algorithm (WOA) versus HS techniques.

### 4.2. Analysis of results

In this work, two reset controllers are used. Each controller is used for one area. A step input is used to modelled the load change disturbance. The load disturbance is used to prove the integral controller robustness when tuned using the proposed technique (WOA). The parameters of the under-study system are mentioned in Table 1. Integral Squre Error (ISE) is used as a performance index in the tuning process. For proper comparison of the two tuning techniques, the algorithms parameters are set equally for both techniques. Equal iterations number is used for both techniques (= 40 iteration) and equal search agents (=20 search agent) as well. Table 2 illustrate the both controllers parameters based the two optimization strategies.

Table 1. System parameters of two-area power plant

| Parameter | Value | Parameter | Value |
|---|---|---|---|
| $T_{g1}$ | 0.50 | $T_{g2}$ | 0.60 |
| $T_{T1}$ | 0.20 | $T_{T2}$ | 0.30 |
| $D_1$ | 0.60 | $D_2$ | 0.90 |
| $R_1$ | 0.050 | $R_2$ | 0.06250 |
| $B_1$ | 0.90 | $B_2$ | 0.90 |
| $H_1$ | 5 | $H_2$ | 4 |

Table 2. Parameters of integral controller

| | $K_1$ | $K_2$ | Cost-function |
|---|---|---|---|
| WOA | 0.5087761 | 0.2200042 | 0.0855221 |
| HS | 0.4929132 | 0.0001211 | 0.0860231 |

From Figure 5 which represent the plot of cost function, it is obvious that the proposed optimization strategy required lower iteration number which demonstrate the fast convergence ability. WOA have lower cost function which means a best solution is attained as compared with HS. Figure 6 and Figure 7 shows ACE plot for both areas. Figures 8-9 shows the frequency deviation for both areas. Figure 10 shows the power exchange of tie-line between the two-area. The load disturbance for proposed work is choosen 0.1.

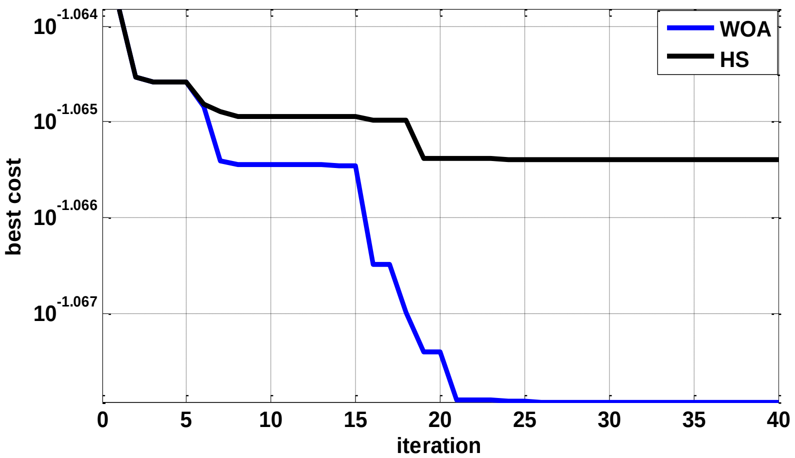



Figure 5. Cost function plot for both techniques

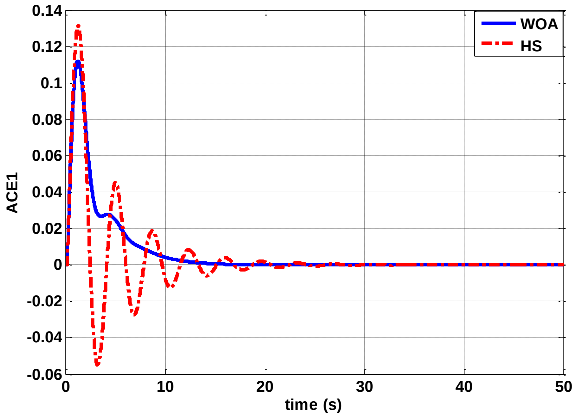



Figure 6. ACE 1 for area 1

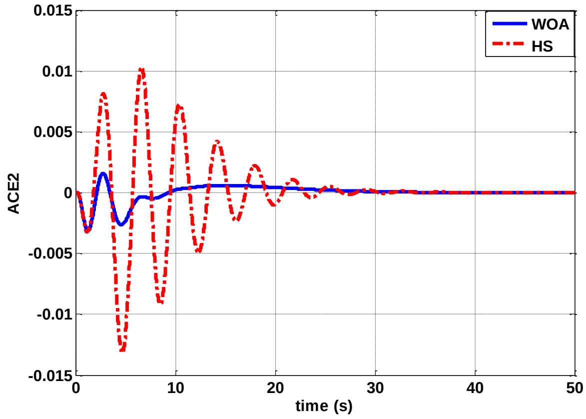



Figure 7. ACE 2 for area 2

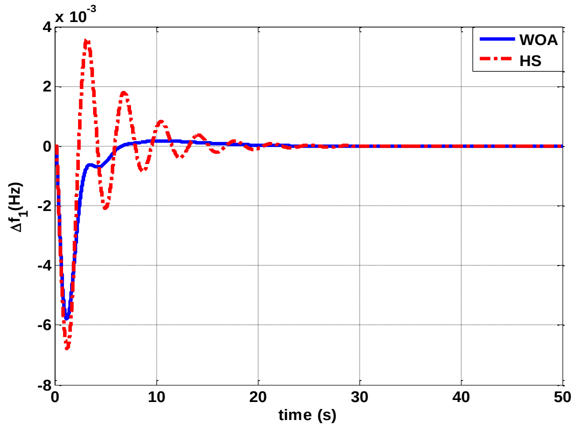



Figure 8. ($\Delta f_1$) for area 1

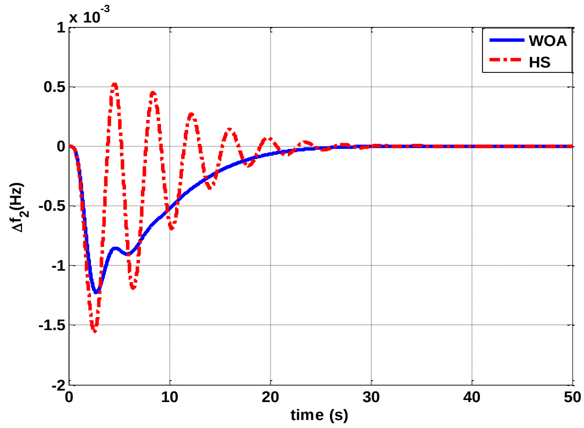



Figure 9. ($\Delta f_2$) for area 2

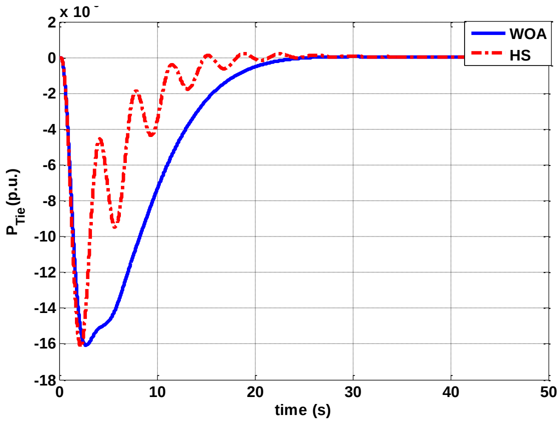



Figure 10. Tie line power for both area

The system transient and steady-state behavior are improved prominently when used integral controller based WOA even under load disturbance. In AGC it is pereferable to use integral controller optimally tuned based WOA due to its ability to settle the frequency deviation and kept it zero aprrox. So, this controller plays an important role in power system control. The porposed WOA tuning technique shows a superior feature in the field of controller optimizing versus HS strategy. WOA has fast convergence ability, lower parameters required, and avoid entrapping in local optimum. The obtained results based WOA shows a very small oscillation as compared with results-based HS. This means very small overshoot and under shoot.

## 5. CONCLUSION

Meta-heuristic optimization strategies play a vital role in the field of controller tuning in the interconeected-power plant. These strategies have the ability to improve the controller performance. This fact leads to appear various types of meta-heuristic optimization algorithms. The meta-heuristic optimization strategies are divided to two distinct phases regardless its nature. The first phase is exploration phase which means investigating globally the problem search space. The second phase is the expoilting phase which means exploring the search space promising regions that found in the exploration phase. Hence the promising region that found by exploration phase are refining by the next phase (exploitation phase). So, in designing any meta-heuristic strategy, it is important to achieve a proper balance between these two phases due to the randomize nature. This fact represents a real challenge in designing any meta-heuristic algorithm due to its stochastical features that make them avoiding local optimum entrapment. This superior feature is prominent in the WOA proposed technique. As well WOA have fast convergence ability, lower parameters required. WOA do well in the field of controller tuning especially in the field of AGC in power plants.

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**BIOGRAPHIES OF AUTHORS**

The Lecturer **Wisam Najm AL-Din Abed** received a bachelor's degree in electrical power and machines from engineering college-Diyala University in 2005 and received a master's degree in electrical engineering / power from the University of Technology in 2011. Area of research interest in the electric power, machinery and control engineering and artificial intelligence and algorithms Engineering Optimization. He has more than scientific research published in local and international journals. Email: wisam_alobaidee@yahoo.com

**Omar A. Imran** received a bachelor's degree in electronic from engineering college-Diyala University in 2006 and received a master's degree in electrical energy from Belgorod Government Technology University Russia's Federal in 2013. Area of research interest in the electric power engineering. He has more than scientific research published in international journals. Email :Omarimran53@yahoo.com

**Ibrahim Saadoon Fatah** received a bachelor's degree in electronic engineering from the University of Sarajevo / Bosnia in 1984 and received a master's degree in electronic engineering from the University of Belgrade / Serbia in 1987. Served as the director for registration in the College of Engineering / University of Diyala for the period from 2010 to 2013. The area of research interest in control engineering and electronics. He has more than scientific research published in local and international journals. Email : saadon@yahoo.com