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Load frequency control of single area power system using Water Cycle Algorithm

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***Abstract*— This paper presents an adaptive controller for load-frequency control of power systems. The proposed controller compared with a conventional PID controllers tuned by genetic algorithm technique, Water Cycle (WCA) Optimization. MATLAB /SIMULINK had used to make a digital simulation. . The overshoots and settling times with the proposed Genetic-(WCA) controller are better than the outputs of the conventional PID controllers.**

Keywords— load-frequency control, power system, adaptive control, Water Cycle Optimization (WCA).

I. INTRODUCTION

Power systems stability depends on Frequency. To provide the stability, constant frequency and active power balance are required. Frequency depends on active power balance. Any change occurs in active power demand/generation in power systems, frequency will not be hold in its rated value. So oscillations will increase in both power and frequency.
A control system is required to cancel the effect of load variation and to keep frequency and voltage level constant. Frequency and the active power control is called load frequency control (LFC).LFC is important to maintain the frequency constant against varying active power loads [1-4].
Recently, various optimization techniques such as genetic algorithms (GA) [5], particle swarm optimizer (PSO) [6-8], Artificial Neural networks [9], and fuzzy logic controller [10].
Genetic algorithms depend on the choice range of each parameter to be optimized.
Water cycle algorithm (WCA) recently developed optimization procedure which inspired from the water cycle process in nature. In the real world, all rivers and streams end up in sea which represents the best optimal solution. Rivers flow to the sea which is the most downhill location. The WCA algorithm is well-matured and one of the most promising evolutionary algorithms that can be used to solve multi-modal with continuous and discrete complicated engineering optimization problems. In addition to, the main advantage of WCA algorithm over other known optimization techniques is that its operation does not require any prior definition of algorithm specific operators. Only initialization of size of search agents and number of rivers and sea, and maximum number of iterations are required for its functionality. WCA offers competitive solutions compared with other population based algorithms based on the reported numerical results. The robustness and exploratory capability of the WCA depends on the nature and complexity of the problems. Recently, WCA has been applied successfully to solve number of power system problems [14].
In this paper, WCA is applied to online tuning of classical PID controller.
This paper is organized as follows.

II. SYSTEM DYNAMICS

The dynamic model of the proposed microgrid power system can be described in the following equations:

$$s\Delta f = \left(\frac{1}{M}\right).\Delta P_d - \left(\frac{1}{M}\right).\Delta P_L - \left(\frac{D}{M}\right).\Delta f \qquad (1)$$

The dynamic of the turbine can be expressed as:

$$s\Delta P_d = \left(\frac{1}{T_t}\right).\Delta P_g - \left(\frac{1}{T_t}\right).\Delta P_d \qquad (2)$$

The dynamic of the governor can be expressed as:

$$s\Delta P_g = \left(\frac{1}{T_g}\right).\Delta P_c - \left(\frac{1}{R.T_g}\right).\Delta f - \left(\frac{1}{T_g}\right).\Delta P_g \qquad (3)$$

Where:
S: differential operator.
ΔPg: the governor output change.
ΔPm: the mechanical power change.
Δf: the frequency deviation.
ΔPl: the load change.
ΔPc: supplementary control action.
H: equivalent inertia constant.
D: equivalent damping coefficient.
R: Speed droop characteristic.
Tg and Tt: are governor and turbine time constants.
The block diagram of the past equations is shown in Fig.1

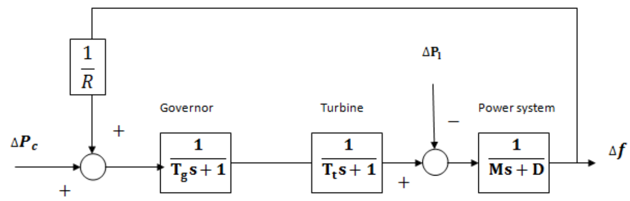

Fig.1 The block diagram of uncontrolled single area.

III. SYTSEM UNDER STUDY

The block diagram of a simplified frequency response model for single area power system under study, it consists of one diesel generator and speed governor with aggregated unit including the proposed Water cycle controller is shown in Fig. 2.

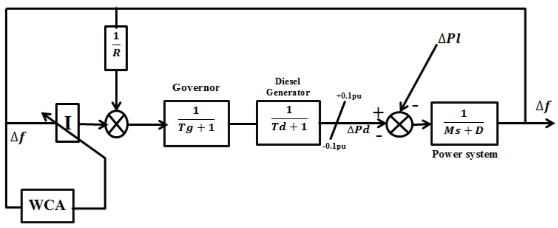

Fig. 2 Block diagram of single area power system

The closed loop transfer function of the control system is given by:

$$\frac{\Delta\Omega(s)}{-\Delta Pl} = \frac{S(1+TgS)(1+TtS)}{S(2HS+D)(1+TgS)(1+TtS)+Ki+S/_{R}} \quad (4)$$

IV. WATER CYCLE ALGORITHM.

Water cycle is new optimization technique for solving engineering optimization problems that presented in 2012[12].

Water cycle has inspired from nature which is began by initialing of variables as Raindrops, based on the observation of water cycle process and how rivers and streams flow to the sea in the real world.

In WCA Algorithm sea is the best value and river or stream as initial population, sea (best value) at last.

One advantage of this algorithm is ability to find maximum or minimum value of function with high speed and accuracy,

In order to solve an optimization problem using population-based on metaheuristic methods, it is necessary that the values of problem variables be formed as an array.

Raindrop is an array of 1 Nvar. This array is defined as follows:

Each raindrop is a 1 × Nvar array and each array is a solution for problem. These arrays are put in a matrix:

$Raindrop_i$ = Xi = $[X_1, X_2, . . . , X_{NVar}]$,

$$\text{Population raindrops} = \begin{bmatrix} \text{Raindrop1} \\ \text{Raindrop2} \\ \text{Raindrop3} \\ . \\ . \\ \text{RaindropNpop} \end{bmatrix} \quad (5)$$

Npop is the number of raindrops

Population raindrops are initial population.

Then cost of each raindrop is calculated by cost function [13].

A. Stream (or river) flow to river (or sea)

The streams had created from the raindrops and join each other to form new rivers. Some of the streams may also flow directly to the sea. All rivers and streams end up in sea (best optimal point).

$\text{Position}^{new}_{stream}$ = Position stream+ rand × C × (Position river – Position stream), (6)

$\text{Position}^{new}_{river}$= Position river+ rand × C × (Position sea – Position river) (7)

C is a number between 1 and 2.

Rand is a uniformly distributed random number between 0 and 1.

If the solution has given by a stream is better than its connecting river, the positions of river and stream are exchanged (stream becomes river and river becomes stream). Such exchange can similarly happen for rivers and sea.

B. Evaporation and Raining

The evaporation and raining prevent Water cycle Algorithm from getting trapped in local optimum solution.

Evaporation process will end if

$$|Position_{sea} - Position_{river}| < d_{max} \quad (8)$$

The value of dmax adaptively decreases as

$$:d^{new}_{max} = d_{max} - (d_{max}/_{\max itration}) \quad (9)$$

Maximum number of iterations is used for end of main loop which at the end loop.

Raining process begins after evaporation process.

In this process, the new raindrops are flowing to streams in the different locations.

New location of streams as Eq (10).

$$Position^{new}_{stream} = Position_{sea} + \sqrt{\mu} \times \text{randn}(1, \text{Nvar}) \quad (10)$$

randn is the normally distributed random number.

µ is small number that leads algorithm to search in smaller region near the sea.

Water Cycle Algorithm (WCA) parameters have been brought in Table 1.

Table 1. Water cycle algorithm (WCA) parameters

Parameters	Value
Nvar	3
Npop	16
C	1
dmax	0.01
µ	0.1
Maxitration	30

The flowchart of Water Cycle Algorithm (WCA) with considering above objectives for detecting optimum solution parameters is shown in Fig. 3.

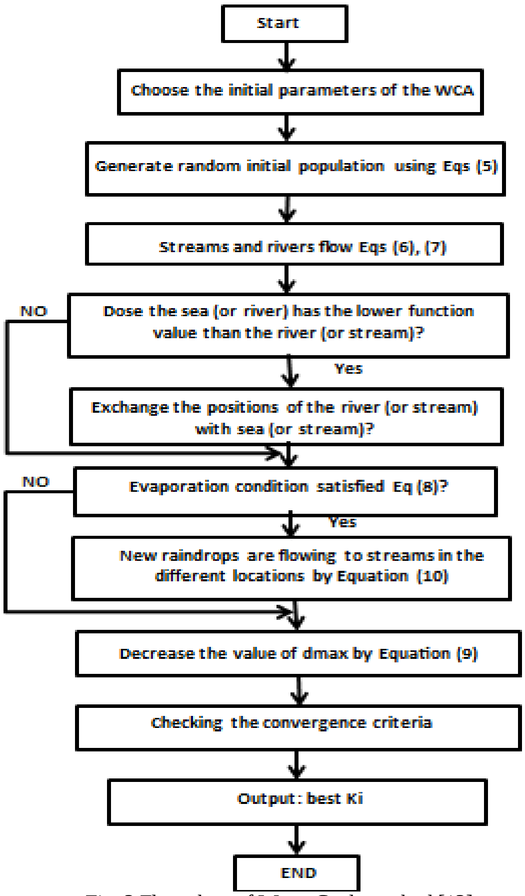

Fig. 3 Flow chart of Water Cycle method [13]

If the solution has given by a stream is better than its connecting river, the positions of river and stream are exchanged (stream becomes river and river becomes stream).

Such exchange can similarly happen for rivers and sea.

V. WATER CYCLE BASED LFC

A simplified power system model shown in Fig. 3 is used to drive the following second order transfer function

$$T.F = \frac{\omega_n^2}{s^{2}+2\eta\omega_n s+\omega_n^2} = \frac{(k_i/_{M})}{s^{2}+(R/_{M.(1+R)})s+(k_i/_{M})} \quad (11)$$

These transfer function used to calculate the parameters $\omega_n, T_s, and\ T_r$. These parameters used in the objective function

$$f = \omega_n + T_s + T_r \quad (12)$$

Where:

Ts: settling time

Tr: rise time.

VI. RESULTS AND DISCUSSIONS

Computer simulations had been carried out in order to validate the effectiveness of the proposed scheme. The Matlab/Simulink software package had been used for this purpose. A practical single area power system shown in Fig1 having the following nominal parameters listed in Table 2.

Table 2 Data of the micro grid power system [17]

Ki	D(pu/Hz)	M(pu.sec)	R(Hz/pu)	Tg(sec)	Td(sec)
-0.3	0.015	0.08335	2	0.8	0.4

Digital simulations had been applied to validate the effectiveness of the proposed adaptive control scheme. The Matlab/Simulink application program has been used as test environment. A microgrid power system shown in Fig.1 consists of 20 MW diesel generator, 17 MW load. The nominal parameters of the system listed in table 2.

The system with proposed controller has been tested with step load change (the ΔPL assumed to be 0.02 Pu at t = 3 sec). Fig. 4 show the simulation results in this case. It has clear that proposed controller gives the better system frequency Also, Fig. 5 show the diesel power and its modification with the suggested tuned controller. While Fig. 6 present the output of the optimizer.

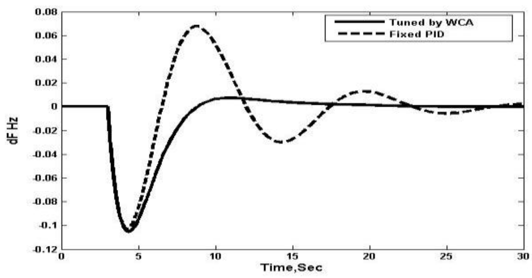

Fig. 4 frequency deviation

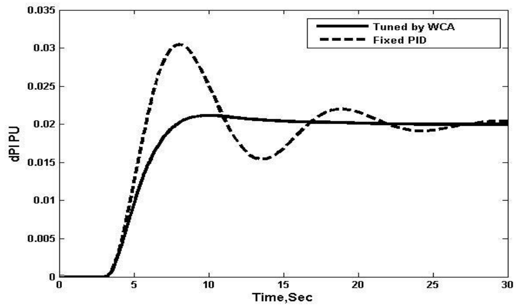

Fig. 5 Diesel power deviation

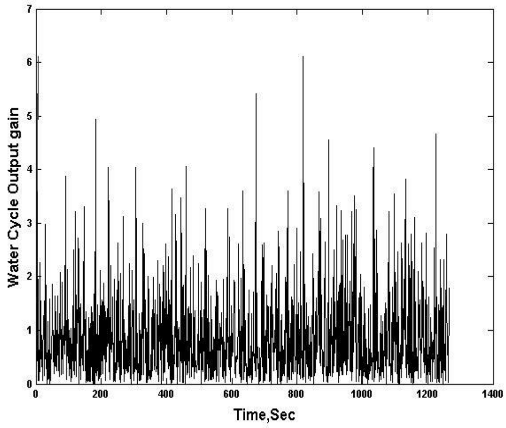

Fig. 6 The output of the optimizer

VII. CONCLUSIONS

This paper presents an on-line tuned controller using new optimization method "Water cycle". The suggested control algorithm has been applied to microgrid power system under load frequency control issue. System has been tested under parameters variations and both step load demand . Simulation results proved that, comparing with fixed gain controller, desired frequency and power responses can be realized using proposed control scheme.

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