Frequency Stabilty of Egyptian Power Grid with Unification of Renewable Energy Sources

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***Abstract*— This wrapping presents a segregated concept of load frequency control strategies in the Egyptian power grid with the puncture of inexhaustible energy sources. The basic model of the Egyptian power grid is broken up into three basic models: non-warm, warm, and hydroelectric power plants. Additional somatic curtailments, like generator rate curtailments and the governor fallen band, are taken in account in this instance. The controller design has been taken for each subsystem to evaluate the frequency stability of the whole system. A harmonic search algorithm has been applied to the accurate modelling of controller gain in a purposed power system, and it enhances the frequency steadiness of a particular Egyptian power system (EPS) model. A MATLAB simulation study has been carried out for a decentralized and centralized power system with different loading patterns. The purpose of the simulation study is to give a better dynamic response, which gives better frequency stability in terms of peak overreach and steady time.**

Keywords— Decentralized power system, Harmony search Algorithm, Static Frequency error, Renewable Energy Sources

I. INTRODUCTION

Today, the electrical loads are continuously increased due to new industries and domestic consumers. This results in increased transmission lines and the interconnection of different power systems. Due to various interconnection issues, frequency oscillation and tie-line power deviation are key indicators in a modern power system [1]. A large violation in frequency deviation may result in equipment failure, loss of different transmission lines, zone protection, and prime mover failure. Today, the major research has carried out under unification of renewable energy sources(RESs) to power grid which impacts on system inertia and frequency oscillation [2]. With the penetration of RES, there is a mismatch between generation and load demand, which is a major factor in the power grid model. Hence, the load frequency control (LFC) model is an important control structure for obtaining the frequency trajectory of a particular European power system. The frequency variation depends on the energetic power, and the voltage fluctuation depends on the reflex power [3].

H. Yousef has proposed the fuzzy control technique for the load frequency control model to mitigate the frequency due to an external load disturbance [4]. The improvement of controller parameters and the design of suitable controller models are the main observations of the fuzzy optimization process. Power uncertainty occurs in the grid through the penetration of renewable energy sources. P. Garasi et al. have given a new dimension to the frequency stability of an isolated system by using electric vehicles (EV), heat pumps (HP), and batteries. They also elaborated on the new intelligent algorithm by using the coefficient diagram method (CDM) to enhance the frequency error against uncertainties [5]. The new robust controller design using the coefficient diagram method has been applied to an isolated small power system model, which was developed by R. Ali et. al. [6]. They have optimized PID controllers gain by using the swarm intelligence method using controllers to track the frequency error and soundness of the proposed power grid model. G. EI-Saddy et al. have given a new concept on Ant Colony Optimization (ACO)-based PID controller design for two-area interconnected power systems [7]. They have evaluated the modified version of performance indices using the MATLAB/SIMULINK platform. They captured the different time domain performances by using an ACO-based PID controller. The drawback of this searching algorithm has many computational burdens. A.B. Kunya and M. Argin have developed a new control grand design by using replica prophetic control for interconnected power grid [8]. They have designed a time-based simulation on 10 generators, of which five are interconnected power systems, to verify the effectiveness of settling time. G. Magdy et al. have also proposed the model predictive control for realistic multi-source power systems. The predictive control model has certain advantages, like fast response, a simple control model, and the ability to the ability to easily handle constraints during simulation, but it takes a longer time for simulation [9].

In the previous literature review reflects on the LFC issue, it reflects that most of the models are considered by taking hydropower and thermal power plants. To achieve a more realistic study, several power system models should be added to the LFC study, which is reflected in this exploration work. Most of the energy system models are linear and straight forward, which mainly depend on synchronous machines. However, the penetration of RESs into the multi-source power system will help analyse the frequency scenario in a better way. H.M. Hasanien presents a novel concept about power system models based on conventional power systems and RESs. The whale optimization algorithm (WOA)-based PID controller design has been applied to AGC problems with a realistic model [10]. M. Ma et al. propose a replica prophetic control theory for a multi-area power grid model [11]. This research work presents a load frequency control model of the Egyptian power system, which consists of both conventional generating systems and renewable energy sources (wind and solar energy systems).

The primary benefit of this research has been examined in this study and is:

- The recently developed perfect PID controller has been built using the harmony search algorithm to increase the frequency analysis's potency under various load patterns, including solar, wind, and industrial loads.
- In this work, the time domain characteristics have been carried out to justify its robustness in terms of performance index, overshoot, and settling time.

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- The different operating conditions of industrial load, domestic load, wind energy load, and PV load have been examined to impact the frequency stability of microgrids.

The major focus of this research work is to design a decentralized load frequency control model and optimize PID controller gains by using the Harmony Search Algorithm (HSA). The decentralized controller for each subsystem has been designed using the HSA algorithm, which easily regulates the frequency error and easily tracks the load demand.

II. STRUCTURE OF POWER SYSTEM

As seen in Fig. 1, the Egyptian power system model is separated into seven zones.. Each zone has amalgamation of non-reheat, reheat, and hydro plants. The European power system is integrated with wind and solar power plants. It has 3% installed capacity. The installed and peak load capacity of Egyptian power grid are 38,000 MW and 29,000 MW, respectively[20]. The upgrade of the composite power system in Egypt by penetrating renewable energy sources will become a smart grid. The peak power capacity of wind power plant is 1140MW and solar power plant have 760MW. The real Egyptian model has rebuilt with some approximation as shown in Fig. 2. Some of the non-linear characteristics have incorporated with Egyptian model are speed governor backlash and generator rate constant(GRC). Here, in this research work the GRC limits have taken 0.2 pu MW/min and 0.1 pu MW/min for non-reheat and reheat turbines respectively. The GRC limits of hydro power plant has taken 0.5pu MW/min.

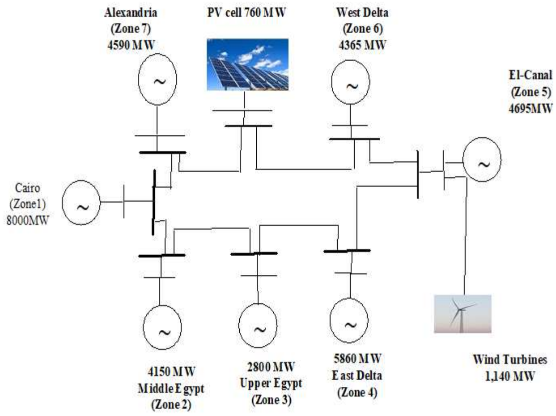

Fig. 1. Pictorial representation of EPS

A. Wind power model

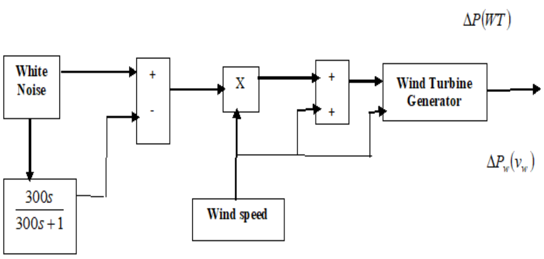

Fig. 3 Wind generator model

The wind power model for the use of load frequency control system is shown in Fig 3. In this model, the wind speed generation has come from SIMULINK toolbox which is multiplied with random white noise block . The integration of wind turbine with Egyptian power system model which consists of 380 wind generating units each have 0.3MW. The detail wind turbine parameters has presented in [3]. The power model of wind turbine has presented below.

$$P_{wind} = \frac{1}{2}\rho A_T V_w{}^3 C_p(\lambda,\beta) \qquad (1)$$

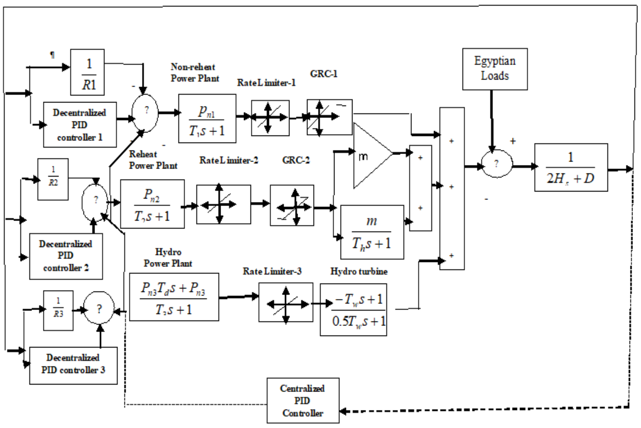

Fig 2. Block diagram of centralized and decentralized Egyptian power system

B. Solar power model

The PV generating stations has generating irregular power due variable weather condition. Due to variable power generation of PV units, it will greatly impacts on frequency deviation and real power generation. Also, it will greatly hazards the system stability. The variable power generation of PV cell has estimated by taking the random insolation which shown in Fig. 4. The randomness of power fluctuation is the product of standard deviation which generated from

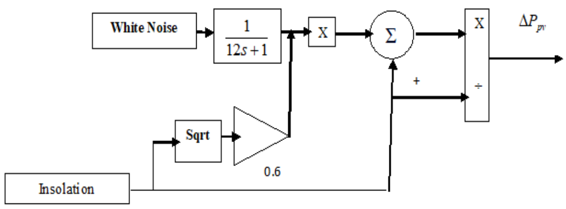

Fig. 4 PV/Solar model

white noise block. The lunatic power calculation is closely related to actual lunatic power by following equation.

$$\Delta P_{PV} = 0.6\sqrt{P_{pv}} \qquad (2)$$

C. Control strategy

In this research work, the PID controller has been taken for evaluation frequency modelling of European power system with RESs. The mathematical modelling of PID controller has represented as follows:

$$H(s) = K_p + \frac{K_i}{s} + K_d s \qquad (3)$$

K_p is the proportional gain, $\frac{K_i}{s}$ is the integral gain and K_d id the derivative gain. The exact controller gain allocation is a

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difficult task for designer by trial and error method. It suffers from robustness and it cannot give optimal result. Therefore, this research focuses on the optimal PID controller tunning by harmony search algorithm (HSA) which diminishes the frequency error. Here, the integral square error (ISE) has taken as the unbiased function for frequency error minimization. The staging index can be composed as follows:

$$ISE = \int_0^{simulation} (\Delta f)^2 \, dt \tag{4}$$

Δf *is* the frequency deviation of the power system model and $simulation$ is the simulation time for the model execution.

III. HARMONY SEARCH ALGORITHM

Harmony search algorithm (HSA) is idiom with the musical instruments [18]. The better harmony has generated by adjusting the pitch of the musical instruments. It has many applications in the area engineering fields. This optimization algorithm is devoid of derivatives. The HSA can search a larger area in a fair amount of time. The following describes each of this algorithm's phases.

1. Initialize the Harmony Memory

A vector reflecting a population pool is generated using a decision variable that minimizes the objective function. $f(x)$, where$x$ is decision variable.$f(x)_{minimize}$ where $X_i \in X(i,j)$ $i = 1,2,\cdots N_p$ $j = 1,2,\cdots decesion\ variables$. $f(x)$ is the function to minimize.$X(i,j)$= population vector or solution vector in the harmony memory. All of the solution data are kept in a population pool vector called harmony memory (HM). $X \in [x_{j-min}\ x_{j-max}]$ where x_{j-min} and $x_{j-max}$are the lower

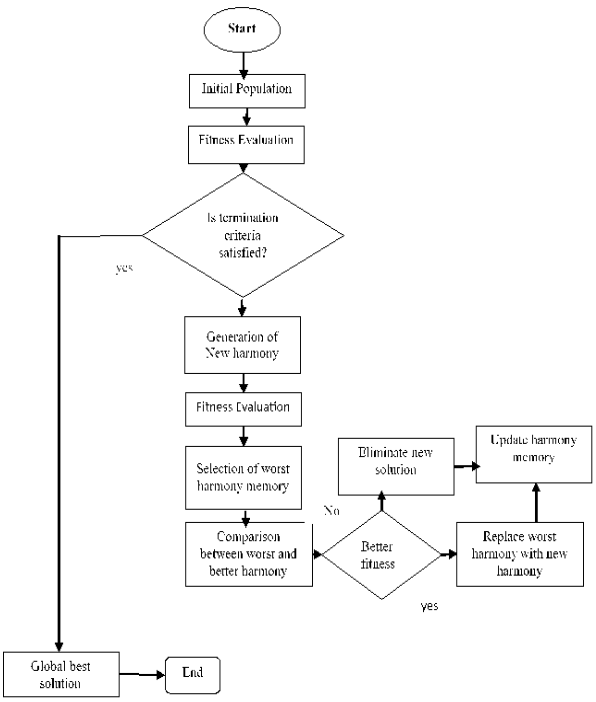

Fig.5 The flow chart diagram of HAS Algorithm

and upper bound of each decision variables. The initialization process as follows

$$X(i,j) = x_{j-min} + rand * (x_{j-max} - x_{j-min}) \tag{5}$$

Where rand is the random number between 0 and 1. The second step is:

1. Create new harmony

"Improvisation"—a term used to describe harmony memory—creates the new harmony vector. Harmony memory improvisation according to specific guidelines: (1) Random selection; (2) Pitch modification; and (3) Memory consideration. A new population vector is created $x'_{new} = (x'_1, x'_2 \cdots x'_{N_p})$ based certain probability criteria.

$$x'_{new} = \begin{cases} x'_{new} \in x'_1, x'_2 \cdots x'_{N_p} if\ rand < HMCR \\ x_{(i,j)} = x_{i-min} + rand * (x_{i-max} - x_{i-min}) with \\ probability\ 1 - HMCR \end{cases} \tag{6}$$

The pitch adjustment concept is applicable to harmony memory to adjust its distance. The pitch adjustment has followed with some probability arguments:

$$x'_{new} = \begin{cases} yes\ probability\ PAR \\ No\ probability\ 1 - PAR \end{cases} \tag{7}$$

So, $x'_{new} = x'_{new} + rand * BW$

BW is distance between the elements of harmony memory.

2. Update the harmony memory

Compared to harmony memory, enhance memory has a higher fitness value. The HM's worst value will be changed.

$$f\ f(x'_{new} < f(x_{worst}))\ x_{worst} = x_{new}$$
$$f(x_{worst}) = f(x'_{new}) \tag{8}$$

3. Checking stopping criteria

If the maximum iteration number is satisfied, the computation is terminated otherwise step 3 otherwise, step 4. is repeated.

IV. APPLICATION OF HARMONY SEARCH ALGORITHM TO LFC STUDY

The computational strategy for harmony search algorithm has been described as follows:

Process-1 Specify the decision variables of the system by taking upper and lower bound of each decision variables. The upper and lower bounds are the PID controller gains.

Process-2 Initialized the population vector among decision variables which is called harmony memory (HM). $HM = [x_1, x_2 \cdots N_p]$ Where N_p is called feasible solution of candidates.

Process-3 Evaluate the fitness value by using equation (4)

Process-4 Create new harmony between two population pool vectors by taking $HMCR$ as conditional probability.

Process-5 The upgradation of harmony memory has achieved by pitch adjustment which followed the equation (7).

Process-6 The comparison has made between the fitness value of improve harmony and old harmony which have better fitness, they have better survival of the fittest.

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V. RESULTS AND DISCUSSION

The reviewed model of Egyptian power grid has established in MATLAB/SIMULINK 2021a platform with 8GB RAM i7 1.80GHz processor to verify the robustness of the proposed model. The purposed model is considering the decentralized LFC model under the variety of loading condition such as RESs, random load (Industrial and Residential load). The harmony search algorithm has written in M. file in editor command and it has been interface with Simulink model. The system data has taken from reference [20]. The dynamic response of the studied power system has evaluated in terms of setting time, overshoot, undershoot and performance index. Here, the performance index is

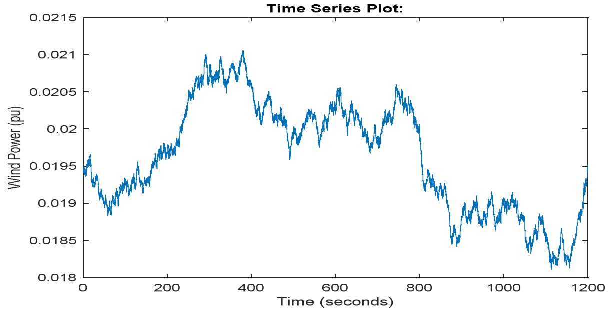

Fig. 6 Wind power fluctuation

considered as the integral square error (ISE). The EPS has tested under the penetration of wind hurricane and lunatic load which presented in Fig. 6 and Fig. 7. This case study has implemented under various loading condition which is shown in Table 1. The frequency digression of decentralized and centralized EPS model using HSA algorithm has shown in Fig 8. The centralized power system has come with more oscillation of frequency with high overshoot. The optimal parameters of HSA algorithm have shown in Table 2. By choosing suitable parameters of HSA methods, the optimal values of PID controller for decentralized and centralized power systems have shown in Table 3. Table 4 represents the settling time and integral square error for EPS with

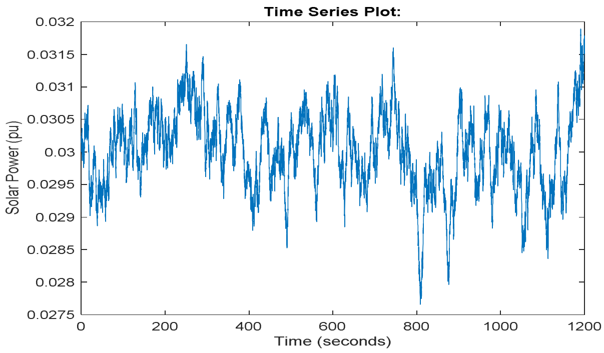

Fig. 7 Solar power fluctuation

100% inertia. From this table the settling time of centralized power system is 12 Sec in comparison with decentralized model. The optimal value of ISE in decentralized model has achieved less in comparison with centralized model. The convergence graph of ISE for both EPS model has shown in Fig. 9 and Fig 10. From this convergence graph the ISE value of decentralized system is 0.0061 which is lesser than

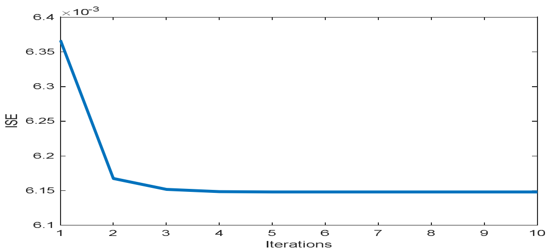

Fig. 9 Converge characteristics of ISE with decentralized system

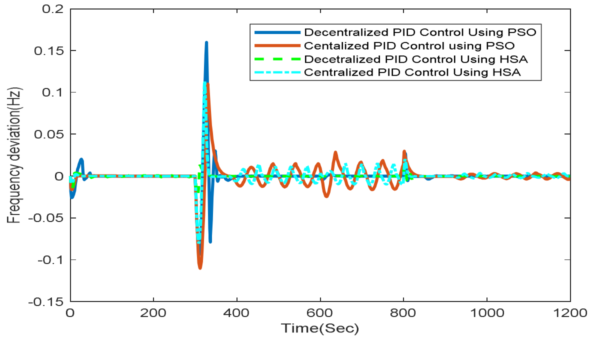

Fig. 8 Frequency deviation of EPS with 100% inertia

ISE value of centralized model. The better frequency stability has achieved by decentralized model with high accuracy.

TABLE I. DIFFERENT OPERATING CONDITION

Types of Disturbance	***Starting Time (Secs)***	***Stopping Time (Secs)***	***Peak Value***
Industrial Load	300	-	0.25
Residential Load	Initial	800	0.13
Wind Turbine Load	600	-	0.03
PV Power Plant	Initial	-	0.02

TABLE II. OPTIMAL PARAMETERS OF HAS

HAS Algorithm	***Parameters***
Number of Population (Harmony memory)	10
HMCR	0.8
PAR_max	0.9
PAR_min	0.6
BW	0.02
No. of Iteration	10

TABLE III. OPTIMAL PID VALUES OF PID CONTROLLERS

Methods	***Optimal PID Parameters***	***Decentralized PID Control Parameters***			***Centralized PID Control Parameters***
		Non-reheat Power plant	**Reheat Power Plant**	**Hydro Plant**	
PSO [20]	K_p	26.537	9.682	38.537	71.2532
	K_i	16.312	0.806	18.1430	5.9055
	K_d	-0.508	18.730	0.101	6.10758
HSA	K_p	69.5060	12.4826	44.4425	88.3036
	K_i	8.5433	51.3838	80.7912	20.0790
	K_d	11.8409	47.7783	53.0855	93.4363

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Fig. 9

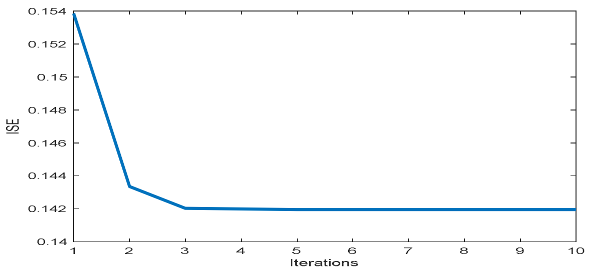

Fig. 10 Converge characteristics of ISE with centralized system

TABLE IV. TIME DOMAIN SPECIFICATION OF EPS

System Inertia	***Optimization Methods***	***Time Specification of Decentralized PID Controllers***			
		US	OS	ST(Secs)	ISE
100%	PSO[20]	0.023	0.009	24	0.2746
100%	HSA	0.011	0.001	2.81	0.0061
Time Specification of Centralized PID Controllers					
100%	PSO [20]	0.025	0.012	46	0.29
100%	HSA	0.011	0.02	12	0.142

VI. CONCLUSION

This research has reflected the frequency steadiness of EPS with the integration of RESs by the HSA algorithm. In this research study, a major focus has been carried out by taking a realistic power system model with the integration of wind power to visualize the frequency mapping of such a combined effect. The non-linearity of the EPS model has increased due to the addition of RESs. To maintain the constancy of frequency by adopting a new PID control strategy for decentralized and centralized power systems. The harmony search algorithm-based PID control technique has been applied to regulate the frequency of the proposed power system. The different loading decorations have been applied to EPS to analyze the robustness of the proposed model. The miniature results show that the different loading conditions of EPS have achieved better frequency regulation in terms of peak overshoot, settling time, and integral square error. The better way to suppress dynamic frequency oscillation in the Egyptian power system is by incorporating a virtual inertia control loop into the power system model, which inherently mitigates the frequency deviation. Another future work in this study is inserting the SMES model into the concerned power system, which gives satisfactory performance in frequency deviation.

DATA AND NOMELCULTURE

A_T =Rotor Swept area in m^2

C_1, C_2= Acceleration Constant

D=Daming Coefficient in pu MW/Hz=0.028

m= Fractional value of turbine power=0.5

H=Inertial Constant pu Sec=5.7096

P_{nrh}=Rated power of non-reheat plant in pu MW=0.2529

P_{rh}= Rated power of reheat plant in pu MW=0.6107

P_{n3}=Rated power of hydel plant in MWpu=0.1364

∇P_{pv}=Output power of Solar in Watt

P_{wind}=Output power of Wind in Watt

R_1= Speed regulation of governor in non-reheat plant=2.5

R_2= Speed regulation of governor in reheat plant=2.5

R_3= Speed regulation of governor in hydro plant=2.5

T_{nrh} =Valve time constant of the non-reheat plant in Sec=0.4

T_{rh}= Vale time constant of the reheat plant in Sec=0.4

T_3=Time constant of the water valve in Sec=90

T_d=Time constant of Dashpot in hydro plant in Sec=5

T_h=Time constant of the reheat plant in Sec=6

T_w=Time constant of the water starting time in Sec=1

β= Pitch angle

λ= Tip-speed ratio

ρ= Air density factor in Kg/m^3

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