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Load Frequency Control of Distributed Generation Systems using Ziegler-Nichols Method

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Abstract –**This paper deals with the load frequency control of Distributed Generation Systems (DGS) consisting of Wind, Solar and Diesel Generator. The Diesel Generator is controlled either by P or PI or PID controller to inject regulated amount of real power to the power system based on its rating. As a result it regulates the mismatch between the real power generation and the load which will lead to a minimum power and frequency deviations. A systematic way of deciding frequency bias parameter along with tuning the gains of the Proportional, Integral and Derivative controller (PID) based on Ziegler-Nichols method and ITSE performance criterion is proposed. The simulation studies are carried out for different types of controllers, and disturbances and it is found that it regulates the frequency with less number of oscillations, minimum peak over shoot, and settling time in the case of PID controller.**

Keywords –**Distributed Generation Systems (DGS), Proportional, Integral and Derivative Control (PID), Ziegler- Nichols method, Optimization methods, Tuning, Frequency Control, Diesel Generators, Wind and Solar, Simulation Analysis.**

I. Introduction

The frequency of the voltage wave must remain within limits to ensure that the electrical supply is carried out under high quality acceptable. Frequency variations away from the nominal value can cause the malfunction of various industrial or domestic equipment [1]. By example, some engines may be forced to rotate at different speeds of the one for which they were designed, and clocks and automatisms that measure the time depending on the frequency of feeding can lead or delay.

The frequency of an electrical system is closely related to the balance between generation and load. In a permanent regime all generators of an electrical network operate in synchronism, that is, the frequency of any of them multiplied by the number of pairs of poles is precisely the electrical frequency of the system (50 Hz). While it persists the permanent regime, the accelerating torque applied by each turbine on each generator is equal, discounting the losses, to the electromagnetic pair which tends to slow down the machine. If at any given moment the load increases, it is say the electrical power demanded in the system, then the torque electromagnetic in the generators, these begin to brake, and the frequency the power decreases progressively.

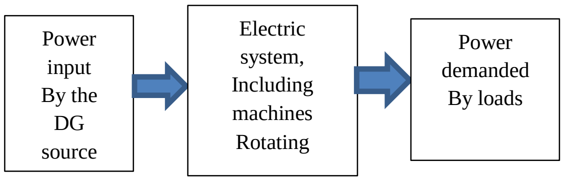

Figure 1: Energy balance in an electrical system

Another way of considering this dependence is in terms of energy balance [2]. While a system operates on a permanent basis, the mechanical power incoming to the system from the DG system is equal to the electrical power consumed by the charges, discounting the losses. This relationship is shown graphically in figure 1. If the electric power consumed by the loads increases, but the mechanical power provided by the turbines remains constant, the increase demand can only be obtained from the kinetic energy stored in the rotary machines. The reduction of the kinetic energy in the generators synchronous is equivalent to the reduction of its speed of rotation, so that the frequency of the system.

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II. Proposed Methodology

The synchronous generator as a regulator of power the basic element for exercising frequency-power control in a system electric is the synchronous generator. Figure 2 shows the basic schematic of a Generator with a turbine that can be from wind or diesel.

The turbine intake valve regulates the incoming flow to the turbine and, therefore, the mechanical power supplied to the synchronous generator. Figure 2 shows the main variables involved in the control of frequency-power. It is often used as input to the control system the speed of rotation of the shaft, easier to process than the electric frequency. Another input to the system is the power set point, received from the outside of the plant [3]. The variable on which the control acts is always the valve of admission to the turbine. Other elements that may be present in an electrical system and contribute to the active power flow are the direct current links, the transformers Phase shifters and electronic systems FACTS (Flexible Alternating current Transmission System). However, they are less frequent, and their influence on frequency-power control in most systems is reduced in comparison with that of the synchronous generators.

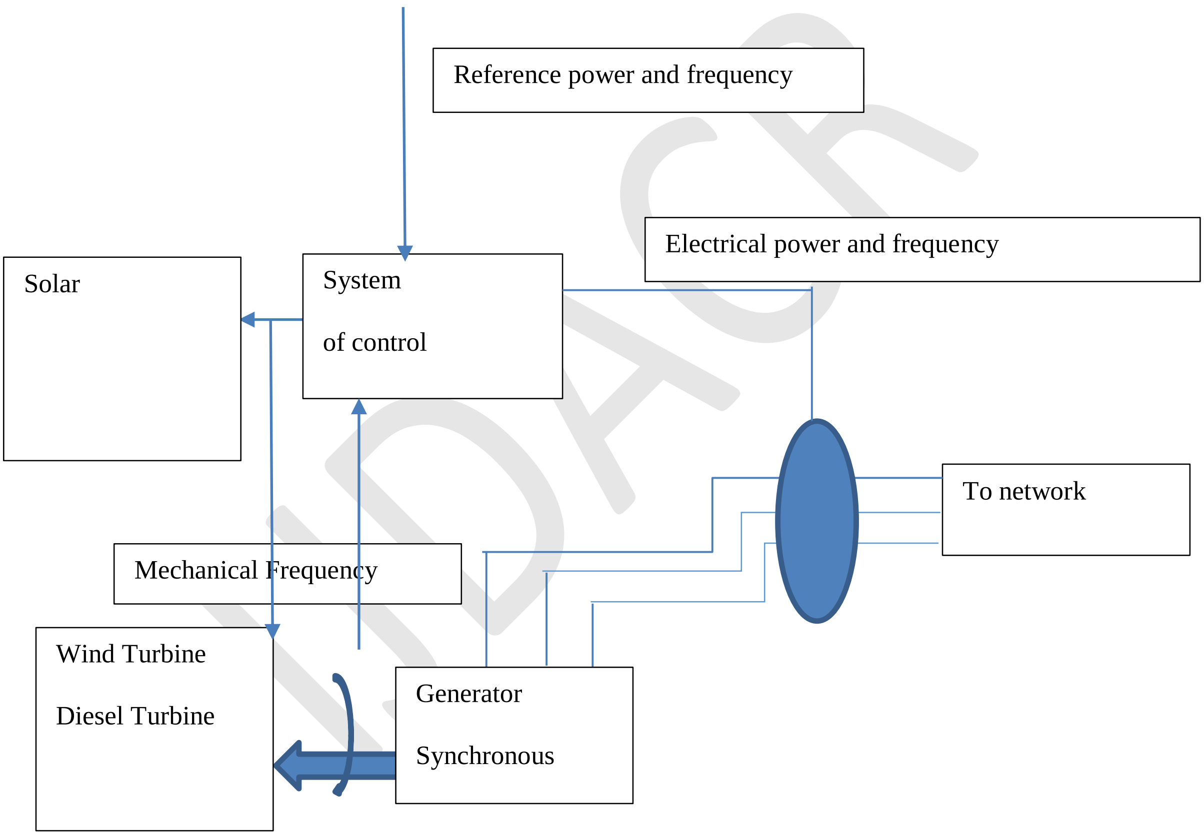

Figure 2: The Block diagram of the Distribution Generation System with Diesel Generator, Wind, Solar power supply and Power System

A. The System Model

The proposed DGS comprises of wind turbine generator, solar and diesel generator. The varying output of wind turbine generator due to fluctuations of wind speed is smoothed using a constant power smoothing strategy [4]. The net power available to the load is determined from the sum of the powers from wind turbine generator, diesel generator, and Solar PV panels. In this paper simplified models with first order approximation are used as transfer functions for the diesel generator, and the power system [5]. The proposed DGS is shown in the Fig. 2 and mathematical models of wind turbine generator, diesel generator, and the power systems are explained below:

B. Wind Turbine Transfer Function

The shaft-turbine assembly of a synchronous generator rotates subjected to two pairs [6], [7] opposite: the mechanical torque Tm supplied from

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the turbine tends to accelerate the shaft, while the electromagnetic pair tends to slow you down. The basic equation of this movement is

$$J\frac{d^2\theta_r}{dt^2} = (T_m - T_e) \quad (1)$$

Where J is the moment of inertia and θ_r is the angle of the rotor. Instead of Second derivative of the angle we can write

$$\frac{d^2\theta_r}{dt^2} = \frac{d\omega_r}{dt} = \frac{d(\omega_r-\omega_0)}{dt} = \frac{d\Delta\omega_r}{dt} \quad (2)$$

Where ω_r is the rotor speed, ω_0 is the reference speed, and $\Delta\omega_r$ is the speed deviation. In this way, we can write equation (1) as:

$$\frac{d\Delta\omega_r}{dt} = \frac{1}{J}(T_m - T_e) \quad (3)$$

If the nominal power of the machine is taken as the base power S_{Base} , base frequency ω_{base} reference frequency and as base pair $T_{Base} = S_{base}/\omega_{base}$, we can divide the left-hand member of the previous equation between ω_{base}, and the right member between $S_{Base}/(T_{Base}.\omega_{base}^2$. Then it remains in unit values:

$$\frac{d\Delta\omega_r[pu]}{dt} = \frac{1}{2H}(T_m[pu] - T_e[pu]) \quad (4)$$

Where H is the inertia constant, defined as

$$H = \frac{\frac{1}{2}J\omega_{base}^2}{S_{base}} \quad (5)$$

C. Solar Generator Transfer Function

Solar/photovoltaic systems [8] to transform sunlight into electricity are also good sources for DGS as sunlight is an abundant resource around the world and solar electric systems are clean, quiet and easy to use, and there is no need of any fuel other than sunlight. Furthermore, they are durable, reliable, and easy to maintain as there is no moving parts. Solar cells, also known as photovoltaic (PV) cells, use special materials called semiconductors that produce electricity when exposed to light, and four promising types of solar electric technology are under development: crystalline silicon (a form of refined beach sand), thin films ,concentrators, and thermo photovoltaic. The output power (in watts) of the studied PV system is determined by:

$$P_{Pv} = \eta S\phi(1 - 0.005(T_\alpha + 25) \quad (6)$$

D. Power and Frequency Deviation

In a power system [9], if the balance between the generation and load changes, the output frequency changes (either increasing or decreasing) depending on the domination of generation or load. The power deviation is the difference between the power generation P_G and the power demand P_L .

$$\Delta P_e = P_G - P_L \quad (7)$$

Due to time delay between the system frequency deviation and power deviation, the transfer function for system frequency variation to per unit power deviation are given by:

$$\Delta f = \frac{K}{Ms+D} \quad (8)$$

Where, K is the system frequency character constant. M and D are the inertia constant and damping constant respectively of power system. In this study D and M are chosen as 0.012 and 0.2 respectively.

E. Diesel Generator Transfer Function

Diesel generators [10, 11] can follow the load demand variations by means of their speed and power control mechanisms. When power demand fluctuates, the diesel generator varies its output via fuel regulation through its governor. On the other hand since this is a synchronous generator, its output voltage can be regulated by controlling the excitation. In this paper the diesel generator is represented with a first order transfer function.

$$G_{DE}(s) = \frac{K_{DE}}{1+ST_{DE}} \quad (9)$$

Where, *DET* is the time constant of the diesel generator. The gain and time constants of diesel generator (DEG) are consider as 1 and 2 sec respectively. For Diesel generator we have also considered the delay in the output as:

$$G_d(s) = \frac{K_d}{1+sT_d}s \quad (10)$$

The saturation band is 0-0.8 included in the model. Where $K_d = 1$ and $T_d = 20$ sec.

F. Ziegler- Nichols Method (PID)

In 1942, Ziegler and Nichols [12] proposed two heuristic approaches based on their experiment and some simulations to quickly adjust the parameters of the regulators P, PI and PID. PID regulators meet more than 90% of industrial requirements and the number of regulators installed in an oil factory, for example, is counted in thousands, the values chosen for the parameters P, I and D are not always satisfactory or adapted to the process to be regulated.

$$p(t) = K_P e(t) + K_I\int_0^t e(t)dt + K_D\frac{de(t)}{dt} \quad (11)$$

Where the $p(t)$ is the control input to diesel generator. $e(t)$ the error i.e. change in frequency. $K_P, K_I,$ K_D are the proportional integral and derivative constants. The Ziegler-Nichols method is a heuristic method of tuning PID controller. It was developed by John G. Zeigler and Nathaniel B. Nichol [13]. It is performed by setting the K_I and K_D to zero, the K_P gain is increased (from zero) until it reaches the critical ultimate gain K_U, at which the output of the loop begins to oscillate.

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III. SIMULATION AND RESULTS

A. Simulation Parameters

Table 1: Simulation parameters

	K_P	K_I	K_D
P- Controller	0.0655	--	--
PI Controller	0.0590	0.0027	--
PID Controller	0.0786	0.0749	3.3366

B. Simulation Results using Ziegler-Nichols

The load is suddenly increased at 100 seconds from 0.9 pu to 0.95 pu, Wind Power 0.6 pu and solar power is 0.3 is kept constant. In this case, a sudden increase of load demand from 0.9 pu to 0.95 pu is under taken at 100 sec. This change in load demand is met by diesel generator.

The Ziegler-Nichols PID controller is implemented and power generation, power deviation and frequency deviation are observed and presented in following figures. It is found that the response with PID controller is better than the P and PI.

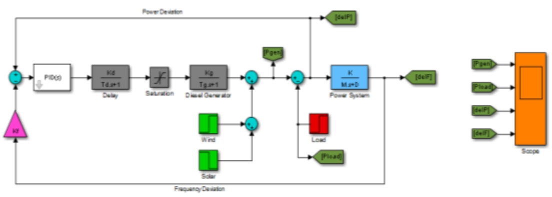

Figure 3: Simulink model of power generation using Ziegler-Nichols

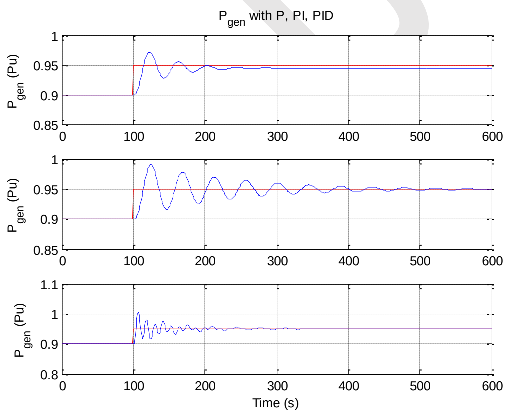

Figure 4: Power generation in system with P, PI and PID in using Ziegler-Nichols

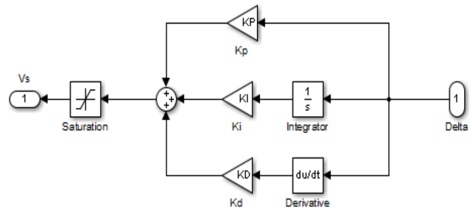

Figure 5: K_p, K_i, K_d Simulink model of Ziegler-Nichols

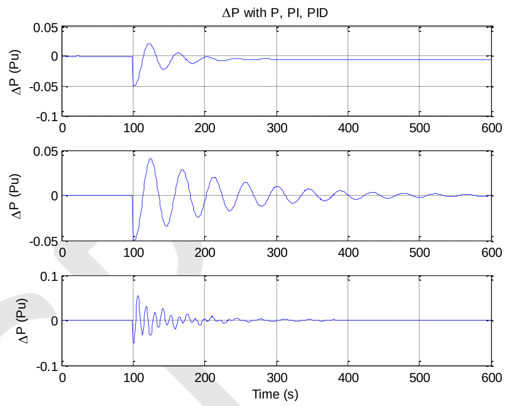

Figure 6: Power deviation in system with P, PI and PID in using Ziegler-Nichols

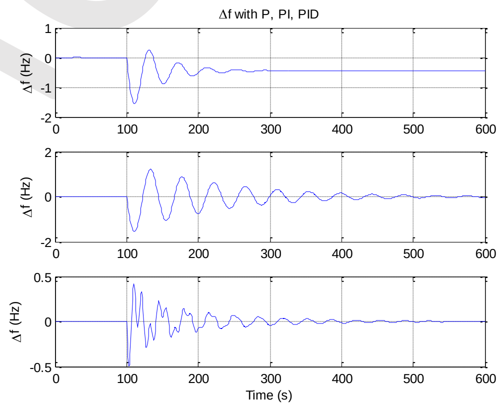

Figure 7: Frequency deviation in system with P, PI and PID in using Ziegler-Nichols

IV. CONCLUSION

Automatic generation control (AGC) plays an important role in power system as its main role is to maintain the system frequency and tie line power flow at their scheduled values during normal period and also when the system is subjected to small step load perturbations. In this research work, the performance of automatic generation control of wind, solar and diesel generator can be evaluated by Ziegler-Nichols method. The performance of controller is evaluated through the MATLAB simulation and it shows that the proposed technique gives better dynamic performances on the basis of

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power generation, power deviation and frequency deviation.

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