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MODELING AND CONTROL OF DISTRIBUTED GENERATION SYSTEMS INCLUDING WIND AND GAS TURBINE ON AZARBAIJAN ELECTRIC NETWORK

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Abstract- This paper concentrates on the modeling and simulation of D.G. systems including wind and gas turbine for damping of oscillation of power and voltage of Azarbaijan Electric Network in during of short circuit and unbalance situation. The Fuzzy Logic controller is designed using the MATLAB Fuzzy Logic toolbox. Distribution test system including a load ,a wind turbine and a gas turbine connected to power grid is simulated using MATLAB/SIMULINK software. Of course the accuracy of the presented model and the proposed multivariable supplementary fuzzy controller are deduced from the simulation results.

Keywords: Distributed Generation, Wind Turbine, Gas Turbine, Modeling.

I. INTRODUCTION

In this paper, we shall explain and investigate different types of power plants and at the end we will simulate a wind-gas complex power plant using MATLAB / SIMULINK with and without Fuzzy logic controller for comparison purpose. We shall discuss the following power plants in this paper:

1- Solar power plants
2- Biomass power plants
3- Wind power plants
4- Fuel combustion power plants
5- Fuel cells
6- Earth heat energy
7- Nuclear power plants
8- Hydroelectric power plants
9- Complex cycle
10- Gas turbine power plants

In the following parts we shall discuss theses power plants one by one.

II. SOLAR POWER PLANTS

1Solar power plants are being used to convert the solar energy to electric energy in different approaches. Solar systems can be used to generate power for different systems in range of 2-3 KW to 200-350 MW. There are 2 major types of solar power plants:

1- Solar cell systems.
2- Centralizer systems.

We shall discuss these types of solar systems in the following sections.

A. Solar Cell Systems

Solar cells which directly convert the light into electricity are used in these systems. The output voltage of an individual cell is very low, therefore, so many of them should be arranged in series to achieve a high enough voltage. Solar cells are composed of semiconductor substances. Semiconductors like silicone used in solar cells will produce a voltage and current due to entrance of photons. In fact, the entrance of the photons will separate the negative and positive load carriers in these cells. Since the produced current is a DC current, an inverter is used to convert the DC current to AC. The arrangement of the solar cells in a power plant is shown in the Figure 1.

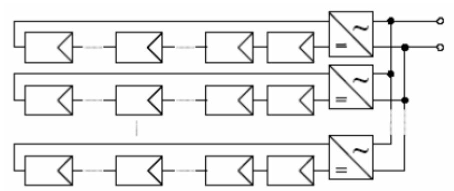

Figure 1. Solar cells arrangement in a power plant

B. Centralizer Systems

Unlike solar cells that use light to produce electricity directly, centralize systems, use sun heat to produce electricity. Solar collectors use mirrors or lens to centralize the light on a thermal receiver. There are different types of centralizer systems as follows:

1- Parabolic trough systems
2- Dish/Motor systems
3- Central receiver systems

B.1. Parabolic Trough Systems

In these systems, parabolic mirrors are used to reflect the sun light on a receiver tube which contains a conductor fluid. The received energy is sent toward the tube and warms up the oil fluid which runs through the tube and the produced heat is used to generate electrical power in steam generators.

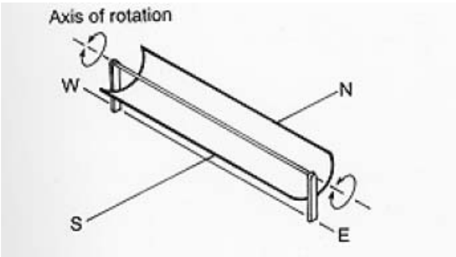

Figure 2. Parabolic through system

B.2. Dish Systems

In these systems, parabolic dish like mirrors reflect the light on a receiver which is installed on top of the dish as illustrated in the picture below. In some dish systems, a motor is rotating the dish toward the sun for maximum use of sun light. The operation of such systems is shown in the Figure 3.

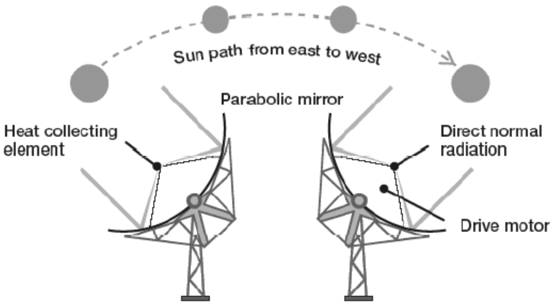

Figure 3. Operation of dish system

B.3.Central Receiver Systems

In central receiver or power tower systems, thousands of sun effect mirrors that are called heliostats are being used. These mirrors reflect the solar energy to the highest part of the tower where the receiver is located. Receiver conducts the heat to a heat conductor which is usually melted salt. The melted salt collects the heat from the receiver. The heat will be used to produce steam for the popular steam turbines.

III. BIOMASS POWER PLANTS

Biomass power plants use fuels like wood, in order to increase the power output and reduce the production cost of the electricity. There are various approaches to produce electricity form biomass. Pressurized air injects the fuel to the reactor through a pressure measurement and tuning unit. The required air is provided by a compressor which is driven by the turbine. Biomass is the fourth important energy source (after coal, oil and gas) of the world which is used to produce heat for different approaches. The main fuel source of these power plants is biomass. Biomass contains all living things such as jungles, plant lambs, leaves, ocean creatures etc. Biomass resources which are suitable for power generation are divided in 6 major groups as follows:

1- Wooden fuels
2- Jungle, farming, gardening and food industry trashes
3- Garbage
4- Bestial garbage
5- Sewerage trashes
6- Industrial trashes

There are also various technologies to produce electricity from biomass.

1- Power plants with only biomass fuel
2- Twofold fuel power plants (coal + biomass)
3- Gas power plants which convert biomass to an medium or low quality fuel
4- Biologic procedures such as digestion or fermentation

In power plants, biomass is used in different ways such as:

1- Co-firing
2- Direct combustion
3- Gas converter
4- Bio fuel
5- Bio gas
6- Vacuum purgation
7- Biomass power plants

We shall discuss each of the mentioned ways in the following sections

A. Co-Firing

Addition of a small percentage of biomass to the supplied fuel for the coal power plant (co-firing) is the simplest way to increase the usage of biomass in electricity production. At the time being, operation of 6 power plants in United States is co-firing of more than 15% biomass fuel. From the other hand a 40% biomass co-firing is a suitable replacement for coal fuel in coal combustion power plants.

B. Direct Combustion

Nowadays, the direct combustion of biomass is widely used in some particular industries such as lumber facilities, furniture, milling facilities and sugar production. Practically, in a direct combustion, biomass is usually combusted in a huge boiler in order to produce steam which yields to ranking cycle. This case is similar to the procedure used in coal power plants except for that the combustion equipments are different. Direct combustion power plants are usually smaller and their efficiency rate is about 20%.

C. Gas Converter

Converting biomass to gas is faster and more effective than direct combustion and is a clean way to derivate heat energy. In this procedure, biomass is warmed up in a medium without oxygen and is turned into organic substances. At the time being, a biomass purgation system is used for purgation of solid particles of garbage to produce 25MW electrical energy in Holland-Groningen.

D. Bio Fuel

Bio fuel is the latest approach to convert biomass into usable energy from organic substances. Bio fuels are defined by DOE which contain alcohols, ethers, esters and other chemical substances produced from biomass. Some of bio fuels are being combusted for electrical power generation but a major part is being used for transportation applications (especially ethanol and biodiesel). More than 1.5 billion gallons (57 million litters) of ethanol is being derived from biomass each year and is being added to petrol to optimize the operation of transport machines and reduce the impurity.

Alcohols are used in the complex of petrol with the scale of 10%. At the other hand, biodiesel is made from vegetable oil and animal fat. About 30 million gallons (1135 litters) is being produced in United States every year which is being used in diesel fuel complex with the scale of 20%.

E. Biogas

Biogas is used as a high efficiency fuel in gas turbines. Gas conversion complex cycle (GCC) includes a high cycle gas turbine and a low cycle steam turbine in order to achieve efficiency as twice as direct combustion.

F. Vacuum Purgation

Another way of energy production from biomass is to use the vacuum purgation of organic substances to produce methane which can be used as a fuel. Vacuum purgation can be used to produce methane from urban, factory, and animal garbage.

IV. WIND POWER PLANT

Wind power plants are one of the most important clean energy sources. The produced energy of these power plants is saved in batteries and will be injected to the network through a DC-AC converter when needed.

The most important part of a wind power plant is the turbine. Depending on the rotation of the wings, turbines are divided into two following groups:

1- Horizontal axis wind turbines
2- Vertical axis wind turbines

The main parts of a wind turbine are:

1- Rotor; which contains wings and the hub.
2- Rotating parts (except rotor); which contains shaft, gearbox, couplings, mechanical brakes and the generator.
3- Nest and the main frame
4- Tower
5- Controllers
6- Electrical system house; which contains the location of cables, switches, transformers and power converters.

In designation of wind turbines, there are some factors including:

- Number of wings (usually 2 or 3)
- Rotor direction (forward or backward wind blow)
- Material used to make wings
- Hub's type
    - Inflexible hubs
    - Up and down
    - Joint hubs
- Constant or variable speed
- Synchronous or inductive generator
- The type of control system
- Gearbox or direct connection to the generator

Output power of the wind turbine is a function of the following factors:

1- The power of the blowing wind
2- The machine's power curve
3- The machine's ability to respond to wind changes

In the next section, we shall model different parts of an ideal wind turbine.

A. Ideal Model for Wind Turbine

In this section we shall introduce an ideal model for wind turbine. The ideal model for the wind turbine was introduced by BETS in 1926.

The main assumptions for this model are:

1- There is no fractional tension.
2- The number of the wings is unlimited.
3- The driving force is equal everywhere in the rotor room.
4- Convoluted flow of the wings has not been taken into account.

Taking the above assumptions into account, no work will be done on either sides of the disk, therefore the Bernoulli function will remain constant on both sides and we have:

$$\begin{cases} P_1 + \frac{1}{2}\rho U_1{}^2 = P_2 + \frac{1}{2}\rho U_2{}^2 \\ P_3 + \frac{1}{2}\rho U_3{}^2 = P_4 + \frac{1}{2}\rho U_4{}^2 \end{cases}$$

Assuming the input and output air pressure and also air velocity of two sides of the wing to remain constant we have:

$$T = A_2(P_2 - P_3)$$

$$\Rightarrow T = \frac{1}{2}\rho A_2(U_1{}^2 - U_4{}^2)$$

$$\dot{m} = A_2 U_2 \quad \Rightarrow U_2 = \frac{U_1 + U_4}{2}$$

$$a = \frac{U_1 - U_2}{U_1} \Rightarrow \begin{cases} U_2 = U_1(1-a) \\ U_4 = U_1(1-a) \end{cases}$$

$$P = \frac{1}{2}\rho A_2(U_1^2 - U_4^2)U_2$$

$$= \frac{1}{2}\rho A_2 U_2(U_1 + U_4)(U_1 - U_4)$$

$$= \frac{1}{2}\rho A U_1^3[4a(1-a)^2]$$

$$C_P = 4a(1-a)^2$$

$$P_{out} = \frac{1}{2}\rho A U^3(\eta_{mech} \cdot C_P)$$

An ideal rotor is on its maximum power when its operation is such that the air velocity on rotor is 2/3 of the original velocity of the wind (a=1/3). In such conditions, the power factor will be 0.5926.

B. Horizontal Axis Wind Turbine with Convoluted Flow of the Wings

In this model, we assume that the angular velocity of the air flow (ω) is small compared to angular velocity of the rotor (Ω); therefore we can assume that when the axial elements of the velocity remain constant, angular velocity of air will be increased from Ω to $\Omega+\omega$ in proportion with the velocity of the wings.

$$P_2 - P_3 = \rho(\Omega + \frac{1}{2}\omega)\omega r^2$$

$$dT = (P_2 - P_3)dA = \left[\rho(\Omega + \frac{1}{2}\omega)\omega r^2\right]2\pi r dr$$

We define the rotational inductance factor as follows:

$$a' = \frac{\omega}{2\Omega}$$

$$\Rightarrow \mathrm{d}T = 4a'(1+a')\frac{1}{2}\rho\Omega^2 r^2 2\pi r \mathrm{d}r$$

$$\frac{a(1-a)}{a'(1+a')} = \frac{\Omega^2 r^2}{U^2} = \lambda_r^2$$

$$\lambda_r = \frac{\Omega r}{U} = \frac{\lambda \cdot r}{R}$$

Where $\mathrm{d}T$ is the partial rotational driving force and λ_r is defined as local tip velocity.

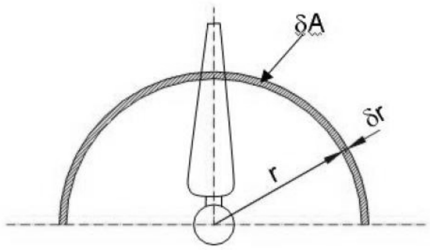

Figure 4. Horizontal wind axes turbine

Rotor's torque is equal to instantaneous variation of the convoluted flow and in partial mode it will be:

$$dQ = d\dot{m}(\omega r)r = \rho U_2 2\pi r dr(\omega r)r$$

$$\Rightarrow dQ = \left[4a'(1-a)\right]\frac{1}{2}\rho U\Omega r^2(2\pi r dr)$$

The power generated by the partial element of the torque is:

$$dP = \frac{1}{2}\rho A U^3\left[\frac{8}{\lambda^2}a'(1-a)\lambda_r^3 d\lambda_r\right]$$

For power factor we have:

$$\mathrm{d}C_P = \frac{aP}{\frac{1}{2}\rho A U^3}$$

$$\Rightarrow C_P = \frac{8}{\lambda^2}\int_0^{\lambda} a'(1-a)\lambda_r^3 \mathrm{d}\lambda_r$$

We will discuss a situation in which we have maximum aerodynamics.

$$a' = -\frac{1}{2} + \frac{1}{2}\sqrt{1 + \frac{4}{\lambda_r^2}a(1-a)}$$

$$\Rightarrow a' = \frac{(1-3a)}{(4a-1)}$$

$$\lambda_r^2 = \frac{(1-a)(4a-1)^2}{(1-3a)}$$

$$C_{P,\max} = \frac{24}{\lambda^2}\int_{a_1}^{a_1}\left[\frac{(1-a)(1-2a)(1-4a)}{(1-3a)}\right]^2 \mathrm{d}a$$

$$= \frac{8}{729\lambda^2}\left\{\frac{64}{5}x^5 + 72x^4 + 124x^3 - 63x - 12\ln x - \frac{4}{x}\right\}_{x=1-3a_2}^{x=0.25}$$

C. Simulation

In this section we have simulated the ideal model discussed in the previous section in we have the results. All the simulations have been performed using MATLAB / SIMULINK software. The block diagrams of the simulation are shown in the Figure 5. The simulation results are shown in the Figure 6.

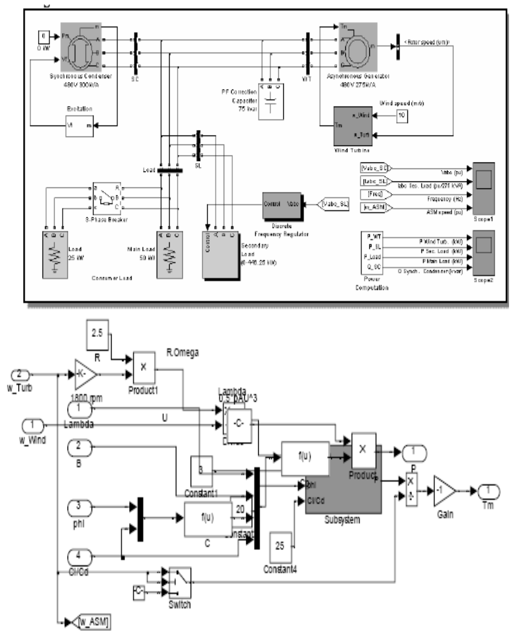

Figure 5. Simulation with MATLAB / SIMULINK

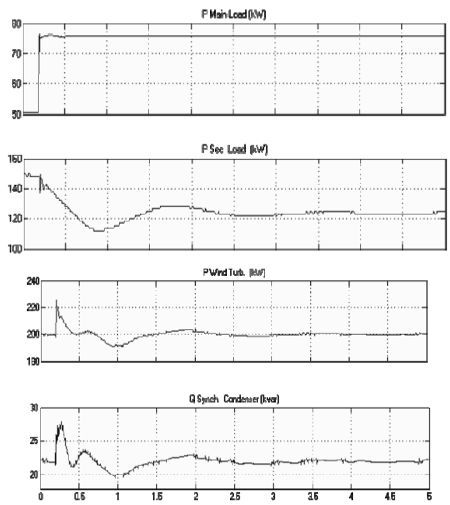

Figure 6. Simulation results

V. FUEL COMBUSTION POWER PLANTS

62% of the world's electricity is being produced by fuel combustion power plants which use fuels such as coal, gas, etc. This percentage will slightly increase till 2050 and afterwards everything will depend on the station of the nuclear energy and the effort for

development of the recyclable energies. Considering the usage rate and found sources, oil and gas will remain respectively till 40 and 65 years from now. Coal is a bit different, since it will remain for more than 2 centuries.
There are many different factors in designation of a fuel combustion power plant. The most important factors are:
1- The location of the site
2- The capacity of the power plant
3- Selection of boiler and its equipments
4- Selection of turbine
5- Selection of condenser units
6- Designation of cooling towers
7- Selection of electrical generators
8- Designation of control and measurement units

Fuel combustion power plants produce electrical energy during two phases where the first phase is to produce steam in the boiler and then the next phase is to produce electricity in the generator.

A. Steam Production

Torches operate with gas or coal and warm the boiler up. In this type of a boiler, water will be turned into a high temperature steam inside a set of pipes. When the pressurized steam reaches the turbine, the turbine will rotate. The steam exiting the turbine will be cooled down again in the condenser and injected to the circuit again.
Condensers are being used in two different types:
1- Open condensers (direct contact)
2- Surface condensers

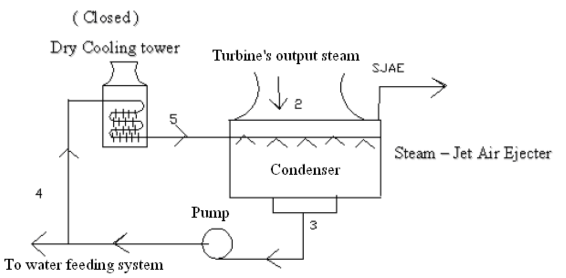

Figure 7. Open condenser

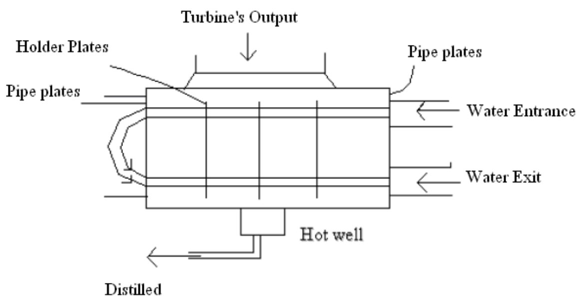

Figure 8. Surface condenser

B. Electrical Energy Generation

By rotation of the turbine, the rotor of the generator will also rotate. Rotor is a metal part which its inside is winded. Current A flows through this winding and inducts a magnetic field B inside the stator. Since the rotor steadily rotates inside the stator, the direction and the intensity of the magnetic field will vary steadily. We know that a varying magnetic field can move the electrons inside a wire and that means electricity. After the electrical energy produced in the generator, a transformer will increase the voltage so it will be transmitted through power lines.

VI. FUEL CELLS

Fuel cells are a kind of energy generator which has appeared lately in energy generation technologies and has been exploited in the world. Lately the basic technology of fuel cells in form of sulphuric acid has been improved to be used in industry. The main interest about these cells is producing a very clean and helpful energy in such small scales as 100KW which has nominated them for distribution of the energy produced nearby users.

Usually fuel combustion technologies produce heat first and then change the heat to electricity. But fuel cells will change the energy from fuel to electricity directly and have efficiency between 45 to 75 percents which may be improved to 90%. Fuel cells have more efficiency in small capacities and don't have any pollution.
Major types of fuel cells are:
1- Alkaline fuel cells
2- With electrolyte polymer
3- Phosphoric acid
4- With carbon foundry
5- Solid oxide

Fuel cells change gas fuels such as hydrogen, natural gas and LPG to electrical energy. Natural attitude of the gas fuel toward anode will cause a force for a chemical reaction in cathode. After ionization of the fuel due to the chemical reaction, the resulting ions will travel through the electrolyte and cause an electrical current. Usually, 4 or 5 fuel cells can be packed in a store with dimensions of about 1 inch (25 mm).

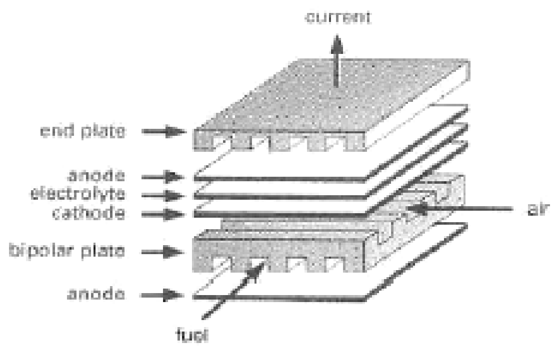

Figure 9. Basic schematic of fuel cells

VII. GEOTHERMAL ENERGY

Hot springs and steam jets are some kinds of geothermal energy which have been used by human in all times and nowadays the effort is to use this energy in a modern way. Considering the high amount of geothermal energy, geothermal power plants are totally different from other types of recyclable energy power plants. Basically geothermal energy production is higher compared to wind and solar energy. United States, Philippines, Mexico, Japan and Italy are using geothermal energy to produce electricity.

Different types of geothermal power plants are divided into the following divisions:

1- Dry steam cycle plant
2- Instantaneous vaporization of 1^{st} stage hot water
3- Instantaneous vaporization of 2^{nd} stage hot water.
4- Dual circuit plant
5- Complex plant
6- Geothermal plant with dual circuit cycle

Basically the geothermal energy will be used to warm up the water in order to produce steam and then the steam will be sent toward the turbines in order to produce electrical energy.

VIII. NUCLEAR POWER PLANTS

Nuclear power plants are for clean and applicable energy production purpose. In order to produce electricity, they use uranium as fuel. Usual types of nuclear plants are:

1- Pressurized Water Reactor (PWR)
2- Boiling Water Reactor (BWR)

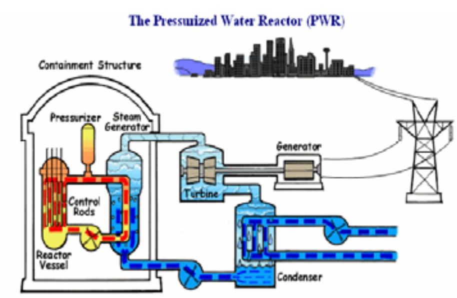

Figure 10. Pressurized Water Reactor (PWR) nuclear power plant

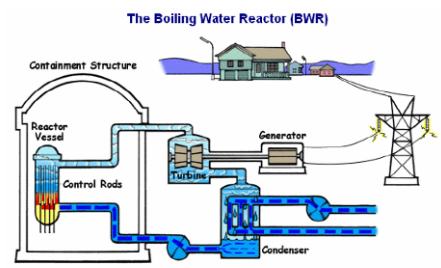

Figure 11. Boiler Water Reactor (BWR) nuclear power plant

In PWR, the water is pressurized so it will be warmed up, but it won’t reach to the boiling point. The water in reactor and the producing water will never be mixed together. In this approach most of the radio active remains inside the reactor. But in BWR water is really boiled. In both ways water will be changed into steam and will be returned to the cycle and will be changed back into water in condenser.

IX. HYDROELECTRIC POWER PLANT

These power plants convert the energy stored in water in heights to electrical energy (with the use of water turbine). Hydroelectric power plants can be divided by two different ways. In the first way the power plants are divided into 3 groups as follows:

1- Hydroelectric power plants without pool
2- Hydroelectric power plants with pool
3- Load peak power plants

The second approach to group the hydroelectric power plants is as follows:

1- High head hydroelectric power plants
2- Medium head hydroelectric power plants
3- Low head hydroelectric power plants

Depending on the type of the plant, different types of turbines will be used where each type of turbine id suitable for a particular type of plant.

X. COMPLEX CYCLE POWER PLANTS

Complex cycle is a procedure which uses gas turbines in hot source temperature and uses steam turbine in cold source temperature. In complex cycle, both gas and steam turbines are used to produce power and apply to the network. The idea of creating a complex cycle is based on Brayton’s cycle (gas power plant) with the usage of the lost heat from exiting gas of the turbine. This is done by regeneration unit.

Advantages of a complex cycle power plant are:

1- High efficiency
2- High output power
3- Flexibility
4- Fast operation for small loads
5- Suitable for Base-load and cyclic applications
6- High efficiency for a wide range of loads

The diagram of a complex cycle power plant is shown in the Figure 12.

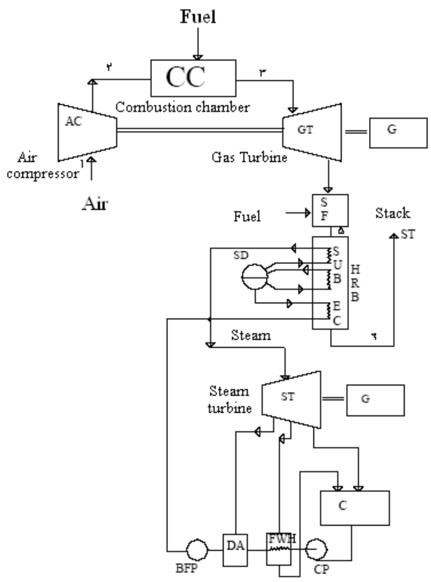

Figure12. Complex cycle power plant

XI. GAS POWER PLANT

A huge part of the energy produced all over the world is being produced by gas power plants. The advantages of these plants are:

1- The entire system and its used materials are small compared to power plants.
2- Have a short starting time.
3- Are very flexible about how to use compressed air and different types of gas or liquid fuels.

4- Pollute the air less than fuel combustion and nuclear power plants.

Gas turbines use different cycles in different plants.

1- Direct open cycle
2- Indirect open cycle
3- Direct closed cycle
4- Indirect closed cycle

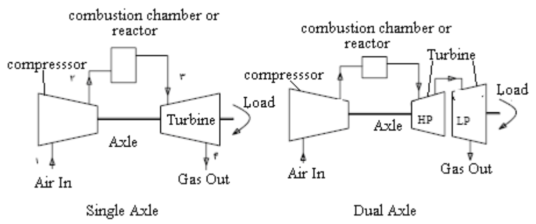

Figure 13. Direct open cycle gas power plant

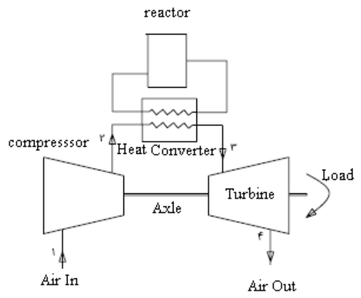

Figure 14. Indirect open cycle gas power plant

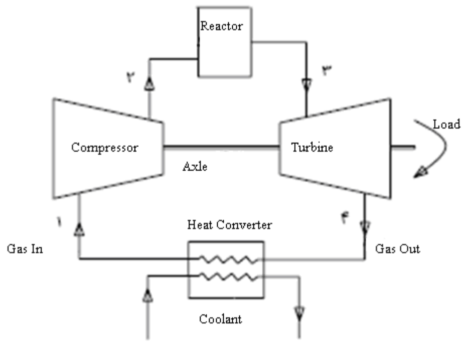

Figure 15. Direct close cycle gas power plant

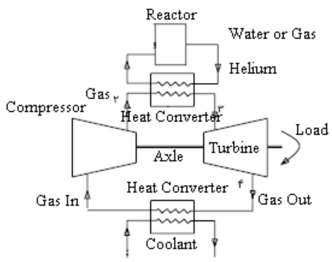

Figure 16. Indirect close cycle gas power plant

XII. SIMULATION OF THE GAS-WIND COMPLEX POWER PLANT IN AZARBAIJAN NETWORK

In this chapter we shall simulate a Gas-Wind complex in Azarbaijan network with and without Fuzzy logic controller and then we shall compare the results.

A. Simulation Results without Fuzzy Logic Controller

Simulation block diagram is shown in the Figure 17. All the simulations has been performed using MATLAB / SIMULINK software.

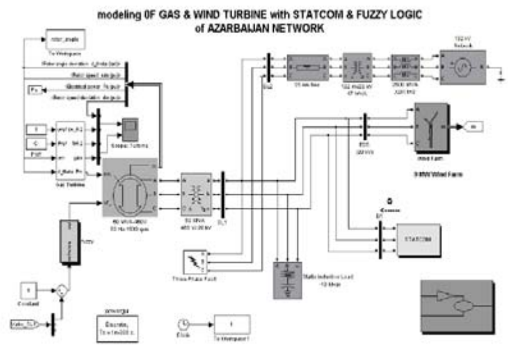

Figure 17. Simulation block diagram without Fuzzy logic controller

In this simulation, a 3-phase to ground fault occurs at t=3sec and we have got the following results without using Fuzzy logic controller.

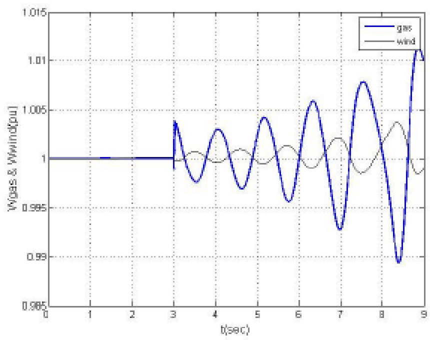

Figure 18. Velocity diagram of the gas and wind turbines (pu)

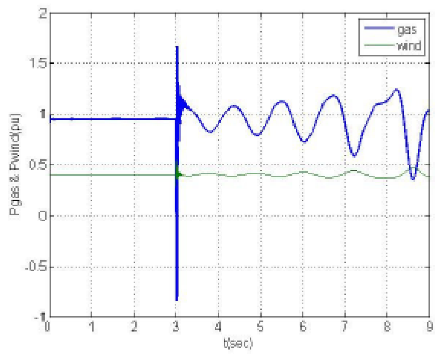

Figure 19. Power diagram of the gas and wind turbines (pu)

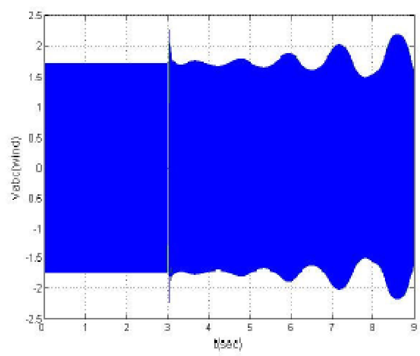

Figure 20. Voltage diagram of the wind turbine (pu)

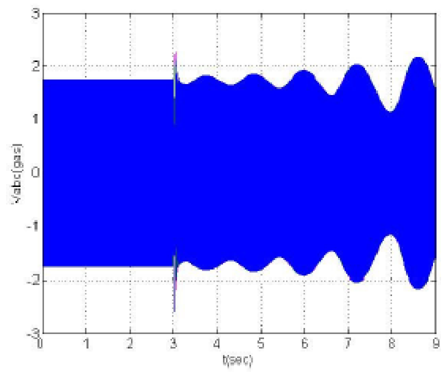

Figure 21. Voltage diagram of the gas turbine (pu)

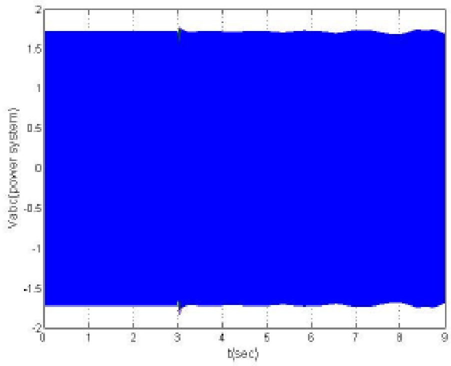

Figure 22. Voltage diagram of the network (pu)

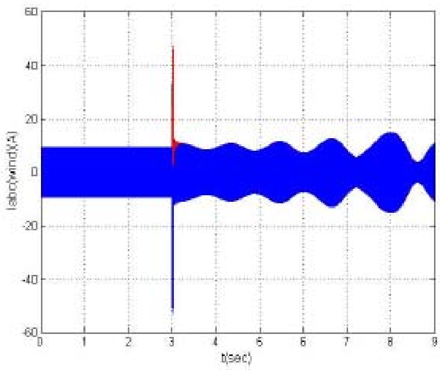

Figure 23. Current diagram of the wind turbine A (pu)

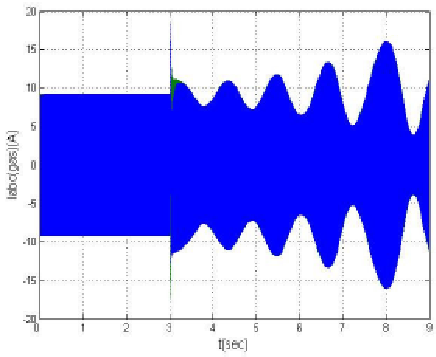

Figure 24. Current diagram of the gas turbine A (pu)

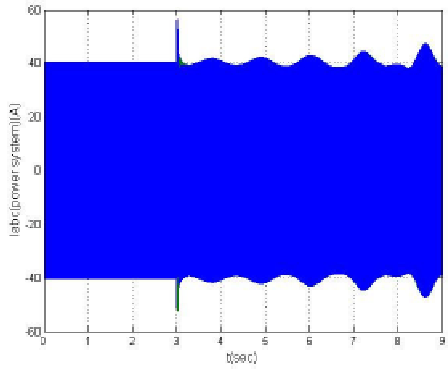

Figure 25. Current diagram of the network (pu)

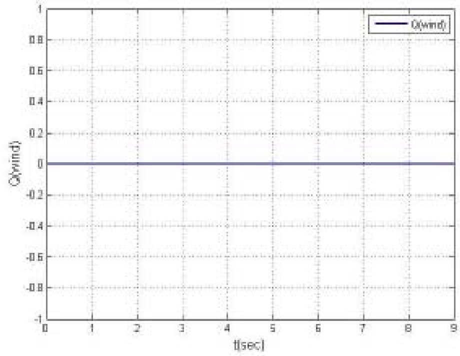

Figure 26. Reactive power diagram of the wind turbine (pu)

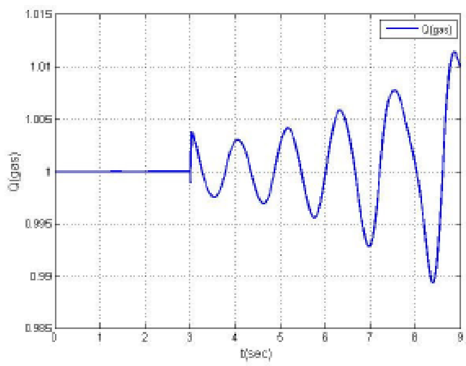

Figure 27. Reactive power diagram of the gas turbine (pu)

B. Simulation Results with Fuzzy Logic Controller

Simulation block diagram is shown in the figure below. All the simulations has been performed using MATLAB / SIMULINK software.

In this simulation a 3-phase to ground fault occurs at *t*=3sec and we have got the following results using Fuzzy logic controller.

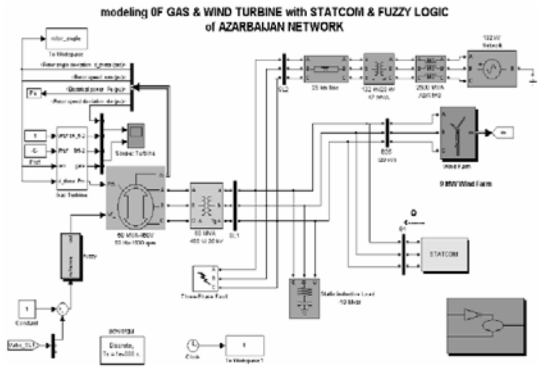

Figure 28. Simulation block diagram with Fuzzy logic controller

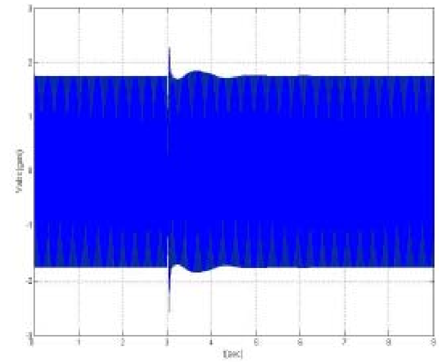

Figure 32. Voltage diagram of the gas turbine (pu)

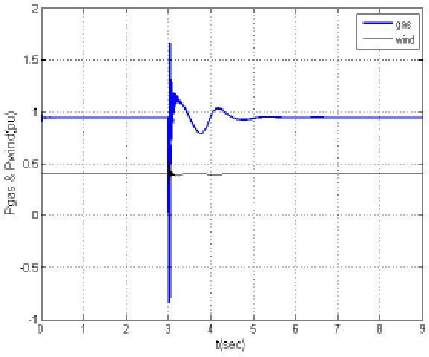

Figure 29. Power diagram of the wind and gas turbine (pu)

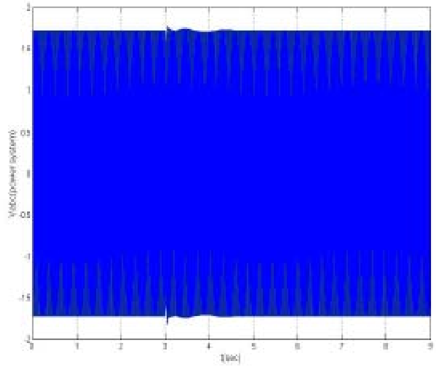

Figure 33. Voltage diagram of the network (pu)

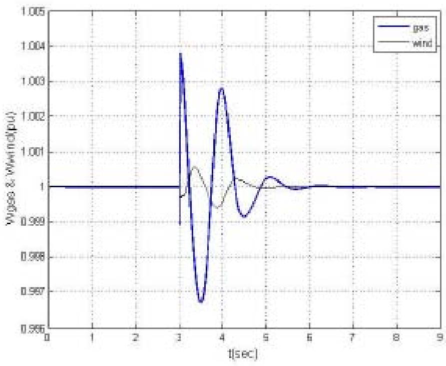

Figure 30. Velocity diagram of the wind and gas turbine (pu)

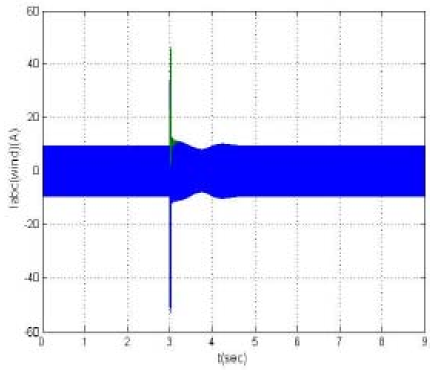

Figure 34. Current diagram of the wind turbine (pu)

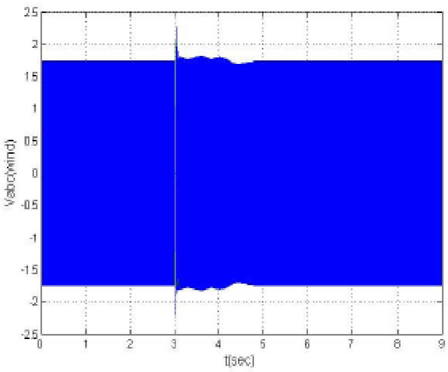

Figure 31. Voltage diagram of the wind turbine (pu)

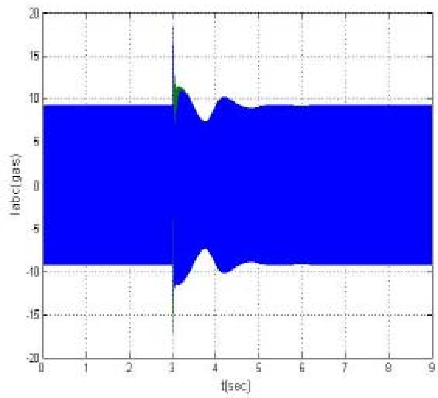

Figure 35. Current diagram of the gas turbine (pu)

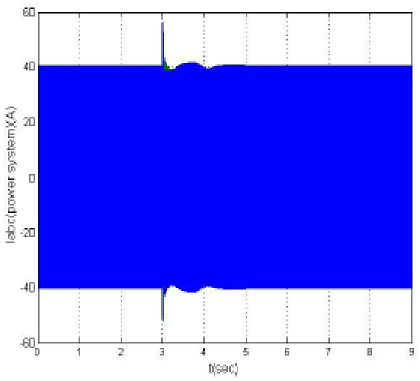

Figure 36. Current diagram of the network (pu)

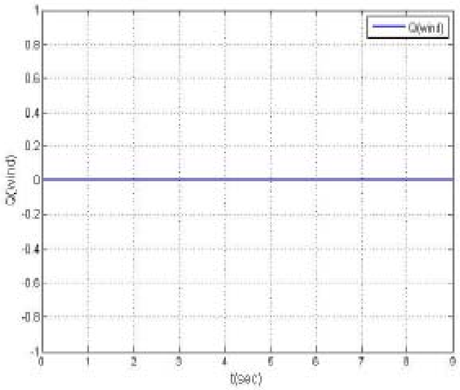

Figure 37. Reactive power diagram of the wind turbine (pu)

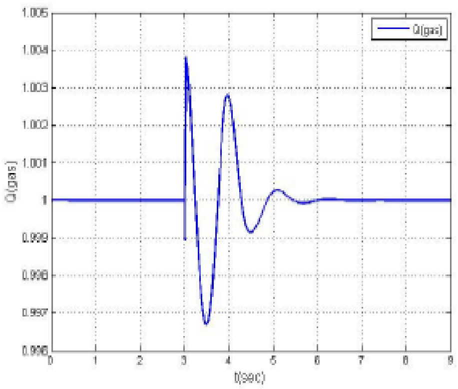

Figure 38. Reactive power diagram of the gas turbine (pu)

XIII. CONCLUSIONS

In this paper a distributed generation system including gas turbine an wind turbine connected to power system of Azarbaijan was modeled and simulated. The Fuzzy Logic controller was designed and tested for this system and Fuzzy Logic toolbox was used to design the test system by Fuzzy controller. The simulation results demonstrate the system characteristics for case with and without Fuzzy Logic controller and results show that the fuzzy controller is more effective for large disturbance and large distance between D.G. plants and power systems.

In this paper a distribution system with only by distribution generation plant including gas turbine and wind turbine was considered. Of course the response of gas turbine to long time disturbance better than to wind turbine and is affected to damping of oscillations.

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