

Fig.3 : Block diagram of distributed control system.

### 2.3 An Existing Control Strategy

The most modern thermal generation plants use a control scheme that is usually named an integrated or coordinated control system. This type of controller simultaneously adjusts firing rate, pumping rate, and turbine throttling in order to follow changes in load demand. Such a coordinated control mode is shown in Fig.2. In this type of control, both pressure and generated output are fed back for the control of both boiler and turbine. In this manner, it is possible to achieve the stable and smooth load changes of the turbine-following mode and still enjoy the prompt response of the boiler-following mode. This is accomplished by making maximum use of the available thermal storage in the boiler. Both pumping and firing rates are made proportional to the generation error so that these efforts are stabilized as the load approaches the required value. Pressure deviation is controlled as a function of the thermal storage and the generation error.

The turbine controls the frequency and power that is supplied to the electric network. To control these parameters, the turbine uses three conventional controllers for speed, power, and pressure. Moreover, the selector makes decision which of these controllers takes control. The selected controller acts on the inlet of the turbine (inlet of HP and MP cores); by acting on the position setter that acts on the valves of the turbine inlets.

Nowadays, the control strategies for the thermal plant is organized using different hierarchical levels. In the supervisor levels, the control strategies are coordinated and the process set-points are determined. However, in the regulations level, the control loops of the dynamic parameters of the power plant have been implemented.

### 3 A Proposed Control Strategy

The proposed controller is based on supervisor level that is required to determine automatically the optimal process set points of regulations level using an economic optimizer and considering the process environmental and operational constraints. After that the supervisor level makes correction continuously through the use of Fuzzy logic to the existing conventional regulations. In order to implement a such control strategy a distributed control system (DCS) is required as shown in Fig.3. The DCS controlling system is based on computer associated with PLC's. The computer is supervisor level that is required to determine automatically the optimal process set points of regulations level. After that the set points values are sent to PLC's that act as the existing conventional regulations. This distributed control system employs PLCs as direct controllers. In our design, four PLC's of Siemens S-200 CPUs are used, wherein control loops algorithms are implemented to act in response with the supervisory controller; three of them are used to control boiler turbine and generator dynamics separately and the fourth one is dedicated to safety measures.

#### 3.1 Simulation using Matlab/Simulink

Simulator has been developed for steam turbine generator using the powerful software program Matlab/Simulink. It includes one boiler steam turbine and generator as shown in Fig.3. Parameters that have been used for testing this simulator have been taken from steam turbine generator (SIEMENS-KWU-SGP) of 176 MW manufactured by consortium of Austria-Germane. The used conventional controllers which are simple in structure, are not suitable for non-linear, higher order, time delayed and complex systems that have no precise mathematical models. Besides, these controllers need

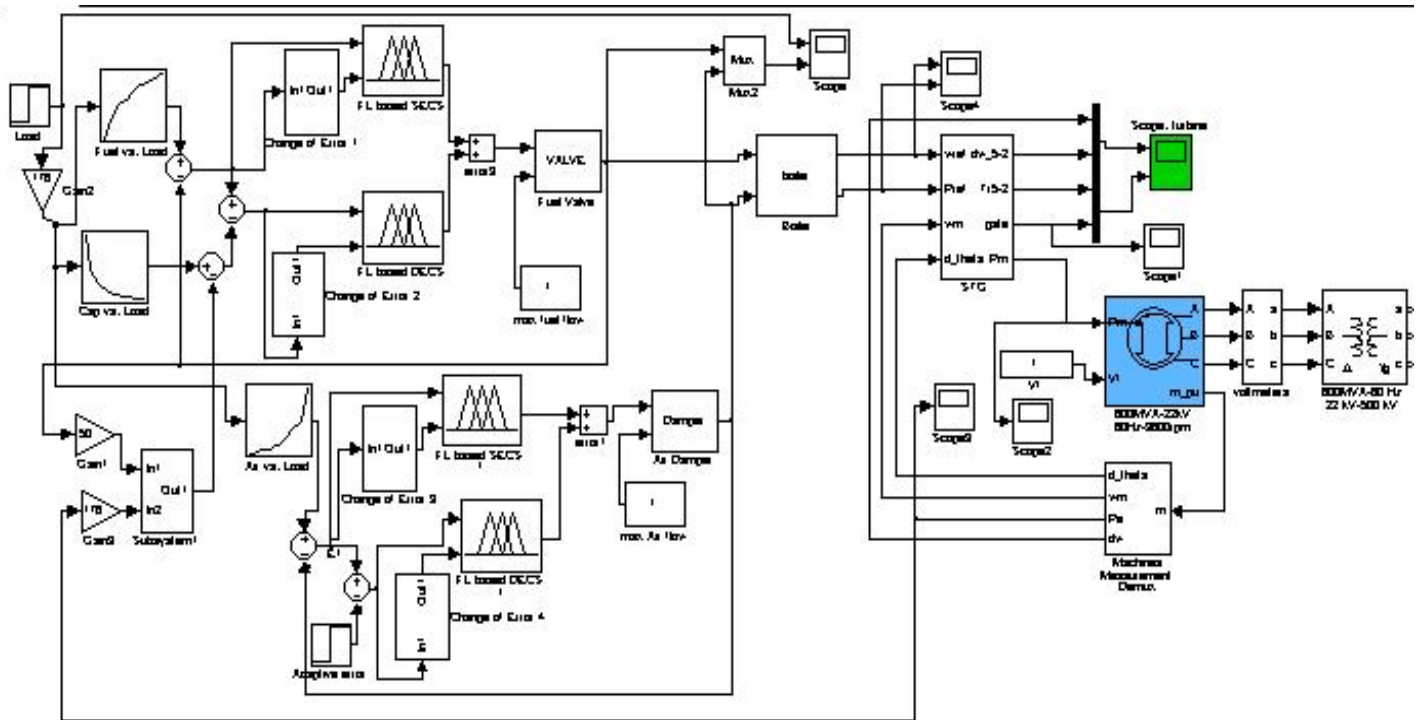


Fig.4 Complete system of power plant using Simulink.

frequent tuning that is not easy task and is also time consuming.

Several methods have recently been developed, most of them are based on controllers with fuzzy system without incorporating any on line adaptive structure and its applications particularly for combustion control of boiler.

Fuzzy systems, as an artificial intelligence approach, emerge in power plant as a complement to mathematical approaches. For a comprehensive survey of fuzzy set theory in power plants, the reader is referred to book[7]. Fuzzy-logic controllers (FLC) can be classified as knowledge based systems (KBS). There are principally two classes of KBSs; namely: supervisory expert control systems (SECS) and direct expert control system (DECS) [7,8]. SECS's use FL to tune the controller in the main loop.

### 3.2 Fuel and Air Controller in the Boiler Using FLC

The proposed fuzzy control for fuel and air control system is shown in Fig.4. The characteristics of thermal power plant (SIEMENS-KWU-SGP) have been used which are shown in two response graphs, one gives load as function of fuel and the other load versus airflow. The fuel and the airflow set points can be derived from the graphs in our simulator from these characteristics. The difference between the set point and the actual air or gas flow is computed as error signal. The proposed DECS implemented for combustion process using fuzzy logic control has two inputs and one output for fuel and

airflow respectively. The inputs are error signal and change in error signal. The universe of discourse of the controller variables are  $e$ ,  $\Delta e$  and  $U$  respectively. The following are the range of database considered. Error ( $e$ ) = -50% to +50%,  $\Delta e$  = -25% to +25%, control valve position ( $U$ )=10% to 100%. The number of linguistic terms for each linguistic variable is 5. ( $e$ ) for fuel = {MN, N, Z, P, MP}, ( $\Delta e$ ) for fuel = {VS, S, M, L, VL}, ( $U$ ) for fuel = {VS, S, M, L, VL}, ( $e$ ) for air = {MN, N, Z, P, MP}, ( $\Delta e$ ) for air = {VS, S, M, L, VL}, ( $U$ ) for air = {VS, S, M, L, VL}.

The triangular membership functions are used to represent the linguistic terms. (VS=very small, S=small, M=medium, L=large, VL=very large, MN=medium negative, N=negative, Z=zero, P=positive, MP=medium positive).

The processed signal from the fuzzy controller is defuzzified and applied to the respective adder circuit. In the proposed FLC based SECS, the difference between feed-forward error and the adaptive error. The error and the change of the error are taken as inputs of the proposed SECS controller. The processed signal is defuzzified and applied to the respective adder circuit. The sum of the DECS and SECS output signal is supplied to the fuel control valve as well as the air damper.

### 3.3 Adaptive Error Factor

To improve the performance, an adaptive variable error set point has been developed to the SECS controller for fuel and air flow. When there is dynamic change due to load demand change the adaptive error calculation is proposed by taking into consideration the

difference between the actual specific heat consumption and the required one. An adaptive error, which is equivalent to the required (adaptive) at particular load, is calculated as follows:

$$e_a = C_{sp} - \left( k_c \frac{Q_f}{P_g} \right) \quad (8)$$

where,  $k_c$  is constant (in this case 9.6),  $P_g$  generated power, and  $C_{sp}$  specific heat consumption set-point determined from the characteristic of the power plant.

### 3.3 Simulation Results and Discussion

The simulator based on the previous equations plus others non described in the paper [2] has been implemented as shown in Fig.4. This paper presents the simulation results that have been carried out on the combustion control of the boiler as shown in Fig.5 and 6. The control objective is to regulate fuel and air flow in proper ratio by including optimization and environmental criteria. The performance of SECS controller is demonstrated for positive changes in the load demand. The closed loop response of the proposed SECS controller scheme (Fig.5 and 6) shows satisfactory offset in the steady state output for optimizing the fuel consumption when compared to conventional controller without optimizer. Moreover, there is less oscillation in controller output.

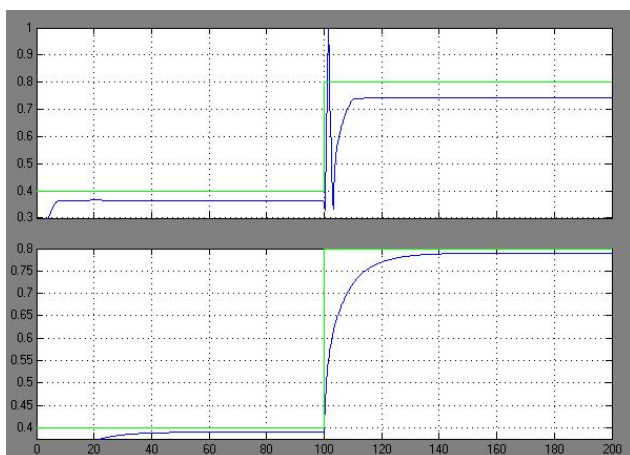


Fig.5 Fuel flow Controller response for positive step change in Load, (a) Upper without optimizer, (b) Lower with Optimizer.

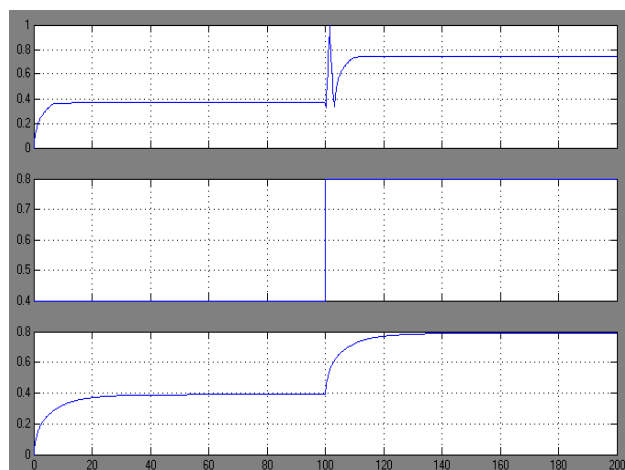


Fig.6 Air flow Controller response for positive step change in Load, (a) Upper without optimizer, (b) medium air flow set point, (c) Lower with Optimizer.

## 4 Hardware Implementation

This work describes an application of DCS for a thermal power plant. The application is based on HMI (Human Machine Interface) implemented in PC that supervises two connected PLCs via a communication system, the two PLCs control two elements of the power plant such as boiler and turbine.

HMI application has been developed using the CitectSCADA that was chosen because of its compatibility with many types of PLCs, such as SIMENS S7-200 PLC used in our application.

This work deals with:

- Design of the boiler and turbine controllers.
- Development of control program which can be implemented in PLC [9].
- Design the Graphical User Interface/Human Machine Interface.

The boiler has been described in details previously however, the turbine controller will be discussed in this section.

### 4.1 Turbine Controller

The Main controller of the turbine manages the overall controlling system: during the starting, the normal operation (when delivering power to the network), normal and emergency shutdown. The main program of this controller as well as the subroutines of other controllers are implemented in PLC. The overall controller of the turbine is shown in Fig.7.

The pressure and power controller work in parallel with the speed controller. The selector chooses the appropriate control.

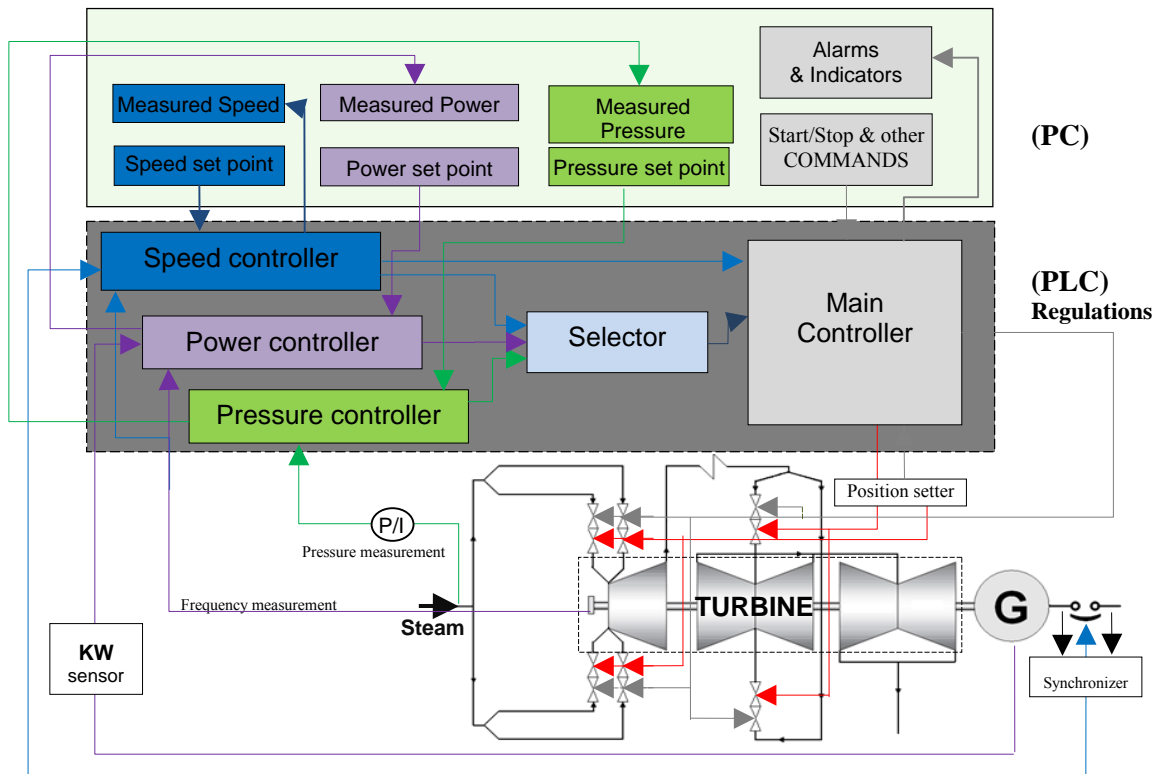


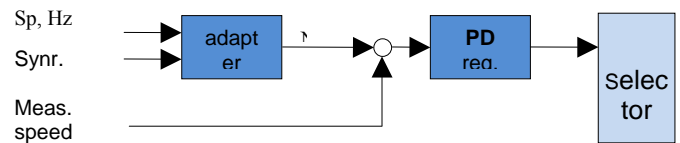
Fig.7 The overall turbine controller.

To start the turbine, the electro-hydraulic motor is switched on in order to have an initial speed of 150 TPM (2.5s-1) and the safety valves are opened. After that, the speed controller is selected by the main controller until the speed of 2820 TPM (47s-1) is reached. When speed of 2820 TPM is reached, the synchronizer and the speed set point via the adapter increases the speed from 2820 TPM to 3180 TPM (53s-1) until the group is synchronized with the network at a speed of 3000 TPM (50Hz) and the alternator is coupled. Hence, the group starts to deliver power to the network.

At that time, the selector selects the appropriate controller. Since a speed of 50Hz is reached, the selector selects the power controller that controls the generated power according to the network need (depending on the load). The pressure controller is selected in case of pressure drop that is not recovered by the boiler in a desirable time.

To stop the turbo-alternator group, the group should be disconnected from the network. The valves are closed by the speed controller when the speed of 210 TPM (3.5s-1) is reached. Besides, the electro-hydraulic motor starts. When the valves are totally closed, safety valves close, and the electro-hydraulic motor keep working until the turbine cools.

**A-Speed controller**



It ensures three functions:

Fig.8 Speed Controller.

- It ensures the control of the group during the start and the synchronization of the group.
- It plays the role of speed limiter during the operation under load, when power is supplied to the network. In case of failure in the network, it limits the speed at 3060RPM (51Hz).
- It takes control of the group in case of failure to the power controller.

The speed controller consists of set point adapter using Fuzzy Logic and PD controller (Fig. 8) [10,11].

At the adapter, the set point is determined automatically by PC and selected by the synchronizer (when synchronization is active), its range is 1 – 50Hz. This set point is compared with the measured frequency and sent to the PD controller. The PD controller sends the signal to the selector.

The PD regulator has the following formula:

$$f(s) = \frac{h(s)}{e(s)} = K_p(1 + T_d s) + v \tag{9}$$

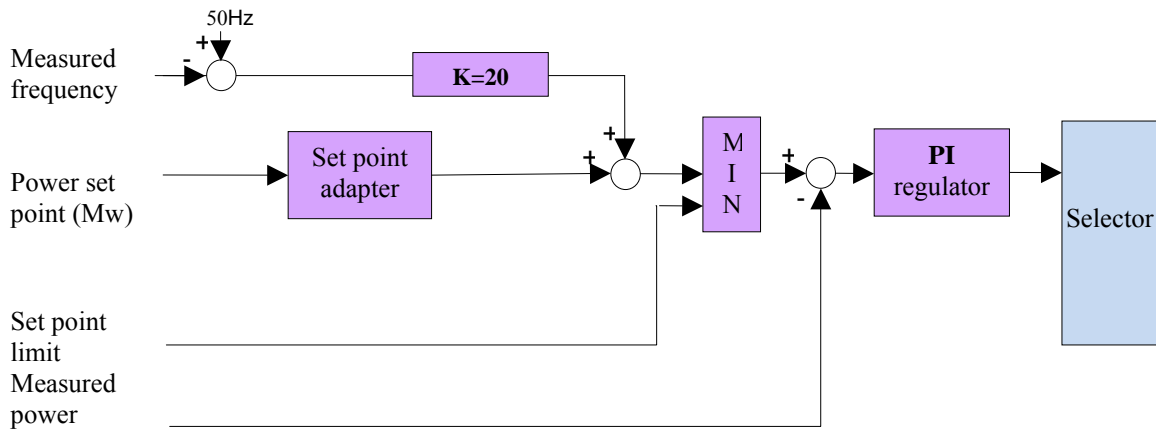


Fig.9 Power controller configuration.

Where,  $h(s)$ : output of the PD regulator(desired speed),  
 $e(s)$ : input error (speed error),  
 $v=0.5$  (offset of PD controller),  
 $K_p=20$ , and  
 $TD=1600ms$ .

**B-Power controller:**

The power controller ensures the control of power after the synchronization of the alternator with the network. It consists of set point selector and PI regulator (see the Fig.9).

In the power controller, the power set point is selected in selector. Before this set point enters the PI regulator, it is combined with the signal that is generated proportional to the influence of the network frequency. The combined signal is limited by the power limit. The difference between the limited power set point and the measured power outputs to the selector.

The expression of the power PI controller is given by:

$$f(s) = \frac{h(s)}{e(s)} = K_p \left( 1 + \frac{1}{T_I s} \right) \quad (10)$$

where,  $h(s)$ : output of the PI regulator(desired power),  
 $e(s)$ : input error (power error),  
 $K_p= 0.1$ , and  $T_I=15$  sec.

**D-Selector:**

It is a logic circuit that selects the maximum signal from the signal of speed controller and power controller. The selected signal is compared with the signal of the pressure controller. The minimum signal from the last two signals takes control of the turbine. In the case when there is an increase of speed over the nominal value, the speed controller is selected. The power controller reacts when the alternator is synchronized with the network. In the turbine, the main controller manages the overall turbine control: during the starting, the normal operation (when delivering power to the network), and shutdown. The flowchart of this controller is shown in the Fig.12.

**4.2 The supervision and control**

The supervision and monitoring of the power plant is performed through the Graphical User Interface or the Human Machine Interface (GUI/HMI) built with Citect Software. The Interface contains three main pages: boiler interface, Turbine interface and generator interface. Each page contains controllers interfaces of that element.

For example the turbine interface contains its controllers tuning interface as well as extra page which is used for alarms as shown in the Fig.13.

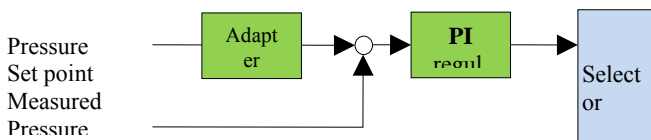


Fig.11 Pressure controller configuration

**C- Pressure Controller:**

The regulator of the pressure maintains the pressure of steam at the set point value by acting on the valves of regulation. The pressure controller consists mainly of a set point adapter and a PI regulator as shown in the Fig.11. The expression of such regulator is given in Equ.(10) with the following parameters:  $K_p= 0.1$ , and  $T_I=15$  sec.

**5 Conclusion**

This work presents the steam power plant simulator using Matlab-Simulink. Where the thermal power plant control strategy design has been presented. It includes the supervisor level SECS control system based on adaptive error factor to correct the regulations level set points. After that, the boiler evaluation tests have been described in more details.

Work has been performed on the implementation test by simulation of the proposed strategy controller. Then, this control system has been implemented in a small scale thermal power plant using PC based DCS.

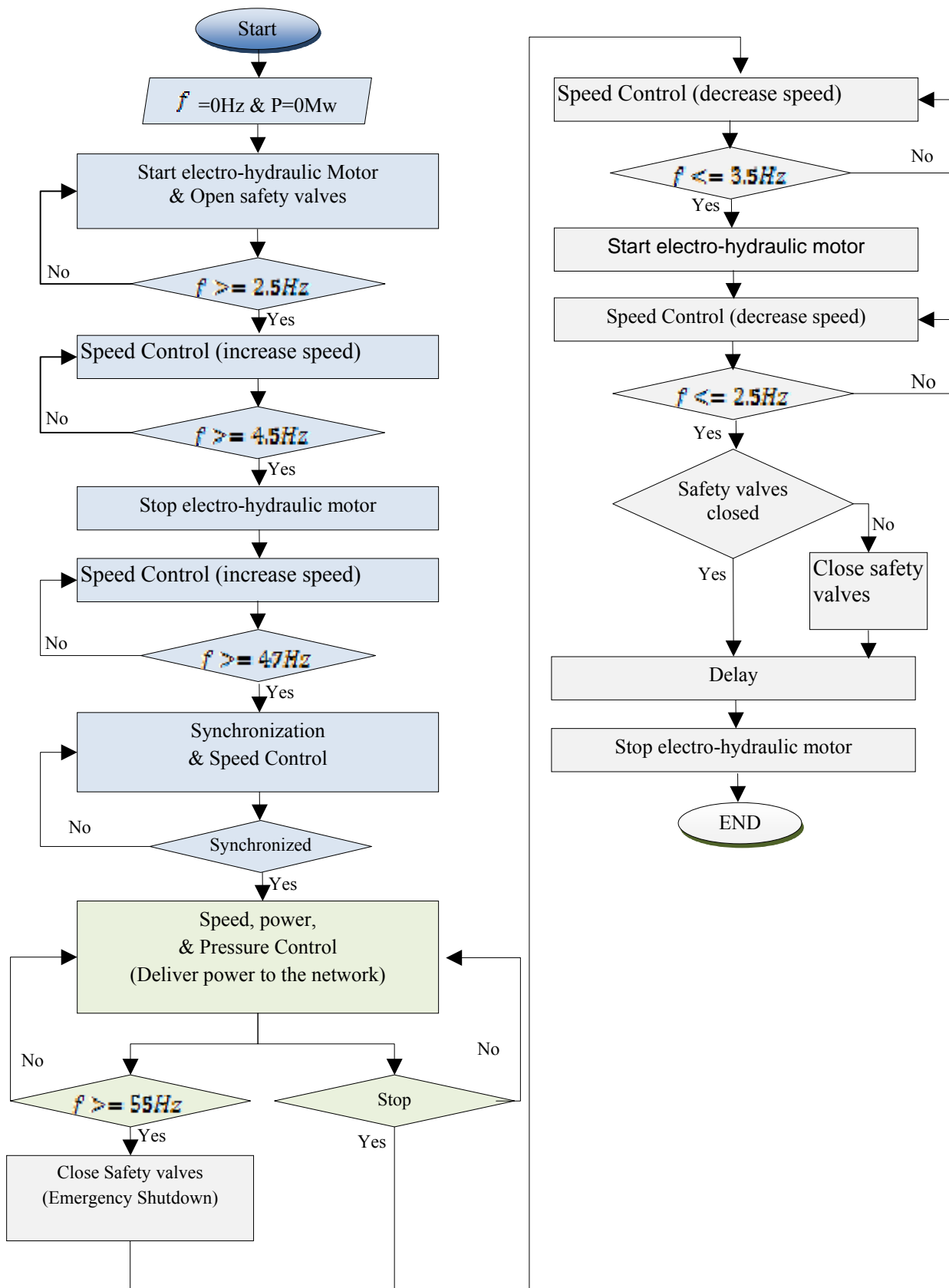
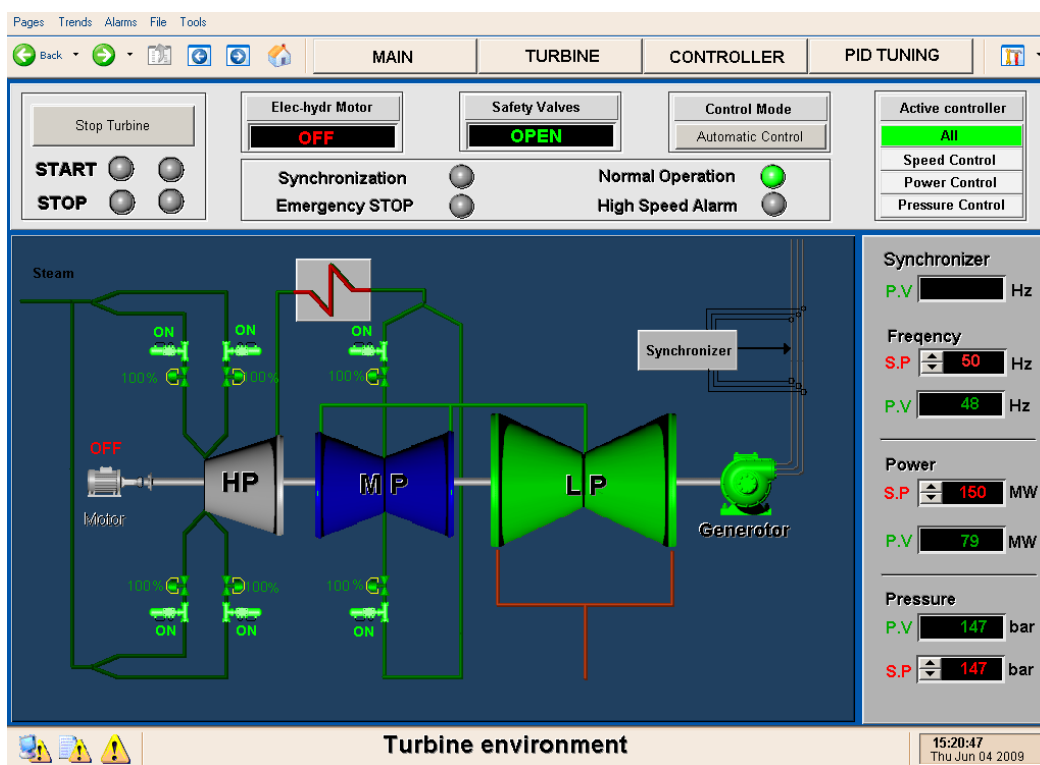


Fig.12 Flowchart of the turbine controller.





Greek Letters

- $\rho$  specific density, kg/m<sup>3</sup>
- DCS distributed control system
- FLC Fuzzy logic controller
- PLC programmable logic controller

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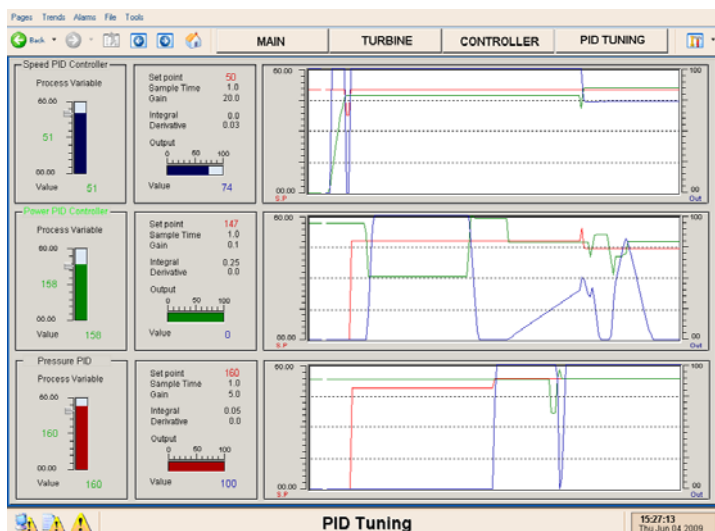


Fig.12 HMI of the turbine

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Nomenclature

- A area, m<sup>2</sup>
- C specific heat, J/kg°C
- h specific enthalpy, W/m<sup>2</sup>°C
- Q heat flow, ppm
- P Power, W
- V volume, m<sup>3</sup>
- w mass flow, ppm

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