FUZZY CONTROLLED SMES UNIT FOR DAMPING POWER SYSTEM OSCILLATIONS IN A COMBINED CYCLE GAS TURBINE

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Abstract: *This paper presents a new approach to control Superconducting Magnetic Energy Storage (SMES) unit for damping power system oscillations in a combined cycle power plant. MATLAB – SIMULINK based dynamic model of a combined cycle stand alone gas power plant and transfer function model of load frequency and temperature control loop with SMES is developed. The SMES unit is used to improve the dynamic performance of P-f of power system, it regulates the frequency and temperature in order to maintain the system stability and safety of the power plant. To get maximum benefit, from the SMES unit, a supplementary control is generated by using the output of fuzzy frequency controller (FFC) and the inductor current deviation (ΔI_{sm}) as inputs. ΔI_{sm} is also used as negative feedback signal to ensure the SMES energy that is restored to its predisturbance level. If temperature is low, it causes low efficiency of the heat recovery boiler, and maintaining temperature higher than allowed will reduce life of the equipment. Hence the temperature has to be regulated to have safe operation of the power plant. Considering these backgrounds. The desired P modulation from the SMES is obtained by adding supplementary control signal to the output of FFC. The effective use of the SMES unit is verified for small as well as large disturbances.*

Key Words: *Gas turbine, fuzzy frequency Controller, super conducting magnetic energy storage, stability analysis, steam turbine, temperature control.*

1.INTRODUCTION

The energy mix of the electricity grid in India has changed greatly over the last decade, with an increasing proportion of CCGT units now being utilized for ancillary services, such as frequency response. Historically, the provision of frequency response has been dominated by coal fired stations that have proven to be very reliable. But a large number of these units will be retired in the coming decade. With these changes in plant mix and an increasing in the proportions of renewable generation expected by 2010, a firm understanding behind the collective dynamic behaviors of generator response is required. CCGT power plant is being installed in increasing numbers round the world where there is access to substantial quantities of natural gas. This type of power plant produces high power outputs at high efficiencies but with low emissions. It is also possible to use the steam from the boiler for heating purposes and so such power plants can be operated to deliver electricity alone.

The dynamic response of such power plants to load and frequency transients is rather problematic, since the compressor and the fuel supply system are both attached to the shaft of the unit. Thus rotor speed and frequency have a direct effect on air and fuel supply [1]-[4] which introduces a negative effect on system stability (CIGRE, 2003). In addition, combined cycle power plants function on the temperature limits (above a relatively low power level) so as to achieve the best efficiency in the steam generator (CIGRE).

This fact raises further issues relative to the response of CCG during frequency drops or variations at load power. Temperature should be maintained (apart from the first 20 seconds of the disturbance) below certain limits for the protection of the plant. This paper is based on the modeling proposed in [5] and [13], while the model developed is integrated into an educational and research simulation package developed in the Electrical Energy Systems Lab of NTUA [4]. Other similar models are presented in [7], [8] and [9], however, the model are slightly different. For instance, in [10] the structure of the steam turbine is more detailed, while in this paper we use a simplified steam turbine model in more detailed way. However, a large scale block out occurred in Malaysia in 1996 [11]. Following a frequency drop about 1.5 Hz, combined cycle and gas turbine plants sequentially tripped out and total generation loss was very high. Because if its importance, several studies were made on response of CCGT to frequency drop [12], [13]. Some models were developed based on models on [13] - [18] to represent practical plants and then used to calculate responses to frequency drop. However, detailed analysis has not been made yet regarding how plant variable behaves for frequency drop with the presents of energy storing devices like SMES. The use of SMES and capacitive energy storage (CES) for load leveling applications and for improvement of the dynamic performance of power system has been described [19] - [22] in the literature review.

In this paper, we analyze dynamic behavior of a CCGT for frequency drops. Several dynamic models of CCGT have been proposed. We combine some of them and build a model for a single-shaft combined cycle plant. We execute numerical simulations to see how the combined cycle plant behaves when the system frequency drops. The gas turbine (Brayton) cycle is one of the most efficient cycles for the conversion of gas fuels to mechanical power or electricity. The use of distillate liquid fuels, usually diesel, is also common where the cost of a gas pipeline cannot be justified. Gas turbines have long been used in simple cycle mode for peak lopping in the power generation industry, where natural gas or distillate liquid fuels have been used, and where their ability to start and shut down on demand is essential. Gas turbines have also been used in simple cycle mode for base load mechanical power and electricity. However, the operation and maintenance of these systems pose many problems when the operating condition varies. SMES [20] - [23] shows satisfactorily for frequency control effect.

The effective use of SMES unit greatly depends on its control strategy. Many kinds of controller for the SMES have been proposed in literature. [24-25]. the gain settings of SMES controllers are usually fixed at values which are determined based on nominal operating point [26]. These fixed gain controllers are always compromise between the best setting for light and heavy load conditions, such as that resulting from a three phase fault in power system. To solve this problem, a PI controller was proposed for the SMES unit in reference [27]. Based on the system eigen values, the controller parameters were determined to provide active power compensation to the power system. But there is no arrangement to bring the SMES energy storage capacity to its predisturbance level without which the SMES unit may not be able to respond for sequence needs. In designing the PI controller, the Q modulation of the SMES unit has not been considered. In practice, being an inductive device, SMES unit consumes reactive power. Also, voltage at the terminal of the generator changes drastically during a three phase fault at adequate Q compensation from the SMES unit will definitely help in restoring stability. Therefore, the effect of reactive power of the SMES unit must also be considered in the design of a SMES controller. As an alternate to these controls, the concept of Fuzzy logic was first introduced by Zadeh [28], and this has been successfully applied to various control problems [29].

The CCGT model shown in figure 3 & 4 and the basic structure of Gas Power plant and it consists of the power generation units and the control branches. The thermodynamic part giving the available thermal power to the gas turbine and the steam turbine is modeled by algebraic equations given in CCGT section 4, corresponding to the adiabatic compression and expansion, as well as to the heat exchange in the recovery boiler. These equations correspond to the block ‘Algebraic equations of energy transform are in subsystem figure 4. These algebraic equations are presented in reference [19].

2. SPEED CONTROL

Figure 1 shows the structure of speed control loop. Basic structure of load-frequency loop has main control loop, during normal operating conditions. The first loop involves the speed governor, which detects frequency deviation from the nominal value and determines the fuel demand signal (F_d) so as to balance the difference between generation and load. Autonomous operation is assumed, so power imbalances will cause electrical frequency deviations. In single shaft combined cycle power plants, the fuel control system as well as the fans, which provide air to the compressor, are attached to the generator shaft, so their performance is directly linked to rotor speed. This affects the stability of the system as will be demonstrated in this analysis. Without speed control, a decrease in frequency will result in a decrease in air and fuel flow (W and W_f), as the shaft of the plant will reduce its speed.

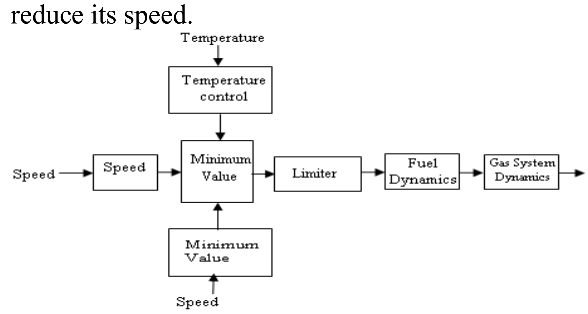

Fig.1 Basic Structure of Speed Control Loop

The decrease of these two parameters will cause a decrease in power generation and consequently the frequency will continue to drop. So even if only a small transient disturbance is applied, it will eventually lead the uncontrolled unit out of service, as at some point the under frequency protection of the plant will be activated. The response of frequency to such a temporary load increase without speed control is shown in Figure 5 with the disturbance in electrical load. Therefore, it becomes obvious that speed regulation is absolutely necessary for the stability of the combined cycle plant.

3. TEMPERATURE CONTROL LOOP

Figure 2 shows the basic structure of temperature control loop consists of two branches. The normal temperature control branch acts through the air supply control. When the temperature of the exhaust gases exceeds its reference value, this controller acts on the air valves to increase the air flow, so as to decrease exhaust gas temperature. In certain situations, however, this normal temperature control is not enough to maintain safe temperatures. Thus, in cases of a severe overheat; the fuel control signal is reduced through a low value select function that determines the actual fuel flow into the combustion chamber.

The second loop is the temperature control and consists of two branches. The normal temperature control branch acts through the air supply control. When the temperature of the exhaust gases exceeds its reference value (T_r), this controller acts on the air valves to increase the airflow, so as to decrease exhaust gas temperature. In certain situations, however, this normal temperature control is not enough to maintain safe temperatures. Thus, in cases of a severe overheat; the fuel control signal is reduced through a low-value-select function (LVS) that determines the actual fuel flow into the combustion chamber. Reference temperature (T_r) is the parameter defined by the supervisory control for the exhaust gas temperature (T_e). This control branch reacts by decreasing T_r when gas turbine inlet temperature (T_f) exceeds its nominal value. Low value select: Inputs to the LVS are the fuel demand signal determined by the speed governor and an overheat control variable, which decreases from an initial ceiling value when the exhaust temperature excee ds its reference. During the operation of the unit, only one of the control branches is active, the one whose control variable has the lowest value. The Figure 2 shows the block diagram of the load frequency control loop of the combined cycle power plant which combines the gas turbine and steam turbine with speed and temperature control loop.

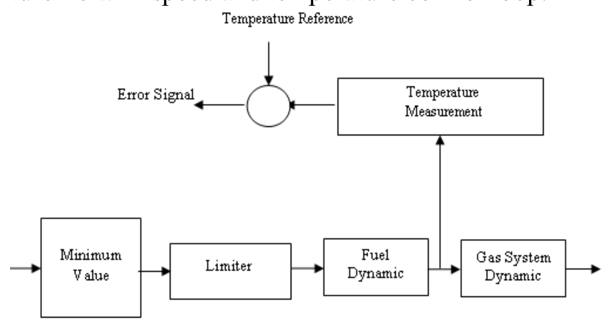

Fig.2 Basic Structure of Temperature control loop

4. COMBINED CYCLE

The combined cycle power plant model shown in Fig. 3 consists of the power generation units and the control branches. The thermodynamic part, giving the available thermal power to the gas turbine and the steam turbine, is modeled, by algebraic equations, corresponding to the adiabatic compression and expansion, as well as to the heat exchange in the recovery boiler. These equations correspond to the block 'Algebraic equations of energy transform' in Fig.1. These algebraic equations are presented below (Spalding and Cole, 1973) [9]. From the adiabatic compression equation the following relation holds, where x is the ratio of input-output temperatures for isentropic
compression

$$X = (P_r)^{\frac{\gamma-1}{\gamma}} \quad \text{(i)}$$

In (i), P_r is the actual compressor ratio. For nominal airflow (W=1pu), this is equal to the nominal ration P_{r0}. When airflow is different from nominal ($W \neq 1$), the actual compression ratio is.

$$P_r = P_{ro} * W \quad \text{(ii)}$$

and therefore:

$$X = (P_{ro} * W)^{\frac{\gamma-1}{\gamma}} \quad \text{(iii)}$$

From the definition of compressor efficiency

$$\eta_c = \frac{t_{d,is} - t}{t_d - t} \quad \text{(iv)}$$

Based on the definition of X in (i)

$$t_d = \frac{t_1(1+X-1)}{\eta_c} \quad \text{(v)}$$

The gas turbine inlet temperature depends on the fuel to air ratio (assuming that air is always in excess). The temperature rises with the fuel injection W_f and decreases with airflow W.From the energy balance equation in the combustion chamber, the following normalized equation results:

$$W_f = \frac{W(t_f - t_d)}{(t_{fo} - t_{do})} \quad \text{(vi)}$$

Then

$$t_f = t_d + (t_{fo} - t_{do}) * \frac{W_f}{W} \quad \text{(vii)}$$

Similar to (4), the gas turbine efficiency is given by

$$\eta_t = \frac{t_{t,is} - t}{t_t - t} \quad \text{(viii)}$$

For the adiabatic expansion, noting from (iii) that the right hand side is the same as in the compression (the mass that enters the compressor is the same with the one in the output of the gas turbine) we have:

$$X = \frac{T_f}{T_{c,is}} \quad \text{(ix)}$$

from which we obtain for the actual exhaust temperature similarly to (v):

$$t_e = \frac{t_f[l-(l-1)\eta_t]}{X} \quad \text{(x)}$$

The power, produced by the gas turbine is proportional to temperature difference (t_f–t_e), and the mechanical power, consumed in the compressor is proportional to (t_d–t_i). Both are also proportional to airflow W (we assume that the mixture of air and gas is almost equal to airflow). Therefore the net power converted to mechanical is:

$$E_g = K_o[(t_f - t_e) - (t_d - t_i)] * W \quad \text{(xi)}$$

The thermal power absorbed by the heat exchanger of the recovery boiler is proportional to airflow and exhaust temperature.

$$E_S = K_1 * t_e * W \quad \text{(xii)}$$

The control branches and the transfer functions are shown in Fig 3 Note that in the control loop temperature variables are replaced by normalized variables T_f, T_e defined as:

$$T_f = \frac{t_f - 273}{t_{fo}} \quad \text{(xiii)}$$

$$T_e = \frac{t_e - 273}{t_{eo}} \quad \text{(xiv)}$$

Note that t_f and t_e are in Kelvin degrees. While t_{f0} and t_{e0} are in Celsius. Thus, for normalized conditions T_f = T_e=1.0 (pu).As it can be easily observed that, there are eight independent variables in the algebraic equations (iii), (v), (vii) and (x)-(xiv). Thus, in order to solve the system during dynamic simulation, it is necessary to define fuel flow and airflow, as shown in the corresponding block of Fig. 3 &4.

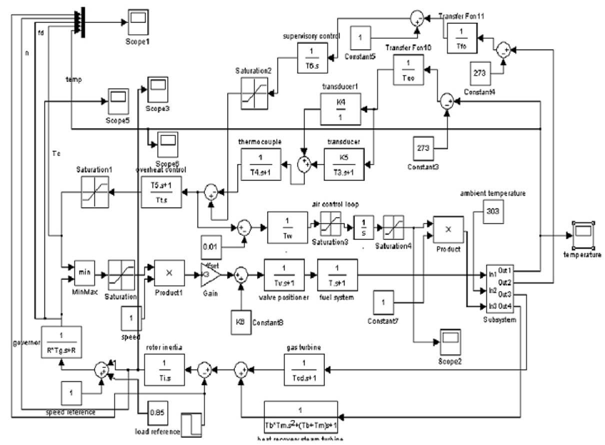

Fig. 3 MATLAB-SIMULINK Model of Single Shaft Combined Cycle Plant with Temperature and Speed Control Loop

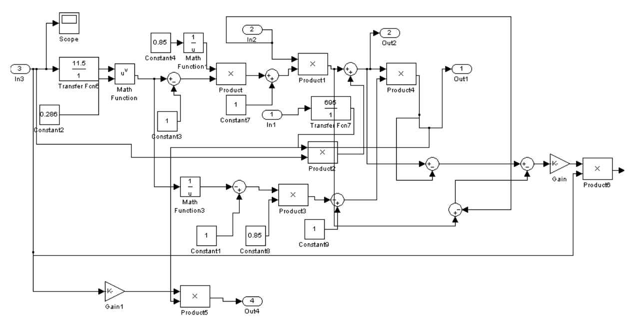

Fig. 4 Sub System

5. SMES SYSTEM

Figure 5 shows the transfer function model of SMES. The SMES unit contains DC Superconducting coil and converter which are connected by Star- Delta/Delta-Star transformer. The control of the converter firing angle provides the DC voltage E_d appearing across the inductor to be continuously varying within a certain range of positive and negative values. The inductor is initially charged to its rated value Ido by applying a small positive voltage. Once the current reaches the rated value, it is maintained constant, by reducing the voltage across the inductor to zero, since the coil is [24-25] Superconducting. Neglecting the transformer and the converter losses, the DC voltage is given by equation (i) Where E_d is DC voltage applied to the inductor (KV), α is firing angle ($^\circ$), I_d is the current, flowing through the inductor (KA).

$$E_d = 2V_{do}\text{Cos}\alpha - 2I_d R_c \qquad \text{(xv)}$$

R_c is the equivalent commutating resistance (ohm) and V_{do} is maximum circuit bridge voltage (kv). Charge and discharge of SMES unit are controlled through change of commutation angle. If alpha is less than 90°, converter acts in converter mod and if alpha is greater than 90°, the converter acts inverter mode. In combined cycle power plant operation, the DC voltage E_d across the super conducting conductor is continuously controlled depending on the sensed error signal. In this study, as in recent literature, inductor voltage deviation of SMES unit of each area is based on error of the same area in power system. Moreover, the inductor current deviation is used as a negative feed back signal in SMES control Loop. So the current variable of SMES unit is intended to be settling its steady state value. If the load demand changes suddenly, the feed back provides the prompt restoration of current. The inductor current must be restored to its nominal value quickly after system disturbances, so that it can respond to the next load disturbance immediately. As a result, the equations of inductor voltage deviation and current deviation for each area in Laplace domain are as follows:

$$\Delta E_{di}(s) = K_{oi}\frac{1}{1+ST_{dci}}\Delta f_i(s) - K_{Idi}\frac{1}{1+ST_{dci}} * \Delta I_{di}(s) \qquad \text{(xvi)}$$

$$\Delta I_{di}(s) = \frac{1}{SL_i}\Delta E_{di}(s) \qquad \text{(xvii)}$$

Where, K_{idi} is the gain for feedback. $\Delta I_{di}, T_{dci}$ is the converter time delay, K_{oi} (KV/Unit) is gain constant and L_i (H) is the inductance of the coil. the deviation in the inductor real power of SMES unit is expressed in time domain as follows.

$$\Delta P_{smi}(t) = \Delta E_{di} I_{dio} + \Delta I_{di}\Delta E_{di} \qquad \text{(xviii)}$$

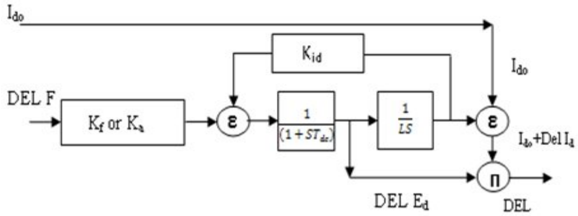

Fig.5 Transfer function model of SMES

This value is assumed positive for transfer from AC grid to DC. The energy stored in SMES at any instant in time domain is given as follows.

$$W_{smi}(t) = \frac{L_i I_{di}^2}{2} \text{ (MJ)} \qquad \text{(xix)}$$

6. PROPOSED CONTROL STATERGY

In this paper, the simple fuzzy logic controller, proposed in [28], is modified to enhance the low frequency damping of the CCGT. In [28] a fuzzy control system for the SMES unit was proposed, considering a small load perturbance at the load end. In the conventional FLC, the membership functions are supplied by an expert or tuned off-line. In this proposed model, the membership functions are generated at the very beginning, using sensed frequency signal. The proposed fuzzy algorithm will be automatically generating the appropriate membership function, for any type of disturbance. To ensure the effective use of the SMES unit, a supplementary signal generated from the FFC output and inductor current is used. The first step in designing a fuzzy controller is the proper choice signal for the controller input. Moreover choosing the appropriate linguistic variables formulating the fuzzy control rules are also important factor in the performance of the fuzzy control system. Empirical knowledge and engineering design plays an important role in choosing linguistic variable and their corresponding membership functions. Using the knowledge gained form experience, generator speed deviation and change in speed deviation of the CCGT are chosen as the input signal to the fuzzy controller.

$$\Delta\dot{\omega}(kT_S) = \frac{\Delta\omega(kT_S) - \Delta\omega[(k\text{-}1)T_S)]}{T_S} \qquad \text{(xx)}$$

Where k is the sampling number and T_s is the sampling period. After choosing proper variable as input and output of Fuzzy controller, it is required to design on the linguistic variables. The variables transform the numerical values of the input of the fuzzy controller, into fuzzy quantities. The numbers of these linguistic variables specify the quantity of the control which can be achieved using the fuzzy controller. As the number of linguistic variable increases, the computation time and memory increase, basically the sensitivity of the variable determines the number of fuzzy subsets. In this study, nine linguistic variable for each of the input and output variable are used. These are VLP (very large positive),LP (Large Negative), MP (medium

Positive),SP(small positive) , Z (zero),SN(Small Negative),MN(Medium negative) ,LN (Large negative),VLN(Very large Negative). The minimum and maximum variables of the each input variables of FFC are generated online following the disturbance. Few samples of the input variable are at required to arrive the maximum and minimum limits which will be used in respective membership function. The basic structure of the membership functions of the input variable used in the fuzzy control system, are the same. The input variable pairs are (i) Angular frequency and it's deviation in P.U. (ii) FFC output P_{sm1} in MW and inductor current deviation in (ΔI_{sm}) KA. Note that the above parameter variables depend on the type of disturbance. The procedure of determination of the FFC parameters is as follows.

(i) Sample $\omega(k)$ and $\omega_{ref}(k)$.
(ii) Compute $\Delta\omega(k)$.
(iii) Compute $\Delta\acute{\omega}(k)$.
(iv) Determine the maximum limit $\Delta\acute{\omega}$.Divide the Maximum $\Delta\omega$ to be used in the corresponding membership function.

The constant k_w is selected, intuitively, depending on the type of the power system and the capacity of SMES unit. Once the upper bound of the membership function is chosen, the other parameter is calculated from this.

7. INDUCTOR CURRENT FEEDBACK AND SUPLIMENTRY CONTROL SIGNAL

It is desired to restore the inductor current to its rated value as quickly as possible after a system disturbance, so that SMES unit can respond properly to any subsequent disturbance. To achieve this, the inductor current deviation is sensed, and used as a negative feedback, in the SMES control loop to achieve restoration of current, and SMES energy level. The active power capability of the SMES unit can be fully utilized, if an adaptive control technique is used. However, this is a complicated process, and requires large computer memory. Another alternative is to generate a supplementary control signal for the P Modulation of the SMES unit. With the inductor current feedback and supplementary control, the desired P modulation of the SMES unit can be obtained as

$$P_{sm} = P_{sm1}+P_{sm2}-K_i\ \Delta I_{sm} \qquad \text{(xxi)}$$

Where P_{sm2}, the upper bound of input (MW), P_{sm2} is the output of the supplementary control, K_i is the Gain, ΔI_{sm} is feed back control signal on firing angles which restricts the operating limits. They are converters, but due to practical reasons, there is limit

$|\alpha|$= 5 Deg, in the rectifier made.

$|\alpha|$= 165 Deg, in the inverter mode

8. STABILITY OF CONTROL LOOPS

The low-value-select (LVS) function acts like a switch that activates one of the two control loops (frequency or overheat) by selecting the lower value of the two control variables (T_c or F_d). Since, as discussed above, the speed control is vital for the stability of the system, its temporary interruption by the LVS during overheat conditions is critical. The calculation of linearized system eigen values is done separately with and without SMES, for the case where the speed control, or the temperature control branch is active. The calculated eigen values are presented in Table I&II. This table shows that when the speed loop is active, the system is stable, whereas with the LVS switched to overheat control, the system becomes unstable with a positive eigen value corresponding to shaft speed. Thus, a necessary condition for the system to achieve a steady state after a disturbance is that the LVS reactivates the speed control soon enough. The other eigen values of Table I&II demonstrate a satisfactory behavior (relatively fast and without undamped oscillations) of the combined cycle plant. This type of control (switching between stable and unstable systems) is typical of “sliding mode” control systems (Utkin et al., 1999). It should be noted that a switching system could become temporarily unstable, and still maintain its overall stability, if the switching device (LVS in our model) performs properly. At this point, it is necessary to note that the airflow control branch, which performs the normal temperature control, has a major influence on the overall stability of the system. When this branch is active, it is possible to increase the power generation without overheating, as a proportional increase of fuel and air will maintain the combustion temperature constant, according to Appendix I. Thus, with proper airflow control, even if the system passes temporarily to the unstable operation, it can eventually end up, in a stable steady state.

During a disturbance (e.g. decrease of frequency or increase of the load), due to the high gain and the small time constant of the speed control loop, a quick increase of the fuel demand signal is observed. Thus, soon after the disturbance, the LVS function activates the temperature control to avoid overheating. When the air control functions properly, it allows the increase of the power, produced with constant temperature. In this way, the frequency error decreases, resulting in the decrease of fuel demand F_d and the system returns to the stable operation of frequency control, and ends up in steady state. If, on the other hand, the generation is not increased, the system does not return to the stable loop of speed control, and the plant will go out of service. The normal response of the plant for an instantaneous 3% frequency drop is shown in Figs. 3&4 for an initial operating point, corresponding to 85% of nominal power output. The frequency drop through the speed governor control immediately results in an increase of F_d, causing the value of this parameter to exceed the ceiling of 110%, while temperatures increase and overheat control is activated.

TABLE-1. – Eigen Values

S. No	Open Loop	Speed Control Loop	Temperature Control Loop
1.	-72.5	-73.8646	-70.4523
2.	-19.99	-19.995	-19.994
3.	8.0031	-3.9985	-2.0001
4.	0.0026	-0.0062	0.0016
5.	0.2405	-1.6406	0.1256
6.	-	-0.5095 + 0.638i	0.4095+0.5830i
7.	-	-0.0003	-0.0003
8.	-	-0.0755	-0.0551

TABLE-2. – Eigen Values

S. No	Open Loop	Closed Loop Without SMES	Closed Loop With SMES
1.	-72.5	-76.8646	-76.8646
2.	-19.99	-19.9985	-33.2545
3.	8.0031	-5.0062	-19.9985
4.	0.0026	-1.6406	-5.0062
5.	0.2405	-0.5095 + 0.6308i	-1.6406
6.	-	-0.5095 - 0.6308i	-0.5095 + 0.638i
7.	-	-0.0280	-0.5095 - 0.6308i
8.	-	-0.0001	-0.0000
9.	-	-0.2400	-0.0755
10.	-	-	-0.0280
11.	-	-	-0.2400

9. RESULT DISCUSSION

In order to demonstrate the damping effect of the proposed fuzzy controller, computer simulation, based on nonlinear differential equations, is carried out for small as well as large disturbances. The differential equations are solved in MATLAB environment. All the nonlinearity, such as SMES voltage limit, inductor current limits have been included. There are many power plants in practical power systems. In this study, we consider a small system, composed of a combined cycle plant and a step and ramp load. Their models have been described in Fig 3&4. We consider a single-shaft combined cycle plant. Its rated output is 32.5MW (Gas turbine 22.9 MW, Steam turbine 9.6 MW). On the gas turbine we use typical parameters provided in [4]. As far as for steam turbine parameter is from [19], for gas turbine parameters are taken from [20-21]. The parameters are listed in the Appendix-I. Fig 6 shows open loop response of combined cycle power plant without controller, in the presence of step input signal.

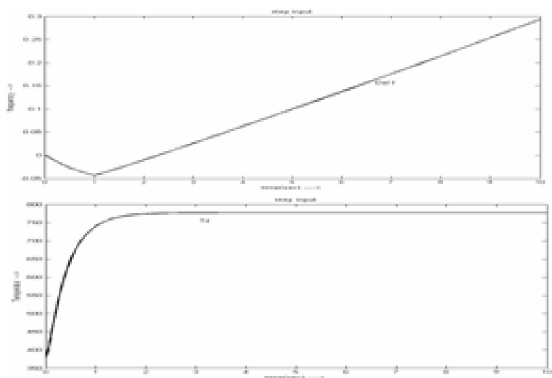

Fig 6. Open Loop Response of CCGT

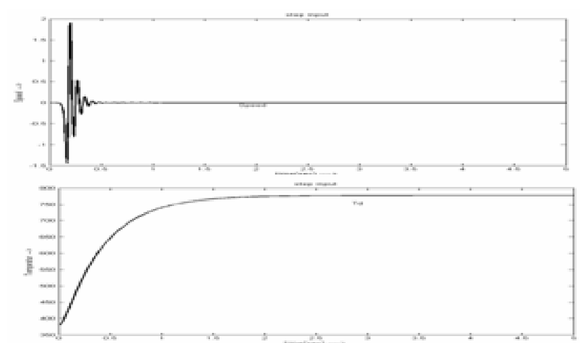

Fig. 7 Open Loop Response of CCGT with SMES

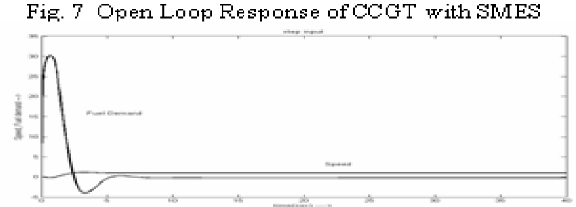

Fig 8. Response of CCGT with N control loop without Temperature Loop & SMES

Response shows that increase, in load, decreases the turbine speed N, and frequency f, increases fuel flow W_f, exhaust temperature T_e and power System lost its stability. So, without temperature and speed control loop, the system becomes unstable.

First we consider the cases in which this system is separated from the large system with a step load following step disturbances. Fig.7 shows dynamic response of combined cycle power plant with speed control, and without temperature control for step input, in this case, once again, the power system becomes unstable but the magnitude of oscillation reduces. In Fig.8 first dynamic responses reveals F_d, input Vs time, it explains during the step period F_d suddenly increases and when the time increases temperature reaches steady state value. Similarly second response relates temperature Vs time.Fig.9 shows dynamic response of combined cycle power plant with speed control and without temperature control for ramp input, in this case once again the power system becomes unstable but the magnitude of oscillation reduces.

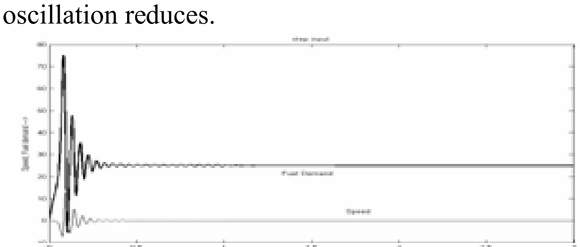

Fig. 9 Response of CCGT with N & SMES loop without temperature Loop

The temperature control is a crucial factor in the above phenomenon. The exhaust temperature is determined by the fuel flow and the air flow and it determines whether the temperature control operates are not. In this section we examine the phenomenon in terms of fuel flow and air flow. Fig. 10 (i)&(ii) shows dynamic response of combined cycle power plant with the presents of both controllers for step input signal with and without SMES result shows that N,F_d,T, air Flow controls are maintained within the limit and the system becomes stable, the power system operates in a stable region. The performance of the system is shown in figure 11. The dotted line represents (…..) without supplementary control and solid line (----) represents with supplementary control when SMES presents and all the simulation result presents in CCGP with temperature and speed control. From the results it is seen that there is no SMES unit. It takes about 4 seconds for the system settle down. Compared to this when the SMES unit is presents, all system states settles down 2 to 3 seconds and maximum overshoots reduces.

The effect of online generation of the membership function and the control rules are evident here. It enables the controller to provide the appropriate weight to the control rules, and also to the upper and lower bounds of the membership functions to the input variable. Eventually, it allows the SMES unit to provide suitable compensation, during the oscillatory period. From these results, it is conclude that irrespective of the degree of disturbance. The power system returns to the perturbation position within 2 to 3seconds when equipped with the SMES unit. The supplementary control plays an important role to achieve these outputs

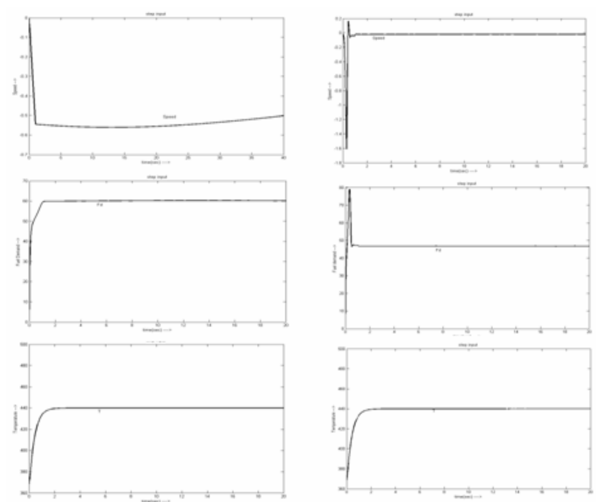

Fig. 10 Dynamic Response of CCPT with N & Temperature Loop (i) With SMES (ii) Without SMES

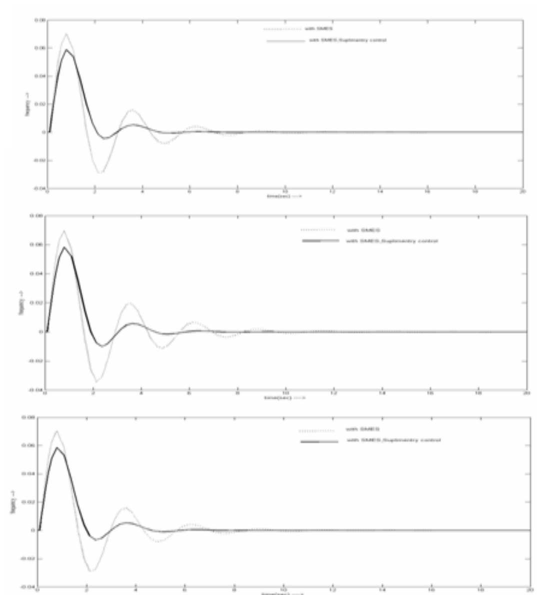

Fig 11 Response of CCGT with SMES, with supplementary control – Different Loads

10. CONCLUSION

This model, including generator unit and SMES unit together, represents the realistic performance of power system, with the present of step signal. The obtained results can be summarized as follows.
(i) Following a frequency drop, the temperature control soon overrides the speed control, and restricts the fuel flow about its initial value. The fuel flow, then slowly, increases as the initial guide vanes open. Their correspondingly affects the stability of power plant. If the inlet guide vanes opens fully. The temperature control and the frequency determine the fuel flow and accordingly the power output.
(ii) The simulation model and dynamic response reveal that the speed control loop is necessary for the stability of the gas power plant, as frequency feedback, in the fuel flow, and air flow render the plant very sensitive to disturbances. The model and the stability of a single shaft combined cycle plant as well as its control loop is analyzed. Furthermore, we examined the behavior of such a plant in the presence of step and ramp signal. Without speed control, the plant is unstable. Thus, by implementing the speed control loop the stability of the plant is improved, and the system ends up in the stable state.
(iii) Low value select function plays a major role in the response of the model. In case of overheat, it enables the temperature control, which limits the fuel supply to the turbine, otherwise it enables the speed control loop which is essential for the system stability. Without frequency control the plant is unstable, so in order to end up in steady state after step and ramp signal a necessary condition is for the LVS to switch back to speed control.
(iv) The temperature control, designed, here, is used to measure and control the turbine exhaust temperature. Thus by implementing the temperature control loop, the exhaust temperature is regulated and the safe operation of the power plant is obtained. Hence the stability of the power plant also increased. Air control contributes significantly to the stability of the plant, as it can help to controls the turbine temperature also it increases the power generation.
(v). In this paper, a simple fuzzy control strategy for the SMES unit is explained. The damping of the generator is greatly improved by the SMES unit, with proposed control system. To ensure the effective use of SMES unit energy, a supplementary control is also added to the output of FFC. The importance of supplementary control is visualized, when the power system is affected by a large disturbance. Since the size of SMES is very small, the SMES unit helps get excellent damping in power system, following any kind of disturbance. Online generation of membership function makes the controller very sensitive any kind of disturbance. The scheme proposed in the present paper makes effective use of active power control of the SMES unit and hence,it,s economic advantage is expected to be stronger than that of earlier schemes. The control strategy is very simple, and does not require heavy computation; therefore implementation is simple and feasible.

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APPENDIX

	Parameter	Value
T_{io}	Ambient Temperature (K)	303
T_{do}	Nominal Compressor discharge temp (c)	390
T_{fo}	Nominal gas inlet temperature (c)	1085
T_{eo}	Nominal exhaust temperature (c)	532
P_{ro}	Nominal compressor pressure ration	11.5
Γ	Ratio of specific heat (C_p/C_v)	1.4
η_c	Compressor efficiency	0.85
η_t	Temperature efficiency	0.85
K_0	Gas turbine output efficiency(1/K)	0.00303
K_1	Steam turbine efficiency (1/K)	0.000428
R	Speed governing regulation	0.04
T_g	Governing time constant (s)	0.05
K_4	Gain of radiation shield –instant	0.8
K_5	Gain of radiation shield	0.2
T_3	Time constant of radiation shield (s)	15
T_4	Time constant of thermocouple shield (s)	2.5
T_5	Time constant of temperature shield (s)	3.3
T_t	Temperature control integration rate(s)	0.4699
T_{cmax}	Temperature control upper limit	1.1
$T_{c\,min}$	Temperature control minimum limit	0
F_{dmax}	Fuel control upper limit	1.5
$F_{d\,min}$	Fuel control minimum limit	0
K_3	Ratio of fuel adjustment	0.77
K_6	Fuel Valve lower limit	0.23
T_v	Valve positioned time constant(s)	0.05
T_f	Fuel system time constant (s)	0.4
T_6	Time constant of T_f control (s)	60
g_{max}	Air valve upper limit	1.001
g_{min}	Air valve lower limit	0.73
T_w	Time constant of air control (s)	0.4699
T_b	Heat recovery boiler time constant	20
T_{cd}	Gas turbine time constant (s)	0.2
T_m	Steam turbine time constant (s)	5
T_i	Turbine rotor inertia constant (s)	18.5
T_{off}	Temperature offset	0.01