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Simulation of Turbine-Generator

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ABSTRACT

This study involved mathematical modeling of turbine generator simulator (TGS) and speed governing system for Fast Breeder Reactor (FBR). All steam turbine system utilize governor controlled valves at the inlet to the turbine to control the steam flow. The previously developed FBR and Pressurized water reactors (PWR) mathematical models (by author) [1] were connected to the same Turbine-generator model and controlled by the same method of control. Then a comparison between the dynamic performance transient response of FBR and PWR controlled plants were considered in two cases, load demand perturbation and reactivity perturbations. The steam chest and inlet piping to the turbine cylinder introduce delays between valve movement and change in the steam flow. The results show that the model is capable of simulating the dynamic transient response for FBR in two cases, load demand perturbation and reactivity perturbations.

Keywords: *Fast Breeder Reactor (FBR), Steam turbine system, Pressurized water reactors (PWR), Mathematical models.*

1. INTRODUCTION

The previously developed FBR and PWR mathematical models (by author) [1] involved rigorous mathematical models and developed of software powerful enough to study both normal and heavy transits of FBR and PWR dynamic performance. These models based on lumped parameters technique which assumes average system parameters over defined lumps. This approach gives moderate internal information of the system depending on the number of lumps used with reasonable accuracy at moderate computer time and cost. In addition, the previously developed FBR and PWR mathematical models included neutronics core heat transfer, piping, heat exchanger and steam generator [1]

In this study both the previously developed FBR and PWR simulators [1] are connected to the same turbine generator mathematical model (TGS) and speed governing system. Simple turbine-generator mathematical model simulator (TGS) as well as the coupling with the FBR and PWR power plant models are presented [1]. Thus it is possible to study the effect of the reactivity change on the uncontrolled and controlled Systems as well as the effect of load demand change on those two systems.

2. Turbine Generator Mathematical Model (TGS Simulator)

All steam turbine systems utilize governor controlled valves at the inlet to the turbine to control steam flow as shown in Fig. (1). The steam chest and inlet piping to the turbine cylinder. Introduce delays between valve movement and change in steam flow.

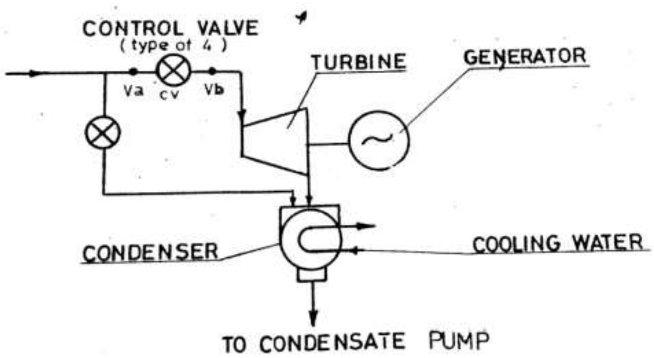

Fig. (1): Simplified diagram for turbine generator unit

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The Turbine power is calculate from the following equation:

$$\frac{dP}{dt} = \frac{WMW - P}{T} \qquad (1)$$

Where:

P = the turbine power actuating the shaft, MW,
WMW = steam work rate, MW,
= 2.931 x 10^{-7} WBT,
WBT = steam work rate, BTU/hr,
$= \eta\ (h_{va}-h_{EX})\ w_{va}$ (2)
η = turbine effective efficiency,
h_{EX}=exhaust enthalpy,
T=turbine time constant (a typical value for a non-reheat turbine is ~0.5 sec),
h_{va}=steam enthalpy at pressure P_{va} and temperature T_{va}(calculated from Table(1))
$h_{va}=h(T_{va}, P_{va})$ (3)

Taking into consideration that the output steam from FBR steam generator is superheated steam, while in PWR system is dry saturated steam [1].

T_{va} can be calculated from the energy conservation of the pipe line between exit of steam generator (so2) and turbine control valve (va) :

$$\frac{dT_{va}}{dt} = \frac{W_{so2}}{M_{sv}}(T_{so2} - T_{va}) \qquad (4)$$

where:

W_{so2} = steam flow rate at the exit of the steam generator, 1b/hr/three loops,
M_{sv}= mass of steam in the section of the pipe lines extending from the exit of the steam generator to the turbine- flow control valves ($1b_m$/three loops),
P_{va} is obtained as follows :
Let: P_{vb}=the pressure behind the turbine control valve (cv), psi,
$P_{vb}=A_{vb}\ .(W_{va} / N_v)$ (5)
Where:
A_{vb} =constant,
N_v =the number of the turbine control valves (normally 4),
W_{va} =turbine flow, $1b_m$/hr

To minimize the number of numerical tables in the simulator, P_{EX} (exhaust pressure) is assumed it to remain constant at 1 psi consequently h_{EX} will depend on X_{EX} (turbine exhaust quality), which in turn depends on S_{va} , where :
$S_{va} = S\ (P_{va}, T_{va})$ (6)

where:

$S\ (P_{va}, T_{va})$ = steam entropy at pressure F_{va} and temperature T_{va} .
For adiabatic expansion of the steam in the turbine at exhaust pressure P_{EX} :
$S_{EX} = S_{va}$ (7)
$S_{EX} = S_f + S_{fg}\ X_{EX}$ (8)
$h_{EX} = h_f + h_{fg}\ X_{EX}$ (9)

where:

S_{EX} = Exhaust entropy, BTU/ ^{0}F ,
h_{fg} =latent heat for exhaust pressure, BTU / 1b,
S_f , S_{fg} , h_f , h_{fg} and S_{va} calculated from steam table at P_{EX} and listed in Table (1) for both FBR and PWR systems.

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The turbine upgraded results for LMFBR (900 MW) can be obtained simply by changing the values of the given parameters (for 380 MW) by the ratio (900/380) . The turbine design data, parameters and state variables for both FBR (380 MW) and PWR (900 MW) are listed in Table (1) .

Applying Newton`s second law of mechanics to the turbine generator rotary system , the following equation is obtainable :

$$\frac{dw_s}{dt} = \left(\frac{a}{Iw_s} \right)\left(P - P_f - P_{eL} - P_e \right) \qquad (10)$$

Where:

W_s = Turbine generator shaft speed, (rad/sec),
I = inertia of the turbo generator ($1b_f$. ft . sec^2 /rad^2) ,
a = conversion factor ,
= 7.376 x 10^5 , ($1b_f$ .ft / MW) ,
P = the turbine power actuating the shaft, MW,
P_f = the frictional power losses, (neglected), MW,
P_{eL} = electrical power losses in the generated damper (neglected), MW,
P_e =the electrical power generated assumed constant, MW.

Table 1. Turbine design data, Parameters and State Variables of a 380 MWe LMFBR and a 900 MWe PWR

Parameters:	FBR	PWR
Design Data :		
P, MW	380	900
W_{va},$1b_m$ /hr	3.34 x 10^6	6.1275 x 10^6
P_e,MW	380	900
Design parameters:		
h_{va}, BTU/$1b_m$	1430.577	1106.1
S_{va} ,BTU/^{0}F	1.5605	1.4019
h_f ,BTU/$1b_m$	69	69.73
h_{fg} ,BTU/$1b_m$	1036.1	1036.1
S_f ,BTU/^{0}F	0.1313	0.1326
S_{fg} ,BTU/^{0}F	1.8487	1.8455
P_{EX} ,psi	1	1
X_{EX}	0.771	0.771
h_{EX} , BTU/$1b_m$	870.273	870.3
State variables:		
w_s , rad/sec.	314	314
P ,MWe	380	900
T_{va} ,^{0}F	900	534.5

3. SPEED-GOVERNING SYSTEM

It is assumed that all turbine control is accomplished by means of governor controlled valves. The speed governing system adjusted the steam flow into the turbine in response to changes in shaft speed. The speed governing system includes the speed governor, speed changer speed control mechanism, and governor controlled valves. In this work it is assumed that the speed governing system is of the mechanical hydraulic type MHC.

All steam turbine systems utilize governor controlled valves, at the inlet to the high pressure turbine, to control steam flow. The steam chest and inlet piping to the turbine cylinder introduce delays between valve movement and change in steam flow. The pressure variation at the valves may be significant in simulating disturbance which results in frequency changes. Between the governor controlled valves and the high pressure turbine there is a steam bowl or chest as shown in Fig. (2-A). This vessel

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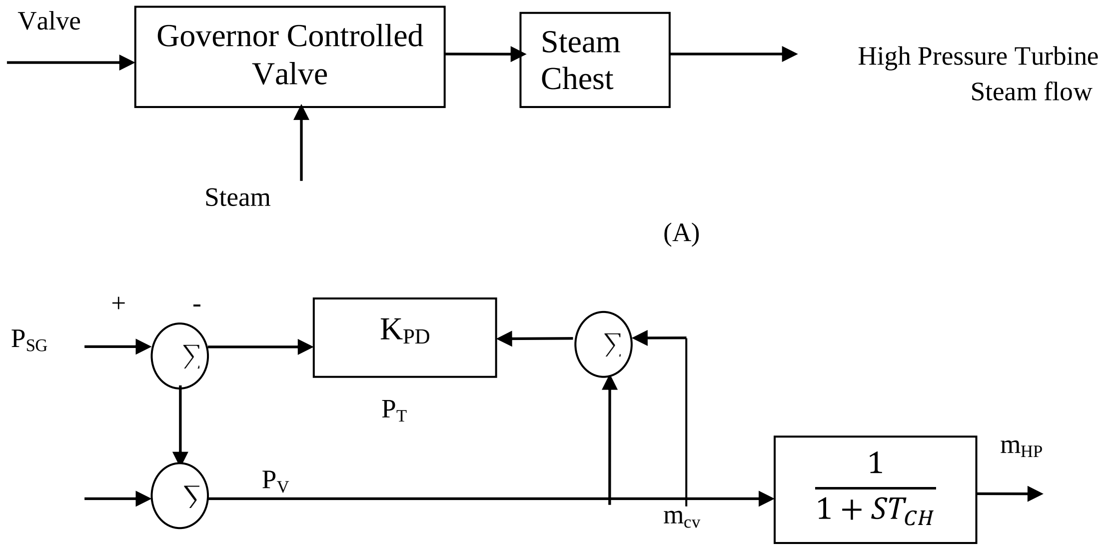
introduces a time delay between changes in valve steam flow and steam flow in the high pressure turbine. The mathematical model of Fig.(2-B) shows this effect as the time constant T_{CH} .

The internal boiler pressure, P_{SG} ,is assumed constant over the study interval while the input to the governor controlled valves, P_T , is a variable pressure . The parameters K_{PD} is a pipe drop coefficient. The flow into the steam chest is given by;

$$\dot{m}_{CV} = P_V \left(P_{SG} - K_{PD}\, \dot{m}_{CV}^2\right) \qquad (11)$$



(B)

Fig. (2): Steam chest and high pressure piping representations

(A) Functional block diagram

(B) Approximate nonlinear model

4. RESULTS AND COMPARISON

The previously developed computer program that was constructed by author to simulate the FBR model is used together with the code that have been developed previously for PWR model (by author) [1] to study the following :

1. The effect of load demand change on the dynamic performance of PBR and PWR controlled plants.
2. The effect of reactivity insertion on the mechanical power of the uncontrolled and controlled nuclear units (FBR and PWR) and consequently on the frequency.

The results are summarized in the following sections:

4.1 Effect of load demand perturbation

Fig. (3) [A,B,C,D] illustrates the controlled plants (FBR and PWR) transient response to a 5% step increase in electrical load. This perturbation causes the turbine to be overloaded by the amount of imposed demand and so the unit speed will then decrease thereby the system frequency will then decrease in proportion to turbine speed. This speed reduction causes the speed relay to be energized and a signal is transmitted to the hydraulic servomotor which operates the control valve. The steam flow to the high pressure cylinder follows the increase in the valve opening but lagging behind it due to the effect of the steam chest. The mechanical power will increase with the increase of the valve opening till it reaches a steady state value. Due to the increase in the temperature difference between the input and output nozzles of the reactor vessel, the nuclear power will be increased to meet the increase in the electrical load demand. Consequently, the fuel temperature will be increased.

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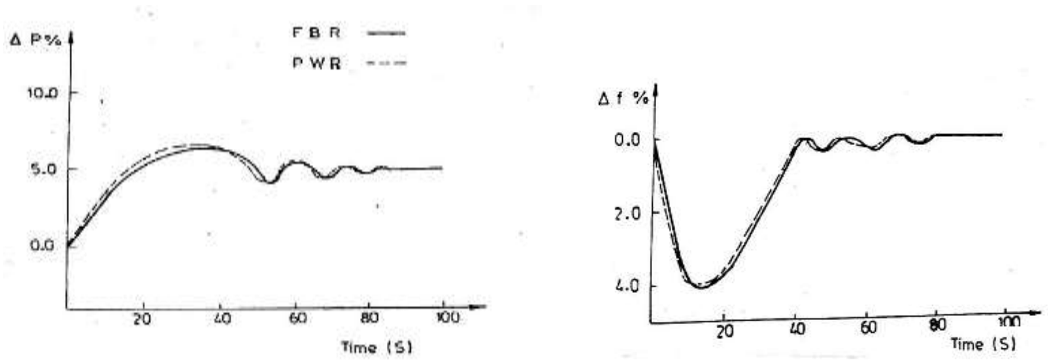
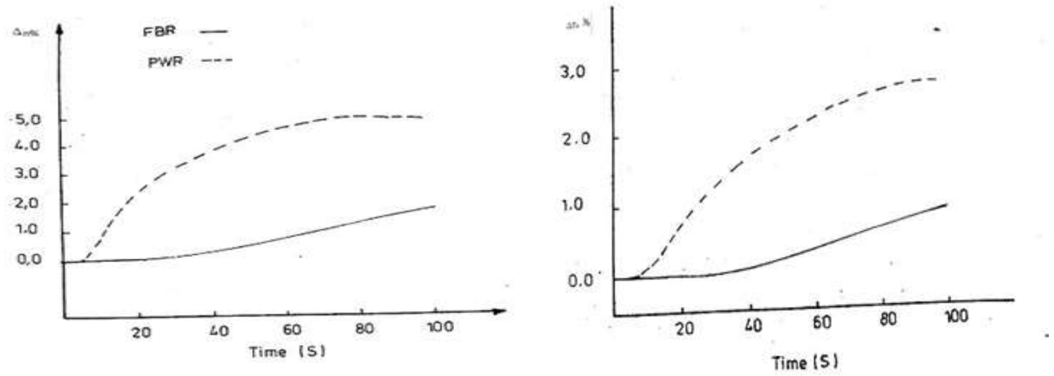


(A) (B)



(C) (D)

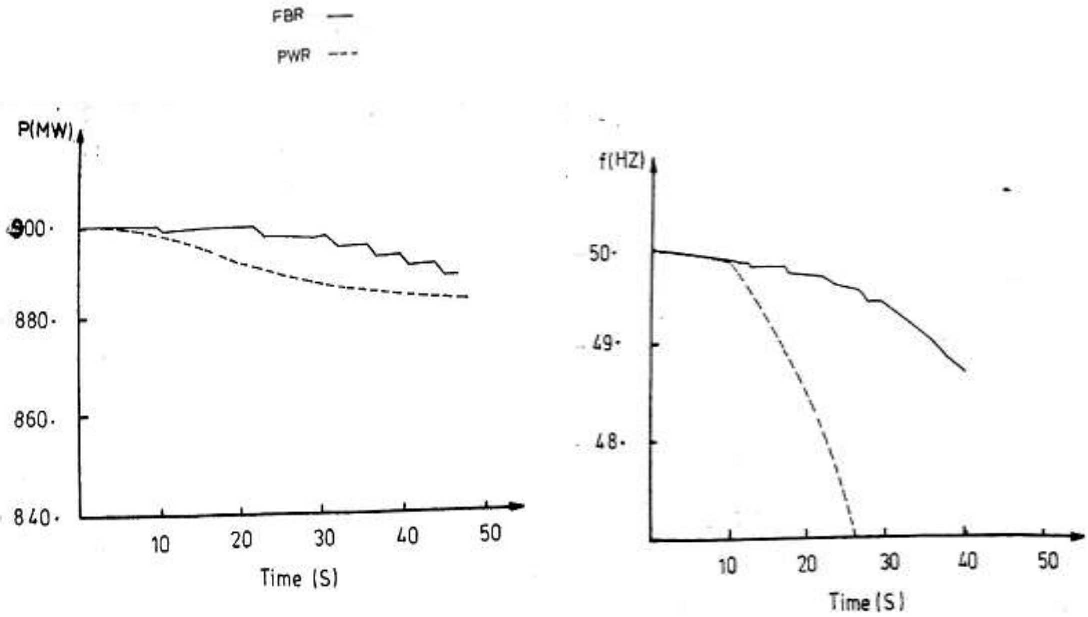
Fig. (3) [A,B,C,D] Controlled plants (FBR and PWR) transient response to a 5% step increase in electrical load (n = normalized reactor power, T_F = Fuel temperature).

As shown from Fig. (3) the FBR power response to a step increase in load demand is slower than that of PWR . This can be attributed to the presence of an intermediate loop in FBR.

4.2 Effect of reactivity change on mechanical power of uncontrolled and controlled units:

4.2.1 Uncontrolled plants (no speed governing system) :

Figure (4) illustrates the uncontrolled plant transient responses of FBR and PWR following a negative reactivity insertion of 60 cent



(A) (B)

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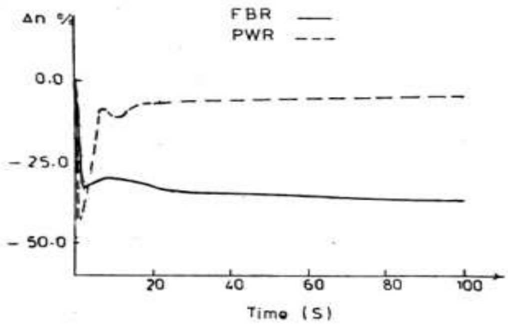
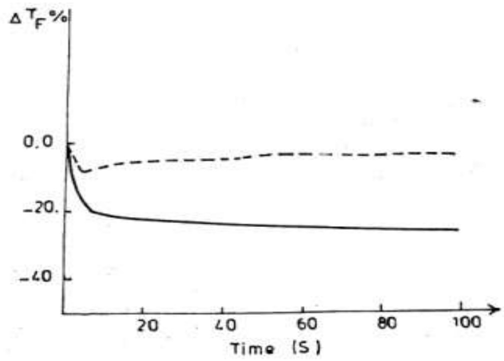


(c)



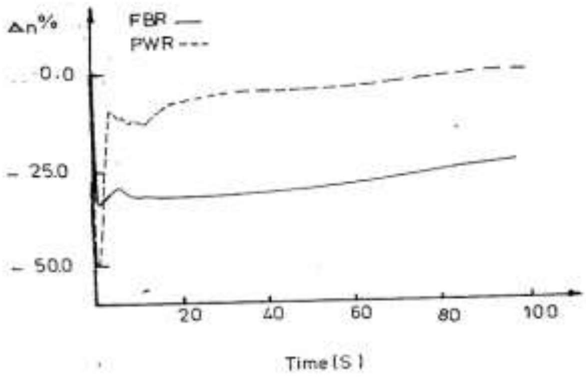
(D)

Fig.(4) [A,B,C,D] response to a 60 ¢ reduction in external reactivity of the FBR and PWR uncontrolled systems

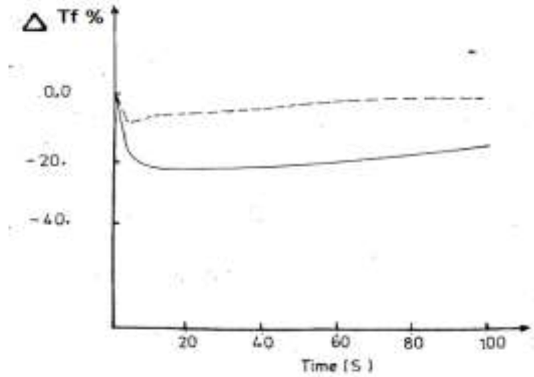
In Fig. (4) [A,B,C,D], the FBR and PWR system nuclear power responses show that the first effect on the primary side is sensed as rapid decreases in power generated due to the external reactivity decrease. Decreasing the coolant temperature inside the core followed by decreasing the upper plenum and lower plenum temperature are also detected. In FBR simulator, the rapid increase of power follow the initial rapid reduction due to feedback reactivity and then slow decrease of power follows that rapid increase. In PWR simulator, the rapid increase of the nuclear power generated following its initial rapid reduction jump, is due to the large feedback reactivity. This rapid increase is followed by a relatively slower increase of power due to the decrease in magnitude of the feedback reactivity till the power reaches a steady state value. The fuel temperature in FBR and PWR is decreased due to the power decrease as shown in Fig. (4). Moreover, the response of the FBR is slower than that of the PWR due to the presence of the intermediate loop in FBR system.

4.2.2 Controlled plants :

Fig.(5) [A,B,C,D] shows the controlled plants transient responses of the FBR and PWR for a 60 cent step decrease in the external reactivity. The effect on the primary side of FBR and PWR for a 60 cent step decrease in the external reactivity.



(A)



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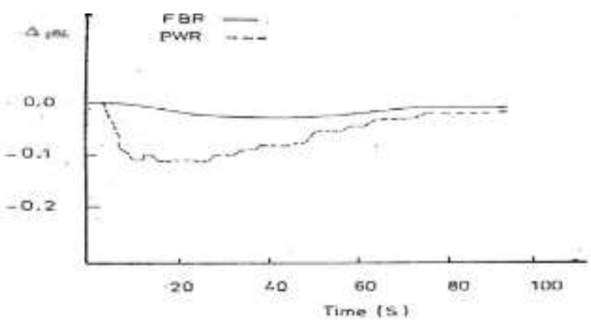

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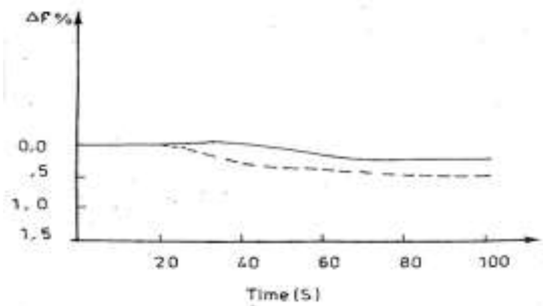

(D)

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Fig.(5) response to a 60 ¢ reduction in external reactivity of the FBR and PWR controlled systems

The effect on the primary side of FBR and PWR is shown in Fig,(5), the power generated and fuel temperature responses were as decreased in section (a) , but the final change of the PWR nuclear power and fuel temperature have returned to their steady state value due to the effect of speed governing system and feedback. The FBR power returned to steady state more slowly compared with the PWR case due to presence of the intermediate loop in FBR system and the inherent stability property of PWR. The effect of speed governing system on PWR and FBR mechanical power and frequency responses is rapid, since the turbine power and frequency changes are controlled as shown in Fig. (5), but the FBR turbine power and frequency responses are lagging and slower than those of PWR due to the presence of intermediate loop in FBR system.

5. CONCLUSION

In this work a Turbine Generator Simulator (TGS) was developed. Then the two previously developed FBR and PWR simulators (by author) [1] were connected to the same TGS and controlled by the speed governing system. The FBR and PWR simulators were successfully applied to assess the role of the speed governing system which provides TGS control during all phases of operation in FBR and PWR nuclear power plant controlled simulators.

In the case of load demand perturbation, results showed that the controlled FBR power response are slower than those of the controlled PWR power due to the presence of the intermediate loop , and the perturbation is coming from the secondary side.

In the case of the controlled plants transient response of FBR and PWR for a 60 cent decrease in the external reactivity, the FBR power returned to steady state more slowly compared with PWR case due to presence of the intermediate loop in FBR system and inherent stability property of PWR reactor than FBR due to the large negative PWR feedback reactivity.

REFERENCES

1. F. A. Gaber, Dynamic Performance of Nuclear Plants with FBR , Ph.D. , Alex. Univ.(1984).
2. P. Selvara etall , Development of Fast Breeder reactor technology in India Research Gate, ELSEVIER, (2017).
3. B. Gellert, Turbine generators in gas turbine System, (2013).
4. R. Nakai, D. Hahn, Sodium Code Fast Reactor (SFR) Risk a Safety Assessment White Paper, GENIV Int. Forum, (2016).
5. Dynamics Models for Steam and Hydro-Turbines in Power System Studies, IEEE Comittes Report, Ions,(1973).
6. O. I., Elgerd, Electric Energy Systems Theory : An Introduction , McGraw- Hill Book company ,New York, Inc. (1982).
7. Clinch River Breeder Reactor Plant Reference Design Report, Westinghouse Electric Corporation,(1974).
8. El-Wakil M.M., Nuclear Energy Conversion, (1982).
9. D. L. Hetrick, BRENDA: A Dynamic Simulator for A Sodium – Cooled Fast Reactor Power Plant, Univ. of Arizone (1978).
10. F. Gottfridssor, Simulation of Reactor Transient and Design Criteria of Sodium Cooled Fast Reactor, (2011).
11. A. Moisseytsen, Investigation of plant control strategies for the super critical co (sub2) Brayton cycle for a sodium cooled fast reactor using the plant dynamics, (2011).

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