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Issues Associated with Selection of Sampling Time for Control Related Studies in Nuclear Reactor

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Abstract - *This project mainly focuses on the development of a discrete time mathematical model of the nuclear reactor core. For the development of this model continuous time mathematical model is taken from the literature and also the 17 node scheme of the reactor is taken from the literature. The main objective of the project is to select optimal sampling time for discretization of the continuous time system. This selection of optimal sampling time is mainly dependent on discretization error and it should be minimum and the poles of the system should satisfy stability conditions in the z plane. For the development the model Advanced Heavy Water Reactor (AHWR) design is used and it is used because of its unique advantages over other reactors.*

Key Words: Reactor Core, 17-Node Scheme, Discretization, Z-Plane Stability, Neutron Flux.

1. INTRODUCTION

Nuclear power generation is the least environmentally polluting source of electrical energy. The heart of nuclear energy is the nuclear reactor; the efficient operation of the reactor is only possible when internal flux state is well known.

In this project a mathematical model of Advanced Heavy Water Reactor (AHWR) is being constructed in continuous time and then it is discretized with selection of sampling time which is optimal for good trade-off between discretization error and stability of the system.

The stability of descritized model is analyzed in the Z domain. And in every sample time Mean Square Error and Root Mean Square Error is calculated by comparing responses with continuous time model response.

For analyzing the core neutron flux, the reactor core is divided into 59 sections for estimating local flux distribution and this scheme is called 17- Node scheme.

2. CONCEPTS

2.1 AHWR

AHWR is a 920 MW(Thermal), vertical pressure tube type, boiling light water cooled and heavy water moderated nuclear reactor, designed by BARC, India. The main advantage AHWR has is, it uses Thorium as its fuel. India has abundant thorium reserves. The heat exchange is done by light water, and heavy water is used as moderator Advantages of using AHWR:

1. Self-Developed reactor technology (by Indian institute BARC)
2. Thorium is used for fuelling the reactor which is abundantly available in India
3. Light water cooled and Heavy water moderated reactor
4. High degree of safety features

The construction of the AHWR is shown in figure

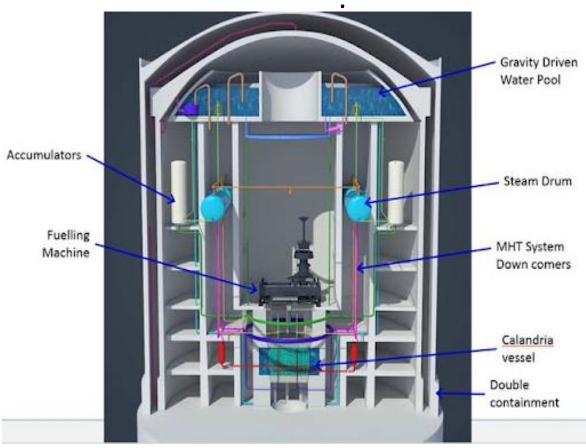


Fig.1.AHWR Construction(Source BARC)

2.2 17-Node Scheme of Nuclear Reactor

The study of the reactor- core and reflector region the reactor is divided into a total of 59 nodes.

In this scheme core of the reactor is divided into 3 layers (top reflector, core and bottom reflector) The 3 layers are divided into 17 parallelepiped shaped nodes which makes 17x3 = 51 and 8 side reflector nodes, making total 8+51=59 nodes, below figure shows the node division of core layer and following figure shows the reactor core node division of AHWR

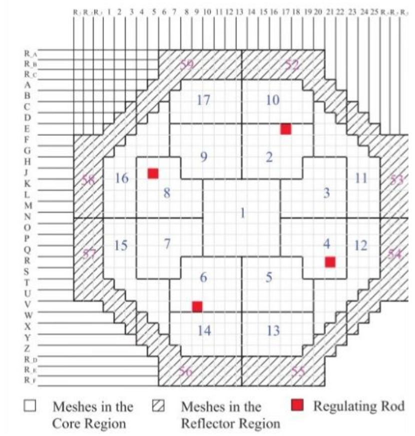


Fig.2 17- Node Division of Reactor Core[1]

3. TRANSIENT RESPONSE OF CONTINUOUS TIME MODEL

The transient is introduced in the reactor model by giving a small voltage to the control rod servos (i.e., by giving values to the input vector in the State Space model), hence control rod position changes, then reactivity changes, then flux values and reactivity values are obtained from the output equation.

Average of the obtained values are taken to get the average flux, and the fluxes in each node is plotted against time, hence we can observe the transient response of the model

Reactivity of System and Control Rod Position

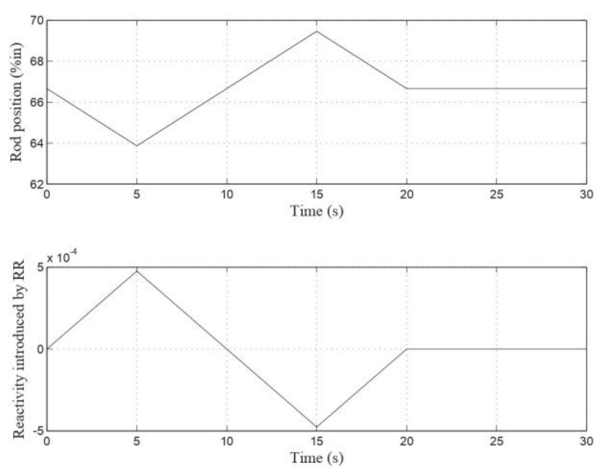
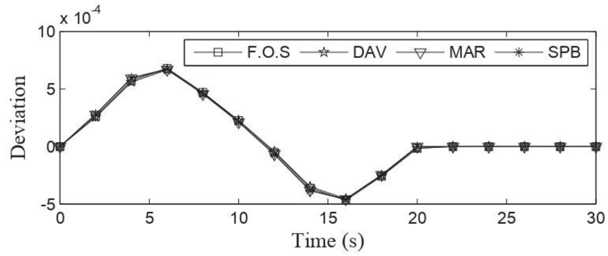


Fig.3.Reactivity with respect to Control rod position

Above plot describes the reactivity deviation from the steady state values with change in control rod position in the steady state

Average Flux Deviation in the System



The above plot describes the flux deviation in their respective nodes the transient time:

1. F.O.S - Full Order System
2. DAV - Davison Model
3. MAR - Marshall Model
4. SPB - Singular Perturbation Model

4. DISCRETE TIME MODEL TRAPEZOIDAL INPUT RESPONSE

The final results of the project are described. That is the reason for selecting optimum sampling time for different control rod input(either 1 or 4 rods). It is important to note that the taken system is a marginally stable system. Hence the descritized model is also a marginally stable system.

Single Input(Only One RR Movement)

1 to 20		21 to 40		41 to 60		61 to 80	
S-Plane	Z-Plane	S-Plane	Z-Plane	S-Plane	Z-Plane	S-Plane	Z-Plane
-475.153	0.386623	-240.747	0.61786	-160.055	0.72607	-0.0629507	0.999874
-470.398	0.390317	-232.713	0.627867	-149.782	0.741141	-0.0627122	0.999875
-414.231	0.436721	-232.177	0.628541	-148.378	0.743226	-0.0625535	0.999875
-399.239	0.450013	-231.242	0.629718	-147.828	0.744043	-0.0625136	0.999875
-390.743	0.457725	-231.112	0.629881	-142.265	0.752368	-0.0623238	0.999875
-378.702	0.468882	-212.483	0.653793	-139.894	0.755944	-0.0620349	0.999876
-326.885	0.520081	-209.34	0.657914	-124.238	0.779988	-0.0619585	0.999876
-326.664	0.520311	-208.86	0.658547	-123.578	0.781019	-0.0611908	0.999878
-302.889	0.54565	-203.942	0.665057	-113.905	0.796275	-0.0608631	0.999878
-302.193	0.54641	-203.45	0.66571	-108.608	0.804757	-0.0604798	0.999879
-277.86	0.573659	-202.823	0.666546	-105.77	0.809336	-0.0597767	0.99988
-277.463	0.574115	-194.771	0.677367	-102.713	0.8143	-0.0588207	0.999882
-276.308	0.575443	-184.863	0.690923	-95.8776	0.825509	-0.0583693	0.999883
-265.107	0.588478	-180.842	0.696503	-92.3587	0.831339	-0.052002	0.999896
-263.939	0.589855	-176.003	0.703277	-76.4026	0.858297	-0.0518517	0.999896
-263.056	0.590898	-171.606	0.709487	-68.7416	0.871549	0	1
-262.741	0.59127	-171.156	0.710127	-38.7784	0.925375	0	1
-255.695	0.599662	-168.327	0.714156	-38.1947	0.926455	0	1
-255.424	0.599986	-165.007	0.718913	-8.45779	0.983227	0	1
-241.675	0.616714	-163.689	0.720811	-0.06297	0.999874	0	1

Fig.4. Poles of the system at optimum sampling time

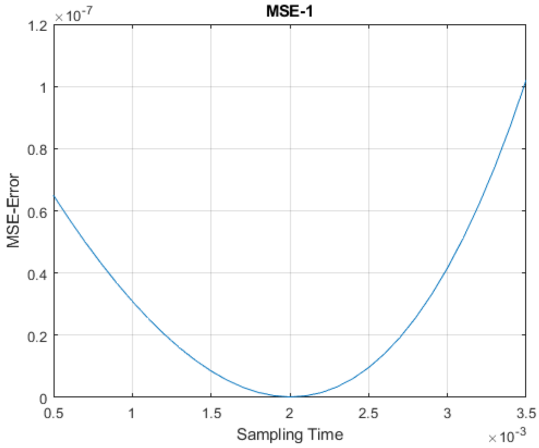


Fig.5. MSE vs Sampling Time

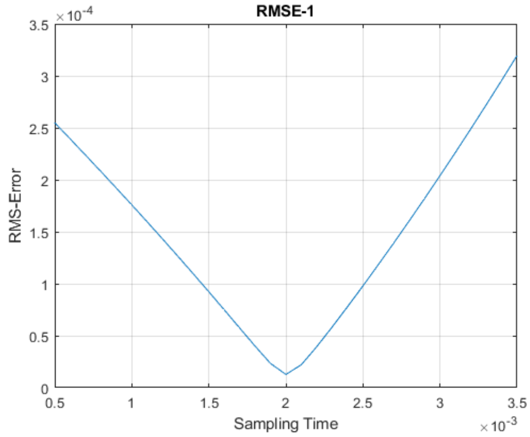


Fig.6. RMSE vs Sampling Time

As we can observe that from Fig:4,5 & 6, That the MSE and Root MSE is minimum around 2 milliseconds (2 ms) and also we can observe that out of 80 Z-Plane poles 75 poles lies in side unit circle and 5 on periphery and this behavior is same as S-Planes.

Hence by these two conclusions we can judge that 0.002 Seconds is optimal sampling time for discretization for single RR input.

Multi Input(Four RRs Movement)

Similarly we can observe that from Fig:7,8 & 9, That the MSE and Root MSE is minimum around 0.52 milliseconds (0.52 ms) and also we can observe that out of 80 Z-Plane poles 75 poles lies in side unit circle and 5 on periphery and this behavior is same as S-Plane.

Hence by these two conclusions we can judge that 0.00052 Seconds is optimal sampling time for discretization for Multi RR input(i.e 4).

In the case of Multi input system sampling time should be finely tuned inorder to get accurate responses in each node.

1 to 20		21 to 40		41 to 60		61 to 80	
S-Plane	Z-Plane	S-Plane	Z-Plane	S-Plane	Z-Plane	S-Plane	Z-Plane
-475.153	0.781078	-240.747	0.882331	-160.055	0.920141	-0.0629507	0.999967
-470.398	0.783012	-232.713	0.886024	-149.782	0.925069	-0.0627122	0.999967
-414.231	0.806219	-232.177	0.886271	-148.378	0.925745	-0.0625535	0.999967
-399.239	0.812528	-231.242	0.886703	-147.828	0.92601	-0.0625136	0.999967
-390.743	0.816126	-231.112	0.886762	-142.265	0.928693	-0.0623238	0.999968
-378.702	0.821252	-212.483	0.895394	-139.894	0.929838	-0.0620349	0.999968
-326.885	0.843681	-209.34	0.896859	-124.238	0.937439	-0.0619585	0.999968
-326.664	0.843778	-208.86	0.897083	-123.578	0.937761	-0.0611908	0.999968
-302.889	0.854275	-203.942	0.89938	-113.905	0.942489	-0.0608631	0.999968
-302.193	0.854584	-203.45	0.89961	-108.608	0.945089	-0.0604798	0.999969
-277.86	0.865466	-202.823	0.899903	-105.77	0.946485	-0.0597767	0.999969
-277.463	0.865645	-194.771	0.903679	-102.713	0.947991	-0.0588207	0.999969
-276.308	0.866165	-184.863	0.908347	-95.8776	0.951366	-0.0583693	0.99997
-265.107	0.871224	-180.842	0.910248	-92.3587	0.953109	-0.052002	0.999973
-263.939	0.871754	-176.003	0.912542	-76.4026	0.961049	-0.0518517	0.999973
-263.056	0.872154	-171.606	0.91463	-68.7416	0.964886	0	1
-262.741	0.872297	-171.156	0.914845	-38.7784	0.980037	0	1
-255.695	0.875499	-168.327	0.916191	-38.1947	0.980335	0	1
-255.424	0.875622	-165.007	0.917774	-8.45779	0.995612	0	1
-241.675	0.881905	-163.689	0.918404	-0.06297	0.999967	0	1

Fig.7. Poles of the system at optimum sampling time

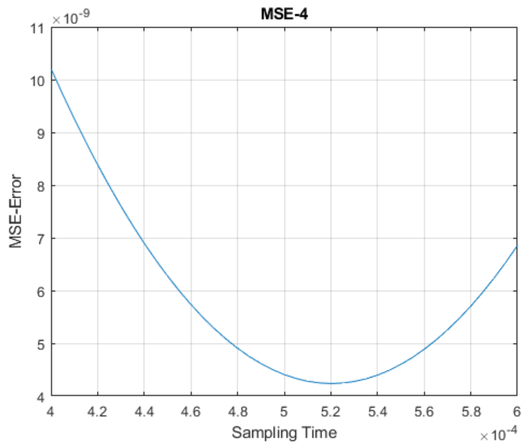


Fig.8. MSE vs Sampling Time

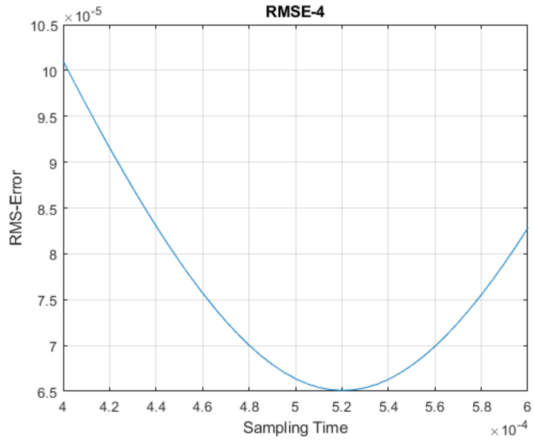


Fig.9. RMSE vs Sampling Time

Core Flux Deviation Response with Input:

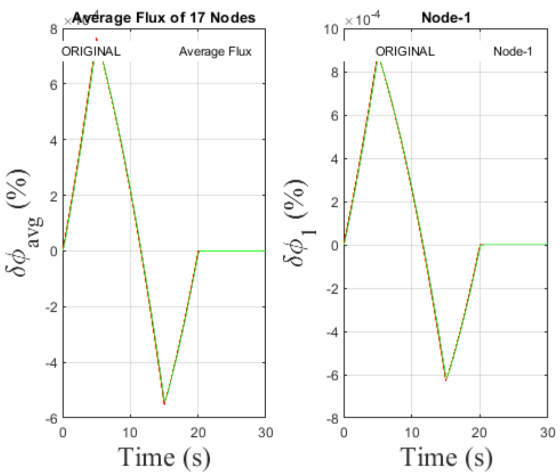


Fig.10. Average and Node 1 Flux (Single RR)

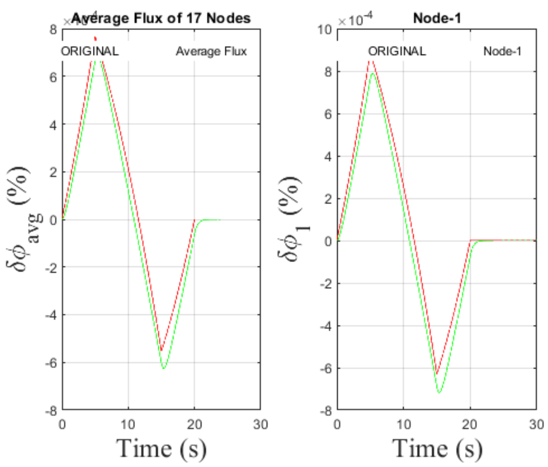


Fig.11.Average and Node 1 Flux (Four RR)

The above plots show only average and Node 1 Neutron Flux deviation.

5. CONCLUSIONS

The primary conclusion is that we can say 2ms and 0.52ms are optimal values of sampling time for 1RR and 4RR respectively and this sampling time system is not unstable and error is also minimum. And a point should be noted that 4RR input, sampling time should be tuned for generating a good response.

The main issues should be considered while selecting the sampling time is time delay introduced in the system and poles location in the z-plane and error in response. and it should be noted that the system taken from the literature is marginally stable system

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