A Review of Advances in Pressurizer Response Research for Pressurized Water Reactor Systems

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Abstract **- In this study we present a research review of investigations and studies carried out on the pressurizer system which deal with theoretical modelling, experimentations and transient operation tests for controlling the design parameters and refer to the use of artificial intelligence techniques in this process.**

Keywords - genetic; pressurizer; transient; nuclear power plant; estimation.

I. INTRODUCTION

A. Nuclear Power in the World Today

Renewable and nuclear energy meet electrical demands for clean and friendly energy with a favorable influence on the environment by reducing emissions of carbon dioxide, and as such nuclear energy was and still does represent an important and necessary share of the total energy needed now and in the future. From the earliest of 1950s, nuclear fission technology was exposed, a massive amount of nuclear reactor plants were used for providing electrically power and still today progressive into the novel generation of nuclear reactor stations. Nuclear reactor stations deliver more than 11% of the demand electricity to the whole worlds, from about 450 power reactors, continuous, reliable power to cover base-load range needed, without carbon dioxide releases as shown in fig.1. PWR constitute the large majority of the world's nuclear power plants and are one of three types of light water reactor (LWRA).So it is clear that the demand for safety nuclear power will be increased in the future, so to emphasize the safety operation for the PWR, it is completely need more study and researchers in the pressurized reactor water systems especially the pressurizer. The importance of safety in nuclear accommodations requires the endless progress of the accurate models for examining the dynamic response of all components specifically those, which are decided the regulatory plant typical operation.

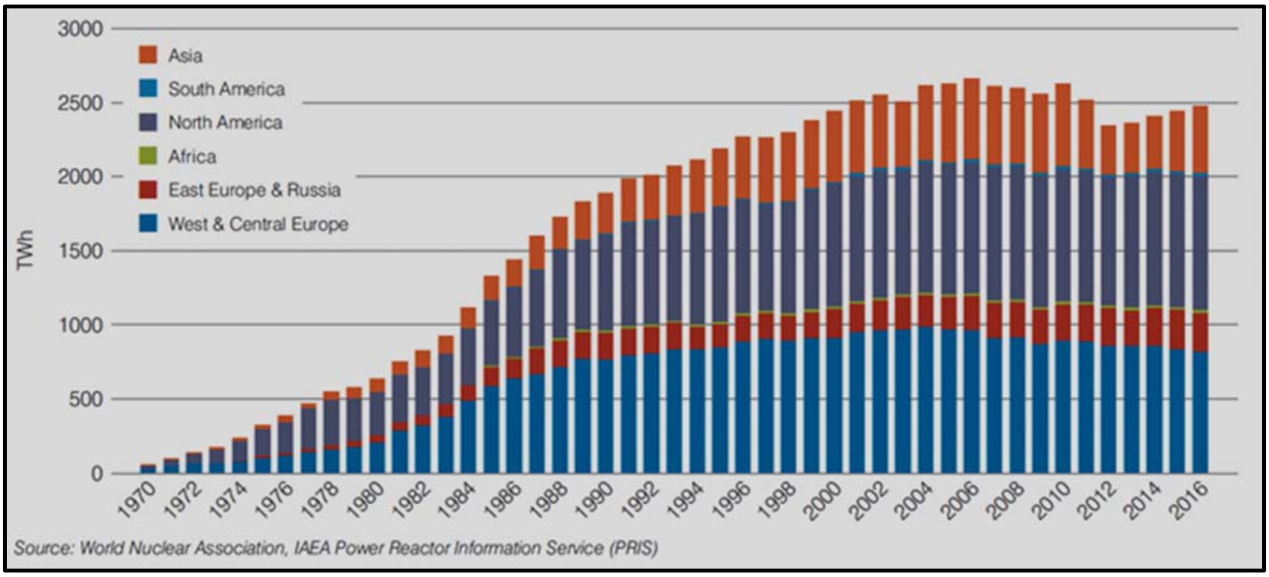

Fig.1.Nuclear Electricity Production.

The nuclear power plants share its output to 25% of the world total electricity production would have a very optimistic effect on air quality, minimizing CO_2 releases, and refining energy safety without the problems of working about disseminated and discontinuous renewable energies see fig.2.

In (PWR), fig .3. In an attempt to be the coolant water not to be boiling, the pressure must be over boiling to prevent water from boiling, and to remain this rising of pressure within limited access, the pressurizer is a basic apparatus of the nuclear reactor to prevent uncontrolled nuclear reactor.

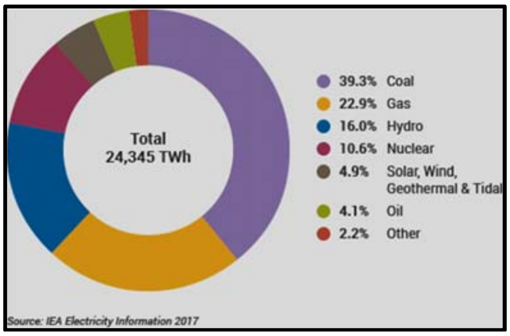

Fig.2.World Production Electricity by Source 2017.

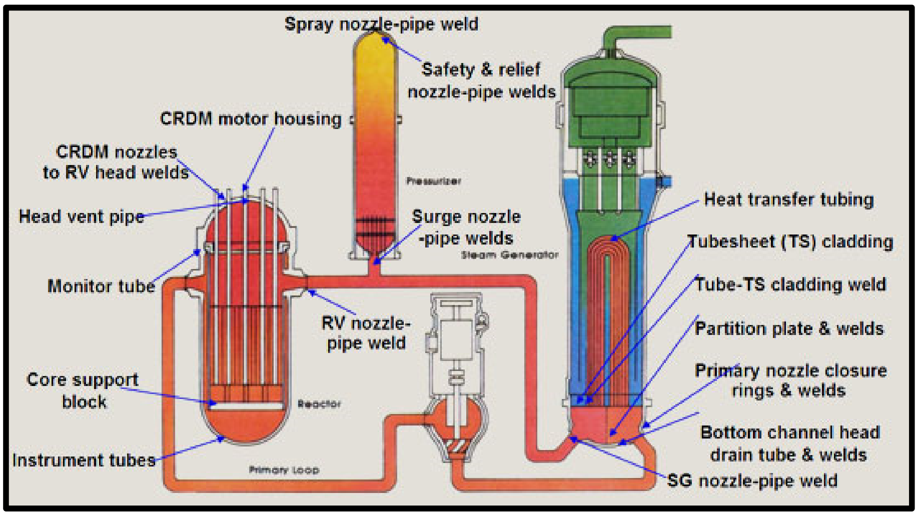

Fig.3. Pressurized Water Reactor Plant.

B. The Pressurizer Function

Therefore, precise inspection of this pressurizer performance is crucial in safety estimation of a PWR reactor. So controlling the pressure system is the chief function of the pressurizer for providing an approach of safety operation of a nuclear reactor generation. The reactor pressure is controlled by the pressurizer by using two components play as a controller's equipment which are electrical heaters, pressurizer spray systems, and the valve operated power which are called safety and relief valves. The pressurizer is an essential tank in nuclear power plant and in all industrial application because it is responsible of controlling the pressure of the reactor.

For this purpose, the model of two zone pressurizer is introduced to estimate the precise system pressure. The present model contains rainout, internal-region heat and mass transfer and bulk flashing. In a pressurized water reactor plant, a typical pressurizer are shown in figure (4), which is a pressure vessel with a cylindrical shape located with curved tops, located vertically inside the reactor containment building elongated axis and straight connected to the reactor coolant system by a single piping leg. Even though the water is the same coolant in the all reactor as it in the pressurizer as in the rest of the reactor coolant system, it is principally stationary. Any pressurizer consists of:

- Surge tank
- Spray water system
- Relief & safety steam system
- electrical heating elements

Under steady state operation circumstances, approximately 2/3 percentage of the pressurizer volume is filled by water and the rest of it by steam. To possess the water at saturation temperature and preserve a constant system operating pressure, an electric immersion heaters, which are situated in the bottom sector of the vessel. When the electrical load decreased result in a transitory increase in average temperature of the reactor coolant with an associated increase in coolant volume. The reactor coolant expansion when the level of the water raised in the pressurizer caused compression in the steam, raising the pressure and activating the valves in the spray lines. To overcome this compression of pressure in the pressurizer by condensing, apportion of the steam by injecting a spray water of reactor coolant into the steam region this is called posits surge and condenses a ratio of the steam. Then the

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pressure reduced by this act and limits the pressure increases. Vice versa when the electrical load increased results in a momentary decrease in the average temperature of the coolant and making a coolant volume contraction. In brief coolant then surge out of the pressurizer into the legs to the reactor, this is called negative surge, thus reducing the pressurizer level and pressure. Flashing some of the saturated water in the pressurizer to steam to boundary the pressure decrease. Then as a consequence of this decreasing in the volume of the steam, the heaters which are immersed in the bottom part of the pressurizer in the liquid phase also turned on to heat and rise water pressure in the pressurizer by transforming some of the water into steam to extra boundary over pressure decreasing. Falls in plant electrical load with resulting pressure increases more than the designs pressure capacity of the spray systems of the pressurizer causes the steam relief valves to be operated open. These valves are automatically opened or manually from the control room at a pressure below system design pressure. If the pressure of the system remains to rise, self-actuating ASME-code safety valves will open. The vapor can flowing through connected pipes from the safety and/or relief valves to the pressurizer relief tank which encloses necessary water for condensing the steam. Cold water can be sprayed into the relief tank pressurizer to growth the heat bowl exchanging capacity. A rupture disc vents the tank to the containment if design pressure is exceeded. [1], [2].

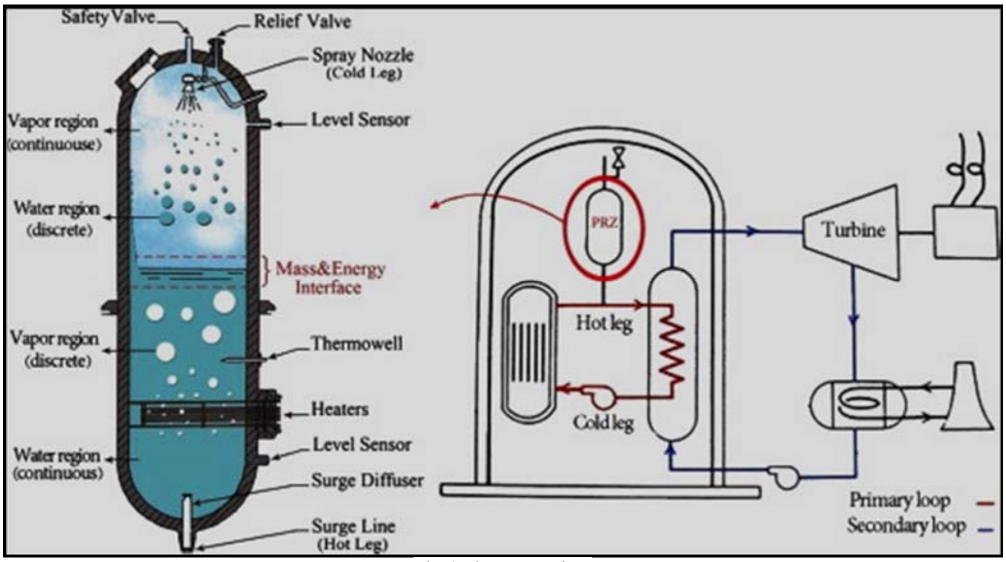

Fig.4.The Pressurizer

II. LITRETURE REVIEW

With the advent of nuclear reactor power plants and the increased with continuous needing the nuclear power as a part of power generation in the world, the expansion of a rigorous theoretical model for predicting the surge tank pressure transients during prescribed changes in liquid level history has been a subject of great interest to insure the safety operation of nuclear power plant and decreases the accident's hazardous. The continuously increasing demand related to the development of safer and more effective nuclear power plants needs either the improvement or complete re-design of different apparatuses. In this regard, dynamic simulation is an essential tool since the development of detailed dynamic models aids the study of a system in order to build or improve it. Modeling leads to deeper thoughtful of the behavior of a system, to the optimization of its technical specifications and to the discovery of its possible weaknesses. The researchers study and discuss the overall situation of pressurizer dynamics experimentally, analytically, empirical and mathematically modeling by codes.

Since 1950's many researchers working on the pressurizer operation within safety limits. In [3] presented a procedure for the analysis and evaluation of thermodynamic transients with illustrative applications to the boiling water reactor and the pressurizer of the pressurized water reactor. For purposes of gaining insight and understanding presented examples of transients in blowing down a gas-filled, cylinder and processes in a cylinder filled with wet steam. The generalized thermodynamic approach is applicable to steady flow and non-flow situations as well as transients. In [4] introduced development of a reliable design code for pressurizers together with a program for predicting the dynamic response of the pressurizer to arbitrary excitements in the reactor cooling circuit. With the aid of a test facility gaps in the theoretical knowledge of the thermodynamic processes have been filled and a new mathematical description of the pressurizer behavior has been designed which is totally maintained by experimentally real. In [5 and 6] the theoretical models with computational methods are utilized for pressure transients predicting during prescribed rates of increase or decrease of tank level. The digital computer program which is initiated on the theoretical models and can be used to calculate pressure transients for any steam surge tank enclosing light or heavy water.

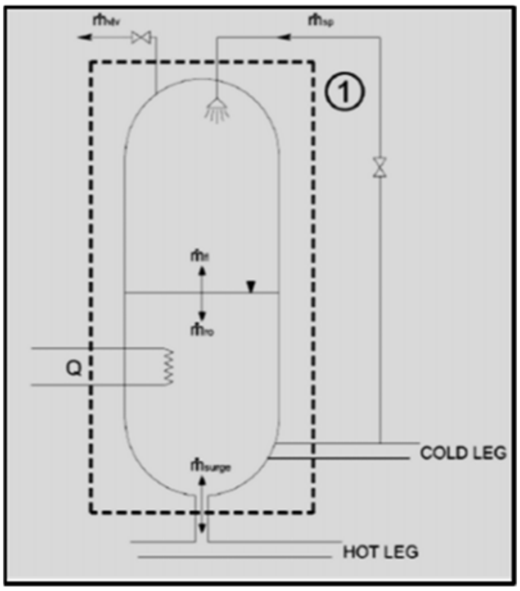

FIG. 5. Two-regions-single-volume pressurizer

Experimental data obtained from numerous tests on an actual heavy water reactor surge tank, for both surge in and surge out, is included. It is found that the isentropic models for the vapor compressed and expanded are highly unsuitable, and agreement between experiment and predictions is obtained with the above program. In [7] fabricated a simply experimental apparatus to training and understanding the multiple surges pressure transients' of the pressurizer of nuclear reactors. The submission model clarifying the related relation between the semi-empirical model and the experimental results.

In [8] a hybrid-computer simulation of reboiler dynamics was equipped, containing models of, heat conduction, tube steam condensation, steam appearing, a surge tank, the steam line carrying and stream-control valve. Then the experimental approach take an important part in investigation such as in [9] performing a categorizations of experiments which helping for providing understanding the fundamental of the phenomena which are essential analyzing of a PWR pressurizer. The transients circumstances are include a partially in-surges to -full tank, out-surges, in-surges to a tank with hot walls, empty tank in-surges, and combined in-surges and out-surges. Experiments are contain the special effects of non-condensable gases, and free surface heat transfer. These experiments may be considered as a statistics base for which references are made for modeling such phenomena, as: (i) hot water stratification of the and incoming cold water, (ii) condensation on the wall, (iii) flashing, (iv) rainout, (v) destruction of flashing, (vi) wall conduction, (vii) how the noncondensable, fig .7, gases effected the wall heat transfer, and (viii) heat transfer on free surface. The universal model of a PWR pressurizer was developed from these experiments. An expectation of the pressure-time performance of a PWR pressurizer during a variety of transients was established.

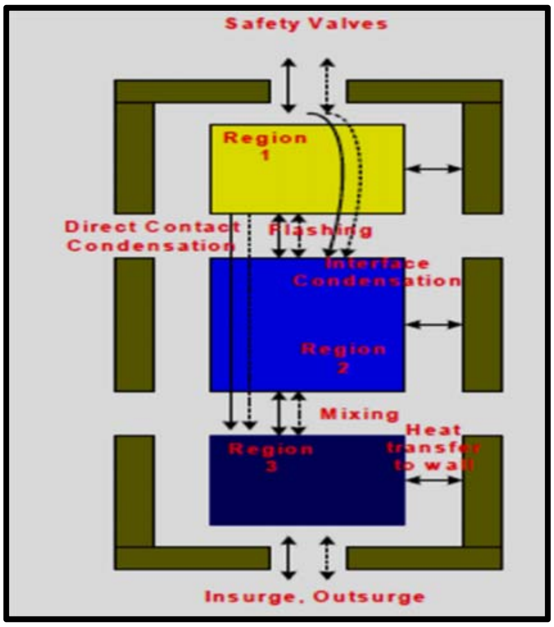

FIG. 6. Three-regions-single-volume pressurizer

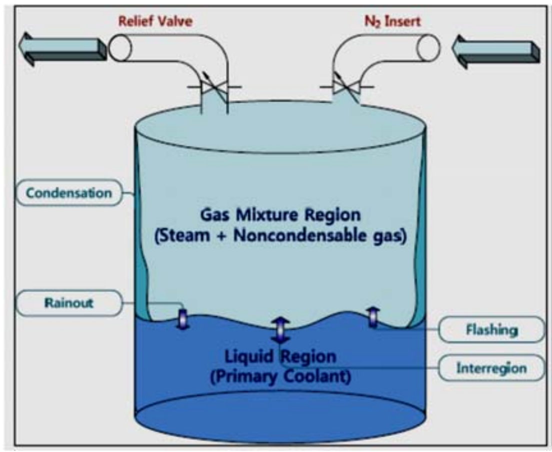

Figure 7: Schematic diagram of the steam-gas pressurizer volume with non-condensable gas

[10] Presented review of pressurizer modeling indicates that the neglecting of the' change in the internal energy of the subcooled water during transients is an acceptable assumption. In [11] due to lack of understanding on non-thermodynamic equilibrium and other local two-phase phenomenon in the pressurizer, worked to prepare necessary tools for a methodical study and investigate of

the pressurizer phenomena under quasi-steady-states and to conclude the special effects of key parameters of pressurizer activity.

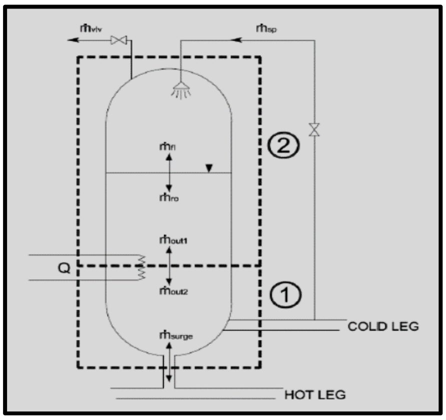

FIG. 8. Two-regions-two- volume pressurizer

Then derived equation of state analytically as well as to support and to guide the rest of the work IDRIFF by using two phase simulating codes. Some general-purpose system codes, such as RETRAN, RELAP4, SOPHT and FIREBIRD. On some occasions, the 'home' model of the system codes such as RELAP5 and SOPHT are directly used to simulate pressurizer transient . [12] Gives a detailed study of a case of normal transient phenomena resulting from a failure in the pressurizer controlling elements in a PWR system. Also study heavy transient phenomena resulting from pressurizer vessel rupture. They derived a novel model for the spray and condensate enthalpy in case of failure of the spray and relief valves.

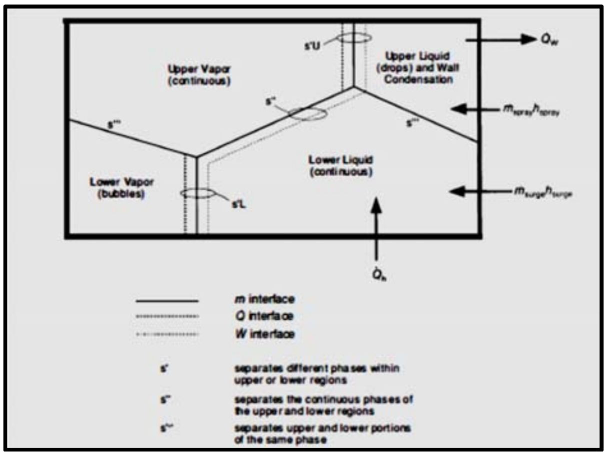

FIG. 9. Four-regions-two- volume pressurizer

In [13] Presented derivation of a basic mathematical model from the first law of thermodynamics which contains all the significant thermal-hydraulic progressions that can happen in the pressurizer. Additionally, the models consider heat exchange processes between steam and liquid regions and thermal dissipations between the entire pressurizer and the external environment. For achieving satisfactory performances, the model is deteriorated and developed into three alternatives: comprehensive lumped parameter and pseudo one dimension representations, two-volumes and three-volume pressurizer models were obtainable in order of increasing difficulty and correctness. Finally, comparison of the three models with the experimental data taking from Shippingport pressurizer tests and with the RELAP5® simulations.

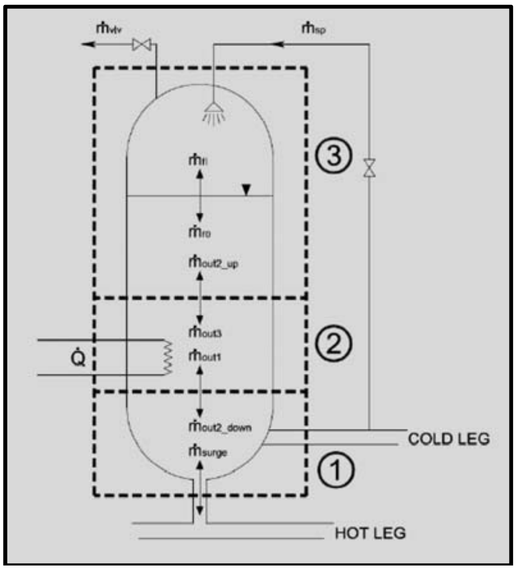

FIG. 10. Two-regions-three- volume pressurizer

In [14, 20 and 21] performed an Analyzing of the transient behavior of the surge tank in a WWER type pressurized water nuclear power plant. By developing an analytical method for predicting the pressure and level of water deviations in the surge tank resulting in or out surge processes. The pressurizer volume parted of three regions in keeping with the phase situation and energy.

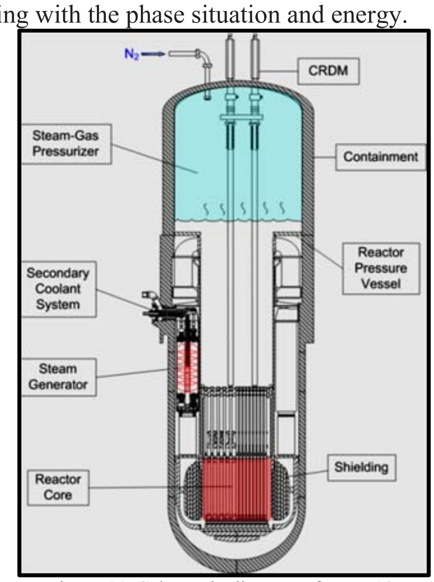

Figure 11: Schematic diagram of REX-10.

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Region 1 is the vapor and non-condensable gas (if any) region containing falling liquid droplet equipped with spray nozzles and relief and safety valves. Region 2 is the saturated liquid region containing rising up bubbles. Region 3 appears when the surge water enters the surge tank. This region is cooperated with electrical heating elements.

Region 2 and 3 are the solution phase with boron as a solute. The analysis also receipts into attention the changes of the thermodynamic mass amounts inside the surge tank. RELAP5/Mod3 and RELAP5/Mod2 were used to compare the result. In [15] Presented two separated volume steam-gas pressurizer model for assessment the precise system pressure for REX10, fig 11. Liquid and gas mixture, separated with an interface. The model contains bulk flashing, rainout, inter-region heat and mass transfer and wall condensation. The results obtained from this proposed model agree with those from pressurizer tests. In [16, 26, and 18] a non-equilibrium models was developed according to the two-region or three-region concept were developed pressurizer model, and by using TRACE code type 5.0 to evaluate its pressure transients. The benchmark of the pressurizer model was performed by comparing the simulation results with those from the tests at the Maanshan, MIT, PACTEL, fig 12. And 13, as well as a full-scale pressurize, The SPACE code input for MIT pressurizer experiment is developed and simulations are performed. In [17] presents the modeling of two-region model nonlinear state-space takes the basic thermo-hydraulic processes into consideration in order to obtain a simple model structure. Real transitory measurement information from the plant was used for standard prediction error minimization and identification procedure for a pressurizer of a WWER-440/213-type PWR.

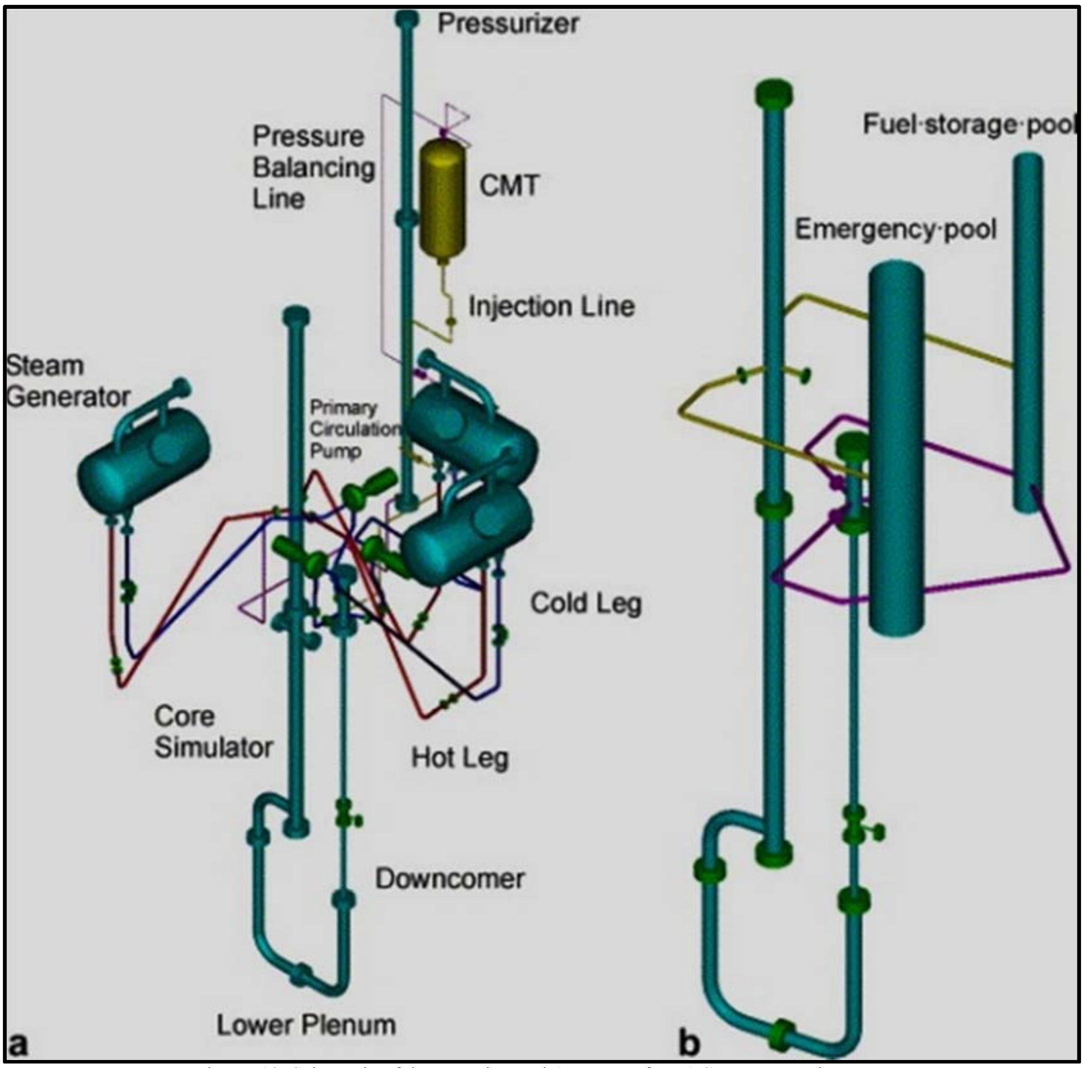

Figure. 12. Schematic of the Experimental Apparatus for PACTEL Pressurizer Test

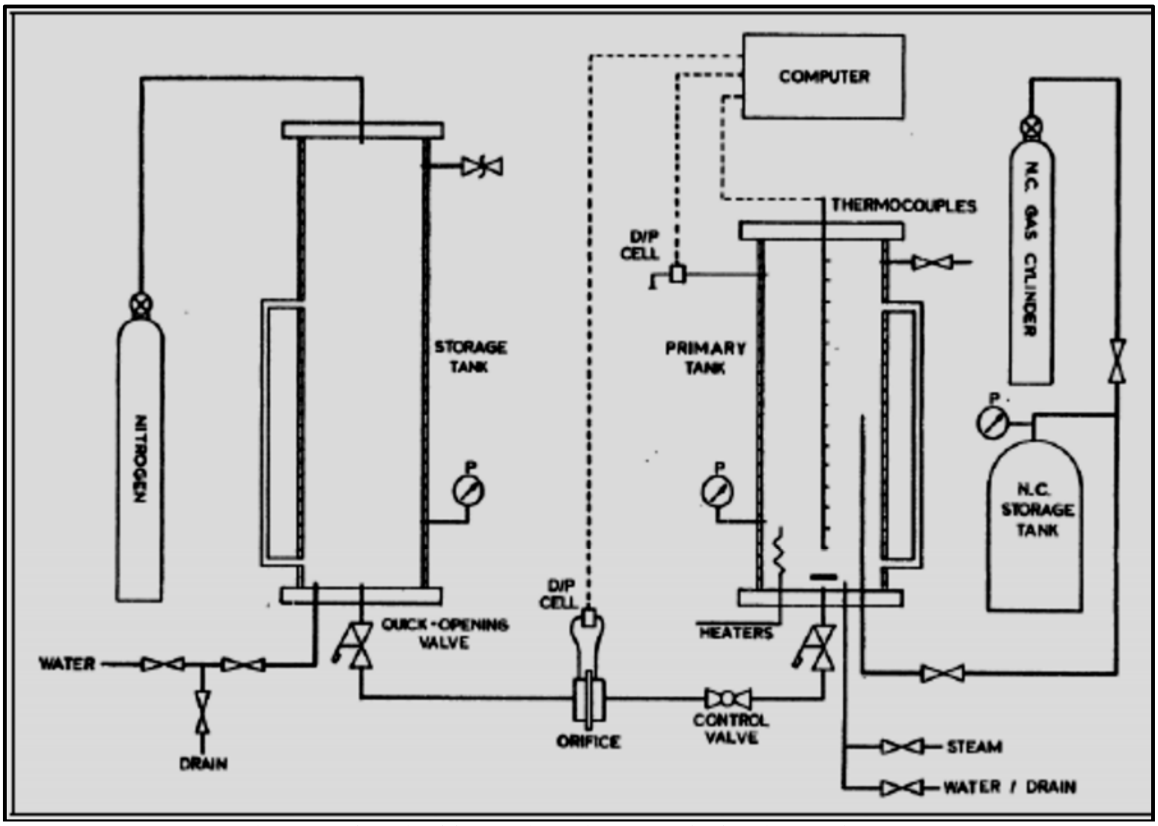

Figure.13. Schematic of the Experimental Apparatus for the Mit Pressurizer Test

In [19] gaining a dynamic two-phase non equilibrium mechanism model by considering the influence of the spray flow, heater and safety valve. An algorithm which is called a Particle Swarm Optimization (PSO) presented for gaining an optimized set of parameters for the pressurizer dynamics model. The parameter optimization algorithm was applied to a simulation case in pressurizer of a 900 MW PWR, By comparing the simulation results of the PWR plant, the precision of modeling and the effectiveness of optimization methods were verified. In [22] presented an imbalance dynamic model of two-phase mechanism of pressurizer in pressurized water reactor (PWR). The pressurizer is divided into two regions, steam region and liquid region but not necessary in equilibrium with each other. Considering the influence of the spray flow, surge flow, safety valve and heater, the model of pressurizer pressure control system is established by MATLAB/Simulink. In [26] a double-district equilibrium model of a nuclear power plant pressurizer dynamic characteristic was established through the approach of theoretical simplified model. Furthermore the proposed model was examined in spray water disturbances and heating disturbances experiments by on-site simulator operating data. The comparison of the experimental results with that of the simulator showed approximately similarity.

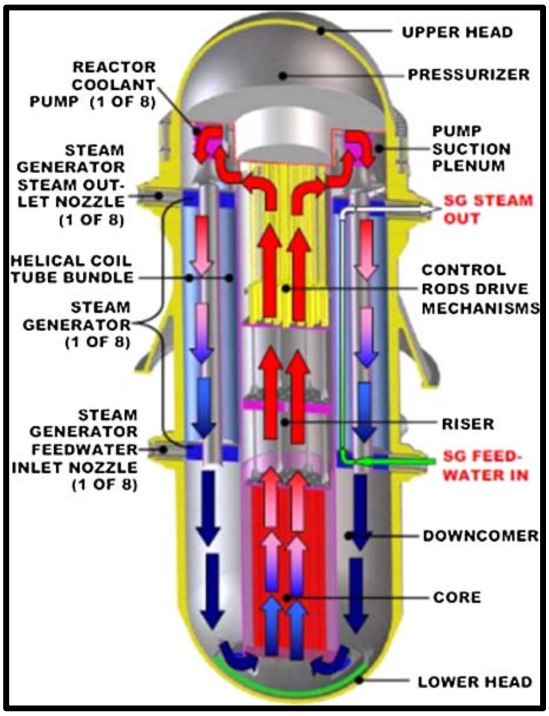

FIG. 14. IRIS Reactor

In the current time , the using of, state space model, fuzzy system , genetic algorithms (GA) and artificial neural networks (ANNs); play an important role to model the pressurizer such as in [24, 25].[31,32,33and 34] which all try to use novel algorithms to study the simulation and modeling of IRIS of either two or three volumes to simulate a typical out-surge transient then using the genetic algorithm (GA) search the scaled models variables are geometrical sizes, the surge mass flow rate, and the heater power needed to control the pressure. They use similarity numbers to describe a "fitness function" to evaluate the quality of the well-defined variables. The system operation is substantiated using a two-volume transient model to simulate a typically out-surge transient. the non- dimensional pressure model agreement of as the model pressure increases, and the worthy agreement of the non-dimensional volumes of different scaled systems recommends this non-dimensional formalism, the GA optimization, and the numeric simulation of a surge transient, to design a sized experiments for demonstrating and restricted dimensions of the International Reactor Innovative and Secure (IRIS) pressurizer which is in future development try to design and built it in minimum dimension, the new application of the method of analyzing the pressurizer level transients according to surge operation was succeeded to determine the scale sizing of the test prototype of about 1/100 volume scale.

III. SUMMARY OF LITERATURE REVIEW

Various models can be derived for the pressurizer, with deferent complexities. Three of them (one zone, two zones, and four zones) are described in [27]. Many researches and thesis discussing the phenomena existed in the pressurizer from early of 1960 till now with different models, thermodynamically, mechanically, analytically and experimentally from the old hand calculation through the development computer calculations and by artificial intelligence methods and finally by using the package cods like TRACE CODE, SPACE, RELAP , NEPTUNE etc. from literature review can see that some researchers deals with a real data and experiments from nuclear reactor plant ,BWR ,PWR and CANDU like WESTINGHOUSE, SHIPPINGPORT, H.B.ROBINSON, Maanshan, PAK,NEPTUN, WWER, and IRIS or with test pressurizer like MIT,PACTEL Also the researchers divided the pressurizer system as closed system by:

- Two region one volume system .fig.5.
- Three region one volume system fig.6.
- Two region two volume system .fig.7.
- Three region two volume system.
- Pressurizer with no condensable gas. Fig.8
- Four region two volume system.fig.9.
- Two region three volume system. Fig.10.

The transient process is In-surge, Out-surge and Combination of in-surg & out-surge. [30]. the two analytical approaches to the dynamic analysis of a pressurizer: Equilibrium thermodynamic model, the two phase are saturated and Non-equilibrium thermodynamic model. Liquid and vapor in the pressurizer distinctly, as a different temperature for each phase. [13]

IV. DISCUSSION AND CONCLUSION

The most significant studies present in literature are based on the following assumptions:

1. The space inside the pressurizer is divided into two or three independent control volumes, steam and water, separated with a liquid interface. Under steady conditions state, the vapor and liquid phases are thermally equilibrium, i.e. saturated.
2. Conservation equations of energy and mass are applied to each phase.
3. The processes of mass transfer going down between steam and liquid phases within a pressurizer are as a result of the speed of steam condensation and also the rate of bubbles rise variation in the normal essential coolant temperature in pressurized water reactor frameworks prompts an immediate variety in the water volume and consequently the weightiness inside the pressurizer.
4. Spray and condensation mixture go into the water phase as saturated liquid
5. The enthalpy of the water sprayed inside the pressurizer is the same as that of the reactor coolant cold leg
6. Pressurizer is adiabatically system.
7. The processes of steam wall condensation and surface water condensation are ignored or not compared to other mass transfer terms
8. Neglected the delay times of bubbles rising and condensate falling.
9. Insurge water mixes totally with water previously existing in the pressurizer.
10. Steam released through the relief valve is taken zero. [13]
11. The heaters must always be entirely liquid-covered, which for a fixed pressurizer geometry prescribes the minimum required liquid volume, approximately the water must be 60% of the pressurizer. [27]

In this review not all the above assumption are verified. All thermal hydraulic mechanisms that may control the phenomena in the pressurizer are:

-1. Energy Transfer:

- Heat transfer across the steam-liquid interface;
- Interphasial heat transfer between bubbles and liquid; droplets and steam;
- Heat transfer between the steam and the wall; liquid and the wall;

- Axial Heat Transfer through the Wall.
- Energy carried out of the pressurizer by the steam-bleed flow;
- Energy carried into and out of the pressurizer by the surge flow;
- Conduction heat transfer within fluids due to temperature profiles;
- Heat generation from the heaters.

-2. Mass Transfer
- Condensation a t liquid-steam interface;
- Evaporation at liquid-steam interface;
- Indirect contact condensation of steam (due to thermodynamic state change or due to spray);
- Direct contact condensation of steam on pressurizer wall;
- Nucleation process in the liquid;
- Boiling of liquid as it is heated by the heaters;
- Local boiling of liquid on pressurizer wall;
- Steam-bleed flow;
- Inflow and outflow of coolant due to in-surge and out-surge.

-3. Momentum Transfer:
- motion of liquid due to in-surge and out-surge;
- Bubble rise;
- However when the flashing scares, the heat loses to the cold wall suppresses the flashing. This will be termed "Suppression of Flashing"
- Condensate droplet drop;
- Local motion of the liquid due to the motion of bubbles;
- Local motion of the steam due to the motion of droplets. [14].

Flashing and Condensation

Figure 16 and Table I give an illustration of spontaneous flashing and condensation. If a unit mass of liquid, at pressure P and saturation conditions 2 is depressurized by an amount ΔP, some of the liquid flashes into saturated steam. The horizontal interception on the temperature-entropy diagram is a measure of the amount of flashing. Similarly, a unit mass of vapor, at pressure ΔP and saturation conditions 3, will partially condense when depressurized by an amount ΔP. Again, the condensation drops amount is given by the horizontal intercept. Figure 5 also shows that, initially subcooled liquid at 1 or superheated vapor at 4, when depressurized, must first reach the saturation line before flashing or rainout to liquid phase. Finally, a pressure increase from P to P+AP suppresses flashing and condensation, regardless of the initial state of the liquid (1 or 2) or vapor (3 or 4).

$M_{SU}dt$ = mass of water surge line from hot leg.
$M_{SUI}dt$ = mass of water entering surge line and mixing with the liquid phase from hot leg.
$M_{SUO}dt$ = mass of water leaving liquid phase surge line to reactor coolant hot leg.
M_{SP} dt = mass of spray injected into the pressurizer from cold leg.
M_{CS} dt = mass of steam condensing on spray droplets.
M_{RO} dt = mass of condensate falling to liquid from steam, or rainout
M_{CW} dt = mass of condensate on the pressurizer wall.
M_{re} dt = mass of steam leaving through the relief valve.
M_{sv} dt = mass of steam leaving through the safety valve.
M_{FL} dt = mass of water leaving from liquid entering steam from bubble rise.
Where m = dm/dt, the rate change of mass, as illustrated in Fig. 15.

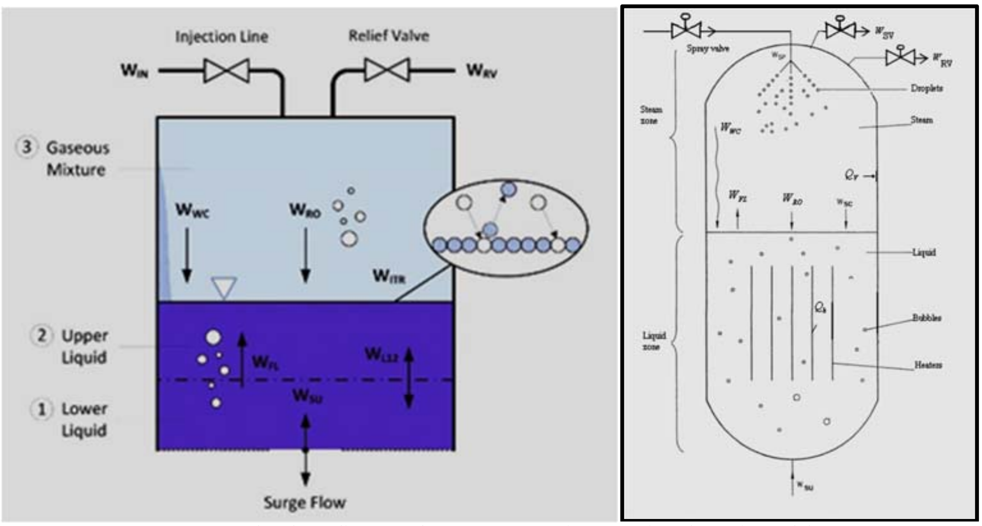

FIG. 15. The phase diagram of pressure system in pressurizer dynamic model

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TABLE I. FLASHING AND CONDENSATION, [37].

The system has the same five prescribed input parameters: mspray , msurge, h spray, hsurge , and Qh							
Cases	Pressure	Condition of Vapor	Condition of Liquid	Condensation	Flashing	Constraints	Unknown
1	Rising	Saturated	Saturated	No	No	h_l,=$h_f(p)$, u_l=$u_f(p)$, h_v=$h_g(p)$, u_v=$u_g(p)$ $W_{RO}=0$,$W_{FL}=0$	P, α_P,
2	Rising	Saturated	Subcooled	No	No	h_V=$h_g(p)$, u_v=$u_g(p)$, $W_{RO}=0$,$W_{FL}=0$	P, h_l, α_P
3	Rising	Superheated	Saturated	No	No	h_l,=$h_f(p)$, u_l=$u_f(p)$, $W_{RO}=0$,$W_{FL}=0$	P , h_V ,α_P
4	Rising	Superheated	Subcooled	No	No	$W_{RO}=0$,$W_{FL}=0$	P, h_l, h_V, ,α_P,
5	Falling	Saturated	Saturated	Yes	Yes	h_l,=$h_f(p)$, u_l=$u_f(p)$, h_v=$h_g(p)$, u_v=$u_g(p)$ $W_{RO}\neq0$,$W_{FL}\neq0$	P, α_P, ,W_{FL}, W_{RO},
6	Falling	Saturated	Subcooled	Yes	No	h_V=$h_g(p)$, u_v=$u_g(p)$, $W_{RO}\neq0$,$W_{FL}=0$	P, , h_l,α_P, W_{RO}
7	Falling	Superheated	Saturated	No	Yes	h_l,=$h_f(p)$, u_l=$u_f(p)$, $W_{RO}=0$, $W_{FL} \neq 0$	P , h_V, α_P, W_{FL}
8	Falling	Superheated	Subcooled	No	No	$W_{RO}=0$,$W_{FL}=0$	P, h_l, h_V, ,α_P

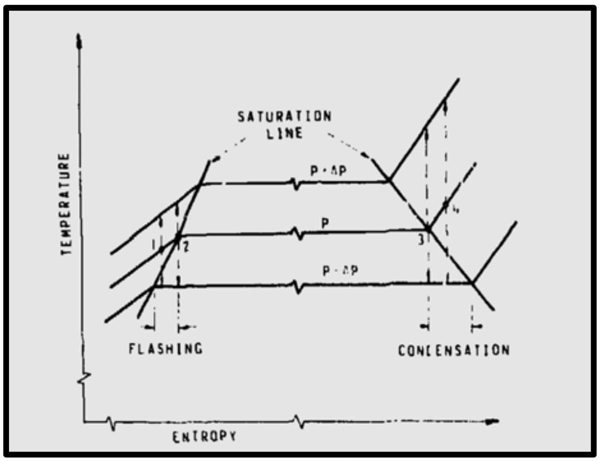

Fig. 16 Temperature-entropy diagram showing spontaneous Flashing and condensation [36]

REFERENCES

[1] The Westinghouse pressurized water reactor nuclear power plant, Copyright © 1984 Westinghouse Electric Corporation Water Reactor Divisions

[2] Dr. Nikola K. Popov , Thermal-Hydraulic Design . ©UNENE, all rights reserved. For educational use only, no assumed liability. Thermal-Hydraulic Design – December 2015.

[3] Brown, D. H. (1957). Transient thermodynamic of reactors and process apparatus ~SMEpaper 57NESC- 81, Second Nuclear Engineering and Science Conference.

[4] Tom Goeman,Mathematical Modelling Of Pressurizer Thermodynamics Laboratory for Thermal Power Engineering (fossile and nuclear)Februari 1972.

[5] Rakesh Kumar Gupta, The Analysis And Computation Of Steam Surge Tank Dynamics For Light And Heavy Water Systems. The University Of Ottawa In Partial Fulfilment Of The Requirements For The Degree Of Master Of Applied Science In Mechanical Engineering Augus T , 1972 .

[6] Kiran Kulkarni, A Csmp Technique For Surge Tank Pressure Prediction During Insurge, Outsurge And Multiple Surge. Submitted To The School Of Graduate Studies Of The Diversity Of Ottawa ! In Partial Fulfillment Of The Requirements For The Degree >Ter Of Applied Science In Mechanical Engineering October 1973.

[7] Cheng .S.C, W. Ng And K.T. Heng, Expiriments On Multiple Surges Pressure transients Leiters In Heatandmasstransfer. Vol. 3, pp. 529 - 538, 1976 Pergamon Press Printed in the United States.

[8] Moeck E.O, And P.D. Mcmorran, Dynamic Simulation Of A Reboiler. Presented At The 4th Ifac Symposium On Aaultivariable Technological Systems, Frederkton, July 1977.

[9] Kim, S. N. & Griffith, P. (1987). PWR pressurizer modeling. Nuclear E n g in e e rin g a n d Design, 102, 199-209.

[10] Khamis, Ibrahim Ahmad, Ph.D. Simulation Of Nuclear Power Plant Pressurizers With Application To An Inherently Safe Reactor . A phd thesis Submitted To The Faculty Of The Department Of Nuclear And Energy Engineering of The Graduate College The University Of Arizona. 1988.

[11] Rayman Sollychin, a Study of Pressure Response and Two-Phase Phenomena in a Nuclear Power Plant Pressurizer. M.A.Sc. McMaster University January 1990.

[12] Abdullah .A.M. "A Study of Sonic Transient Phenomena Resulting from Failure of pressurizer in a PWR System" ,2nd International Conference on Heat Exchangers, Boilers an & pressure Vessels (UEB9S) 1995.22 - 2J April, Alexandria, Egypt.

[13] Antonio Cammi, a Control-Oriented Model for Pressurizer Transient Dynamics, Facoltà Di Ingegneria Industriale E Dell'informazione Corso Di Laurea Magistrale in Ingegneria Nucleare.2013.

[14] R.Zarghami, F.Jalali, N.Mostoufi, R.Sotudeh, K.Sepanloo F.Dastjerdi And N. Ahmari, The Dynamic Modeling Of The Pressurizer Surge Tank Transients In Light Water Reactor Nuclear Power Plants. Iranian Journal of Science & Technology, Transaction B, Engineering, Vol. 29, No. B5 .Printed in The Islamic Republic of Iran, 2005, © Shiraz University.

[15] Jong-Won Kim1, Yeon-Gun Lee, Goon-Cherl Park, Numerical Analysis on Transient of Steam-gas Pressurizer, Interlaken, Switzerland, 20 – 26 September 2008 Paper No. 192.

[16] Yi-Hsiang Cheng, Jong-RongWang, Hao-Tzu Lin, Chunkuan Shih. Benchmark calculations of pressurizer model for Maanshan nuclear power plant using TRACE code.

[17] A.G´abor, K. M. Hangos, G. Szederk´enyi, Modeling and Identification of the Pressurizer of a VVER Nuclear Reactor for Controller Design Purposes.2010.

[18] Dong Hyuk Lee , Yo Han Kim, Chang Keun Yang , Seyun Kim , Bum Soo Youn , Kim Sang Jun Ha,Simulation of MIT Pressurizer Experiment using SPACE Code, Transactions of the Korean

Nuclear Society Autumn Meeting Jeju, Korea, October 21-22, 2010.

[19] MA Jin, LI Yongling, HUANG Yu, WANG Bingshu, CHAN Afang, Mechanism Model and Simulation of Pressurizer in the Pressurized Water Reactor Nuclear Power Plant. Proceedings of the 30th Chinese Control Conference July 22-24, 2011, Yantai, China.

[20] Samad Khani Moghanaki1, a, Mohammad Rahgoshay,Pressurizer Modeling: Using Different Thermodynamic Models and Comparing Results with RELAP Code Results. Applied Mechanics and Materials Vols. 423-426 (2013) pp 1444-1448.

[21] Samad Khani Moghanaki1, a, Mohammad Rahgoshay Simulation of two-region and four-region models for typical PWR pressurizer and benchmark obtained results using available results. Annals of Nuclear Energy 63 (2014) 302–308.

[22] Andri Gautama Suryabrata , Tatang Mulyana and Deden Witarsyah, Pressurizer Simulator, Proceeding of International Conference on Electrical Engineering, Computer Science and Informatics (EECSI 2015), Palembang, Indonesia, 19 -20August 2015.

[23] Z.B. Xu, J. Wu, Z.T. Quan, X.S. Zhang, X.Q. Ma, Model and Simulation Study on Pressurizer Pressure System. International Conference of Electrical, Automation and Mechanical Engineering (EAME 2015).

[24] Mauro V. Oliveira and José C. S. Almeida, Fuzzy Control Applied To Nuclear Power Plant, Pressurizer System , 2011 International Nuclear Atlantic Conference - INAC 2011.

[25] A.Ashaaria, T.Ahmadb, Mustaffa Shamsuddinb, S. Zeniana, Fuzzy State Space Model for a Pressurizer In a Nuclear Power Plant . Malaysian Journal of Fundamental and Applied Sciences Vol. 11, No. 2 (2015) 57-61.

[26] Ghonche Baghban , Mohsen Shayesteh , Majid Bahonar , Reza Sayareh, Simulating and evaluating the pressurizer dynamic behavior in various sizes. Progress in Nuclear Energy 93 (2016) 406e417.

[27] Neil E. Todreas and Mujid J. Kazimi, Nuclear Systems Volume 0ne-Thermal-Hydraulics Fundamentals. Crc Press –Second Edition 1990.

[28] NUREG/CR-5535/Rev I-Vol III.

[29] Kim, S.N., Griffith, P., 1987. PWR pressurizer modeling, nuclear engineering and design. Nucl. Eng. Des. 102, 199e209.

[30] G. Szederk´enyi, Z. Szab´o, J. Bokor and K.M. Hangos, Analysis of the networked implementation of the primary circuit pressurizer controller at a nuclear power plant. 2008

[31] David A. Botelho, Paulo A. B. De Sampaio, and Maria de Lourdes Moreira, Simulationofirispressurizer Out-Surge Transient Using Two And Three Volumes Simulation Models 2005 International Nuclear Atlantic Conference - In Ac 2005 Santos, SP, Brazil, August 28 to September 2, 2005.

[32] David A. Botelho, Paulo A. B. De Sampaio, And Maria De Lourdes Moreira, Optimization Procedure To Design Pressurizer Experiments.2005 International Nuclear Atlantic Conference - IN AC 2005 .Santos, SP, Brazil, August 28 To September 2, 2005.

[33] David A. Botelho , Paulo A. B. De Sampaio, Maria De Lourd , Fractional Scaling Analysis Applied To Scale A Pressurizer Test Facility .2007 International Nuclear Atlantic Conference - Inac 2007 Santos, Sp, Brazil, September 30 To October 5, 2007 Associação Brasileira De Energia Nuclear – Aben Isbn: 978-85-99141-02-1 Es Moreira , Antonio C. O. Barroso ,.

[34] David A. Botelho a, Paulo A.B. De Sampaio a, Celso M.F. Lapa a, Cla´udio M.N.A. Pereira a,Maria de Lourdes Moreira a,*, Antoˆnio Carlos de O. Barroso, The IRIS pressurizer: Simulation of out-surge transients and optimization procedure to design scaled experiments. Progress in Nuclear Energy 50 (2008) 730e739.

[35] https://www.doc.ic.ac.uk/~nd/surprise_96/journal/vol1/hmw/article1.html.

[36] E.O. Moeck And H.W. Hinds." A Mathematical Model Of Steam-Drum Dynamics" Presented At The 1975 Summer Computer Simulation Conference, San Francisco, And July 21-23, 1975.

[37] Nibal Fadel Farman , Shaymaa A.Mahdi And Zeina Ali Abdul Redha ,Mathematical Analysis Of The Transient Dynamic Of Surge-In Or/And Surge-Out Of The Pressurizer Of Pwr. Doi 10.5013/Ijssst.A.18.04.05.