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COMPARISON OF LOAD FOLLOWING CAPABILITIES OF VARIOUS TYPES OF COMMERCIALLY PROVEN NUCLEAR POWER PLANTS AND THEIR IMPACTS ON THE GRID SYSTEM RELIABILITIES

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A B S T R A C T

The load following capabilities of different types of reactors and their impacts on grid system is one of the dominating factor in addition to various other complex constraints and characteristics in making the selection of a power reactor. All the nuclear power plants are required to be operated on base load but in order to meet load changes in the grid these plants are also required to have load following capabilities. The capabilities are limited because of nucleonic characteristics of the reactor core, fuel behaviour and problems associated with the rapid temperature changes of the plant materials.

Pressurized Water Reactor (PWR) system is usually designed to be capable of making step changes in load of 10 percent of rated power and ramp changes of 5 percent per minute of rated power. It is able

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of following a reference 12-3-6-3 daily load cycle consisting of 12 hours at full power, decreasing load to 50 percent power level over a 3 hours period, remaining at 50 percent power for 6 hours and returning to full power over a 3 hours period. This load cycle can be followed daily through all the fuel cycle. PWR is normally capable of accepting 50 percent load rejection from rated power without reactor trip and can be designed to accept complete load rejection without reactor trip. PWR plant takes 13 hours to go to full power if started from cold condition and only one hour from hot condition.

In case of Boiling Water Reactors (BWR) a typical cold start takes about 6 hours, and a hot start about 1½ hours. The BWR has unique feature because its power level can be varied over a power range of 25% by adjustment of the reactor recirculation flow without any movement of control rods. This method allows for load following at rates of upto 1% of the rated power per second. A load change rate of about 20 MWE per minute is attainable using control rod movement, which is the normal method of making large changes in reactor power for daily or weekly load cycles. BWR is capable of accepting full load rejection without reactor scram.

Normal loading rate in case of Heavy Water Reactor (CANDU type) is 3-5% of full power per minute. This way it takes 6 to 9½ hours to go to full power from cold condition and 1-2 hour from hot condition. During steady state operation load can be changed of 30 MWE/minute only to 60% of operating power level without poisoning out, which sets a limitation for cyclic operations. In case of reactor scram from full power the plant must be re-loaded within about 40 minutes to avoid reactor poison out, which may last 36-40 hours.

Such load following capabilities of these proven types of reactors and their impact on the reliability/manoeuverability of grid system would be highlighted in this paper.

INTRODUCTION

The energy crisis has commanded worldwide attention for the last few years. In view of the several surveys/studies of energy sources and the analysis of the flood of information has made it clear that nuclear energy offers positive assurances for an expansion of our energy resources on the near or long term basis.

Alternative sources of - energy - solar, wind, tides and geothermal - are not now competitive and others cannot meet future needs. The new methods of utilizing coal will help, but the only viable solution for the future problem is to shift our energy base to a nuclear - powered electrical system.

Major question is: can nuclear power plants for generation of electricity be constructed to meet the standards of reliability?

DEVELOPMENT OF NUCLEAR POWER PLANTS

During the last 25 years tremendous developments have taken place in the field of nuclear power industry. The nuclear energy-although latest fuel-but has vast potentials. Therefore, nuclear power has been becoming the back-bone of electrical energy economy throughout the world.

During the period 1954-65 several promising nuclear power systems emerged which bridged the gap between prototypes and industrial plants. The decade from 1965 to 1975 was marked by the rapid introduction of large nuclear power stations in the electrical grids of several industrialized countries and the construction of a few small and medium size plants in some developing countries.

In 1956 there were only two nuclear power reactors with a total capacity of 7.4 MWe only in two different countries through the world. By 1965 there were 45 nuclear power plants operating in 9 countries with a total installed capacities of 4887 MWe. In 1975, the number of nuclear power reactors in operation was 180, with a total generating capacity of 76,000 MWe in 19 different countries. This way nuclear power contributed about 5% of the total installed electric capacity of the world.

The competitive economic advantages of nuclear power has markedly improved because of the rise of the prices of fossil fuels. Partly as a result of this, new orders for nuclear power plants rose by 25% in 1974 but because of the problems of financing of a nuclear-based electricity generating system and the decline of world economy, there has been a

tendency of slow down in the rate of growth of nuclear power. The latest forecast of the nuclear installed capacity made on the basis of the International Atomic Energy Agency (IAEA) and its percentage share of the total electric generating system of the world is shown below:-

*Forecast of installed total Electric & Nuclear Capacities (in thousands of MWe)

	1975	1980	1985	1990	2000
Electrical	1600	2300	3200	4500	8900
Nuclear	76	220-250	460-850	1300-1900	3600-5300
Percentage share of nuclear (%)	4.8	10-11	18-27	29-42	40-60

IMPACT AND IMPORTANCE OF NUCLEAR POWER ON THE GRID SYSTEM RELIABILITIES

As given in Figure 1 & 2 the projections of nuclear capacity show a very rapid increase in its share of total installed electrical capacity. The Figure 3 shows contributions of various primary energy sources to electricity generated by the year 2000. It is expected that by the end of the century the nuclear energy would generate almost half of the total electric energy of the whole world. It is also becoming obvious that nuclear energy would be the second largest primary energy source, surpassed only by oil.

There may be some uncertainties in these estimates but the current energy situation would cause many countries to revise their nuclear power programmes upwards. The above estimates and forecasts are fairly representative at least upto 1990 because these are based on the national commitments and firm planning. Nevertheless, it is clear that nuclear energy is expected to play a major role in the world's future energy supply and would have large impact upon the system reliabilities of the grids.

In view of the major share of nuclear power plants it is pertinent that these are reliable in all aspects so that their is minimum disturbance in the electrical grid.

Distribution of unit sizes of additions of nuclear power plants, in developing countries, during the period of 1981 to 1990 is shown in

*Note:- This paper was prepared in 1976; therefore some forecasts are outdated.

Figure 4. It is estimated that almost 80% of the new plants built during 1981-90 will be of sizes 600 MWe and above. The remaining 20% which would be about 150 units will be of sizes below 600 MWe. Sizes and generating capacities of reactors have increased to more than 1100 MWe and even larger sizes are being contemplated. These rapid increases have been followed by increased complexity of design and operational procedures while the need for higher reliability has been stressed by the public and power industry.

Therefore the introduction of bigger unit sizes and higher contribution of nuclear plants have larger impact on the electrical grid reliabilities.

MIXTURE OF DIFFERENT TYPES OF NUCLEAR POWER PLANTS

There are various types of nuclear power plants differing from each other because of types of their coolants, moderator, fuel, control, steam quality, system pressure and temperature etc. Broadly speaking there are seven different types of nuclear power reactors.

There are several promotors and suppliers of these reactors which in turn place their own innovations and commercial touch. At times, it is quite possible that reactors which have little experience may look most attractive because the natural enthusiasm of their proponents will highlight the advantages of the system while the difficulties and limitations may not have been discovered because of lack of experience. Then there are rapid changes and fast improvements in the technology. This way all these different types of nuclear power plants having various complex characteristics and parameters are plagued by so many constraints which make the task of selection of a particular type of plant quite difficult.

Some of the reactor types are still in the demonstration and prototype stages. Their load following capabilities are not so well established and also many such plants will not be constructed till the year 1990. So those will not be discussed in more details.

Two light water reactor types (i.e.) pressurized (PWR) and boiling water (BWR) and one heavy water reactor type (CANDU HWR) have been declared to be commercially proven reactors. The mixture of three types of reactors will contribute major portion in the generation of electricity as may be seen in the following Table. Therefore the load following

capabilities of their standardized design of reactors will be discussed in more detail.

MIXTURE OF DIFFERENT TYPES OF REACTORS' INSTALLED CAPACITY (GWe)

	1976	1980	1985	1990	1995	2000
1) PWR	39.4	115-132	308-400	540-780	840-1260	1020-1620
2) BWR	23.4	75-90	200-273	424-585	580-917	714-1090
3) HWR	3.2	11	23-29	46-62	73-104	101-147
4) FBR	0.6	3.5	5-6	43-57	247-348	856-1228
5) HTGR	0.3	2	10-12	43-57	116-163	206-302
6) GCR/AGR	9.5	13	13	13	13	13
7) SGHWR	0.4	0.4	4.4	4.4	4.4	4.4

FACTORS AFFECTING LOAD FOLLOWING CAPABILITIES OF NUCLEAR POWER PLANTS

Major factors which affect the load following capabilities of nuclear power plants are the nuclear characteristics of the fuel core and the thermal behaviour of the plants materials. These are briefly described as below:-

1) Reactivity in the nuclear fuel core of the reactor (permanent fuel and on power fuelling).
2) Effects of changes of reactivity because of change of temperature, pressure, voids etc.
3) Effects of build up of fission products especially xenon and iodine.
4) Effects of absorber rods and booster rods.
5) Effects of other reactivity regulating systems like injection or removal of nuclear poison materials, hydraulic control rods etc.
6) Fuel behaviour under stresses of temperature variations.
7) Therma_ stresses and strains of reactor materials.
8) Turbine loading rate limitations.

9) Effects of radiation and environment factors.

10) Plant safety and protection systems.

11) Fuel (replacement) loading programmes (i.e.) fuel management.

12) Maintenance and repair of plant equipment.

13) Cold and hot plant heat up rates.

NUCLEAR POWER PLANT CONTROL SYSTEM

Plant Control System

The overall plant control system is similar to that used in conventional steam plants. Digital computers are used to perform all the control and monitoring functions.

Plant control requires the pressure in the steam drum of the steam generators to be kept relatively constant. Two operational modes are available; as shown in Figure-5.

Normal mode (reactor follows plant loads)

The turbine-generator load is set by the operator. The steam generator pressure control programme requests variations in reactor power to maintain drum pressure constant. For example a frequency drop would cause the turbine control valves to open further. The resulting drop in steam drum pressure would cause the steam generator pressure control programme to request an increase in reactor power.

Alternate mode (turbine follows reactor)

Reactor power is controlled to a set point supplied by an operator. The steam generator control programme manipulates the plant loads to keep steam drum pressure constant. This mode is used:

- At low power when the steam drum pressure is insensitive to reactor power.
- Upset conditions where it may not be desirable to manoeuver reactor power.

Turbine load control programme

The turbine load control programme or unit power regulator changes turbine load as demanded by the local operator or by a remote load Control Centre. The programme maintains generator output at the desired set point.

Steam generator pressure control programme

The steam generator pressure control programme controls pressure to a constant set point by changing the reactor set point or by adjusting the plant loads. The programme also controls the primary heat transport system warm-up and cool-down.

Steam generator level control programme

This programme manipulates the feedwater valves in order to maintain the water level in the steam generators at a set point dependent upon reactor power.

Reactor regulating system programme

This programme monitors various power demands to determine the reactor neutron power set point, and adjusts the reactor's reactivity devices to maintain power at that set point.

Keeping in view the above mentioned factors theoretically the nuclear power plants can be made to follow any load changes. There is a wide margin between the normal operating power and the power at which reactor safety becomes a consideration, but fundamental requirement of the system is an economic one. While designing nuclear power reactor one has to keep in view various practical limitations and economical considerations. This makes the major difference in the load following capabilities of different types of reactors as explained below:-

NUCLEAR POWER PLANT OPERATION

The ability of a generating unit is to operate on a system may depend on the method selected for the loading of the unit, and how it shares load with other units during normal and transient conditions. Important consideration is plant operation relates to the ease and stability with which swings in power can be accommodated during the operating cycle.

In brief procedures for nuclear plant operation is described which is more or less common for all types of reactors.

Cold Startup:

A procedure for a normal cold startup is summarized as follows. This information is presented to indicate the nature and scope of the programme. Details may be modified as the final planning and execution progress.

- Prior to actual startup, a complete and detailed list is verified to ensure that all equipment and systems are in proper conditin for operation, that all safety circuitry and interlocks are operative and in service where applicable, that valve and control settings are proper for startup, and that the reactor is properly filled with water. The reactor protection system and the neutron flux level scram sensors are set to operate to protect the reactor in the event of an off-standard condition. The actual startup then proceeds.

- The reactor is brought to critical by withdrawal of control rods in a prescribed sequence.

- To avoid developing undesirable thermal stresses in the reactor vessel walls, power is adjusted to maintain a competent metal temperature rate of rise not to exceed 100 F per hour.

- Recirculation, condenser, circulating, and other pumps are started.

- Cleanup system is started.

- Turbine is put on turning gear.

- The steam seal regulator is placed in service.

- Vacuum pumps are placed in service.

- Air ejectors are placed in service when sufficient steam pressure is available.

- Feedwater flow and/or blowdown is adjusted as required to maintain the proper water level.
- Warming of turbine valve chest begins.
- As system pressure increases, the pressure regulator is adjusted upward until the operating pressure is reached.
- The turbine generator is brought to speed by admitting steam into the turbine.
- The turbine generator is synchronized and lightly loaded.
- The electrical load is increased to the desired value. This is accomplished by control rod withdrawal and recirculation flow increase to establish the desired steam flow rate.

Hot Startup:

Whenever the plant has been shut down for a short period of time and the reactor vessel and auxiliary systems remain at or near operating temperature, a hot startup procedure is followed to return the plant to service. This procedure is essentially independent of the cause of shutdown, assuming that the cause is recognized and all non-standard conditions have been corrected. The reactor instrumentation is reset and downscaled as required, and a hot startup check list is completed prior to the withdrawal of control rods. The startup proceeds in a manner similar to the normal cold startup procedure outlined previously.

Full Power Operation:

Normal power operation of the station, including adjustment to rapid load changes, is controlled by the manual or automatic adjustments of control rods are used to shape core power distribution and to change reactor power levels due to daily load requirements.

PRESSURIZED WATER REACTOR (PWR)

Reactor Fuel and Reactivity System:

Standardized series of PWR plants have core of multiregion type

and its fuel is shuffled once a year. Fuel assemblies having the highest enrichment are placed on the periphery of the core and those with lower enrichment are mixed in the central region of the core. Their enrichment ranges between 1.9 to 3.2% of U-235 depending upon the design and arrangement of core. Reloading of fuel every year consists of removing one third of the spent fuel from the core, relocating the depleted fuel in the central zone, and placing new fuel on the core periphery.

Rod Cluster Control consists of neutron absorber rods. It is used for reactor startup, to follow load changes and to control small transient changes in reactivity by raising or lowering it in the reactor core.

Control rods provide rapid reactivity control while the boric acid concentration is varied to control long-term reactivity changes as well as for emergency shutdowns. The combination of chemical shim and control rod clusters provide overall reactivity control. Estimated startup time required is given in table below:-

TABLE

ESTIMATED STARTUP TIME IN HOURS REQUIRED BY REACTOR

Operation	Hot*	Cold**
1. Raise primary system pressure to 400 psig and raise pressurizer temperature to saturation at 400 psig.	-	6.5
2. Drain pressurizer to no-load operating level, maintaining a system pressure at 400 psig.	-	2
3. Withdraw rods to criticality and raise output to power range level.	0.5	0.5

Operation	Hot*	Cold**
4. Raise Reactor Coolant to no-load conditions (T_{avg} = 557°F, system pressure 2250 psia).	-	3.5
Secondary plant operations, such as drawing a vacuum in the main condenser and rolling the turbine, can be done before the coolant reaches no-load conditions.		
5. Raise the reactor output to full power (5 percent per minute).	0.5	0.5
Total	1.0	13.0

* Hot ——— 557°F reactor coolant temperature, 2250 psia, no-load pressurizer level.

** Cold—— Less than 140°F reactor coolant temperature, 140°F in pressurizer.

Load Follow Capability:

The reactor and its control system is designed to the following basis:-

1. The reactor is capable of following load changes automatically throughout the range of 15 percent to 100 percent of rated power. This capability exists throughout the life of the core.

2. The reactor is capable of automatically making step changes in load of 10 percent of rated power and ramp changes of 5 percent of rated power per minute.

3. The reactor is capable of following a reference 12-3-6-3 daily load cycle consisting of 12 hours at full power, decreasing load to 50 percent power level over a 3 hour period, remaining at 50 percent power for 6 hours and returning to full power over a 3 hour period. This load cycle can be followed daily through all of the fuel cycle.

4. The reactor has a reserve capability of returning to full power at the design ramp rate at any time during the reference daily load cycle through at lease 85 percent of the equilibrium fuel cycle (i.e. minimum burnup of 11,000 MWD/MTU).

5. The reactor is capable of accepting 50 percent load reduction from rated power without reactor trip. This capability is based upon the ability of secondary plant systems to accept 40 percent steam dump and to maintain adequate feedwater supply to the steam generators.

6. The reactor is capable of accepting complete load rejection from the maximum rated power level with reactor and turbine trip.

As an option, the reactor can be designed to accept complete load rejection from rated power without reactor trip and to continue producing the power required by the station auxiliary systems. This optional capability is based on the ability of secondary plant systems to accept 85 to 90 percent steam dump and to maintain adequate feedwater supply to the steam generators.

BOILING WATER REACTOR (BWR-6)

BWR-6 model of boiling water reactor plant has fuel assemblies which contain rods of four different enrichment of 1-6% - 2.8% U-235. Low enrichment uranium rods are used in the corner rods and in the rods nearer the water gap; higher enrichment uranium is used in the central part of the fuel bundle. Annual refueling includes discharge of 25% of centre core fuel assemblies; shuffle 25% of the core from outside-in and reload 25% of the pheripherical locations with previously channeled new fuel.

In case of BWR the steam void co-efficient of reactivity is predominent and negative at all power levels. At full power their value is 3 to 4% of reactivity.

The neutron absorber moveable control rods system is capable of providing reactivity control from the cold shutdown condition to the full load condition.

Load Following Capabilities:

The steam output of the nuclear boiler system can be changed to accommodate variations in load demands in two ways. One method is to insert or withdraw the control rods by manual operation of the control rod drive system and the other method is by manual or automatic operation of the reactor water recirculation system flow control valves.

CONTROL ROD LOAD CHANGES:

Control rods may be withdrawn or inserted in ganged groups (or individually) in single notch increments (six inch) or continuously, by use of a notch over-ride switch. When used in the single notch mode, the six inch motion requires approximately 20 seconds, including an allowance for operator selection of the desired control rod or control rod gang. When used in the continuous mode, single control rods can be fully withdrawn or inserted in about one minute, and control rod gange in about 1-1/2 minutes.

Control rods can be withdrawn from a state of minimum load (i.e. the reactor is hot and critical and the turbine-generator is synchronized, with the generator carrying unit auxiliary load at 5% to 10% rated power) to rated power in about one-half hour. Furthermore, the time required to withdraw control rods to recover from a hot scram to the state of minimum load is about one hour. Power increases or decreases with control rod maneuvering can be accommodated at an average rate of 1 Mwt/second which is approximately 2% of electrical output per minute.

FLOW CONTROL LOAD CHANGES:

By varying the reactor water recirculation flow rate, and thus varying the coolant flow through the core, the resulting change in core void content (moderator density) produces a change in power level. This provides a rapid way of achieving power increases or decreases, which is approximately @ 1% of rated power per second.

The range over which this mode of control is available is established by transient stability analysis. This has resulted in establishing the design range of 25% of the full recirculation flow power level. That is, for a given control rod pattern or setting such as those shown by the A,B,C, and D lines on Figure 4 the range is 25% of the power level achieved with full flow at that pattern. Thus, for 100% of rated power with control for configuration A, reducing flow to the lower limit point results in decreasing core power to 75% of rated power. However, if the control configuration is established at the C level, where the full flow power level is 60% of rated power, the power change available by reducing flow to the lower limit is one-quarter of 60% (or 15% of rated power), so that, at the reduced flow point, the power is 45% of rated power.

The minimum rod pattern lime in the load following range roughtly corresponds to the D curve of Figure 6. The actual limit is established to avoid the possibility of cavitation in the various elements in the recirculation system, particularly the flow control valve and the jet pumps.

Combined Load Following Capability:

Average load change rates with flow control depend upon the control rod pattern line of operation (Line A,B,C, or D of Figure 6, and the system capability can be expressed as follows:

$$LFR = \frac{P}{PO} \times \frac{PO}{100} \quad MWT/sec$$

Where: LFR is the Load Following Rate expressed in units of Mwt/sec.

Po is the rated core thermal power at the condition of full rated core flow; and P is the actual core thermal power, again at the condition of full rated core flow, for any given control rod pattern line (Lines A,B,C or D- or any other similar lines- on Figure 6)

Positive step demands of 10% rated power or less carry a response of 90% of the demand change in Po/P/10 LFR seconds.

For those positive step demands, "d" greater than or equal to 10% rated power (i.e. d $\geq$ 10% rated power), 90% of the demand change will be achieved in d/Po/100 LFR seconds. For example, from an operating

condition on the rated rod pattern line (Line A result in achieving a 9% of rated power change in 10 seconds as illustrated in Figure 7.

For decreasing step demand, the response rates are as shown in Figure 8. Where the demand is greater than a 10% step decrease, the steam bypass valves open for a few seconds, allowing catches up to the decreased power level, at which point the bypass valves close and the balance of the step decrease is taken by the flow control system.

For demands that are not step requirements, but are ramp demands, the flow control system automatically adjusts itself to the desired ramp rate up to the elgebraic response rate (LFR).

BWR-6 incorporates a 35% turbine bypass capability, allowing a 35% rejection of load without scram. However, BWR plants have been built, and are capable of being built, with a 100% turbine bypass capability, allowing a full load rejection without reactor scram.

BWR-6 takes about 6 hours for cold start and about 1/½ hours for hot start.

HEAVY WATER REACTOR (CANDU HWR-600)

This type of reactor is fuelled with natural uranium in the cylindrical-bundle form placed in fuel channels. The fueling system is based on the power, bi-directional, push-through method. Heavy water (D_2O) is used as moderator and coolant.

Reactivity - control mechanism has adjuster rods, absorber control rods, fast poison injection, and zone control assemblies as explained below:

Adjuster rods are provided to optimize neutron flux and fuel-burnup, and to provide excess reactivity to overcome surges of xenon-135 following power reduction. The reactor is designed to develop full power with all the adjuster rods inserted.

The zone control assemblies are used to adjust the flux level in the reactor. This is accomplished by introducing light water in varying amounts in the zones to provide the local control of neutron absorption. Solid control absorbers adjust the flux level and times when greater reactivity rate or depth is required than that provided by the zone control system.

Vertical shutoff rods utilizing cadmium absorber elements are provided to shutdown the reactor under normal and emergency conditions. A fast poison (gadolinium nitrate dissolved in heavy water) is used as injection shutdown system in addition to the shutoff rods.

Since the fuel in the CANDU system is changed on-line, the principal penalty for exceeding the operating requirements is an increase in fuel failure rate and the attendant cost of earlier fuel replacement. The regulating system limits the neutron flux in which any fuel bundle is operating to 115% of its nominal rating. In certain cases the reactor cannot be loaded @ faster than 1 MW/hour beyond power level not seen by the fuel in the previous few weeks. This limitation is imposed to safeguard the integrity of fuel bundles which become structurally set if they are operated at particular power level for a long time. Because fuel has to be conditioned and set before permitting rapid power changes so difficulty arises as because of on power fuelling.

Salient features of the load following capabilities of CANDU reactor are as follows:

1. Starting from steady full power and with equilibrium xenon, the plant is able to decrease to 60% of full power at the rate of 30 MWe/min (8 minutes, approximately) and if power is increased immediately, the same rate of change of power may be employed during the power rise. After a long "hold" at 60% power, the rate of power increase will be slightly less, but the time of recovery of full power will not exceed five hours in any case.

2. Starting from 60% power, with equilibrium conditions, the plant is able to decrease to 35% of full power, and to recover to full power, at any time, at rates of power change of 30 MWe/minute.

The above capability is attained without turbine-bypass. Turbine bypass is provided on all of these plants, however, allowing dumping of steam directly to the condenser. Use of this system allows variation of turbine output to a large degree independent of reactor power, and in many circumstances such as inability of the utility to accept the full, plant output it allows the operator to avoid poison-out.

Full load rejection by the turbine does not necessitate reactor shutdown provided that the turbine bypass system, the main condenser and the feed train are operable.

After a reactor shutdown from equilibrium full power, criticality must be attained, and a power increase started, within 40 minutes to avoid poison-out. The poison-out period various from 36 to 40 hours.

Start up times of the 600 MWe HWR plant from different conditions are given below :-

1) For start-up from cold conditions and essentially zero xenon: 340 minutes to full power from zero power.

2) With a hot system, condenser vacuum established, zero xenon: 110 minutes.

3) With a cold system and maximum xenon: 440 minutes.

4) With a hot system, condenser vacuum established and with maximum xenon: 360 minutes.

CONCLUSION

Nuclear power plants are going to play an important role in the reliabilities of the national and international electrical grids as their present share of 5% would increase to about 50% by the end of the century. There are different types of nuclear power reactors but only three types like pressurized water reactor (PWR), boilding water reactor (BWR) and heavy water reactor (CANDU HWR), are commercially proven and would contribute maximum in the near future. The load following capabilities of these reactors and their impacts on the electrical grid system reliabilities is one of the dominating factor in addition to the various other complex constraints while making any selection of the type of reactor to be installed.

The reliability of a generating unit to operate in a system depends on the method selected for loading the unit and how it shares load with other units during normal and transient conditions. Important considerations in the plant operation relates to the ease and stability with which swings in power can be tolerated during operating cycle. Plant availability and reliability of nuclear and fossil fuelled plants are proved to be nearly the same in various grids.

Major factors which effect load following capabilities

of nuclear power plants are the nucleonic characteristics of the core, reactivity mechanisms, fuel behaviours, thermal stressed and turbine limitations. The load following capabilities of nuclear power plants can, in theory, be virtually infinite; however, economic restraints have dictated practical limits on the design and operation of plants. Usually such capabilities of the reactors are chosen and incorporated to suit the demands of the utility operating the plant keeping in view the entire grid system. The capabilities of nuclear power plants to follow system load are quite adequate required by most of the utility grid systems. These are capable of following a reference daily load cycles. Nuclear plants are designed to accept different levels of load rejection without reactor trip. Major drawback of nuclear plants is that they are liable to poison out for a period of 36-40 hours if they are not restarted and loaded within 40 minutes after reactor trip.

PWR is capable of accepting sufficiently large step and ramp changes in load and has shown inherent stability. It has been accepted to be the most proven and reliable to many utilities. Although boiling in the reactor core, in case of BWR plants, have shown instability; but now it has been claimed that due to strong negative void co-efficient of reactivity these plants are intrinsically stable against xenon oscillations. The ease of following load changes by flow control is a distinct BWR's advantage over other reactor types. HWR CANDU type plant have some limitations on the excess reactivity because of natural uranium fuel. The fuel behaviour also does not encourage rapid load cycling for the full power range.

It may be concluded that with appropriate design and operating conditions the nuclear power plants can follow load changes for in excess of that required by most of the utility systems. This way these contribute to the grid system reliabilities. Therefore the constraints lie not so much in the fuel resources of the world, but rather in technological and engineering problems which can be resolved as shown by scientific history.

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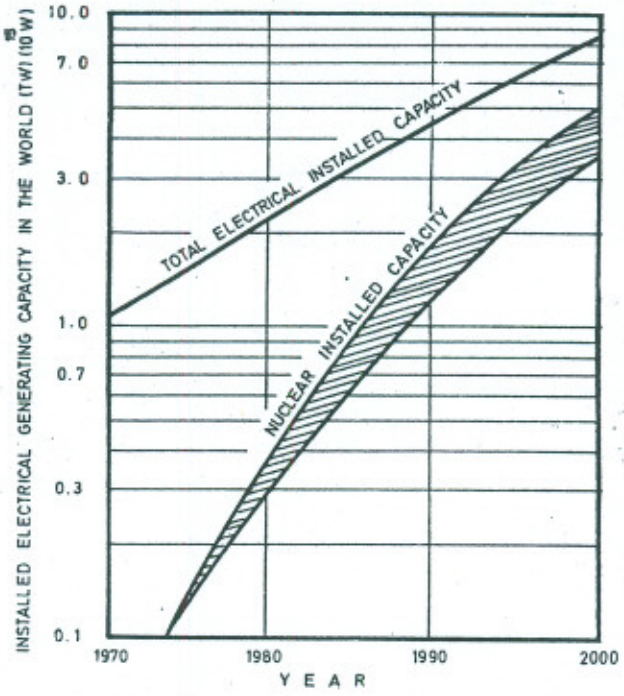


FIG.1 NUCLEAR ELECTRICAL GENERATING CAPACITY IN THE WORLD TO THE YEAR 2000

(Paper No. 442)

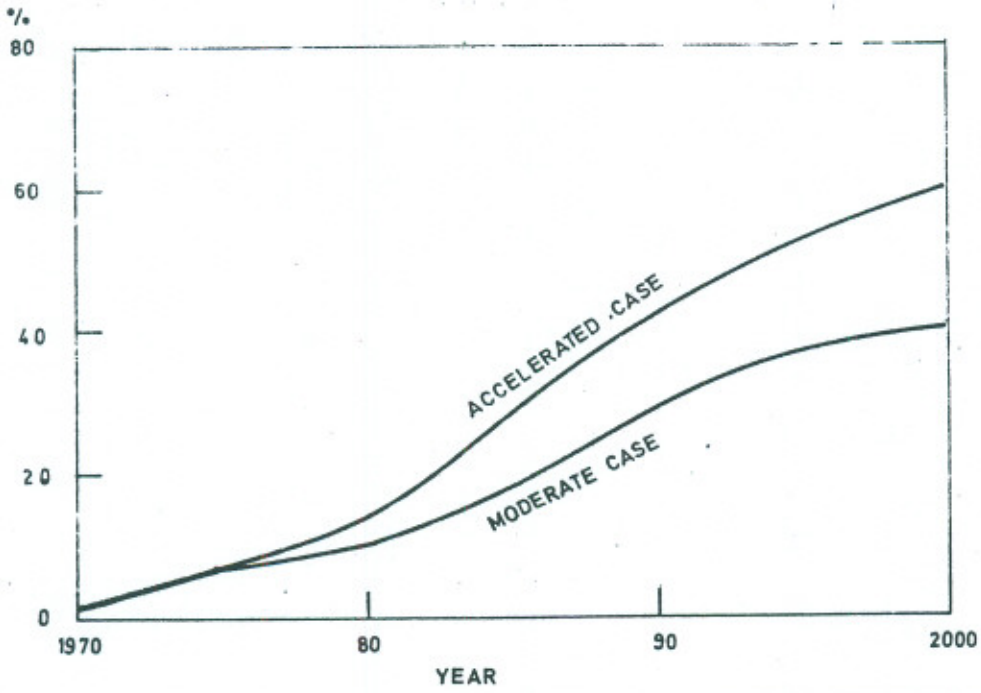


FIG. 2 NUCLEAR SHARE OF TOTAL ELECTRICITY GENERATED TO THE YEAR 2000.

(Paper No. 442)

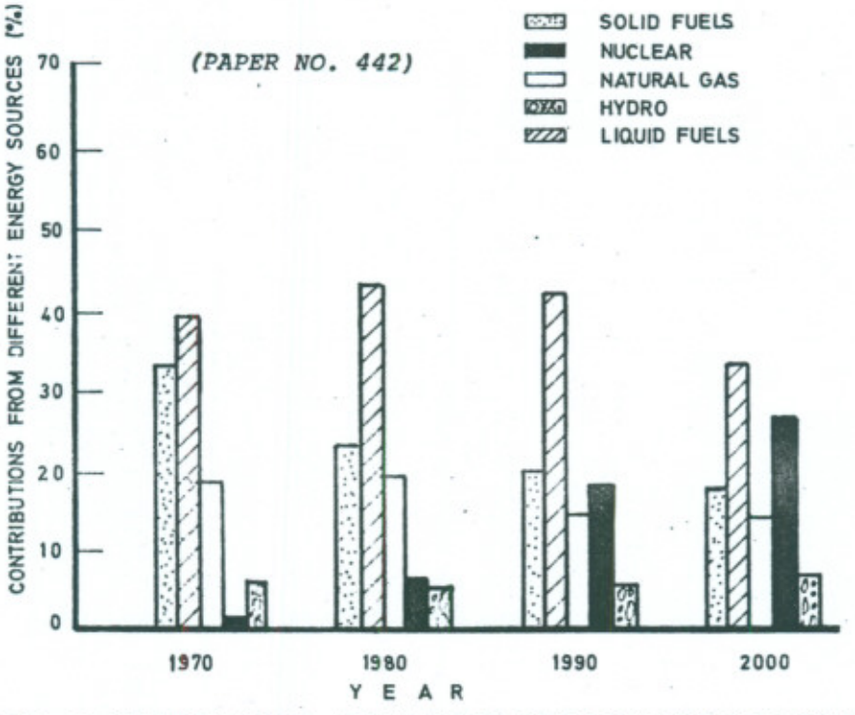


FIG. 3 CONTRIBUTIONS OF VARIOUS PRIMARY ENERGY SOURCES TO ELECTRICITY GENERATED TO THE YEAR 2000.

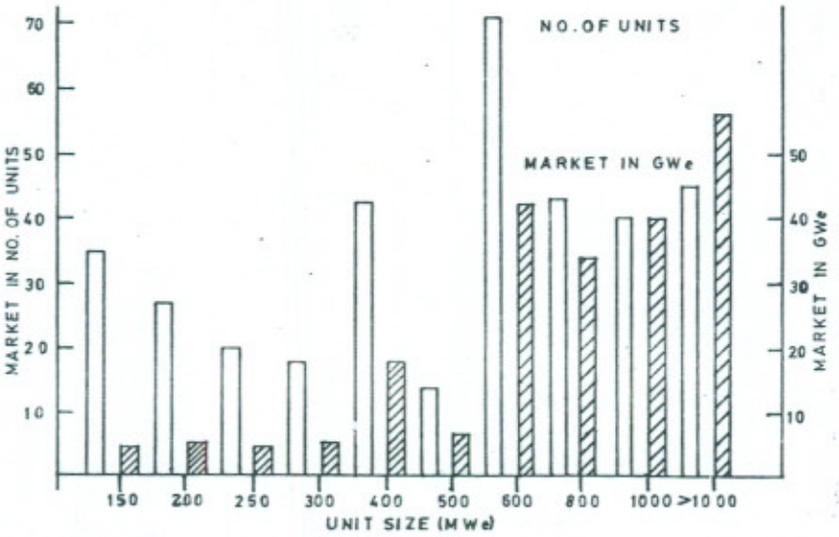


FIG 4 MARKET FOR NUCLEAR PLANTS BY UNIT SIZE
(IN DEVELOPING COUNTRIES)

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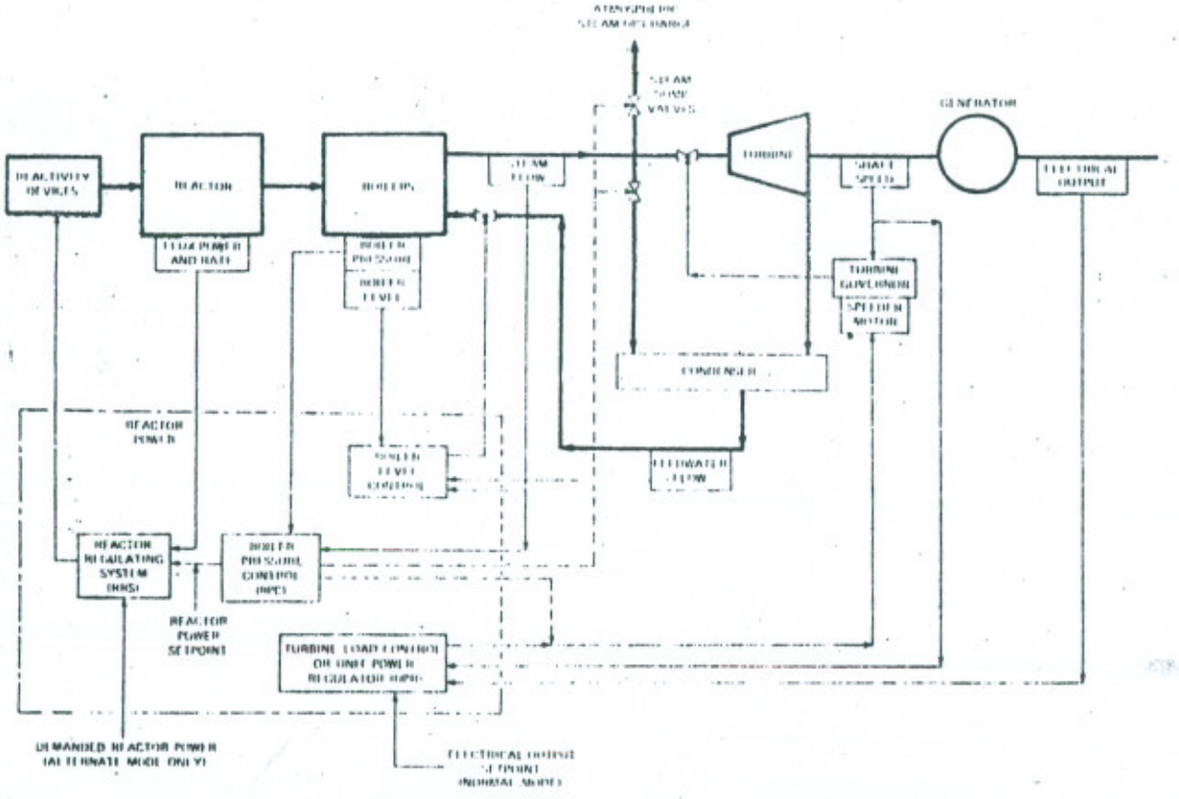


FIGURE 5 OVERALL PLANT CONTROL – BLOCK DIAGRAM

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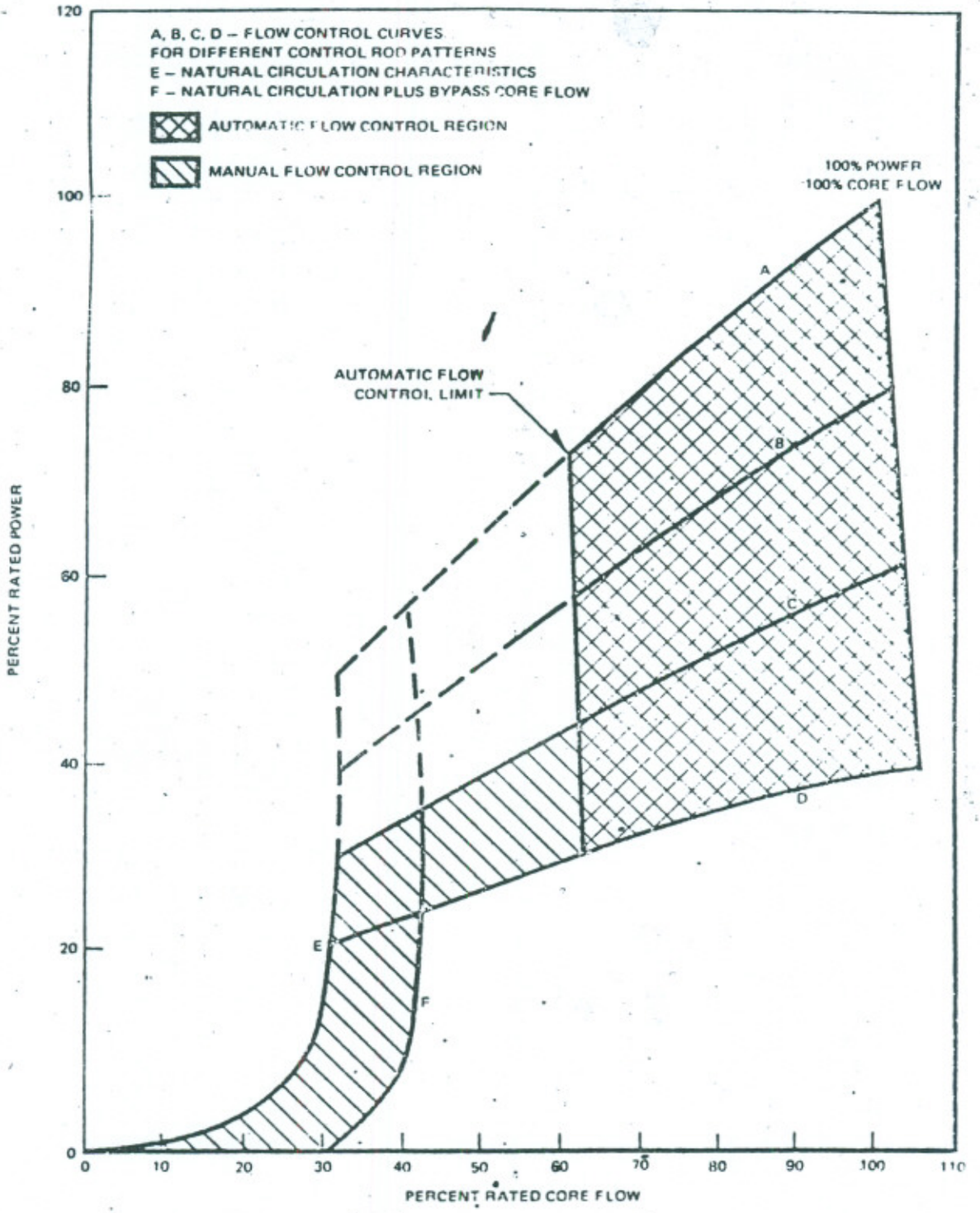


FIG. 6 POWER–FLOW CHARACTERISTICS

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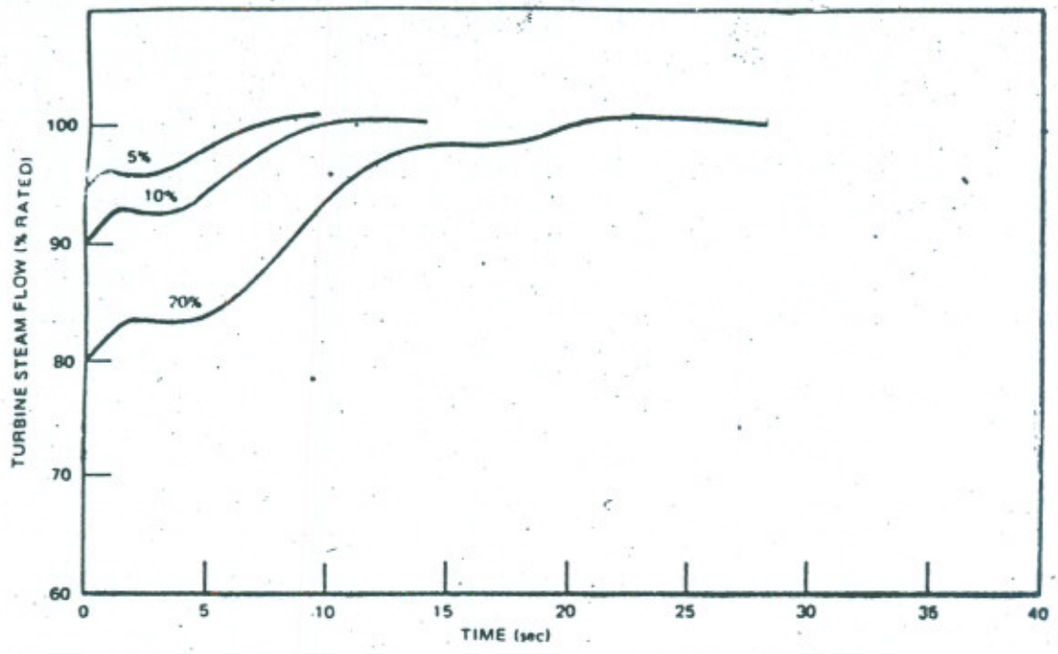


FIG. 7 RESPONSE TO POSITIVE LOAD DEMAND STEPS

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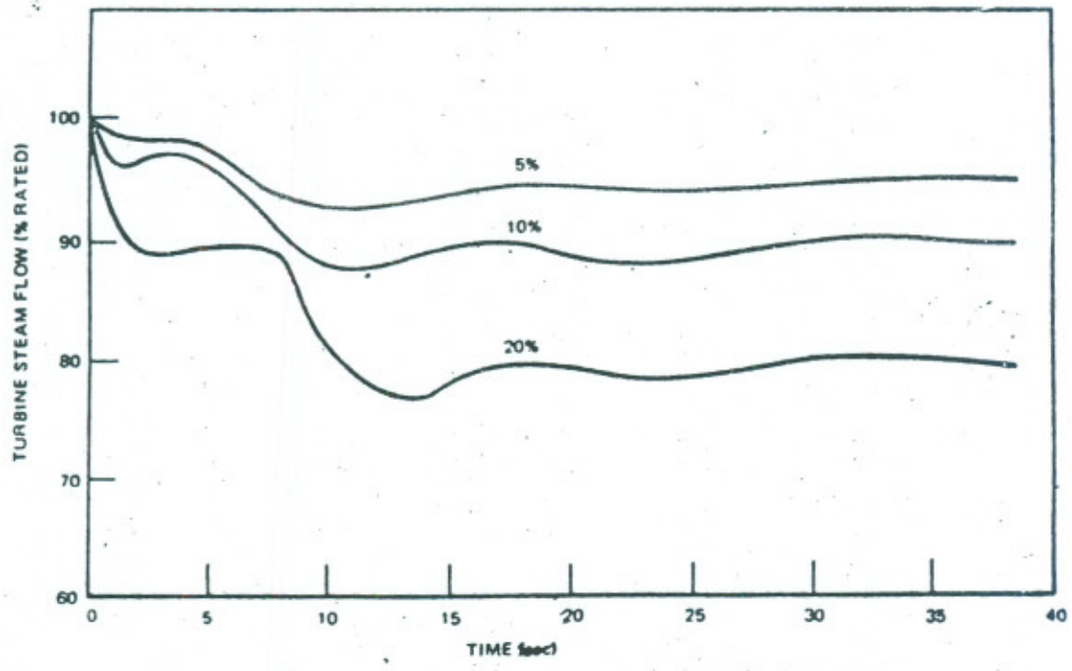


FIG. 8 RESPONSE TO NEGATIVE LOAD DEMAND STEPS

(Paper No. 442)