경상국립대학교
GYEONGSANG NATIONAL UNIVERSITY

에너지전환과 적정전원구성(BGM)

한국원자력학회
Korean Nuclear Society

2022. 07. 11. (월) 16:00-17:30

ON LINE

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Table 2. Planned power system generation mix to achieve the NZE goal

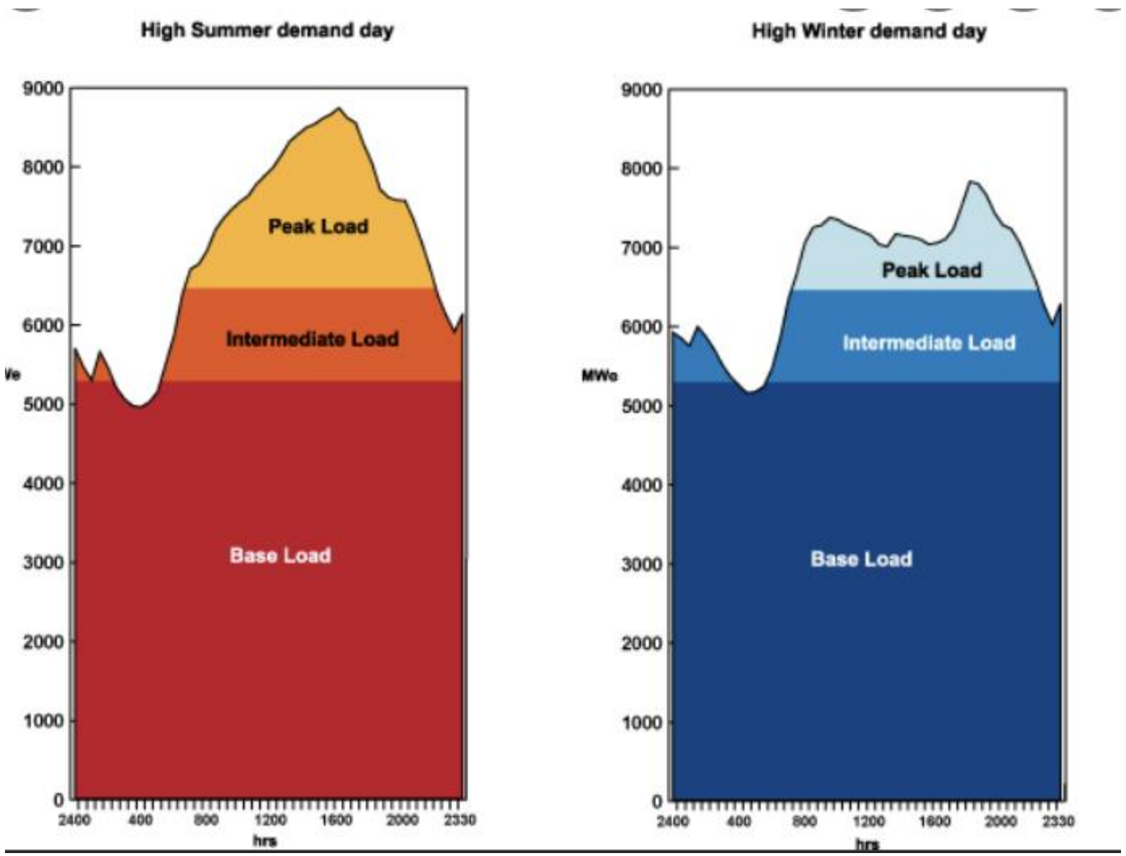
Capacity Proportion ([GW],[%])	2020	2023	2030	2034	2050
Nuclear	23.3 (18%)	26.8 (18%)	20.4 (12%)	19.4 (10%)	12 (2.8%)
Thermal	35.8 (28%)	40.4 (27%)	32.6 (19%)	29 (15%)	0
LNG	41.3 (32%)	44.3 (29%)	55.5 (32%)	59.1 (31%)	64 (15.2%)
Renewable	20.1 (16%)	34.7 (23%)	58.1 (34%)	77.8 (40%)	335 (80%)
Others	7.2 (6%)	6 (4%)	6.4 (4%)	7.7 (4%)	8 (2%)

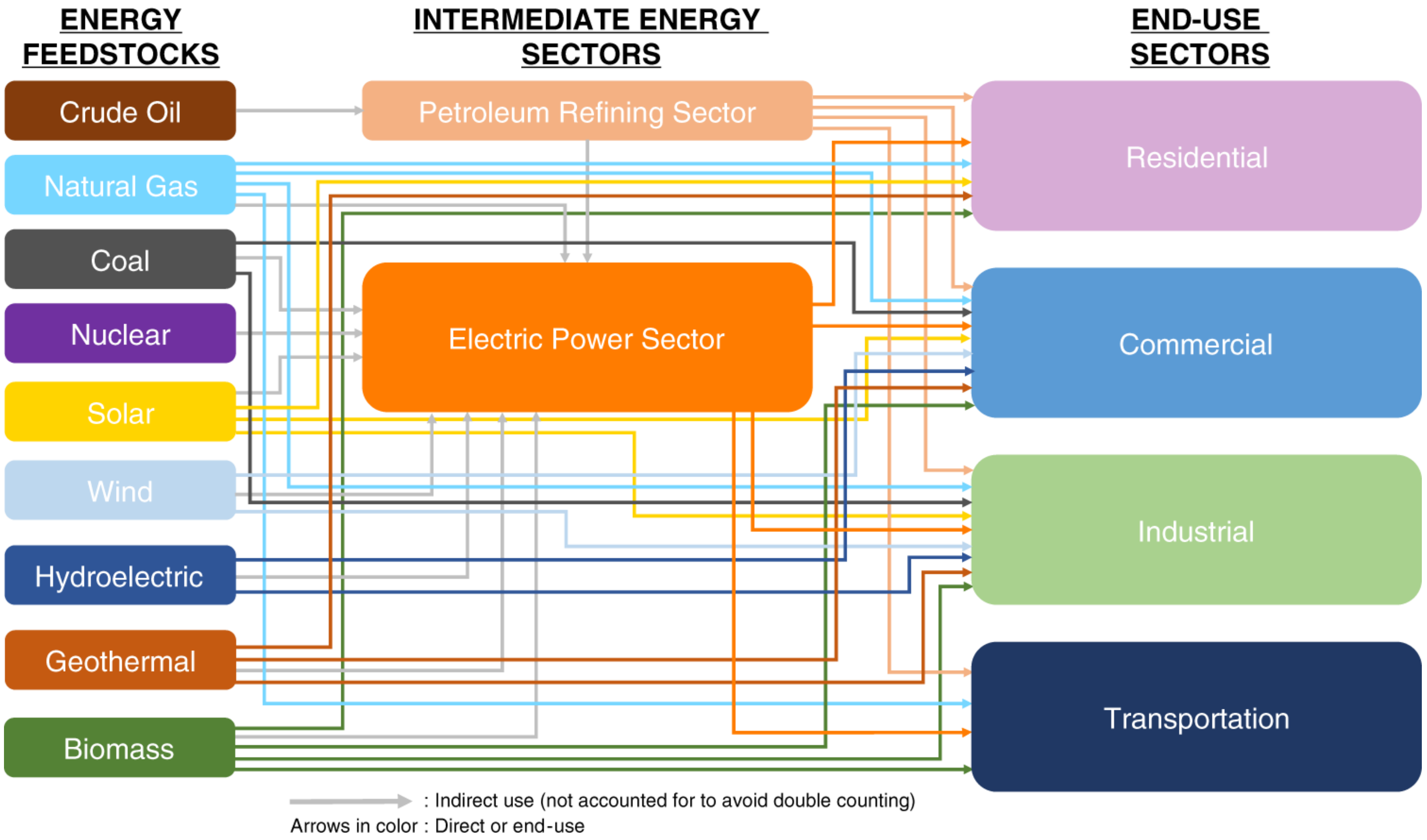
In addition, the microgrid research in Korea started in 2007. In the early days microgrid research was led by universities, research

- PART I. 전력 산업의 역사를 돌아보다.
- PART II. 적정전원구성 (BGM)
- Q&A

https://ourworldindata.org/energy-mix

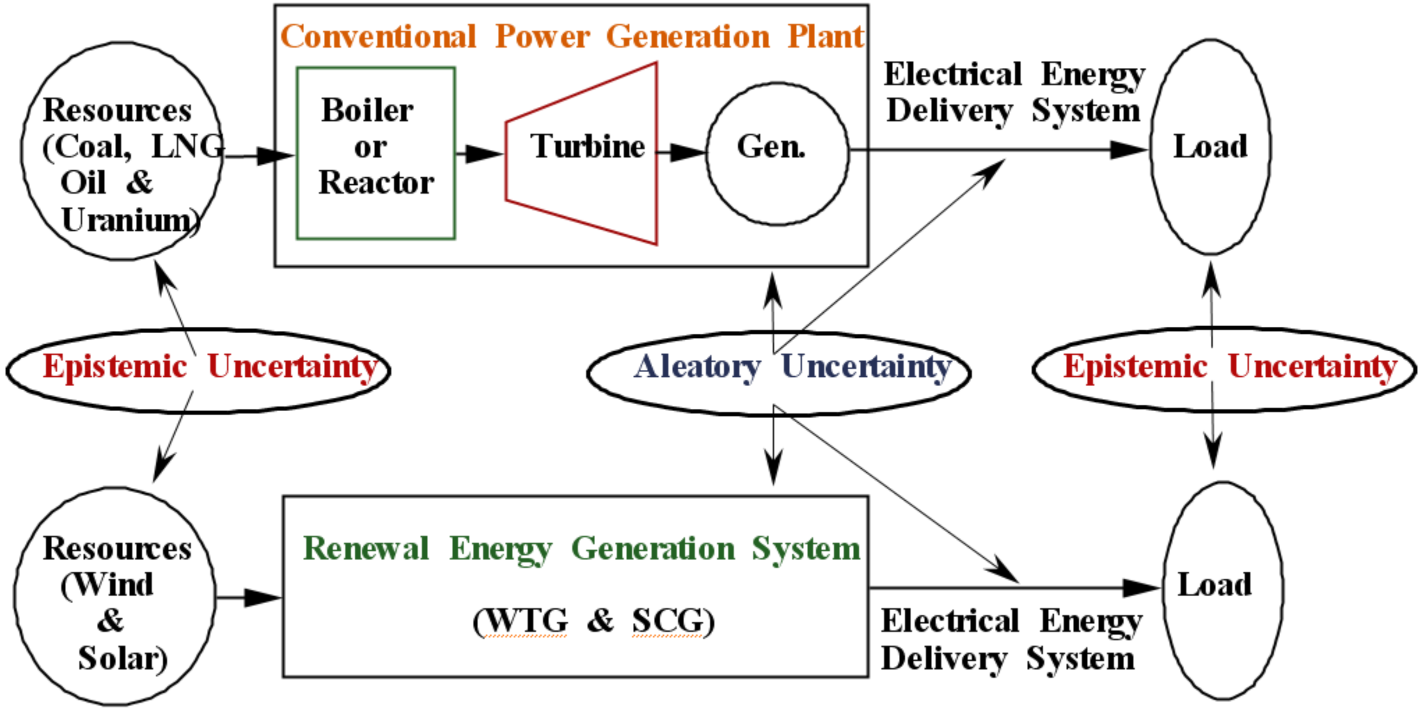
https://www.visualcapitalist.com/visualizing-50-years-of-the-g20s-energy-mix/




ENERGY FEEDSTOCKS
INTERMEDIATE ENERGY SECTORS
END-USE SECTORS
Crude Oil
Natural Gas
Coal
Nuclear
Solar
Wind
Hydroelectric
Geothermal
Biomass
Petroleum Refining Sector
Electric Power Sector
Residential
Commercial
Industrial
Transportation
: Indirect use (not accounted for to avoid double counting)
Arrows in color : Direct or end-use

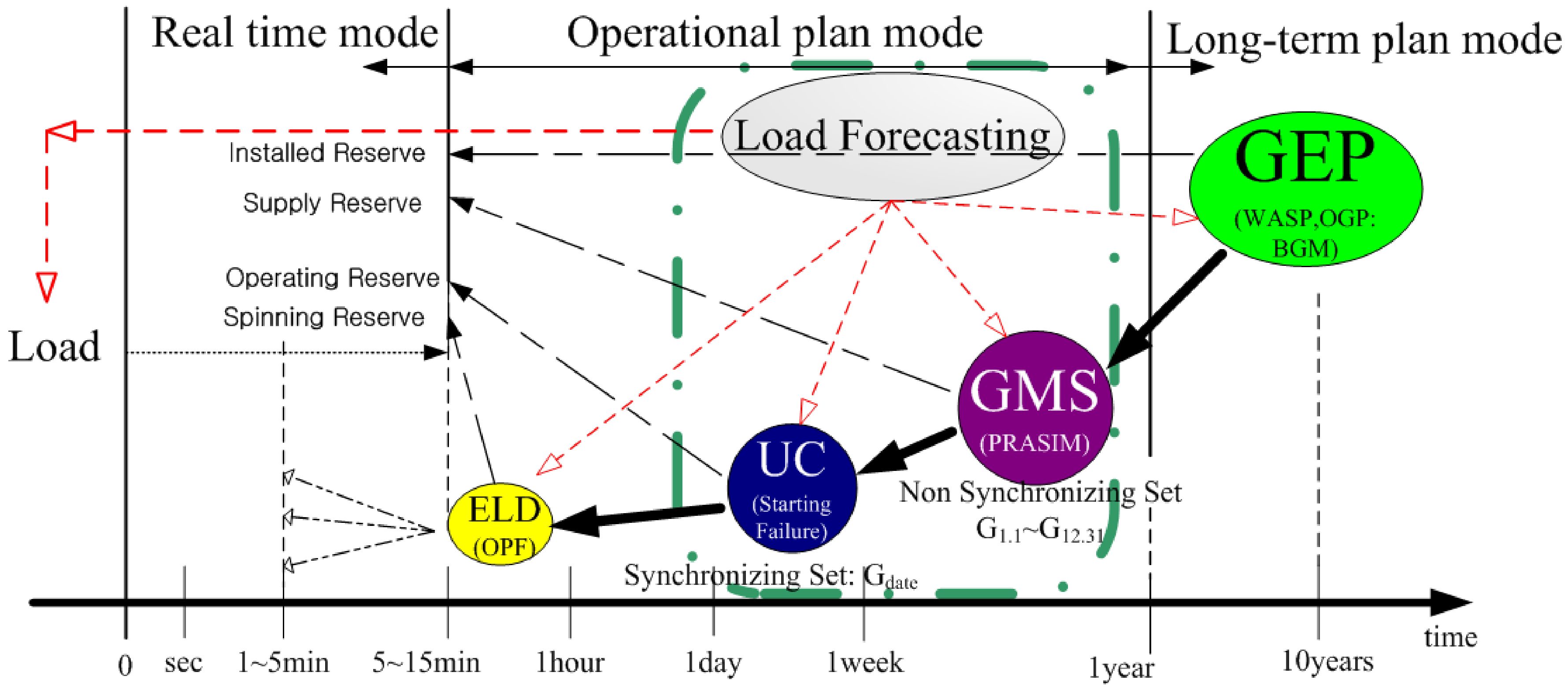
1. What is the kind of uncertainties in power system in REG?

- Aleatory uncertainty: Outage of Unit (Ex, Outage of Generator, Lines..)
- Epistemic uncertainty: Uncertainty of Information
  (Ex, Forecast of Load, Supply of Resources)*

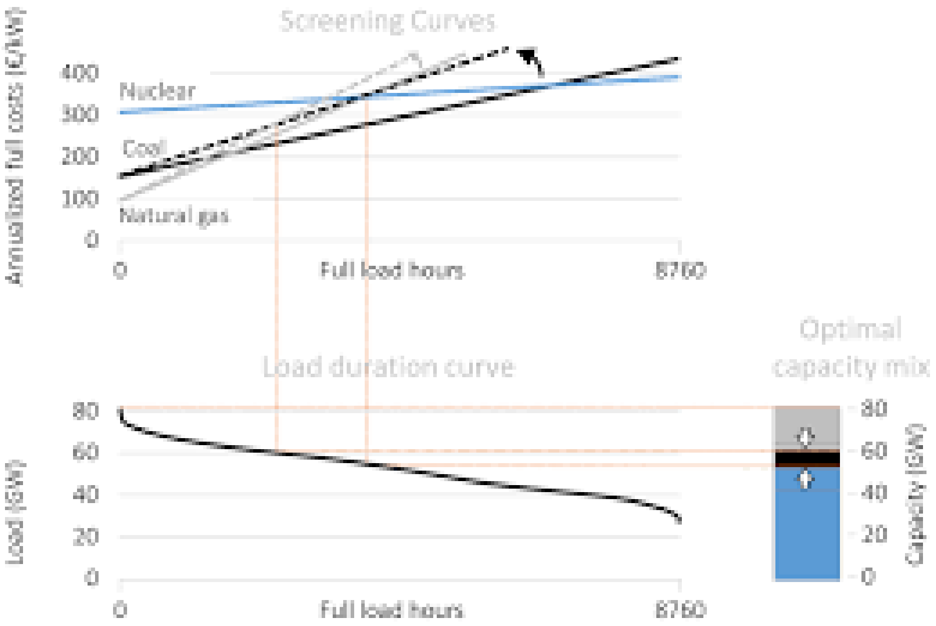


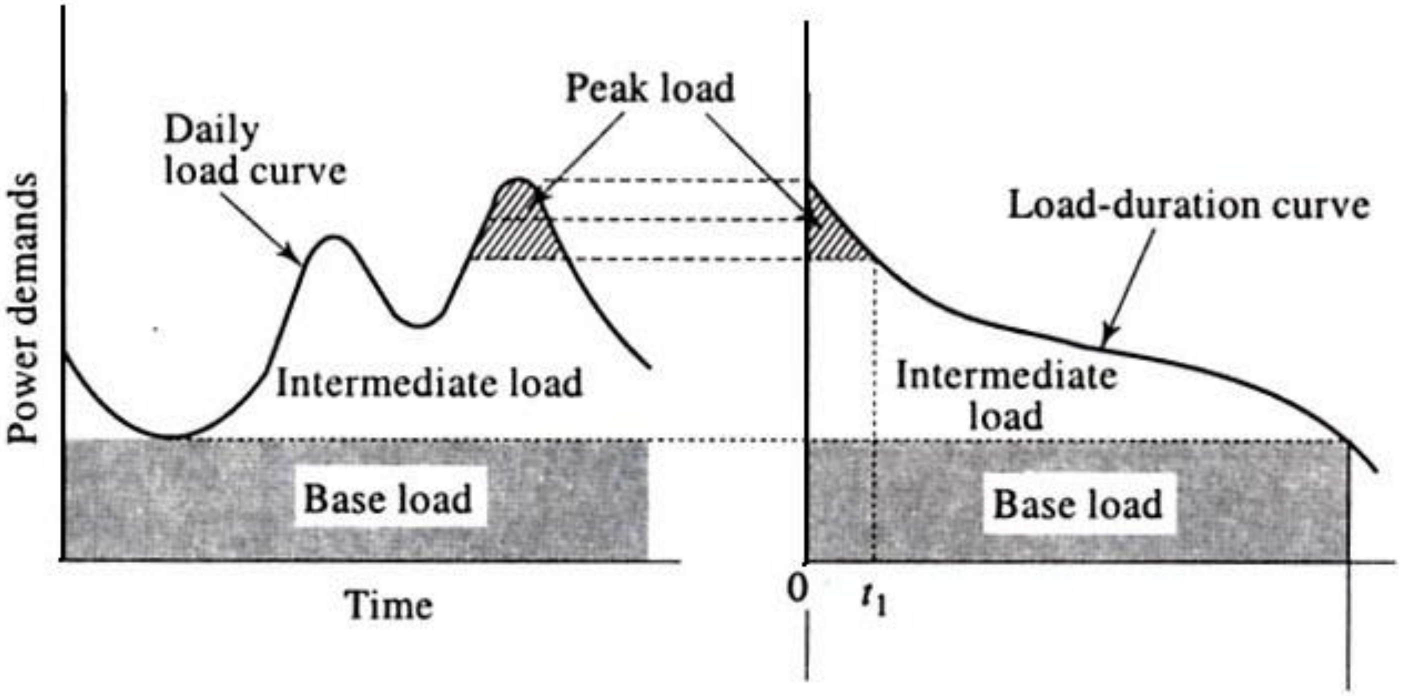
* Roy Billinton and Dange Huang, "Aleatory and Epistemic Uncertainty Considerations in Power System Reliability Evaluation", PMAPS, May 25-29, 2008.

2. Real Time & Generation Scheme



Conventional BGM: Screening Method





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25. A New Type of Line Trap for Power Line Carrier System. H. Kumlewski. Report no. 337, CIGRE, 1958.

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Determination of an Optimized Generator Expansion Pattern

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J. W. GALLAGHER
MEMBER AIEE

Summary: A series of programs developed for a small-scale digital computer, such as the IBM (International Business Machines Corporation) 650, to optimize the selection of future additions to generating capacity are discussed. Two detailed programs show how the annual load-duration curve has been adapted to propagate a series of new generator-requirement curves. These curves, giving new generation needs by type for future years, are then available for use in other programs mentioned which develop real expansion patterns and all costs associated with them.

ONE OF THE MAJOR difficulties in attempting to develop an economical generator expansion pattern has been the necessity of studying an enormous number of plans.[1-4] This paper discusses a series of programs developed for a small-scale digital computer, such as the IBM 650, to optimize the selection of future generating capacity additions, thereby minimizing the number of plans to be studied. The programs are being converted for use on a larger machine, specifically the Honeywell 800.

Paper 61-1033, recommended by the AIEE System Engineering Committee and approved by the AIEE Technical Operations Department for presentation at the AIEE Fall General Meeting, Detroit, Mich., October 15–20, 1961. Manuscript submitted June 5, 1961; made available for printing August 7, 1961.

R. J. Fitzpatrick and J. W. Gallagher are with the Philadelphia Electric Company, Philadelphia, Pa.

The authors wish to acknowledge the helpful suggestions made by W. C. Marble and R. J. Birney of the Philadelphia Electric Company regarding the digital computer approach described in the paper.

Basic Considerations

It is generally recognized that, in the past, generators have been purchased to operate in the base load area of the load-duration curve, forcing less economical generators to operate in the intermediate and peaking areas.[4] Anticipated advances in turbine and generator design may not provide sufficient improvements in the incremental operating rate to compensate for displacing very efficient existing machines and using them for cyclic operation. In addition, there is now sufficient margin among the capital costs of various types of units to warrant serious consideration of units with other than minimum operating costs. Obviously a change in philosophy is needed, and the change in philosophy presented here, though not new, is the basis on which the digital programs are built.[5]

The philosophy consists, simply, in buying capacity to fit the need at a particular time, at whatever combination of capital cost and operating cost will be most economical over the long range. Every year all areas under the load-duration curve (base, intermediate, and peaking) are growing. The need for generating capacity resulting from this growth is best satisfied by purchasing new capacity specifically designed to operate over the long range in the area of need. This policy will insure the most efficient use of existing generators, which will continue to operate economically.

Procedure

The general method of solving the problem begins with the computation of an annual load-duration curve; Fig. 1. All the capacity and energy under this curve, plus a fixed percentage reserve, are then assumed to be supplied entirely by whatever new types of generators are available for study. Each new generator

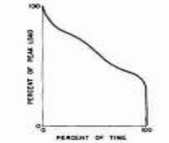

Fig. 1. Annual load-duration curve in per cent

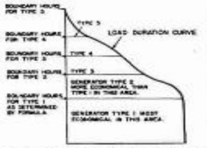

Fig. 2. Annual load-duration curve divided into most economical areas of operation for new generator types

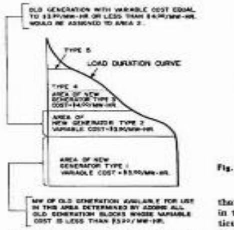

Fig. 3. Allocation of existing generators to economical areas of operation for new generator types

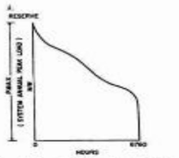

Fig. 4. Assignment of values to annual load-duration curve

type will be required to operate within a load band determined by calculating the point on the load-duration curve where the sum of annual fixed costs and annual operating costs for a given machine equals the corresponding sum for the new generator type with the next highest operating cost; Fig. 2. The purpose of this first step is to fit new generators to their economical positions under the load curve, and obtain an indication of the type of new generator to be purchased to fill areas of capacity deficits most economically.

The next step computes the capacity of existing generation to supply each por-

the load estimate for the first year of the study; Fig. 4. Existing hydroelectric capacity is inserted into the load-duration curve by calculating the number of hours required for the hydro to generate its average annual energy; Fig. 5. Each of the areas under the load curve are then studied to determine the difference be-tween the capacity required and the

that generating capacity can be bought in the exact quantity required in a particular year without affecting the price per kw of the type of generator. Of course, this assumption is incorrect. Generating capacity comes in discrete ratings, and the price per kw is dependent upon the rating of the generator purchased. Therefore, at this point in the study, it is necessary to make some adjustments.

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Fig. 1. Annual load-duration curve in per cent

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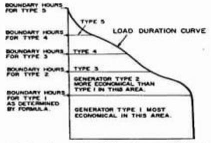

Fig. 2. Annual load-duration curve divided into most economical areas of operation for new generator types

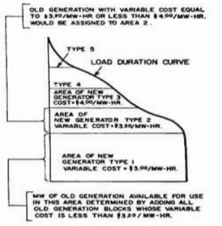

Fig. 3. Allocation of existing generators to economical areas of operation for new generator types

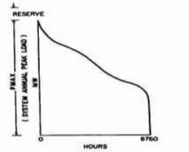

Fig. 4. Assignment of values to annual load-duration curve

type will be required to operate within a load band determined by calculating the point on the load-duration curve where the sum of annual fixed costs and annual operating costs for a given machine equals the corresponding sum for the new generator type with the next highest operating cost; Fig. 2. The purpose of this first step is to fit new generators to their economical positions under the load curve, and obtain an indication of the type of new generator to be purchased to fill areas of capacity deficits most economically.

The next step computes the capacity of existing generation to supply each portion of the load-duration curve; Fig. 3. This allocation of available capacity is based on a comparison of the operating costs of existing and new generators.

For all the foregoing calculations, the load-duration curve is in per cent of an annual peak load. A mw (megawatt) value is then placed on the curve by assigning to the 100% level the value of the load estimate for the first year of the study; Fig. 4. Existing hydroelectric capacity is inserted into the load-duration curve by calculating the number of hours required for the hydro to generate its average annual energy; Fig. 5. Each of the areas under the load curve are then studied to determine the difference between the capacity required and the existing capacity. This difference is the amount of new capacity of the particular type of generator needed in the year under study. This procedure is repeated for each year of the study. Thus, a series of optimum curves is obtained which show the exact amount of each new type of capacity required throughout the study to supplement most economically the existing capacity; Fig. 6.

Up to this point, it has been assumed that generating capacity can be bought in the exact quantity required in a particular year without affecting the price per kw of the type of generator. Of course, this assumption is incorrect. Generating capacity comes in discrete ratings, and the price per kw is dependent upon the rating of the generator purchased. Therefore, at this point in the study, it is necessary to make some adjustments.

The curves obtained are excellent guides in determining just what proportions of the various types of new capacity, base, intermediate, and peaking units, will fit most economically the system requirements. The next step is to employ a curve-fitting process to develop generator expansion patterns which will use actual generator ratings, and stay as close as possible to the optimized curves already developed. By varying the permissible upper limit of installed reserve, different expansion patterns are obtained, all of them closely matching the optimized curves, Fig. 7.

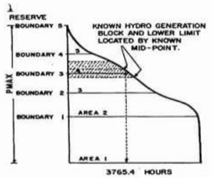

Fig. 5. Assignment of existing hydro generation to annual load-duration curve

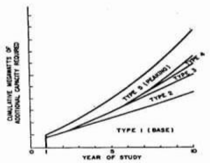

Fig. 6. Optimized curves of capacity requirements derived from Programs I and II

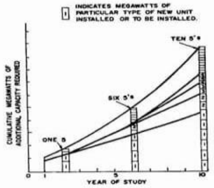

Fig. 7. Results of one expansion pattern shown for years 2, 6, and 10 of a study

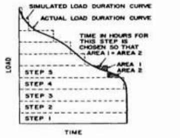

Fig. 8. Step-by-step simulation of annual load-duration curve

Finally it is necessary to make a cost comparison of the various expansion pat-

analysis. By observing the expansion pattern output of program IV, an expansion pattern can be developed around the type of unit in question so that the first and second units of the type go to the lowest cost location, etc.

Conclusions

The programs developed in this paper are useful tools in the selection of the most economical development for the electric production system.

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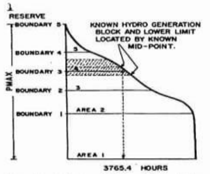

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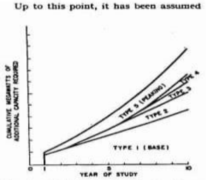

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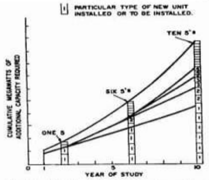

Fig. 7. Results of one expansion pattern shown for years 2, 6, and 10 of a study

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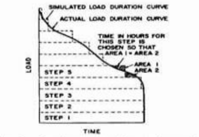

Fig. 8. Step-by-step simulation of annual load-duration curve

Finally it is necessary to make a cost comparison of the various expansion patterns. The costs computed include the fixed charges and fixed operating costs on new units, incremental, start up, and spinning costs of new and existing units, and present worth of all costs.

Very briefly the functions of the five programs designed to apply this philosophy to an electric system are as follows:

1. Program I determines the most economical area of operation for each new generator type under the load-duration curve, eliminates unsuitable generator types, and calculates the mw of existing nonhydro generation available for each of the new generating areas established.

2. Program II takes the output of program I and inserts existing hydro generation, shifts existing steam generation to avoid excesses in any area, and determines the minimum new generation requirements by type to satisfy the peak load estimate, plus reserve. Program II is repeated automatically for each year of a study.

3. Program III calculates the annual costs per year of a study using the optimized new generation requirements determined in program II.

4. Program IV develops automatically on one run up to 14 different generator expansion patterns using actual ratings of new generators. Each of the 14 plans, though different from one another, varies only slightly from the optimized expansion pattern of program II. Additional expansion patterns can be developed by conducting additional computer runs using program IV.

5. Program V calculates all costs, including the present worth, associated with a definite generator expansion pattern, such as those developed by program IV. The details for programs I and II, together with a brief discussion of programs III, IV, and V, are presented in the Appendix.

Other Considerations

Units at Different Sites: The programs discussed in this paper consider generating costs only. The problem of plant location must also be included in any final analysis. By observing the expansion pattern output of program IV, an expansion pattern can be developed around the type of unit in question so that the first and second units of the type go to the lowest cost location, etc.

Transmission Costs: Transmission costs are not included in the program computation. They must be added after generator expansion patterns have been developed. These costs are not usually known in advance, and in general are determined through load flow studies integrating the proposed generators with the existing transmission system. If, however, transmission costs in the form of dollars-per-mw are known in advance they could be included in the fixed cost of program I. The programs presented herein greatly reduce the number of transmission plans which must be considered in arriving at the final answer regarding future system additions.

Retirements: Retirements may be included in program V. Their inclusion will affect only the yearly operating costs thereafter.

Hydro Capacity: The programs were designed primarily for a system with a small percentage of existing hydro generation. They cannot be used directly to optimize the selection of new hydro generation as against steam generation, and probably would be useless for optimizing the selection of new steam generation on a system with a high percentage of existing hydro.

Other Limitations: Spinning reserve turbines, that is, turbines with a normal rating plus a short-time overload rating at a higher heat rate, cannot be handled in the optimizing portion (programs I and II) but can be handled properly in program V. Their costs can then be compared with those for the scheduled capacity additions developed by programs I, II, and IV to select the most economical pattern.

A second limitation is that, if several different sizes of units were available with different fixed costs, but exactly the same variable costs, the computer would always pick the unit with the lowest fixed cost per kw. This unit, of course, is usually the one with the highest capacity, but it may not be the most economical in the long range plan, depending on the relation of this unit size to the system peak load and system rate of load growth. This limitation, too, can be overcome by prudent application of the input data. A method for having the computer take care of this problem is presently being studied.

Conclusions

The programs developed in this paper are useful tools in the selection of the most economical development for the electric production system. These programs will greatly reduce the number of alternatives to be studied, and will provide the planner with the assurance that he has examined all practical variations of expansion patterns.

Appendix. Description of the Programs

Program I

Items of Input

A list must be made of all types of generators to be included in a study, from the high-capital-cost low-operating-cost steam turbogenerator types to the low-capital-cost high-operating-cost types, such as the diesel generator. To insure optimum results, this list should include all generator types that are expected to be available throughout the study period. Two costs are then developed for each type. The first, to be designated the variable cost in this paper, is composed of an aggregate of all costs which can be broken down to a dollars-per-mw-hr (megawatt-hour) figure. The bulk of this cost is derived from the incremental charges associated with the use of fuel and with maintenance, but can include other costs caused by the generation of electric energy. The second, to be designated the fixed cost in this paper, is composed of an aggregate of all the costs which can be broken down to a dollars-per-mw per year figure. Included in this cost would be any yearly expenses of a fixed nature associated with installed capacity, fuel, maintenance, or others. When the variable and fixed costs have been established for each generator type considered, they are arranged in tabular form in the order of ascending variable costs, and numbered from one starting with the type of lowest variable cost. These tables are then used as input to program I.

For a study, it is assumed that the shape of the load-duration curve, plotted as per cent of peak versus per cent of time, Fig. 1, will not change. The load-duration curve is simulated by representing it in tabular form as a series of percentage steps each having a definite time in hours to establish its length; Fig. 8. To conserve memory space, the number of steps used to simulate the load-duration curve is limited to a maximum of 100. Any number equal to or less than this may be used, but once the number of steps has been decided upon, it cannot change throughout a study. However, the part of the peak load covered by each step will change from year to year. For example, if 100 steps are used, then each step represents 1% of the peak of a given year. For a peak of 3,500 mw, a step covers 35 mw, but later in the study for a peak of 10,000 mw, a step will cover 100 mw.

At the beginning of a study, existing

system steam generation is supplied to the computer as a table of convenient blocks of megawatts, again due to memory limitations. One method of obtaining a convenient block would be to sum up all the ...

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At the beginning of a study, existing

system steam generation is supplied to the computer as a table of convenient blocks of megawatts, again due to memory limitations. One method of obtaining a convenient block would be to sum up all the mw of steam generation on the system, regardless of location, which have the same variable cost. The blocks are listed in the order of ascending variable costs and numbered from one, starting with the block of lowest variable cost.

Four single items complete the input to program I. They are the number of new generator types to be studied, the number of the last group of existing mw, the number of the last or top step used to simulate the load-duration curve, and an availability factor. The last mentioned is a decimal figure which reflects the probability of scheduled and forced outages of installed capacity. In program I, the availability factor is a constant throughout the entire range of the load-duration curve and is applied to all mw of capacity, new or old, used in the load area of the curve.

Program Logic

Operating on the list of variable and associated fixed costs for new generators, program I will determine the hours of annual use for which 1 mw of a new generator type will result in the same total annual cost as 1 mw of the next generator in order, starting with generators 1 and 2 and proceeding in turn with generators 2 and 3, 3 and 4, etc., until all have been considered. The formula used in this calculation is

$$\text{Hours of equal cost for 1 mw of generators } (n) \text{ and } (n+1) = \frac{\text{Fixed cost } (n) - \text{Fixed cost } (n+1)}{\text{Variable cost } (n+1) - \text{Variable cost } (n)}$$

The hours determined by this formula set boundaries between new generators under the load-duration curve because generator (n) is more economical for usage greater than this number of hours, and generator (n+1) is more economical for usage less than this number of hours; Fig. 8. Since the largest annual usage to be encountered under the load curve is equal to 8,760 hours, the program checks the boundary hours calculated for generators 1 and 2 against this figure. If the hours for generator 1 are greater than 8,760 hours, generator 1 is eliminated. The remaining generator values are renumbered consecutively in the order in which they originally were read. The program then starts over and repeats this process until a value of boundary hours for generator types 1 and 2 is obtained which is less than 8,760 hours. It then proceeds with the calculation of boundary hours for the other combinations.

As each new value of boundary hours is calculated for a pair of generators after the 1–2 combination, the program checks the value just calculated against the value previously calculated. If the value of hours previously calculated is less than the value of hours just calculated, the program eliminates the generator involved in both calculations; Fig. 9. Remaining generator values are renumbered so that no numbers are missing, and the program starts to calculate the boundary hours over again beginning with generators 1 and 2. It is necessary to start the program again to guard against the possibility that the new value of calculated hours might be greater than the last two values calculated, in which case, perhaps two generator types will be eliminated.

This editing procedure and restarting is carried out by the computer automatically. When the computer has run through all the generator combinations successfully the boundary hours for each suitable generator type are available. These boundaries indicate the load and time limits to be used for new generation of suitable types in order to obtain installed capacity yielding the lowest total annual costs, with fixed and variable costs considered.

In the next phase, starting with the boundary hours which separate new generator type 1 from type 2, program I compares the boundary hours, determined in the initial phase, with the decreasing values of hours of the simulated steps of the load-duration curve. It continues until a step is selected for which the hours are equal to or less than the boundary hours. If the step hours are less than the boundary hours, the program backs off one step. It then computes the number of steps in the area for the new generator under consideration by subtracting from the number of the load-duration step, which is equal to or slightly greater than the boundary hours, the total number of steps assigned to make this area. Record is kept of the number of the step which is the top limit of each area, assigned to particular machines.

If the difference between the boundary hours of two new generators is less than the difference between the hours of two adjacent steps in the simulated load-duration curve, the highest numbered new generator type of the two will be dropped, and the list of generator types revised accordingly. The net result is a modification of the list of generator types to eliminate only new generator types whose areas of economic operation cover one step or more will remain for further calculations.

After computing the number of steps covered by the area of a new generator, the program determines the mw of existing generation which are available for use in the area. It does this by summing the mw blocks of existing generation with variable costs less than the variable cost of the new generator of the area directly above the one being considered under the load-duration curve; Fig. 3. Each existing generation block is then reduced by the availability factor as the mw are added.

In the manner described above, program I proceeds from one new generator area to the next, computing the steps covered by each new generator area and the amount of existing generation which is available for use in this area of operation. All remaining existing generation is used up in the area of the top new generator. When data for every new generator area have been completed, they are punched out for use in later programs.

Program II

Items of Input

Three tables and two single items punched at the end of program I are used as input to program II. The tables are: first, the list of the number of steps of the load-duration curve contained in each of the new generator areas; second, the list of the numbers of the steps which are the top limit of each of the new generator areas; and third, the list of the sums of existing generator mw available for use in each of the new generator areas. The two single items are the number of new generator types being considered after editing in program I and the availability factor.

Also required for input to program II are a list of the estimated mw peaks for each year to be studied up to a maximum of 28 years, and a list of the percentage installed reserve requirements for each year. The program is not designed to develop the yearly reserve requirements. It simply acts on the percentage values which are supplied as input. The method of deciding upon a satisfactory value for these percentages is left to the user.

Single items to complete the input to program II include (1) the number of years for which the study is to be made; (2) the total capacity of hydro in mw including hydro; (3) the percentage of the peak mw which one step of the load-duration curve covers; (4) the installed capacity of existing hydro in mw; (5) the hydro availability factor; and (6) the number of the load-duration curve step which contains the midpoint of the hydro-generation band. With regard to this last item, the mw hours of hydro generation available are assumed to be used up in the load-duration curve at a point where the effective capacity operates for an average number of hours equal to the total mw-hrs from year to year until the entire hydro (Fig. 5). For example, if 507 mw of existing hydro capacity has an average yearly production of 1,702,000 mw-hrs from an average effective capacity of 452 mw, then the average yearly hours of operation are 1,702,000/452 or 3,765.4 hours, and the number of the step of the load-duration curve which has a time most nearly equal to 3,765.4 hours is used as input. If hydro generation is not to be considered, items 4–6 are zero.

Program Logic

Operating on the input data described, the program determines certain values which will remain constant for the given year starting with year one of the study. The values determined are: (1) the total mw of generation required to provide for peak load plus the desired reserve; (2) the additional mw of new generation required to satisfy the total after the existing generation is considered; (3) the mw of peak load covered by a step of the simulated

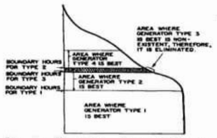

Fig. 9. Elimination of unsuitable new generator type

load-duration curve; (4) the number of steps of the load-duration curve covered by the block of existing hydro generation; and (5) the lower limit of this block of hydro generation in terms of steps of the load-duration curve.

This lower limit of the hydro-generation block is then compared with the upper limits of the new generator areas, starting with area one of new generator type 1, and proceeding upward until an area is reached whose upper limit is equal to or higher than the bottom limit of the hydro block. Portions of the hydro block are then assigned to the new generator areas into which they fall. One limitation on this procedure, which must be met, is that the hydro block cannot overflow into the reserve area. Whether it will or not can be determined prior to a study and adjustments made. With regard to Fig. 5, as the system peak load increases from year to year, the mw values of the areas will get larger while the hydro block remains fixed and encloses a constant value of mw-hrs. The apportionment of the hydro generation to the areas will therefore change from year to year until the entire hydro block falls within one area.

After the hydro block has been allocated to the proper areas, the program returns to the bottom area and calculates the new needed complexly to satisfy this area's requirements for the year being studied. It then reduces this requirement by the amount of hydro which may have been assigned to the area. If generation is still needed in the area after hydro has been applied, the program further reduces the new requirement by the amount of existing generation allocated to the area in program I. Three conditions can result: (1) the requirements of the area could be exactly satisfied; (2) the requirements may not be exactly satisfied; and (3) the requirements of the area may be more than satisfied. The program reacts to these conditions as follows:

(1) and (2). If the requirements are exactly satisfied, or not satisfied completely, the program assigns a value of new generation to the area equal to the amount needed to fulfill the area requirements. In the former case this value would be zero.

(3). If the requirements are more than satisfied, the program sets up the excess to be shifted from the area, in a manner to be explained later, and schedules the new generation requirements for the area to be zero. For some areas it is possible that the hydro assigned will completely supply the area requirements. In this case, all the old generation originally allotted to the area will be shifted and no new generation will be scheduled.

The program employs the procedure just explained to move from the bottom area to the top area of the load-duration curve, thereby developing a schedule of tentative new generation requirements by type. The schedule of new generation is tentative at this time because the values determined for a particular type could be reduced as existing generation is shifted from areas where it is in excess to areas where it is not; or, in other words, to areas where new generation has tentatively been assigned.

Reserve is treated as a separate area that requires mw of installed capacity from which no mw-hrs of generation are expected. Because no existing generation has been assigned to the reserve area by the logic of program I, and because hydro cannot be, nothing is done at this point to provide reserve generation.

Entering the next phase, two values are set up which will be referred to by the program as it proceeds again from area to area starting at the bottom area. The first value, designated TOAP, is the space above the area being considered into which existing generation might be shifted. Initially, the value is obtained by summing all the tentative new generation allotments and adding generation required for reserve. The second value set up, designated BOAP, is the space below the area being considered into which existing generation might be shifted. BOAP is equal to zero for the bottom area, but will be equal to the cumulative total of the tentative new generation allotments that are encountered as the program moves up from the bottom area through all the areas under the load-duration curve. These tentative new generation allotments will be the adjusted allotments if any prior shifts have occurred.

The next part of the program is best explained by reference to an area other than the bottom area; however, the same procedure will apply to the bottom area for which shifts must be made upward. Proceeding to this area, the program checks new generation requirements. If there are new generation requirements, no shifting must be done; consequently, BOAP is increased by the amount of the new generation requirement. TOAP is decreased by the same amount, and the program moves on to the next area.

If new generation is not required, the program checks whether there is an excess of existing generation which should be shifted to other areas. An indication of no excess will cause the program to move on to the next area. When an excess exists the program goes into the following routine:

(1). It checks for space available to shift generation below the area being considered. If BOAP is zero, it sets up the total amount to be shifted for insertion in the region above the area being considered. If BOAP is not zero, it splits the amount of excess in half and tries to shift one half below and the other half above the area being considered. If the space available in either direction is not large enough to absorb the entire half, the amounts are adjusted so that all the space is used up in the short direction, and all the shift is used up in the other direction. The program, however, first tries to shift half-and-half.

(2). The existing generation is shifted in such manner that the tentative new generation assignments nearest the area under consideration are eliminated first. Thus, the program proceeds outward, in both directions from the area being considered until the excess existing generation has been shifted out of the area. Because the generation required for reserve was included in TOAP, the program will shift existing generation into the reserve area during this phase, if available.

After the program has processed each area under the load-duration curve in this way, it computes the amounts of new generation required for reserve as the difference between the adjusted total required reserve generation, and the amount of existing generation shifted into the reserve area. By the "adjusted total reserve" is meant that amount of reserve which is still required after the total required capacity, as determined by the per-cent reserve factor, has been reduced by the total capacity already required for generation.

New generation required for reserve is assigned to the new generator type of the top area under the load-duration curve. This assignment causes the existing generation with a high variable cost to be moved into its proper spot in the reserve area during the cost calculations of program III, and compensates for the lack of an assignment of existing generation to the reserve area in program I.

The method employed in the foregoing, to shift an excess of existing generation out of an area, is necessary because the area limits were determined by types of new generators, and the blocks of existing generation do not fit into these areas in a uniform fashion. New generator blocks will never have to be shifted in this phase of the program because it is assumed, for the purpose of optimization, that any amount of any type of new generator is available to fill exactly a deficit in any area after the existing generation has been assigned and shifted.

The method, whereby the excess of old generation in an area is split in half and each half shifted in the opposite direction, is an approximation due to the differences in the incremental costs of generation and differences in time at the upper and lower limits of an area. This approximation, however, will have a negligible effect on total annual costs during a long-range study so that a more complicated approach is not justified. The tendency in the past to install base load machines will probably result in the largest shift of existing generation being encountered in the base load area. Shifting upward from this area causes no error, and no shifts can be made downward. Furthermore, the program starts over each year to determine the best generator assignments for that year, and is not influenced by what was done the previous year. This approximation, therefore, will occur only during the first few years of a study. After that, the areas will grow in mw requirement while the existing generation remains constant, and there will be no excesses to be shifted.

After the program has shifted the existing generation excesses and determined the reserve generation requirement, it has effectively set up a complete schedule of optimized new generation assignments which will satisfy the total new generation requirements of the particular year and which will yield, in conjunction with the existing generation, a value for total annual cost of generation that will approach the minimum. The whole procedure of program II is then repeated for each year of a study.

Program III

Program III is much the same as program V and the main features of the two will be discussed later under program V. The one difference of program III is that it is

designed to accept the output of program II directly and, therefore, can be used only to calculate the total annual costs of generation associated with the optimized generator expansion pattern developed by programs I and II.

Program IV

Program IV can best be described as a curve-fitting or a block-matching type of program. There are three main items of input. The first item is the optimized generator expansion pattern previously derived; the second is a list of the actual sizes of machines in mw associated with each of the new generator types used in the optimized generation expansion pattern; and the third consists of lists of factors which can be used to adjust the specified percentage reserve of program II to various alternative maximum and minimum values.

It is not the intention here to give a detailed discussion of program IV since it is a purely mathematical process. The program selects the first set of intended maximum and minimum reserve limits from the input lists, and then attempts to build an actual generator expansion pattern that closely matches the optimized expansion pattern within these limits according to a set mathematical procedure. The program is repeated to develop a different actual generation expansion pattern for each set of limits provided.

Program V

Program V calculates the total annual cost of generation for an actual expansion pattern. Input is derived from the output of program IV or from the user's calculations; however, the former should yield the most economical plans. Output for each year consists of the annual fixed and operating costs as well as the cumulative present worth of all costs which have been referred to the beginning of the first year of study.

Annual fixed costs are calculated for new machines only, and their present worth is carried as far into the future as the user cares to specify. Annual operating costs are calculated by incrementally loading available machines at the beginning of a year in accordance with the annual load-duration curve. Included in this calculation are costs such as the peak-prepared-for costs (start-up and spinning costs), which were not included in the analysis of program I. Also in this calculation the availability factor mentioned in program I may be changed once during a yearly calculation in order to permit the use of a different factor for base load and other machines.

Fig. 10 gives some idea of the method of treating the peak-prepared-for costs. Plotted as a percentage-of-peak, the daily peak occurrence curve can be superimposed on the load-duration curve. When each point of the daily peak occurrence curve is raised by a percentage corresponding to the specified daily per-cent spinning reserve, a curve is derived that is called the daily spinning requirement curve. Reference to this curve and to the simulated load-duration curve yields for each step of the latter a value in days per year that any machine used in this step should spin either for load or reserve. This method would seem to result in costs being calculated on the basis of units starting only once each day. This is not strictly true, however, since the peak-prepared-for costs are derived from past experience in the use of the units which includes an actual number of yearly starts. Therefore, the fact that a unit may start more than once a day is averaged into the cost and not the days.

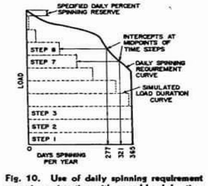

Fig. 10. Use of daily spinning requirement curve in conjunction with annual load duration curve to compute peak-prepared-for costs

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Discussion

C. H. Hoffman and H. D. Limmer (Public Service Electric and Gas Company, Newark, N. J.): The novel feature of this paper is its emphasis on optimum pattern selection by logic. Other investigators[1–3] have instead used generator expansion patterns as input. Their models, or programs, compare the economics of one pattern with another. No matter how many patterns are studied, there is no built-in assurance that the optimum pattern has been included. This is particularly true in what could be called a mixed-strategy approach, wherein one might seek to optimize a mix of various unit sizes, heat rates, and types of fuel.

The general approach that the authors have used consists of two major steps:

1. An idealized system expansion is found, represented by programs I and II. This expansion is based on a method which necessarily involves a number of simplifications; some of these are details, but others are of a fundamental nature. The most fundamental is implicit in the method, which assumes that the optimum solution for the entire period is the one in which the costs for each individual year are minimized in that year; in other words, it neglects the fact that it may be possible to increase the costs in one year slightly and thus obtain a much larger saving in succeeding years. Other factors neglected in this simplified solution are the discrete ratings in which generators are available, the effect of generator size, type, and reliability on reserve and transmission requirements, the effect of larger reserve capacity on production costs, and all the secondary effects that result from the interaction of the foregoing and other factors.

2. A number of more realistic expansion patterns based on the idealized output of the first step, are created in program IV and then compared in terms of revenue requirements in program V. Some of the factors neglected by the necessarily over-simplified logic of the first step can be introduced by manual intervention between programs IV and V in the second step, and, if necessary, by the addition of other factors such as present worth of transmission costs to the results of program V.

The results, in order to assure that the optimum expansion pattern has been found, must satisfy three conditions:

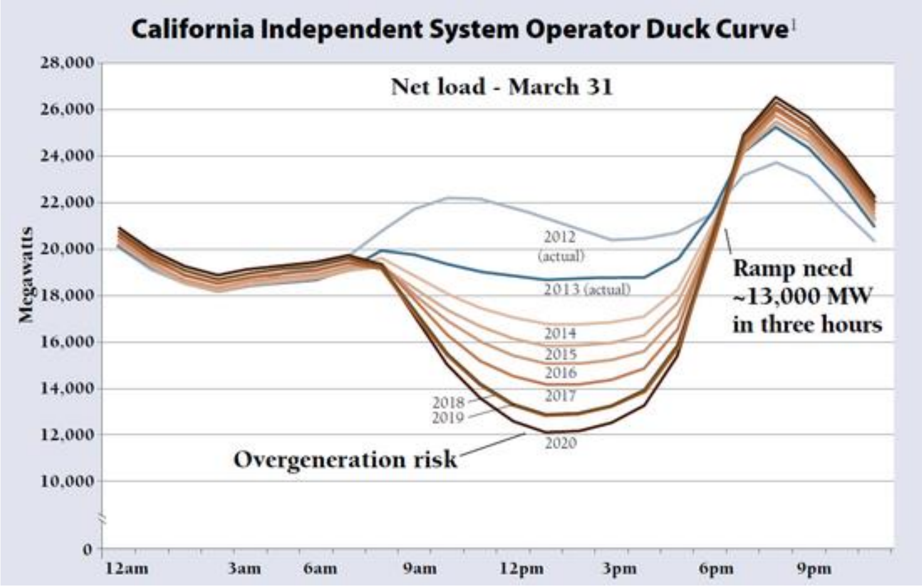
1. The optimum pattern must have been included among the patterns entered in program V.

2. The patterns entered in program V must be equivalent, that is, they must provide the same quality of service; otherwise, it can be expected that the pattern providing less reliability will be chosen.

3. The economic comparison must be carried out for a term of enough years to permit the present worth of the subsequent years' revenue requirements to be safely neglected.

The big problem is, of course, to satisfy the first two conditions. The factors neglected in programs I and II are of considerable importance; as a result, the optimum pattern may differ considerably from the idealized one, and a fairly wide range of patterns may be necessary as input to programs IV and V. Some of the calculations required properly to prepare the data for this second step may require a separate study. The main task of this separate study would be to determine the capacity requirements as they vary with the various sizes and types of units involved. To do this adequately may require a program that is larger in scope than the entire study described here.

This suggests that perhaps th[illegible] approach may be most useful [illegible] patterns for more intensive [illegible] cause of the large investme[illegible]



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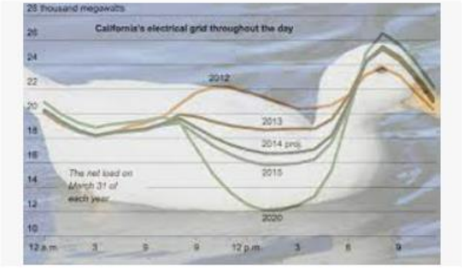

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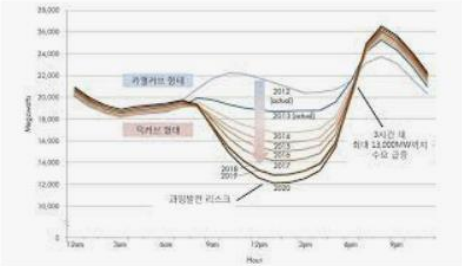

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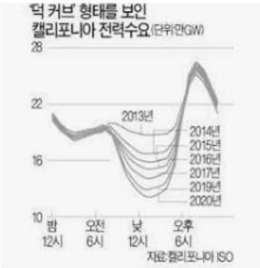

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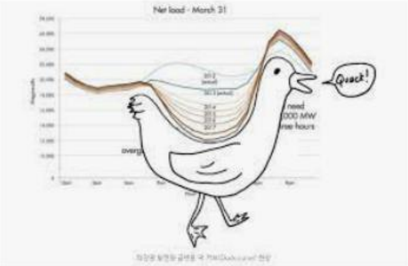

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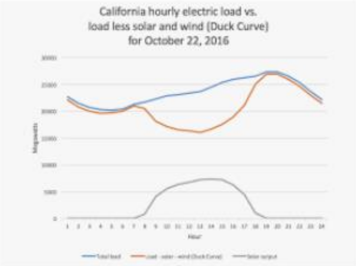

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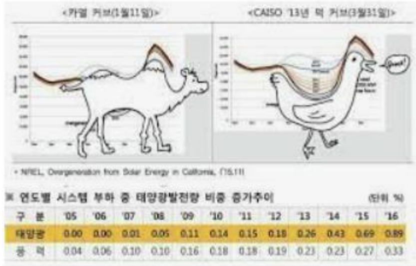
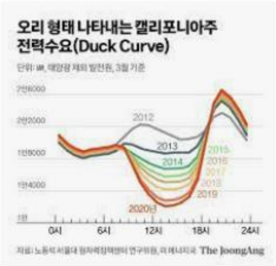
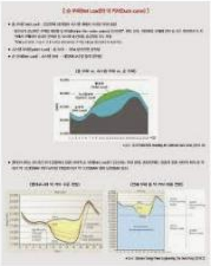
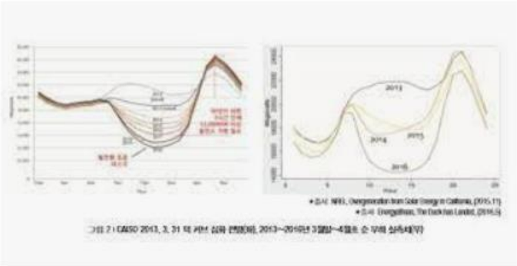
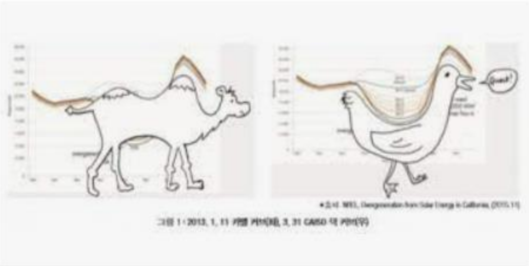




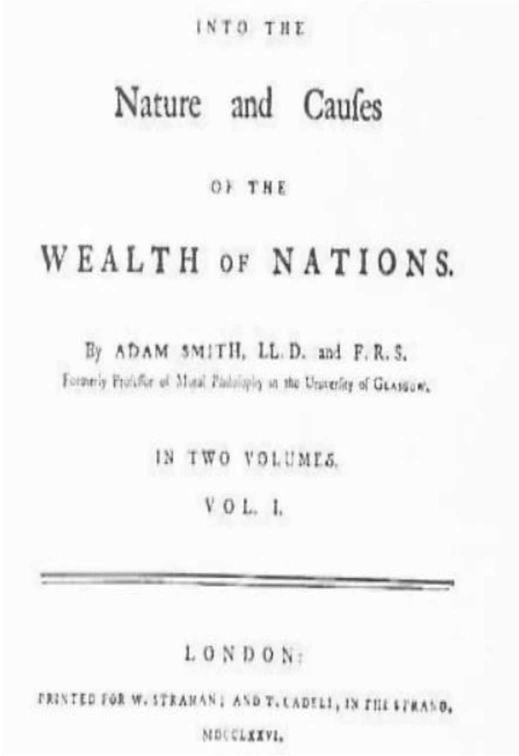


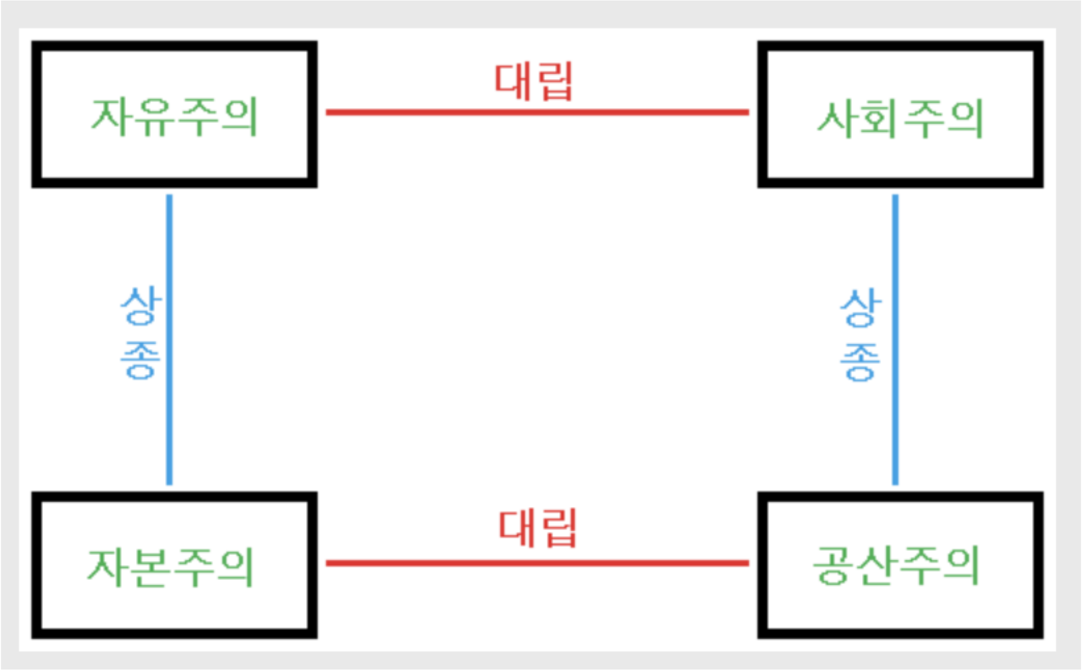


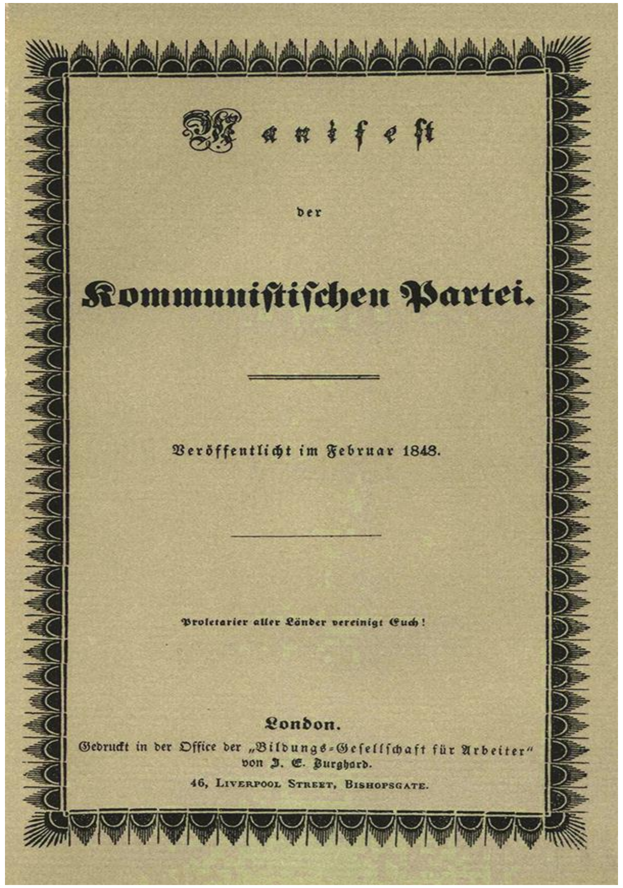


PART I. 전력 산업의 역사를 돌아보다.
(Back to History of Power Industry)

Ch 0. 19세기: 자본주의(자유주의)와 공산주의(사회주의)의 이념 갈등 및 인류의 고난과 극복의 역사







《**국부의 본질과 원인에 관한 연구**》(國富의 本質과 原因에 關한 研究, *An Inquiry into the Nature and Causes of the Wealth of Nations*), 또는 《**국부론**》(國富論, *The Wealth of Nations*)은 계몽주의 시대인 1776년 3월 9일에 출판된, 영국의 경제학자 애덤 스미스의 주요 저작이다.

《**공산당 선언**》(共産黨 宣言, 독일어: *Manifest der Kommunistischen Partei*)은 공산주의 사상가인 카를 마르크스와 프리드리히 엥겔스에 의하여 집필된 공산주의자들의 최초의 강령적 문헌으로, 1848년 2월 21일 첫 출판되었다.

Ch 1. 20세기 후반: 자본주의 승리-> 무한 자유경쟁체제 사회시스템으로의 인식 전환확산

- **소련의 붕괴**는 1991년 12월 26일 소련 최고평의회의 142-H 선언으로 일어났다.[1]
- 이 선언문은 모든 소련의 공화국의 독립을 인정하며 독립국가연합(CIS) 수립을 허용하는 안이었다. 그 전날인 1991년 12월 25일엔 소련의 대통령이자 소련의 지도자였던 미하일 고르바초프가 대통령직을 사임하고 소련 지도부를 해체했으며 소련의 핵무기 발사 시스템을 포함한 전권을 러시아의 대통령 보리스 옐친에게 승계했다.[2]
- 이날 저녁 7시 32분, 모스크바 크렘린에 마지막으로 소련의 국기가 내려가고 혁명 이전에 사용된 러시아의 국기가 게양되었다.[3]
- 그보다 전인 1991년 8월부터 12월 사이에는 러시아를 포함한 소련의 모든 공화국들이 연방에 탈퇴하거나 소련 수립 조약에 탈퇴했다.
- 연방이 공식적으로 해체되기 일주일 전, 소련의 11개 공화국은 소련 해체에 합의하고 CIS 수립을 선언한 알마아타 조약에 서명했다.[4][5] 1989년 혁명과 소련의 붕괴는 냉전 종식의 신호탄이었다.
- 전 소비에트 국가들 중 몇몇은 독립국가연합, 유라시아 경제 공동체, 러시아 벨라루스 연맹국, 유라시아 관세동맹, 유라시아 경제 연합 등을 통해 소련 붕괴 이후에도 러시아와 긴밀한 유대 관계를 맺고 있다.
- 반면에 발트 3국은 북대서양 조약 기구(NATO)와 유럽 연합(EU)에 가입하며 서구권과 긴밀한 유대 관계를 맺고 있다.

공산주의의 보스인 소련의 붕괴

8월 쿠데타 기간 도중, 붉은 광장에 있는 전차.

날짜	1991년 12월 26일 (30년 전)[1]
위치	소련
참여자	소련 인민 연방 정부 공화국 정부 자치 공화국
결과	소련의 해체 및 신생 독립국 수립 냉전의 종식

구소련 국가들. (알파벳 순)

1. 아르메니아
2. 아제르바이잔
3. 벨라루스
4. 에스토니아
5. 조지아
6. 카자흐스탄
7. 키르기스스탄
8. 라트비아
9. 리투아니아
10. 몰도바
11. 러시아
12. 타지키스탄
13. 투르크메니스탄
14. 우크라이나
15. 우즈베키스탄

폴란드 저주받은 군인들
1953년 봉기
플젠 봉기 · 동독 소요
1956년 시위
조지아 시위 · 포즈난 시위
1956년 헝가리 혁명 ·
노보체르카스크 사건 (러시아)
1968년 사건
프라하의 봄 · 체코슬로바키아 침공 ·
붉은 광장 시위
77 헌장 (체코슬로바키아)
연대자유노조 (폴란드)
젤토크산 (카자흐스탄)
브라쇼브 반란 (루마니아)
4월 9일 비극 (조지아)
검은 1월 (아제르바이잔)

냉전기 사건 [접기]

마셜 플랜 ·
1948년 체코슬로바키아 쿠데타 ·
티토-스탈린 결별 · 베를린 봉쇄 ·
1961년 베를린 장벽 위기 ·
쿠바 미사일 위기 ·
1980년 모스크바 하계 올림픽

해체 [접기]

노래 혁명 · 폴란드 원탁회의 ·
1989년 혁명 · 베를린 장벽의 붕괴
1991년 1월
리투아니아 사건 · 라트비아 사건
유고슬라비아 해체 · 유고슬라비아 전정
· **소련의 붕괴** · 알바니아 공산주의 붕괴

v · t · e

Ch 2. 20세기 후후반: 자유경쟁체제로의 모든 분야 확대: 기술혁신에 대한 공포(?)와 외침 그리고 기술자들의 동조?

- 연료전지등의 등장에 따른 기존 전력(발전)산업시스템의 붕괴
- 스마트시대 도래
- 4차산업혁명에 따른 사회변화
- ICT 정보전쟁 준비, IoT,.....
- 5G, 6G 시대 도래
- 인테넷 상거래, 빅데이이터.... Block-Chain...
- 지속가능한 발전과 21 세기 에너지정책 - 에너지체제 전환의 필요성과 에너지정책의 바람직한 전환방향

- 경제학자+ 정치가+기술자+과학자 =??? 사회시스템 변화

연료전지 동네 슈퍼마켓에서 판매?

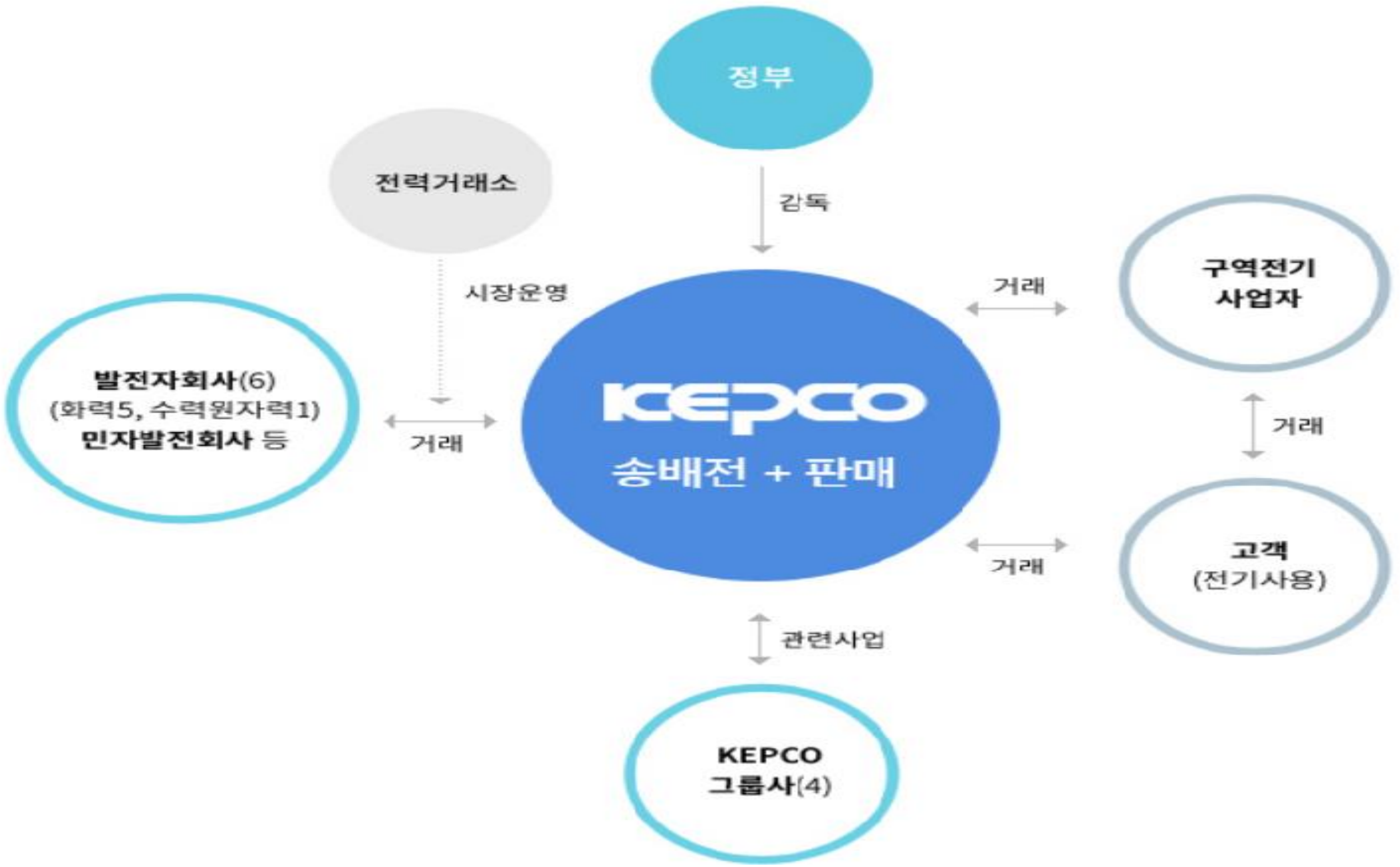
Ch 3. 20세기 후후반 21세기 초초: 이에 대비 (변혁 기술자도 정치 및 경제에 혁신 동조) -> 전력산업구조개편 추진의 국내 및 전 세계적인 열풍 확산!

- 모든 학술대회주제 및 연구논문등이 이 분야로 전환! 집중! 해당분야 주제 세션은 청중이 가득가득함. 복도까지 청중이 꽉 참!

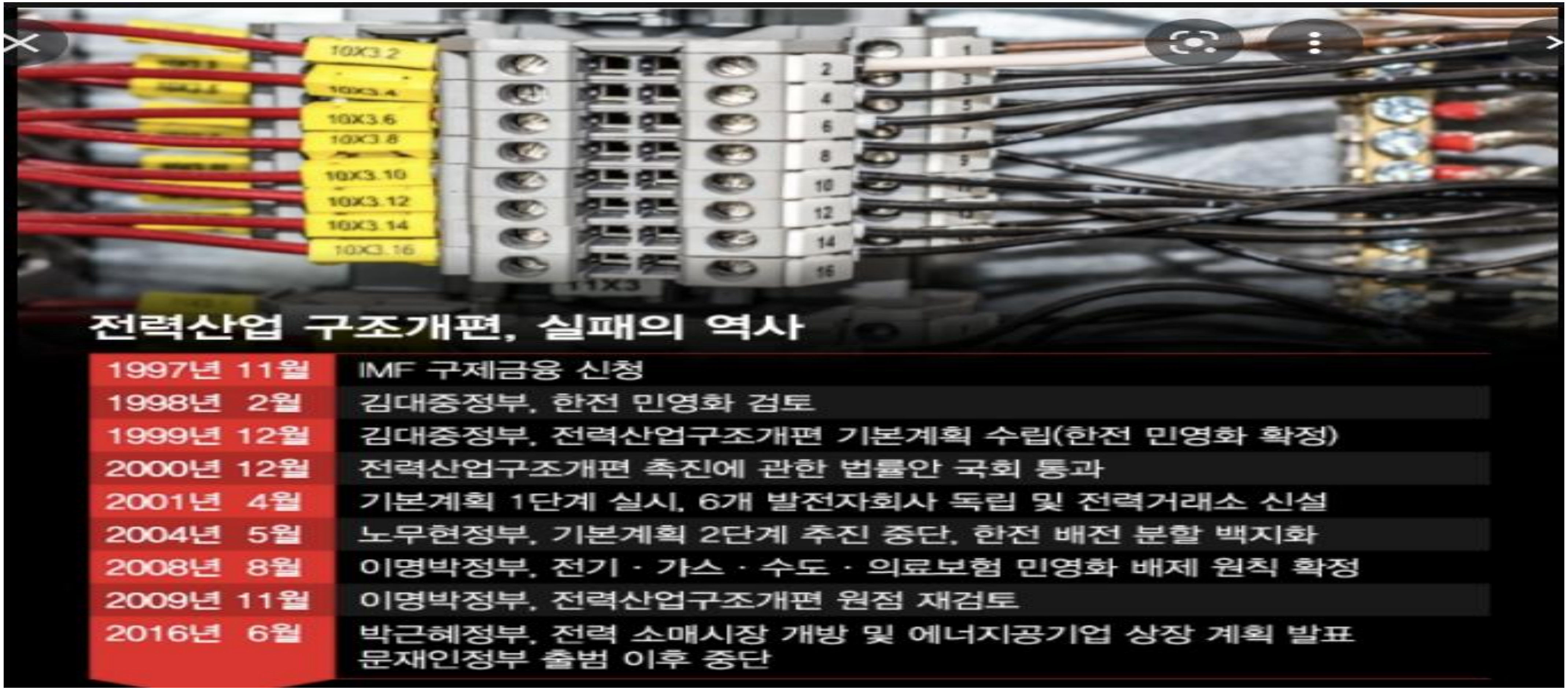
- 전력산업 연구자의 이동

- 거의 모든 분야연구자가 전력시장디자인 분야로 대이동!

Ch 4. 21세기 초초: 전력시장 디자인에만 너무 집중화. 기초의 부실화로 문제의 핵심을 잘 파악하지 못함.



Ch 5. 구조개편의 국내 중단과 문제점 발생 (신구세력의 힘겨루기?)



-승욱호 산업통상자원부] 전력산업 구조개편 바람 부나
:n.kr

이슈]전력산업구조개편 20년 "발전분할까지 했더라면 큰일...
skenews.kr

-전, 전력생산, 판매 독과점 종지부는?
.ecoday.kr

우리나라 전력산업 경쟁체제 도입 현황 및 향후 전망 : 네이...
m.blog.naver.com

시사저널e

전력산업 기형 구조 바꿔야" 한목소리...속도·전제조건 등 각론은 다양 - 시사저널e - 온라인 저널리즘의 미래

방문

저작권 보호를 받는 이미지일 수 있습니다. **자세히 알아보기**


에너지전환과 전력산업 구조개편(양...
kyobobook.co.kr
국내 전력 시장 차선희 전북대학교 전력시스템연구...
slidesplayer.org
전력거래소
가. 제1단계
한국전력공사
발 전
송 전
배 전
민자발전 사업자
소 비 자
○ 한전이 발·송·배전을 모두 독점
○ 일부 민자발전사업자가 한전에 전력공급
전력시장 개편, 전기 민영화만이 답이 아니야! - 에너지...
energycenter.co.kr
급조된 발전회사 분할로 손...
labortoday.co.kr
전력 제로' 부르는 나홀로 산업, 경쟁체...
cm.asiae.co.kr
전국전력노동조합 (r216 판) - 나무위키
방폐장반대 잘했네 < 울진게시판 < 게시판 - ...
전력산업 기형 구조 바꿔야" 한목소리·...
배전분할 저지투쟁 승리 보고대회
2004년 6월 24일 한국노총 전국전력노동조합
나무위키
전국전력노동조합 (r216 판) - 나무위키
방문
저작권 보호를 받는 이미지일 수 있습니다. 자세히 알아보기
관련 이미지
더보기

Ch 6. 문제 인식 부족, 해결책 토대의 부실성과 전력계통계획및 운영과실로 전 세계적으로 대정전의 동시다발적 사고 발생.

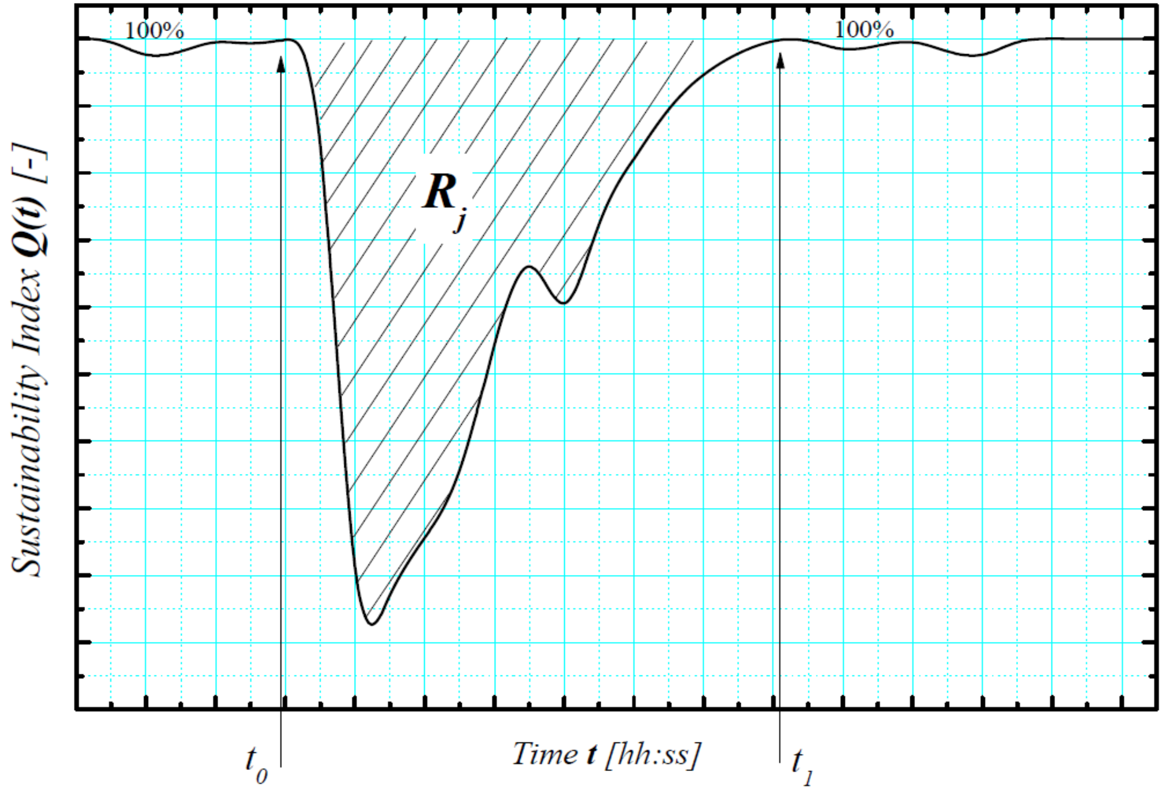
- 아래의 그림은 2003년 미국 북동부에 대정전이 발생하였을 당시의 위성사진이며, 이 사건으로 인해서 전력, 교통, 통신, 의료 마비로까지 확산되었으며, 약 5천만명 이상이 3일간 피해를 경험하게 되었다.

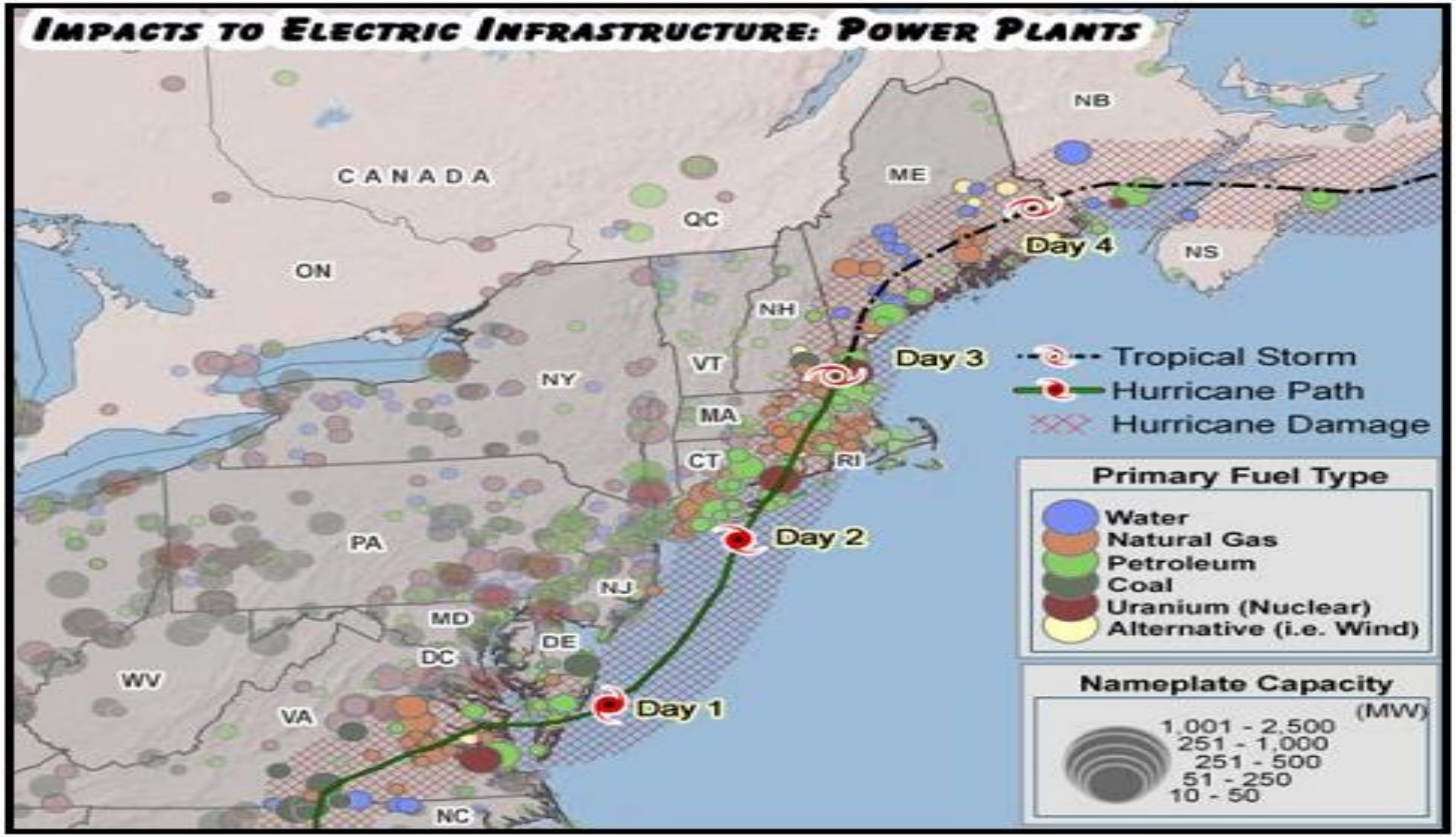

003/45/7844
56 millions inhabitatnts affected

Ch 7. 21세기 초: 환경문제 대두, 마이크로 및 스마트그리드의 열풍

- 에너지전환 대두 그리고 이의 현실화에 따른 문제점 발생. (정반합- 정반합의 되돌이표!)

Ch 8. 21세기 초: 진화론적 관점에서 본 에너지전환과 인류의 생존문제 및 재난, 재해 문제 대두, 전력계통 복구력(Resiliency) 이슈화.





More than 6.5 million people in the United States lost power during Hurricane Irene, which includes over 30 percent of the people living in Rhode Island, Connecticut and Maryland (U.S. DOE 2011).

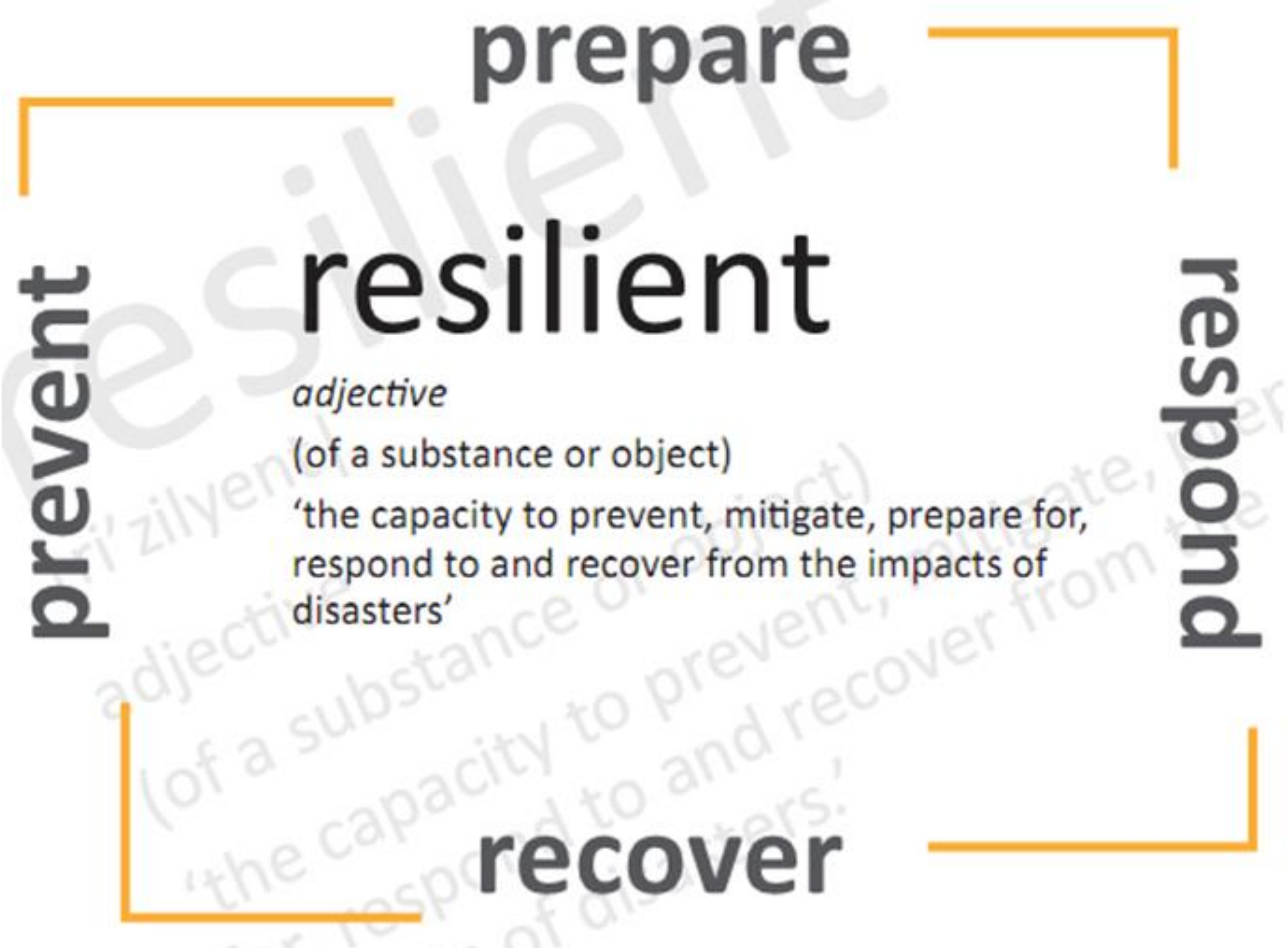


Figure : Cycle of resilience

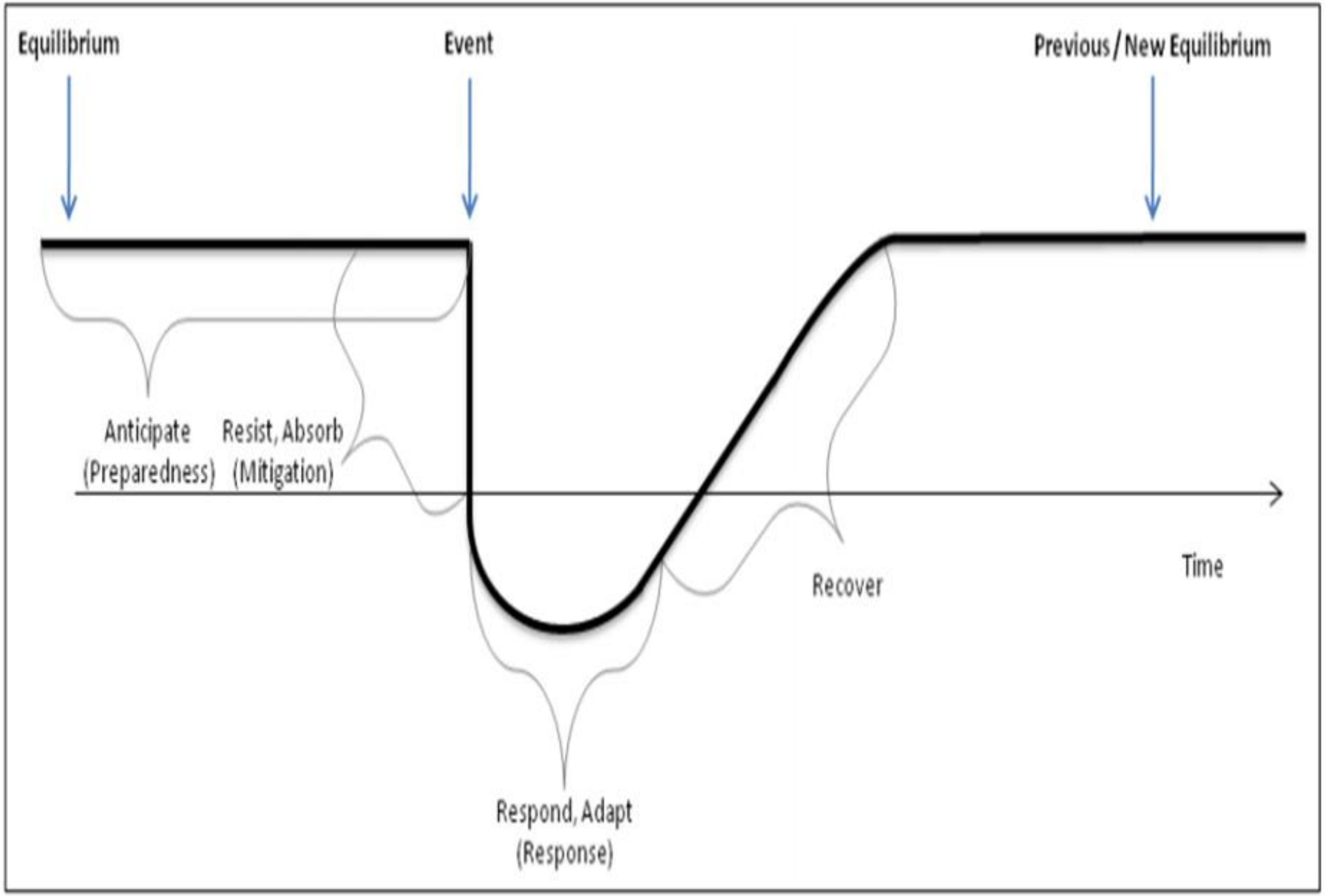
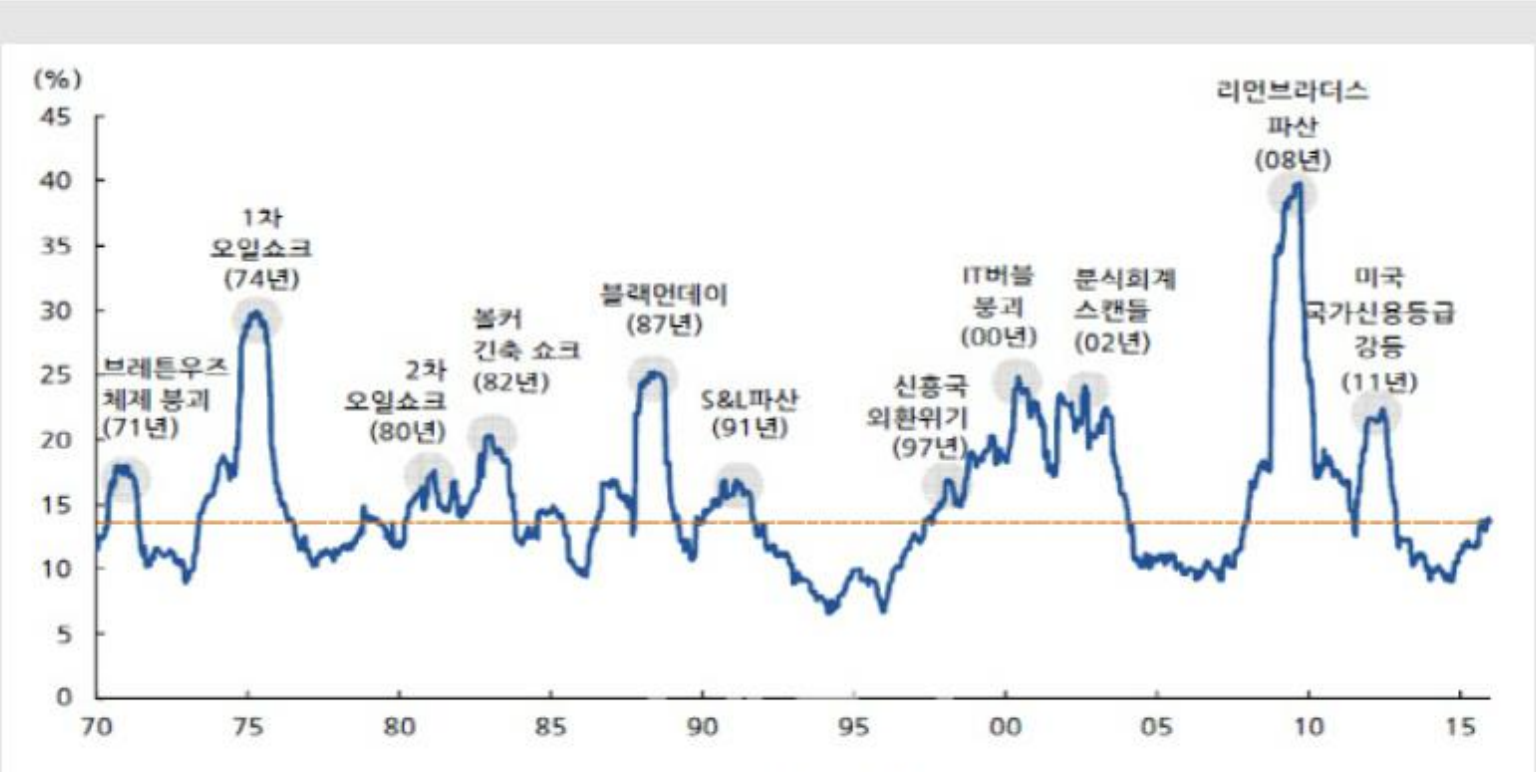


Figure : Components of Resilience and the Timing of an Adverse Event

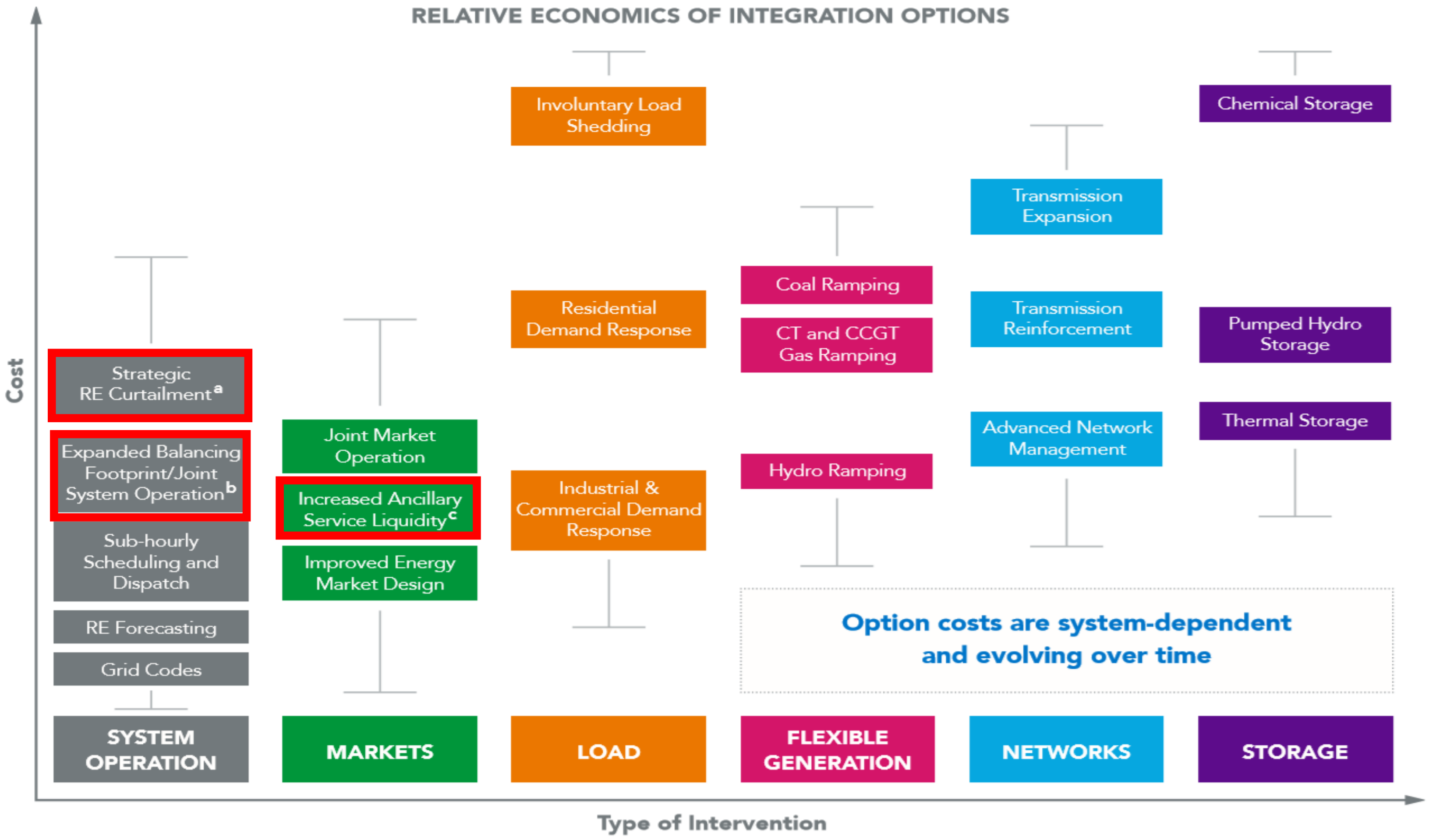
Ch 9. 미래는? 전력산업구조개편 30년 주기설?

Example!



글로벌 증시의 변동성(출처:블룸버그, KDB대우증권)

How Can Policymakers and Regulators Help Increase Flexibility?

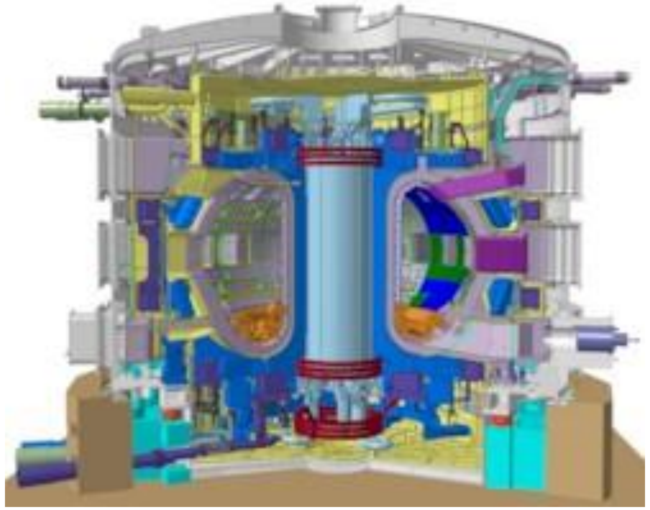


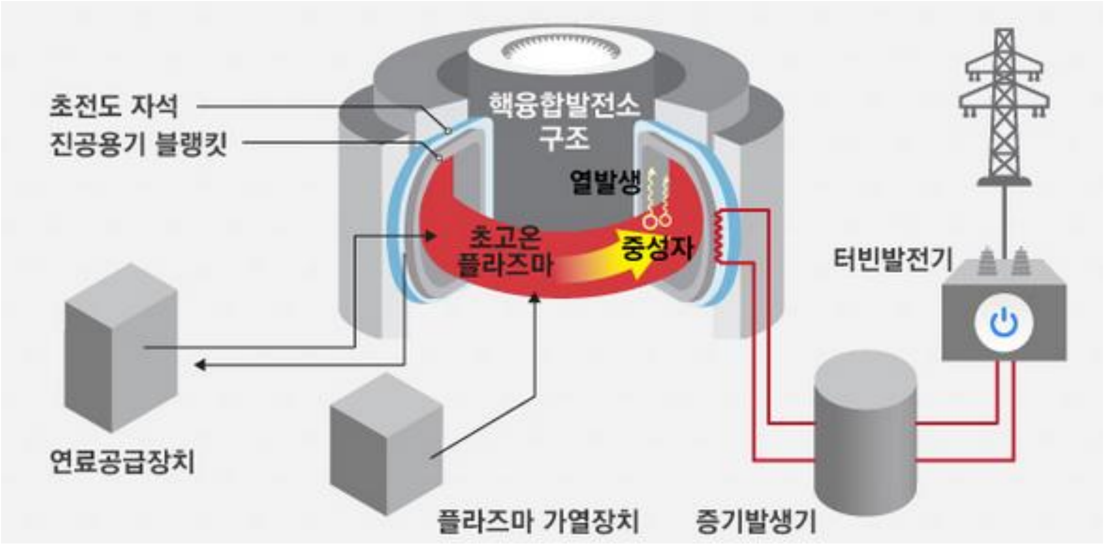
a. There is a tradeoff between costs of flexibility and benefits of reduced (or no) curtailment, hence a certain level of curtailment may be a sign that the system has an economically optimal amount of flexibility.

b. Joint system operation typically involves a level of reserve sharing and dispatch co-optimization but stops short of joint market operation or a formal system merger.

c. Wind power can increase the liquidity of ancillary services and provide generation-side flexibility. Curtailed energy is also used to provide frequency response in many systems, for example Xcel Energy, EirGrid, Energinet.dk.

Ch 10. Final Energy DNA?
Nuclear Fusion (Artificial Sun)

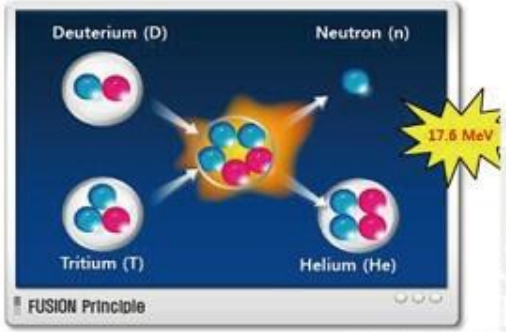




"인류가 1,000년 이후에도 지구에 생존할 수 있을지 여부는 에너지 문제에 달렸다고 해도 과언이 아니다"

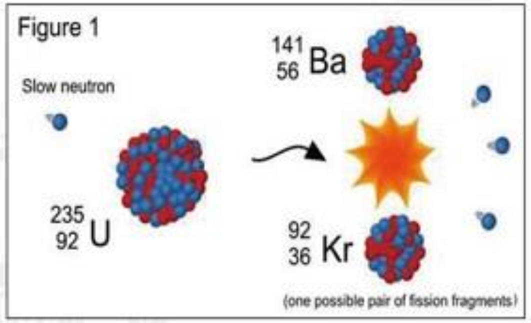
핵융합과 핵분열 반응의 차이점

핵융합 반응

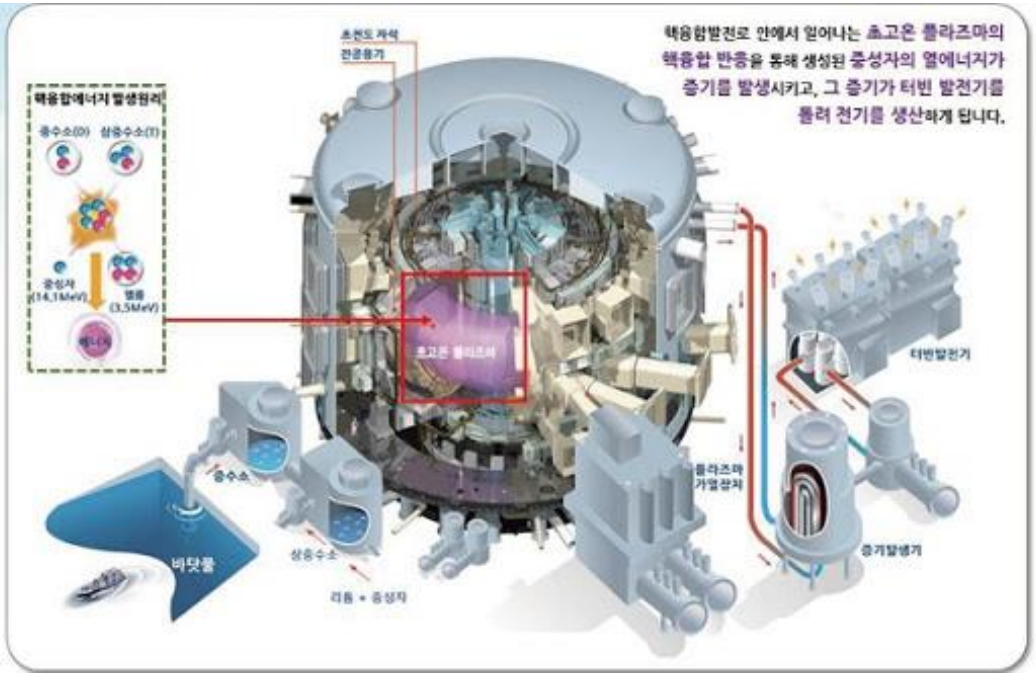


- 질량 (D+T) ~ 5 amu
- 발생 에너지 ~ 17.6 MeV
- 단위질량 당 에너지 ~ 3.5 MeV/amu

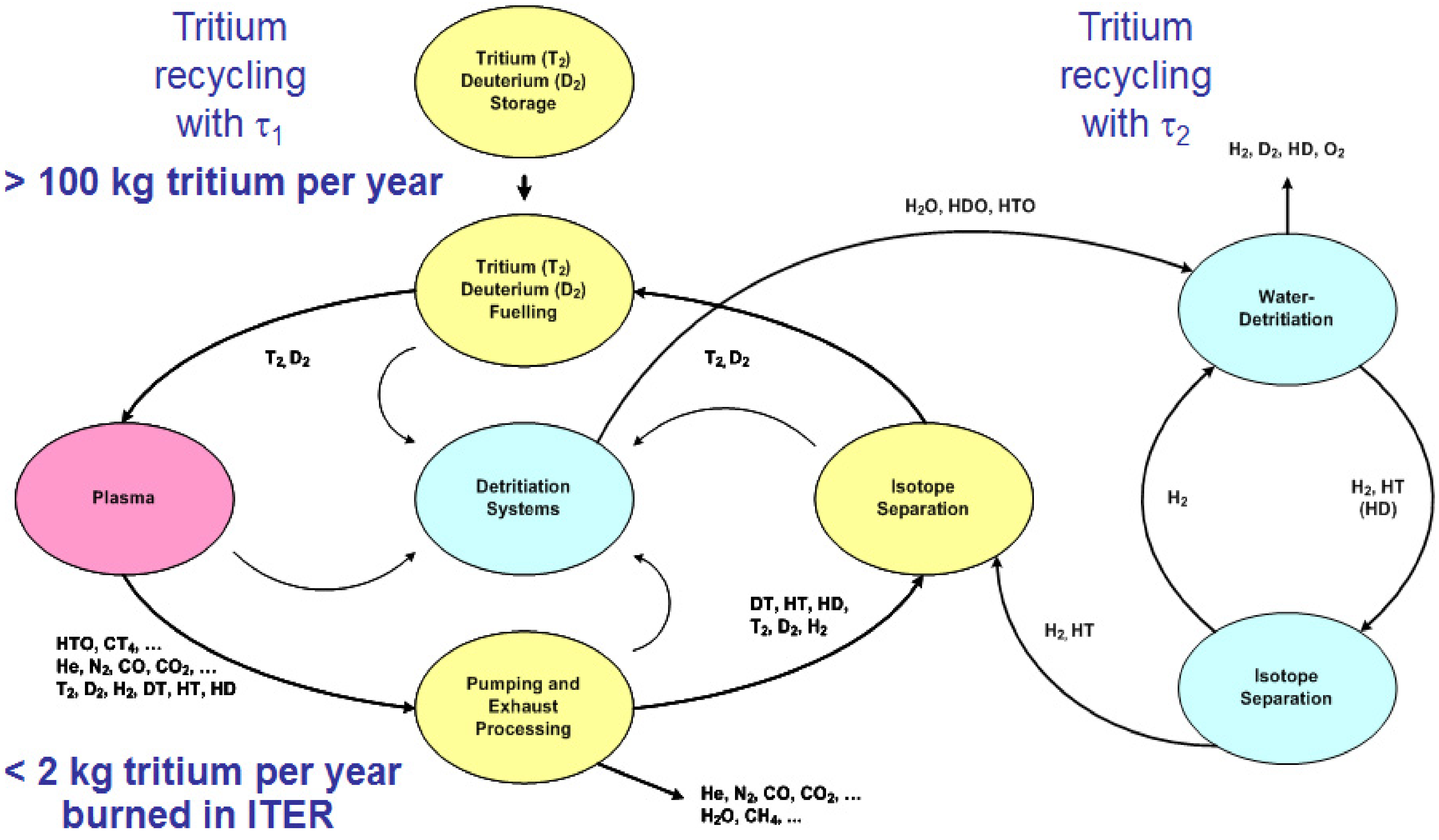
핵분열 반응



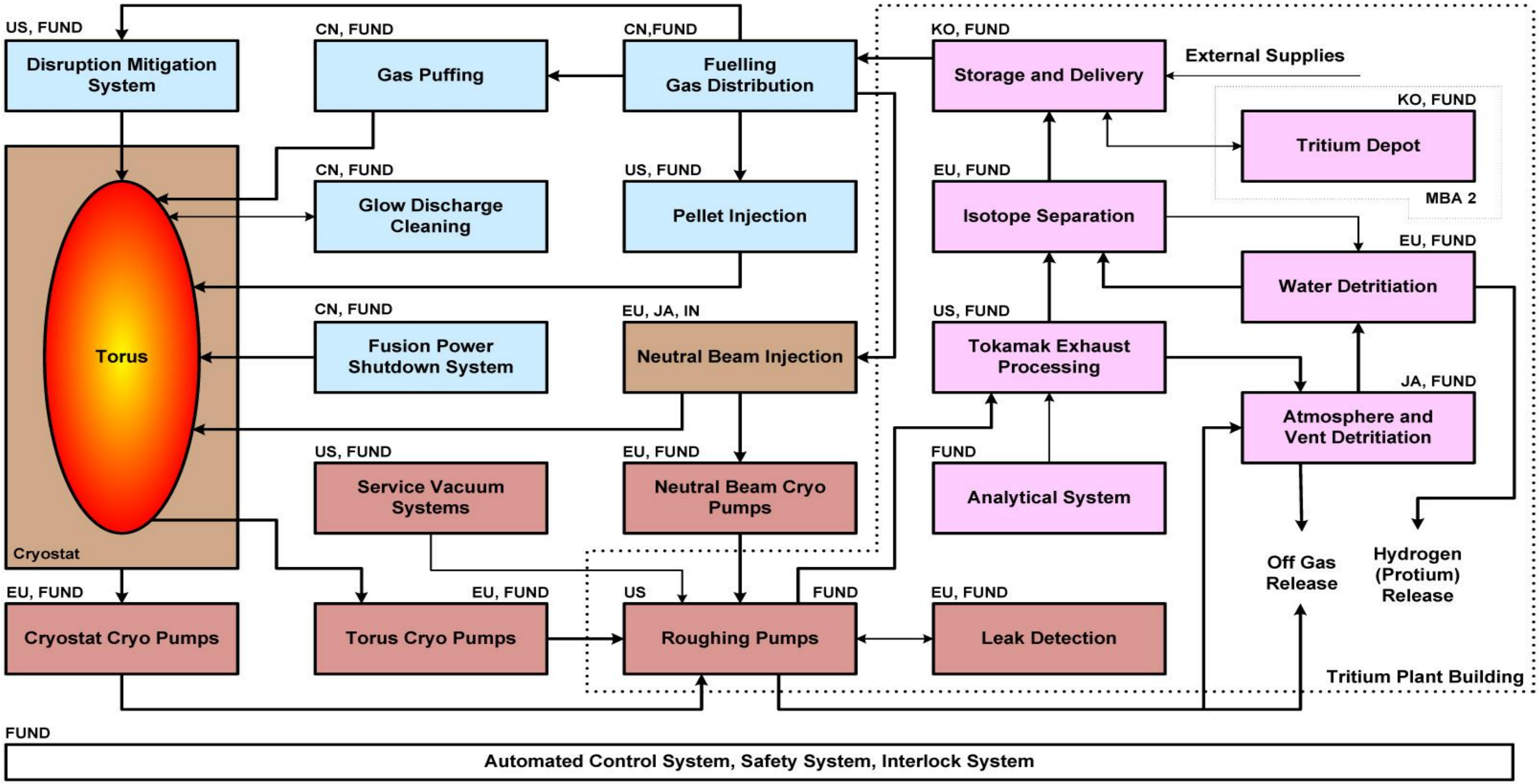
- 질량 (U235) ~ 235 amu
- 발생 에너지 ~ 200 MeV
- 단위질량 당 에너지 ~ 0.85 MeV/amu



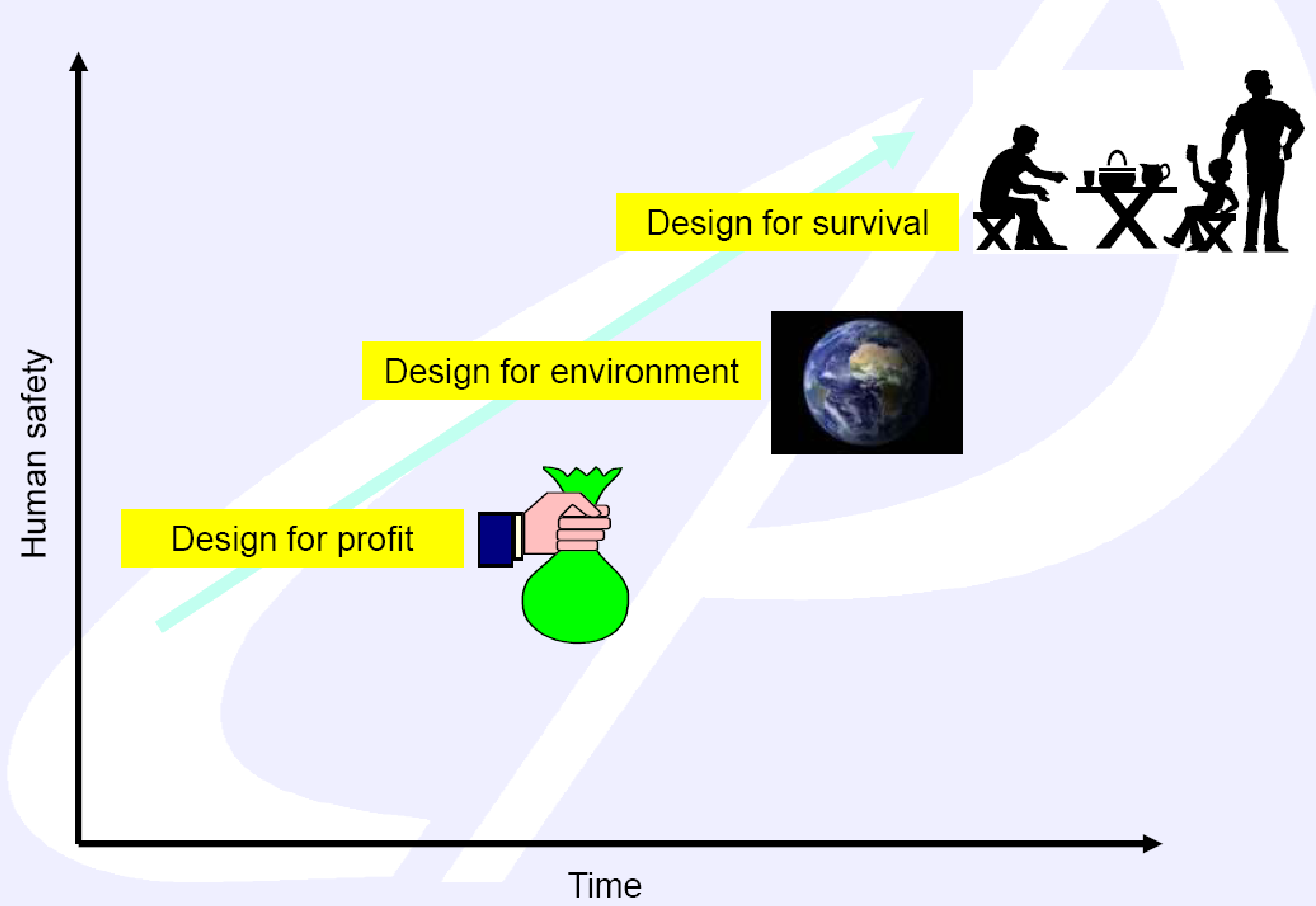
- D + T → 4He(3.5MeV) + n(14.1MeV) + Energy (1)
- n + ^{6}Li → T + ^{4}He (2)



Funding for ITER



Ch 11.多樣性과 柔軟性이 이긴다? Why?
융복합이 우성DNA? Why?


Design for survival
Design for environment
Design for profit
Human safety
Time

Ch 12. Summary and Discussion

- Energy Evolution : Winner DNA!
- Conditions for Winner DNA?
- DNA of Survival Energy: if yes, What?
  - What is Clean & Sustainable Energy DNA?
  - Human (Citizen) Survival?
  - Near Future: Renewable Generation System?
  - Far Future: Nuclear Fusion Generation System?
- For Pulling up Flexibility?
- Resilience of Power System?
- Human Survival without Electrical Energy?
- Elements for Resilient Power System?
- What is Making Money(Business Model) in future?

References

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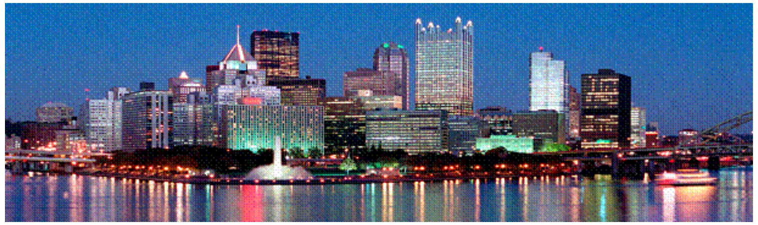
PART II. 적정전원구성
(BGM: Best Generation Mix)
Two Approaches : FLP, FDP

Flexible Best Generation Mix for Korea Power System Considering CO_2 Constraint – Vision 2030



IEEE PES GM'08
July 20-24, 2008
Pittsburg, PA, USA

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1. Introduction

• This paper proposes a fuzzy linear programming based solution approach for the long-term generation mix with multi-stages (years) considering air pollution constraints on CO_2 emissions, under uncertain circumstances as like as ambiguities of budget and reliability criterion level.

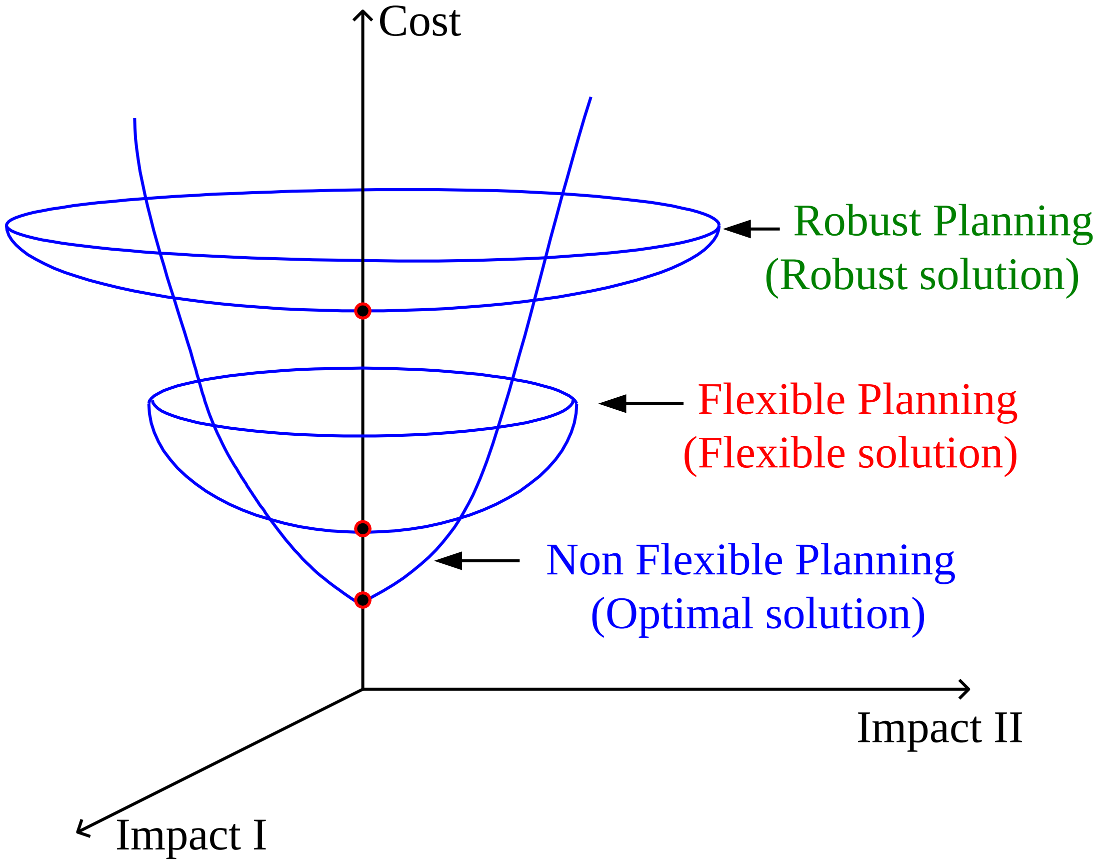
• The effectiveness of the proposed approach is demonstrated by applying it to solve the multi-years best generation mix problem on the Korea power system which contains nuclear, coal, LNG, oil and pumped-storage hydro plants.

• This paper approaches to flexible generation mix problem for 2030 year in Korea eventually, which is called vision 2030. The proposed approach may give more flexible solution rather than too robust plan.

2. The Concept of Flexible Planning

Flexibility?

"Although not necessarily gives the optimum solution for the basic forecasted conditions, yet can keep the reasonable scheduling solution from being significantly worsened by any assumed changes in the surrounding situations" [8,9].

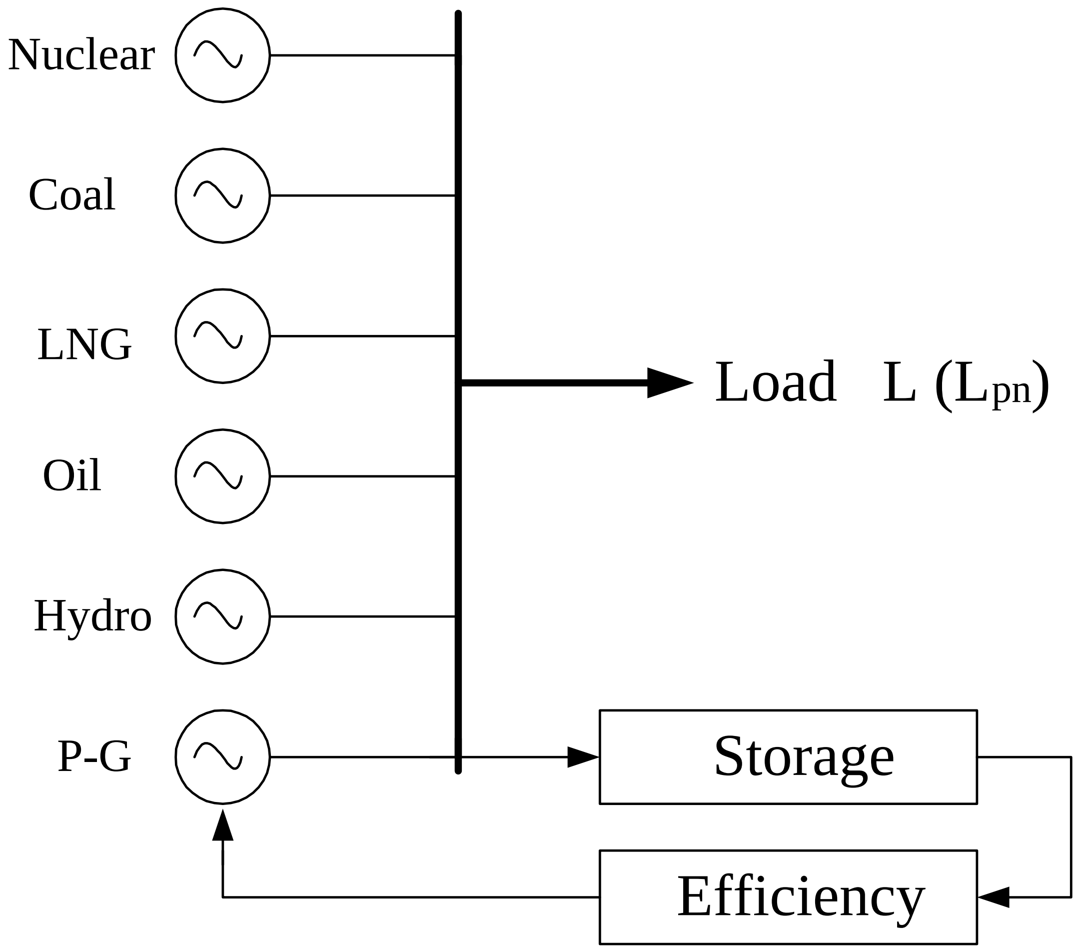


The useful methods for flexible generators mix problem and flexible scheduling problem of generators maintenance using fuzzy LP, DP, IP and search method have been developed by the authors [3-23].

It is expected that more flexible solution can be obtained with the proposed methods because the fuzzy set theory can reflect the subjective decision of decision-maker.

This paper uses fuzzy set theory in order to get a flexible long-term generation mix solution in Korea power system considering CO_2 emission constraint.

3. The LP Formulation of Best Generation Mix



A system model for the proposed method

3.2 Objective functions

$$Minimize\ Z = \sum_{n=1}^{N}\sum_{i=1}^{NG} K_{cin} d_{in} \alpha_i \Delta x_{in} + \sum_{n=1}^{N}\sum_{i=1}^{NG} K_{fin} f_{in} y_{in}$$

$$= F(\Delta x_{in}\ ,\ y_{in})$$

where,

i : unit type

N : number of total consideration year

NG : number of unit type

$K_{cin} = ((1+e_{ci})/(1+r))^{n\ T_n}$

$K_{fin} = ((1+e_{fi})/(1+r))^{n\ T_n}$

e_{ci} : apparent escalation rate of construction materials of i-unit

e_{fi} : apparent escalation rate of fuel of i-unit

r : discount rate

T_n : steo size years of study years

d_{in} : construction cost of the i-unit in n year

f_{in} : marginal fuel cost of the i-unit in n year [won/MWh]

α_i : annual expenses rate

Δx_{in} : construction capacity of the i-unit in n year [MW]

y_{in} : generation capacity of the i-unit in n year [MWh]

3.3 Constraints

1) Installed capacity constraint considering supply reserve rate reliability

$$\sum_{i=1}^{NG}(x_{in-1}+\Delta x_{in})+HYD_n \geq L_{Pn}(1+R_n) \quad n=1\sim N$$

where,

L_{Pn}: peak load at *n* year

R_n: supply reserve rate in *n* year. [p.u]

HYD_n: capacity of hydro generator in *n* year, the HYD_n is given in this study.

2) Energy constraint of demand

$$\sum_{i=1}^{NG} y_{in} = (L_{Pn}+L_{Bn})\times 8760/2+V_n \quad -HYD_n\times 8760\times CF_H \quad n=1\sim N$$

where,

L_{Bn}: base load at *n* year

V_n: the added demand energy is caused by pumped-storage generator

CF_H: average capacity factor of hydro generator

3) Production energy constraint of generation system

$$y_{in} \le (x_{in-1} + \Delta x_{in}) \times 8760 \times CF_i \qquad i = 1 \sim NG, \quad n = 1 \sim N$$

where, CF_i: average capacity factor of the *i*-unit

4) Capacity constraint in initial year

$$x_{i0} = EX_i \qquad i = 1 \sim NG$$

where, EX_i: capacity of the *i*- existing unit

5) Constraint of mutual relationship between existing generator and new generator capacity (state equation)

$$x_{in+1} = x_{in} + \Delta x_{in+1} \qquad i = 1 \sim NG, \; n = 1 \sim N$$

6) Energy constraint of LNG thermal plant

$$y_{3n} \geq LEP_{\min\ n} / \xi_3 \qquad n = 1 \sim N$$

where, $LEP_{\min\ n}$: LNG thermal generator production energy for LNG minimum due to consumption in *n* year

ξ_3: the rate of fuel consumption of LNG [Ton/MWh]

7) Constraints of reservoir capacity of pumped-storage generator

$$y_{5n} = \eta_g \times V_n$$

where, η_g: efficiency of pumped-storage generator

8) No load following power constraints of nuclear power plant

$$(x_{1n} - x_{5n}) \leq L_{Bn} \qquad n = 1 \sim N$$

9) Upper-lower constraints of new unit capacity

$$\Delta X_{in} \le \Delta X_{\max\ in} \qquad i = 1 \sim NG, \quad n = 1 \sim N$$

10) CO_2 air pollution constraint

$$\sum_{i=1}^{NG} CO2_{in} \xi_i y_i \le CO2_{\max\ n}$$

where,

$CO2_{in}$: CO_2 density of the i- unit in n year [ppm/Ton]

ξ_i : fuel consumption rate of the i- unit [Ton/MWh]

$CO2_{\max\ n}$: maximum quantity of CO_2 permitted in n year [ppm/year]

11) SO_X air pollution constraint

$$\sum_{i=1}^{NG} SOX_{in} \xi_i y_{in} \le SOX_{\max\ n}$$

where, SOX_{in} : SO_X density of the *i*- unit in *n* year [ppm/Ton]
$SOX_{\max\ n}$: maximum quantity of SO_X permitted in *n* year [ppm/year]

12) NO_X air pollution constraint

$$\sum_{i=1}^{NG} NOX_{in} \xi_i y_{in} \le NOX_{\max\ n}$$

where, $NOX_{i,n}$: NO_X density of the i- unit in n year [ppm/Ton]
$NOX_{\max\ n}$: maximum quantity of NO_X permitted in n year [ppm/year]

4.1 The Optimal Decision by Fuzzy Set Theory

The fuzzy decision D

$$D = \left(\bigcap_{i=1}^{q} G_i \right) \cap \left(\bigcap_{j=1}^{p} C_j \right)$$

Membership function resulting from fuzzy goals and constraints

$$\mu_D(x) = min\left[\min_{i=1\sim q} \mu_{Gi}, \min_{j=1\sim p} \mu_{Cj} \right]$$

The fuzzy mathematical programming problem consists of finding the maximum of the fuzzy decision D

$$\mu_D\left(x^*\right) = \max \mu_D\left(x\right)$$

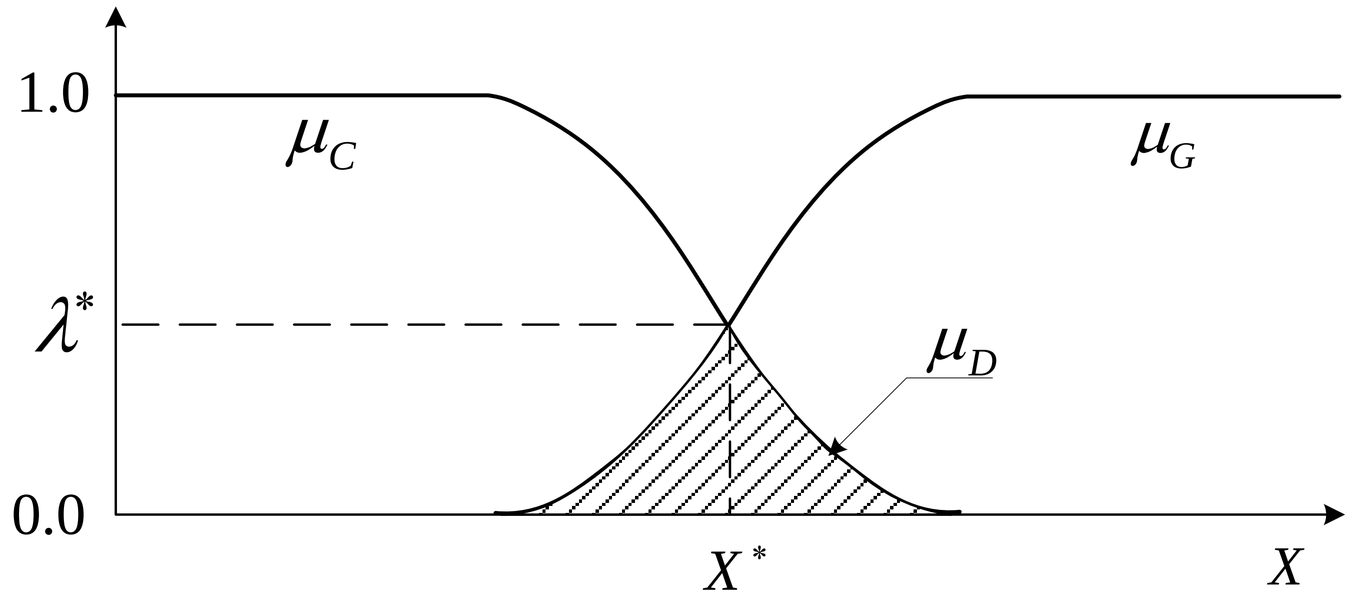
$$\mu_D\left(x_1^*, x_2^*, \cdots, x_N^*\right) = \max_{x_1 \cdots x_N} \mu_D\left(x_1, x_2, \cdots, x_N\right)$$

To maximize the satisfaction level, λ of the decision maker subject to fuzzy construction cost/budget

$$\lambda^* = max\ \mu_{D(x)} = max\ \left\{ min \left[\mu_{G(x)}, \mu_{C(x)} \right] \right\}$$

$$= \mu_{D(x^*)}$$

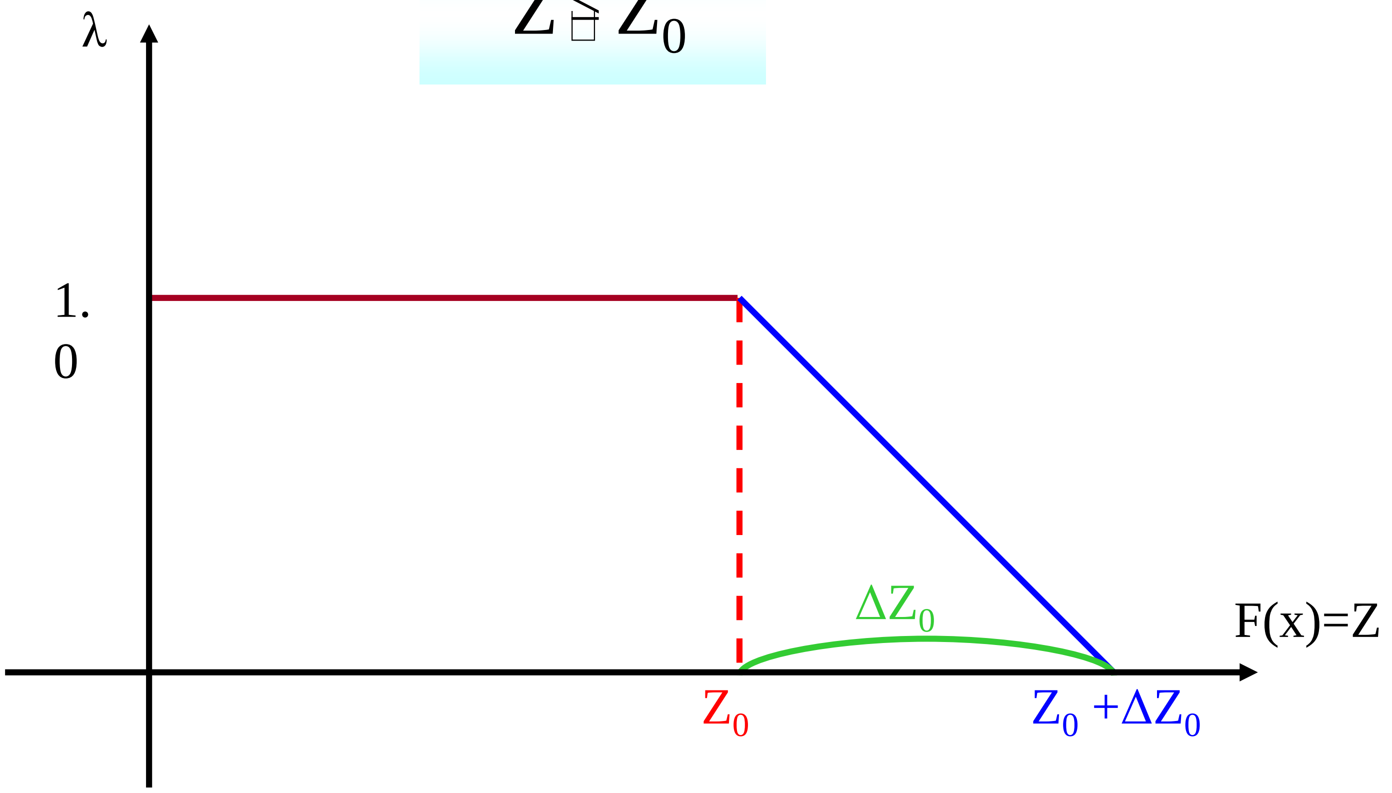
The concept of fuzzy optimal decision making



4.2 The Fuzzy LP Formulation for Flexible Generation Mix

Membership Function of Fuzzy Cost Level

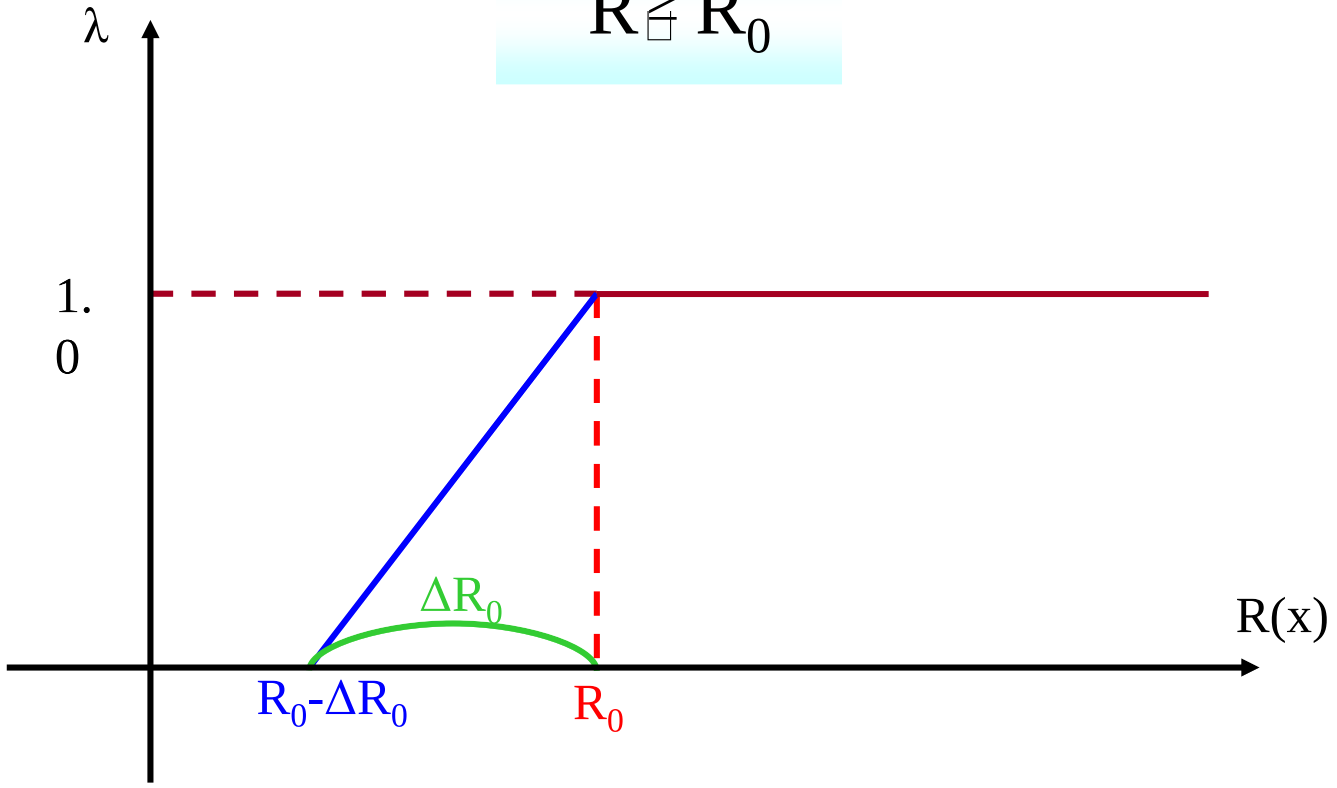
$$Z \leq Z_0$$



$$F(\Delta x_{in}, y_{in}) + \Delta Z_0 \lambda \leq Z_0 + \Delta Z_0$$

Membership Function of Fuzzy Reliability Level

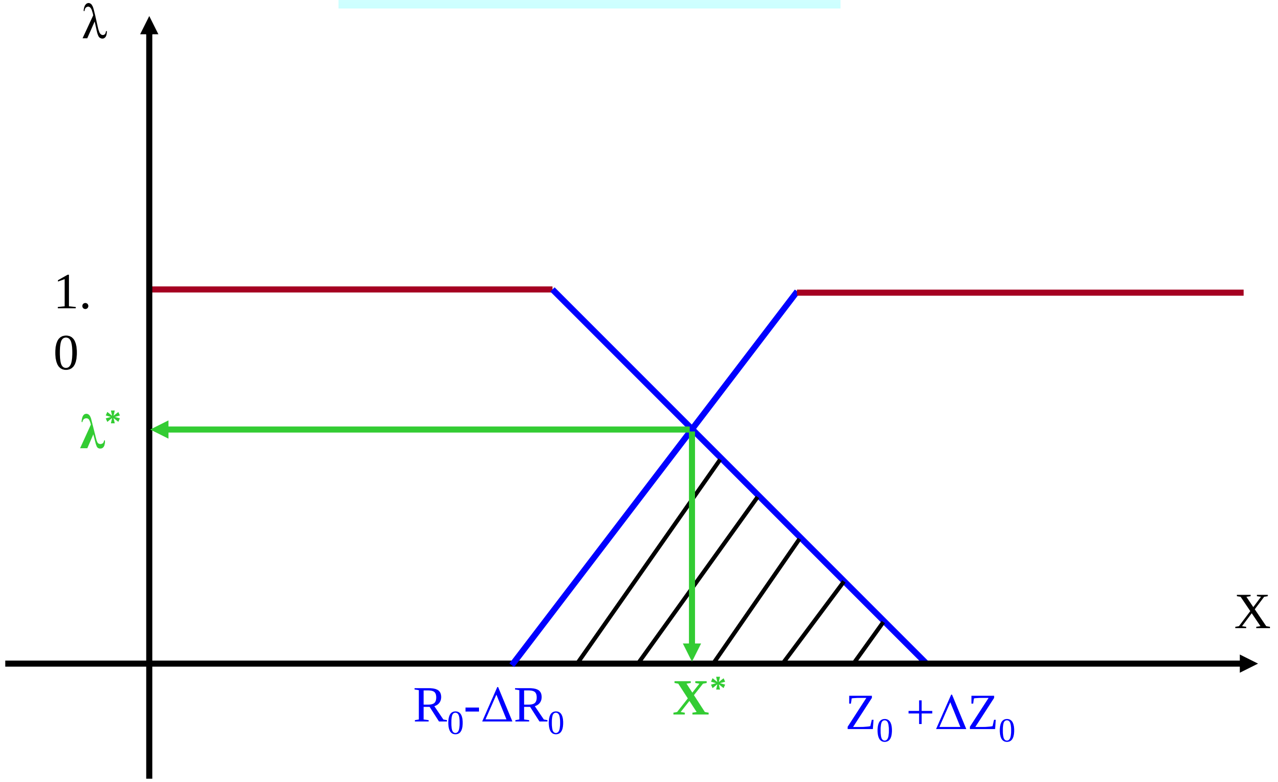
$R \geq R_0$



$$\left(\left(\sum_{i=1}^{NG}(x_{in-1}+\Delta x_{in})+HYD_n\right)-L_{Pn}\right)\Big/L_{Pn}-\Delta R_0\lambda = R_0-\Delta R_0$$

Objective function

Maximize λ*



Flexible best generation mix problem by using fuzzy set theory

Objective functions: *Maximize* λ

Constraints : *Subject to* $F(\Delta x_{in}, y_{in}) + \Delta Z_0 \lambda = Z_0 + \Delta Z_0$

$$\left(\left(\sum_{i=1}^{NG} (x_{in-1} + \Delta x_{in}) + HYD_n\right) - L_{Pn}\right) / L_{Pn} - \Delta R_0 \lambda = R_0 - \Delta R_0$$

$$\sum_{i=1}^{NG} y_{in} \geq (L_{Pn} + L_{Bn}) \times 8760/2 + V_n - HYD_n \times 8760 \times CF_H$$

$$y_{in} \leq (x_{in-1} + \Delta x_{in}) \times 8760 \times CF_i$$

$$x_{i0} = EX_i$$

$$x_{in} = x_{in-1} + \Delta x_{in}$$

$$y_{3n} \geq LEP_{minn} / \rho_3$$

$$y_{5n} = \eta_g \times Vn$$

$$(x_{1n} - x_{5n}) \leq L_{Bn}$$

$$\Delta x_{in} \leq \Delta X_{max\ in}$$

$$\sum_{i=1}^{NG} \xi_i y_i \leq CO_{2MAXn}$$

$$\sum_{i=1}^{NG} SO_{Xin} \xi_i y_n \leq SO_{XMAXn}$$

$$\sum_{i=1}^{NG} NO_{Xin} \xi_i y_n \leq NOX_{MAXn}$$

5. Case Studies

- Maximum load, minimum load, and hydro plant at standard years

Years	Peak load L_P [MW]	Base load L_B [MW]	Hydro [MW]	LEP (10^3Ton)
2006	58,990	35,394	1,800	--
2011	65,940	39,564	2,000	4,500
2016	70,050	42,030	2,200	5,500
2021	74,000	44,400	2,400	6,500
2026	77,000	46,200	2,600	7,500
2030	80,000	48,000	2,600	7,500

➢ The characteristics and economic data summary

Gen. Type	Initial capacity [MW]	Fixed charge (d_i) [10^5won/kW]	A_{ER} of fixed charge (ec_i) [%]	Marginal fuel cost (f_i) [Won/kW]	A_{ER} of fuel cost (ef_i)[%]
Nucl.	17,716	144.4	3.5	4	1
Coal	18,465	79.7	3.4	17	1
LNG	17,437	61.4	3.3	67	1
Oil	4,686	153.2	3.3	87	4
P-G	3,300	63.4	3.5	0	0

Annual cost rate [%]	Capacity factor [%]	Fuel consumption rate (ξ_i) [Ton/MWh]	Density CO_2, SO_X, NO_X [ppm/Ton]		
19	90	--			
17	90	0.2300	700	450	500
17	60	0.1100	450	200	300
17	55	0.2000	600	200	100
13	30	--			

- Maximum and minimum of capacity per a stage year of new generators ([MW])

Gen. Type	ΔX_{max}	ΔX_{min}
Nuclear	**5,000**	**0**
Coal	**5,000**	**0**
LNG	**5,000**	**0**
Oil	**500**	**0**
P-G	**1,000**	**0**

- Maximum permissible limitation of air pollution of air pollution emission

Air pollution	2011	2016	2021	2026	2030
CO_2	**40**	**40**	**40**	**40**	**40**
SO_X	**40**	**40**	**40**	**40**	**40**
NO_X	**40**	**40**	**40**	**40**	**40**

where, CO_2 : 10^3[Ton/year], SO_X, NO_X : 10^5[Ton/year]

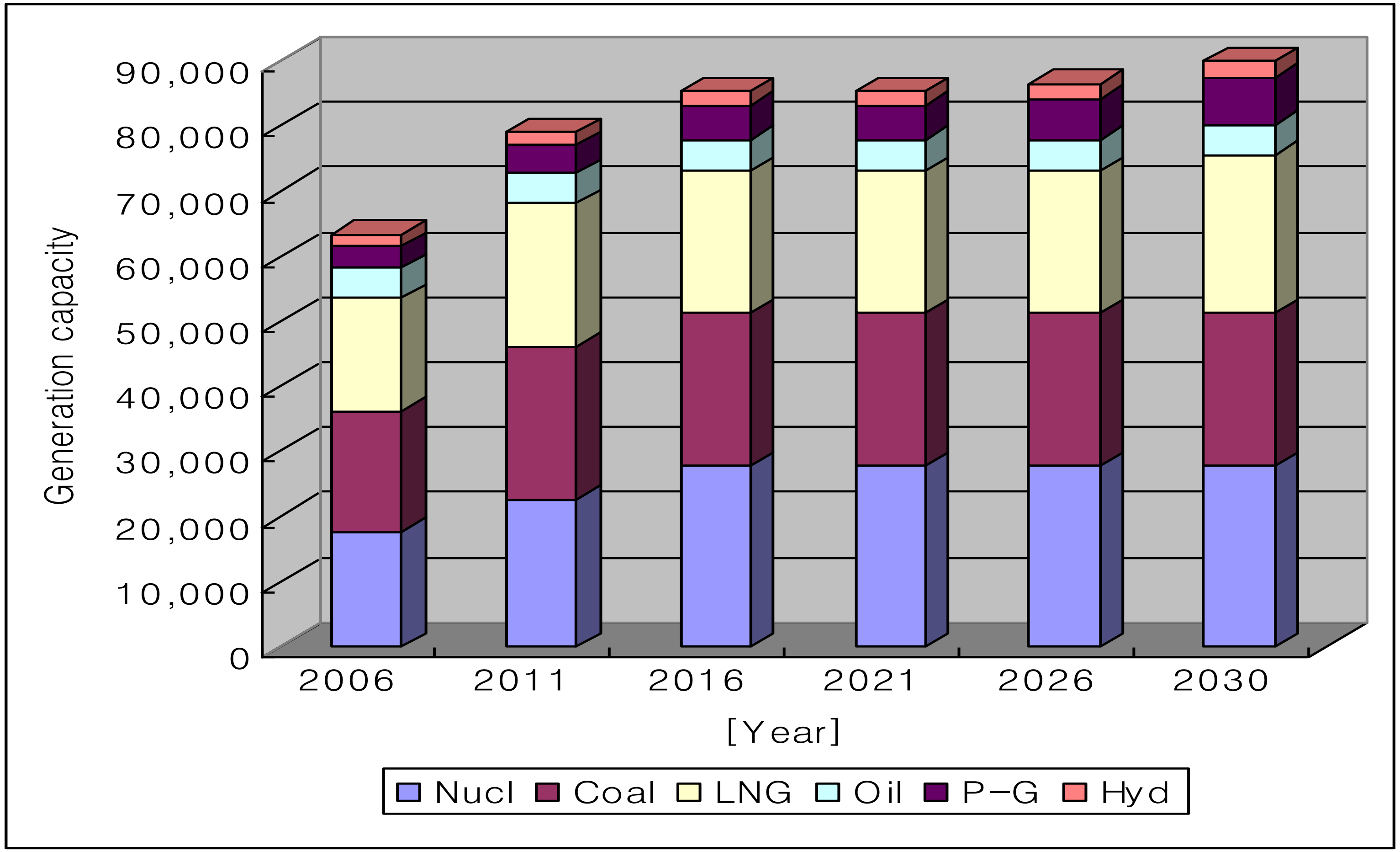
Results of Flexible BGM

➢ **Flexible generation mix for APC reinforcement mix [%]**

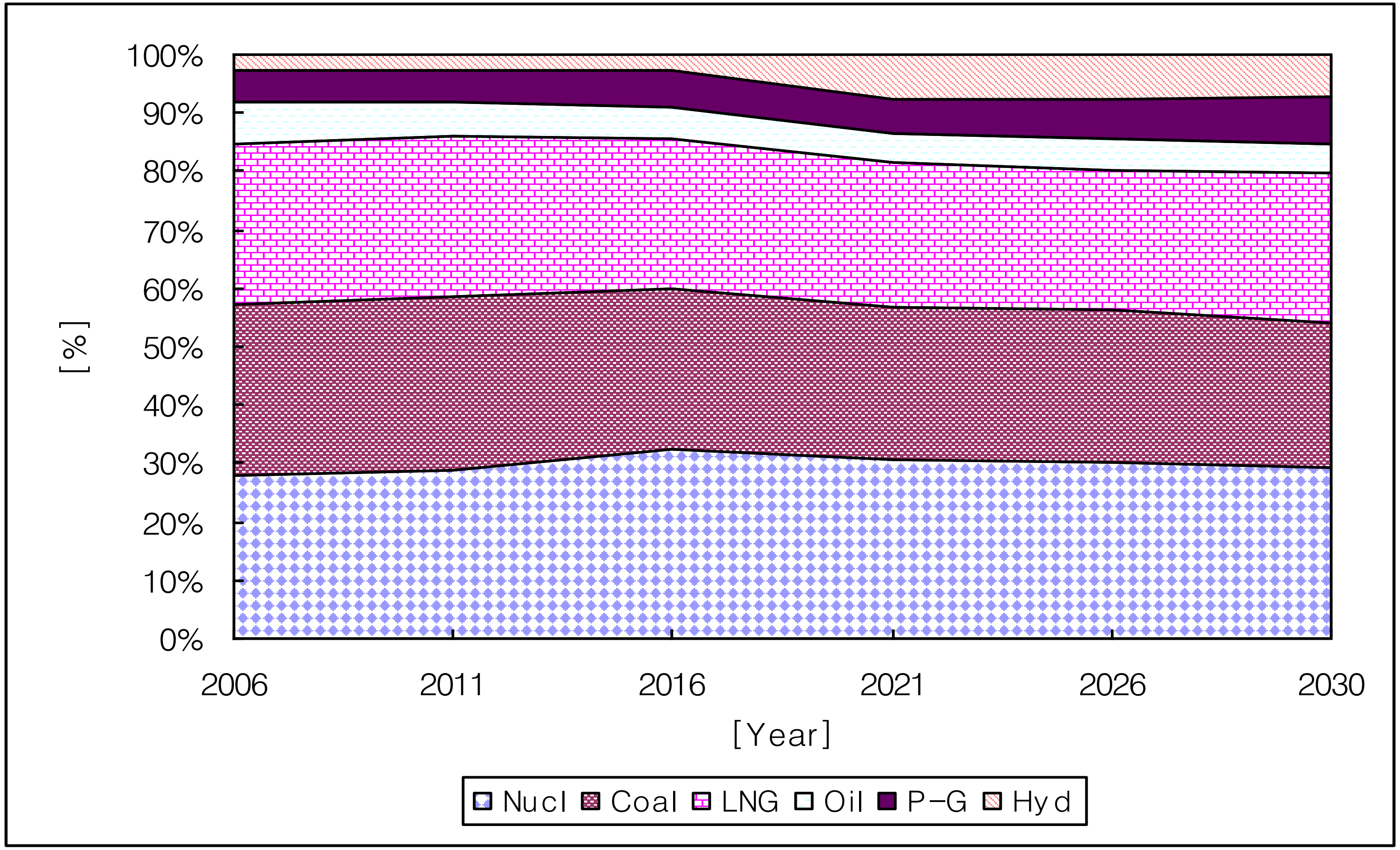
Z_0 = 16.4 Trillion Won

Gen. type	Proposed method - APC reinforcement mix (Case F1)					
	2006	2011	2016	2021	2026	2030
Nucl	27.94	28.71	32.47	35.62	35.16	33.91
Coal	29.12	29.65	27.53	25.71	25.38	24.48
LNG	27.50	27.75	25.73	24.03	23.71	25.37
Oil	7.39	5.92	5.49	5.13	5.06	4.88
P-G	5.20	5.43	6.21	6.89	7.88	8.65
Hyd	28.4	2.53	2.58	2.63	2.81	2.71

Best generation mix by proposed method with CO_2 air pollution constraint (case F1): Total Capacity



Best generation mix by proposed method with CO_2 air pollution constraint (case F1): Percent Mix



➢ Comparison of Conventional and Proposed BGM

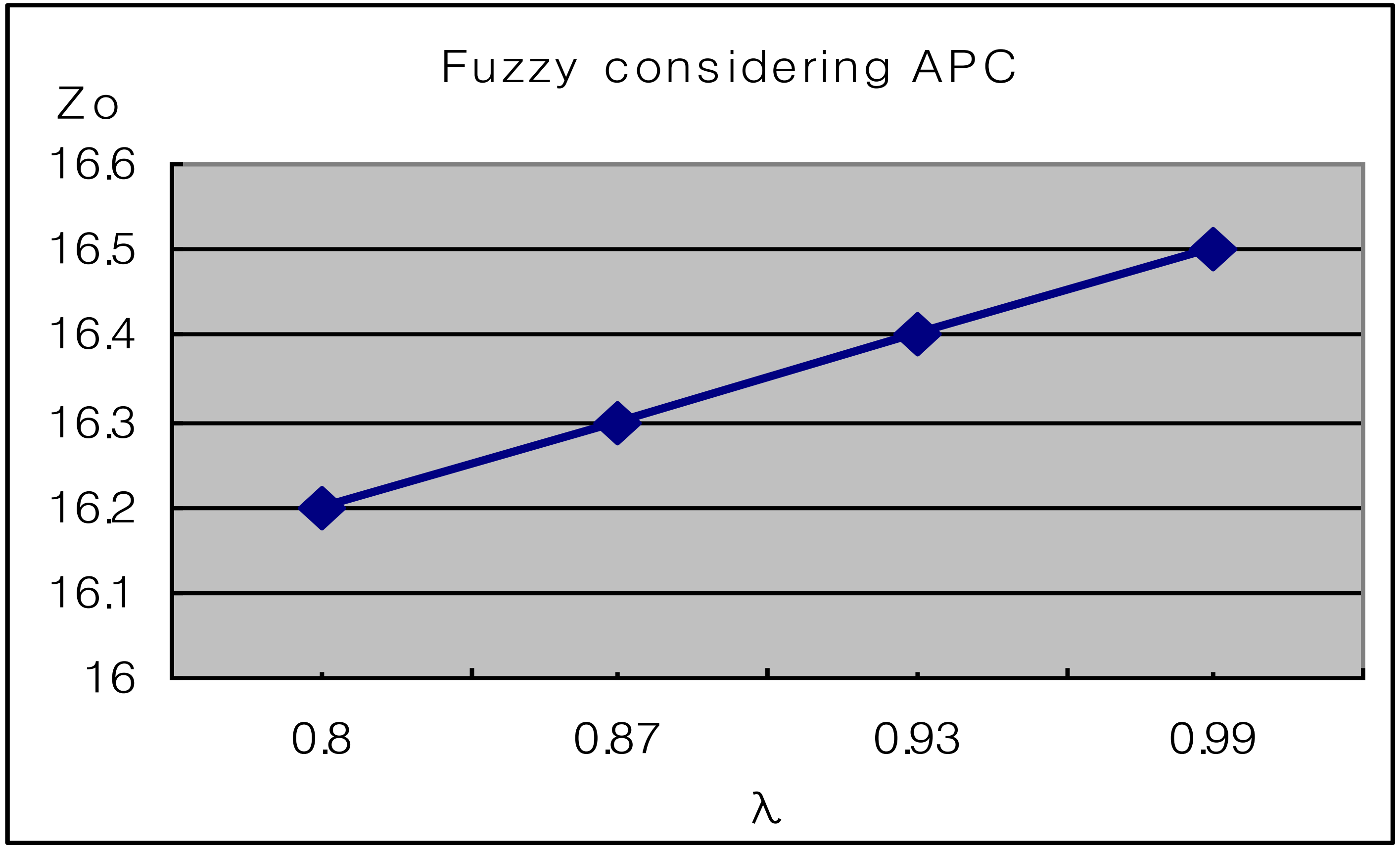
	Construction Cost [Billion Won]	Operation Cost [Billion Won]	Total Cost [Billion Won]	SL (Satisfaction Level)
Conventional (Optimal)	4,475.10	11,238.99	15,714.09	-
Proposed (Flexible)	4,498.82	12,018.50	16,517.32	0.93
Difference			813.23	
Robust ?				

➢ Sensitivity analysis I: SL (Satisfaction Level) according to Z_0

	Cases	Z_0 [10^3 Billion Won]	SL (Satisfaction Level)
Fuzzy considering APC	F0	16.5	0.99
	F1	16.4	0.93
	F2	16.3	0.87
	F3	16.2	0.80

The relationship between Z_0 and SL (Satisfaction Level)

[10^3 Billion Won]



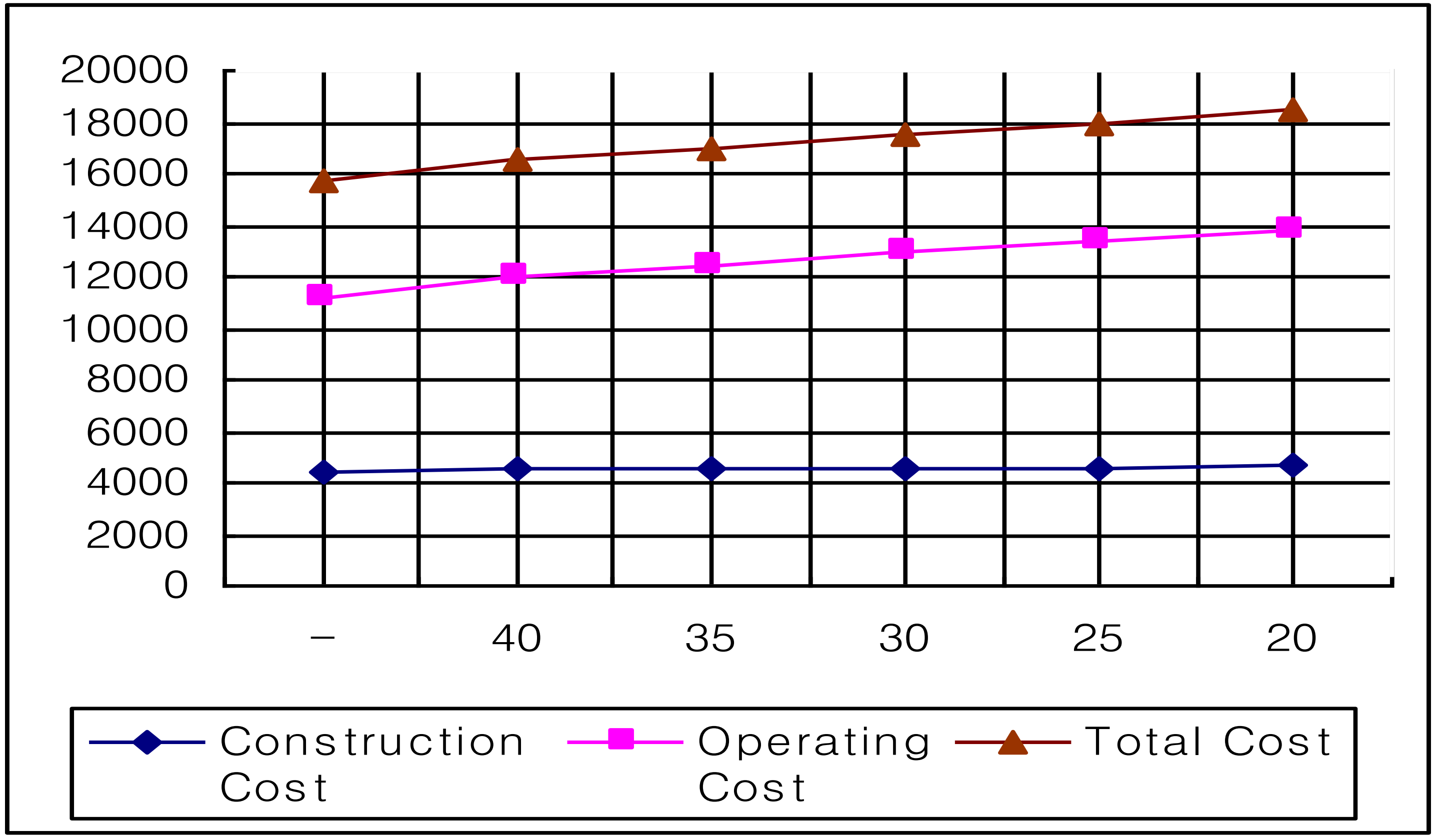
Satisfaction Cost: 150 Billion Won / 0.1SL(Satisfaction Level)

➢Sensitivity Analysis II: Cost variation according to changing of the CO_2 gas air pollution constraints.

[Billion Won]

	Permissible maximum For CO_2 constraint x 10^6 [Ton/yr]	Construction Cost	Operating Cost	Total Cost	Increased Cost
Case 0	-	4,475.10	11,238.99	15,714.09	
Case 1	40	4,498.82	12,018.50	16,517.32	803.28
Case 2	35	4,531.21	12,468.79	17,000.00	483.68
Case 3	30	4,563.62	12,919.07	17,482.69	482.69
Case 4	25	4,596.02	13,369.35	17,965.37	472.68
Case 5	20	4,638.19	13,826.55	18,464.74	499.37

Construction, fuel and total costs variation according to gas emission constraints.



CO_2 constraint cost: 10^5 Won / [CO_2 Ton/yr]

6. Conclusions

- The proposed Flexible Generation Mix in 2030 year

Satisfaction	Nuclear	Coal	LNG	Oil	P-G	Hydro
0.93	**33.91**	**24.48**	**25.37**	**4.88**	**8.65**	**2.71**

- The Total cost is 16,517 billion won until 2030 year for Korea power system (Note : 970 won/US$)

- Air pollution Emission Cost

•Considering air pollution constraints (Cost) – Not considering air pollution constraints (Cost)

•The cost for air pollution constraints is 803 billion won

Specially, CO_2 constraint cost is obtained as 10^5 Won / [CO_2 Ton/yr]

- This paper describes that mutually exclusive objective function on cost minimization and reliability maximization can be easily solved with Fuzzy linear programming

Acknowledgment

This study was done by KEEI(Korea Energy and Economics Institute), ERI(Engineering Research Institute , Gyeongang National University) and EPRRC(Electrical Power Reliability/Power Quality Research Center), Korea.

The support of the Ministry of Commerce, Industry and Energy (MOCIE) of Korea is acknowledged.

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Emissions Constrained Multi-Criteria-Best Generation Mix Using Fuzzy Dynamic Programming

International Symposium on Management Engineering

March 10 ~ 12, 2006

Waseda University

Kitakyushu, Fukuoka, JAPAN

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Contents

Introduction

Electricity utilization is environmentally benign and as a form of energy carrier ele ctricity is **clean** and **safe**. It causes no pollution or environmental emissions at the point of end user.

Carbon dioxide (CO_2), which is the main gas suspected of causing global war ming (greenhouse effect), is far more difficult and expensive to control.

Increasing prospects ratification of the **Kyoto Protocol**, liberalization and privatizat ion of the electricity supply industry is becoming a global trend.

The paper proposes a fuzzy dynamic programming based approach for multi-st ages (years) the long-term generation mix with considering **emission constraints** under the uncertain circumstances.
Essentially the theory consists of the imposition of the framework of a fuzzy decisi on on the dynamic programming concept.

The method can accommodate an arbitrary shape of membership functions and t he operation of the pumped-storage hydro plants. Economics, reliability, air polluti on and load uncertainties are evaluated from the membership functions given at all states.

Fuzzy Dynamic Programming

* $D = \left(\bigcap_{i=1}^{q} Gi\right) \cap \left(\bigcap_{j=1}^{p} Cj\right)$ (1)

* $\mu_D(\mathbf{x}) = \min\left[\min_{i=1\sim p} \mu_{Gi}, \min_{j=1\sim q} \mu_{Cj}\right]$ (2)

* $\mu_D(\mathbf{x}^*) = \max \mu_D(\mathbf{x})$ (3)

* $\mu_D(x_1^*,x_2^*,\ldots,x_N^*) = \max_{x_1\ldots x_N} \mu_D(x_1,x_2,\ldots,x_N)$ (4)

* $\mu_D(x_1^*,x_2^*,\ldots,x_N^*)=\max[\max\{\min(\mu_D(x_1),\mu_{F2}(x_2),\ldots,\mu_{FN-1}(x_{N-1}),\mu_{FN}(x_N))\}]\quad x_2..x_{N-1}\ x_1$

$= \max_{x_2..x_{N-1}}[\min\{\mu_D(x_1^*),\mu_{F2}(x_2),..,\mu_{FN-1}(x_{N-1}),\mu_{FN}(x_N))\}]$ (5)

* $\mu_D\,(x_1^*,x_2^*,..,x_N^*)=\max_{x_n..x_N}[\min\{\mu_D(x_1^*,x_2^*,..,x_n^*),\mu_{Fn+1}(x_{n+1}),..,\mu_{FN}(x_N)\}]$ (6)

* $\mu_D\,(x_1^*,..,x_n^*)=\max_{x_1..x_n}[\min\{\mu_D(x_1^*,..,x_{n-1}^*),\mu_{Fn}(x_n)\}]$ (7)

Best Generation Mix

◆ Problem statement

① The annual loads are given.
② The number of generator is not that of units but that of types.
③ Nuclear power plants are able to perform load following.
④ hydro generator construction is separately planned

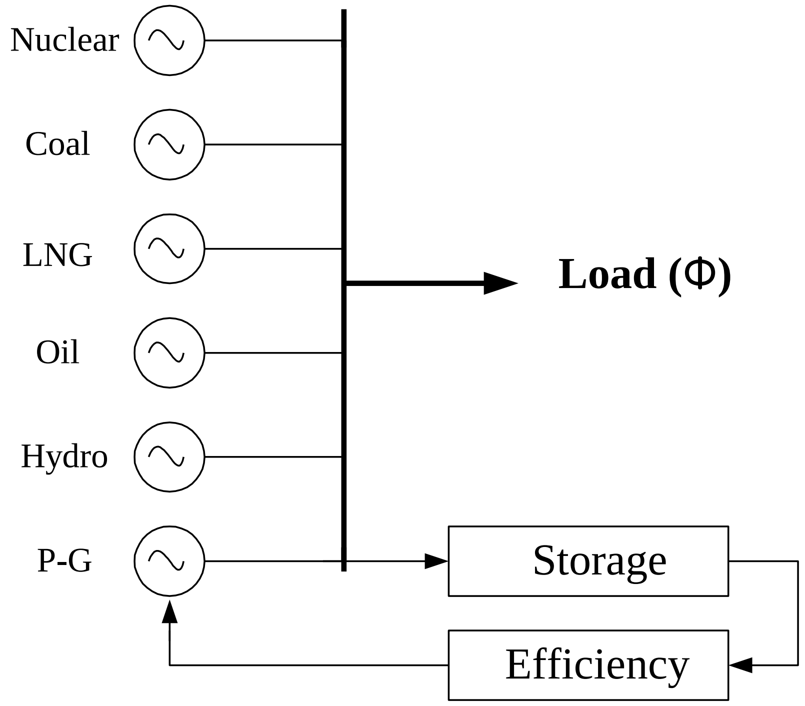


Fig 1. Model for the propose method

◆ Objective Functions

(1) The economic criterion (C)

$$\text{Minimize } Z_1 = \sum_{n=1}^{N}\sum_{i=1}^{NG} K_{cin} d_{in} \alpha_i \Delta x_{in} + \sum_{n=1}^{N}\sum_{i=1}^{NG} K_{fin} f_{in} y_{in} = C(\Delta x_{in}, y_{in}) \quad (8)$$

where,

i: unit type number (1 for nuclear, 2 for coal, 3 for LNG, 4 for oil, and 5 for pumped-storage generators are specified in this paper)

N: number of total study stage years

NG: number of unit types

$K_{cin} = ((1+e_{ci})/(1+r))^{n\Delta T}$

$K_{fin} = ((1+e_{fi})/(1+r))^{n\Delta T}$

e_{ci}: apparent escalation rate of construction materials of type-i unit

e_{fi}: apparent escalation rate of fuel of type-i unit

r: discount rate

ΔT: step size years of study years

d_{in}: construction cost of type-i unit n years

f_{in}: marginal fuel cost of type-i unit n years [$/MWh]

α_i: annual expenses rate of type-i unit

Δx_{in}: new construction capacity of type-i unit in n years [MW]

y_{in}: generated energy from type-i unit in n years [MWh]

C: Total cost function

$$Z_1 \lesssim Z_{01} \quad (9)$$

Where,

Z_{01} : aspiration level of decision maker for the total cost

(2) Reliability criterion (R)

$$\text{maximize} Z_{2n} = (\sum_{i=1}^{NG} x_{in} - L_{pn}) / L_{pn} \qquad n = 1 \sim N$$
$$= R(x_{in}) \quad (10)$$

Where,

R : Supply reserve rate function

$$Z_{2n} \gtrsim Z_{02n} \quad (11)$$

Where,

Z_{02} : aspiration level of decision maker for supply reserve rate in n year

(3) Air pollution criterion (A)

$$\text{maximize } Z_{3n} = \sum_{i=1}^{NG} CO2_i \rho_i y_{in} \qquad n = 1 \sim N$$
$$= A(y_{in}) \quad (12)$$

Where,

CO_{2in} : CO_2 density of type-i unit [ppm/ton]

ρi : fuel consumption rate of the type-i unit [Ton/MWh]

A : Air pollution function

$$Z_{3n} \lesssim Z_{03n} \quad (13)$$

Where,

Z_{03} : aspiration level of decision maker for air pollution CO_2 emission

◆ Constraints

1) Power supply constraint

$$\sum_{i=1}^{NG} x_{in} \geq L_{pn}(1+R_{esn}) \quad n = 0 \sim N \tag{14}$$

where,
R_{esn} : supply reserve rate criterion in n. [p.u]

2) Constraint for peak load uncertainty

$$L_{pn} \cong L_{pfaspn} \tag{15}$$

where,
L_{pfaspn} : forecasted aspiration level of decision maker for forecasting load in year n

3) Relation constraints between new plants and existing plants

$$x_{in+1} = x_{in} + \Delta x_{in} \quad i = 1 \sim NG, \; n = 1 \sim N \tag{16}$$

4) Unit generation limit constraints

$$Xminin \leq Xin \leq Xmaxin \tag{17}$$

5) SO_X and NO_X emissions constraints

$$\sum_{i=1}^{NG} SOX_i \rho_i y_{in} \leq SOX_{\max n} \qquad n = 1 \sim N \tag{18}$$

$$\sum_{i=1}^{NG} NOX_i \rho_i y_{in} \leq NOX_{\max n} \qquad n = 1 \sim N \tag{19}$$

where,

SO_{Xi} , NO_{Xi} : SO_X and NO_X emission densities respectively of type-i unit [ppm/ton]

SO_{Xmaxn}, NO_{Xmaxn} : Maximum permissible amount of Sox and NO_X emissions in n year [Ton]

◆ Membership functions

(1) The membership function for economic criterion (C)

$$\mu_C(x(t-1),u(t)) = \begin{cases} 1 & : \Delta C(\bullet) \le 0 \\ e^{-W_C \Delta C(x(t-1),u(t))} & : \Delta C(\bullet) > 0 \end{cases} \quad (20)$$

where,

μC(·) : membership function for economic fuzzy set

$\Delta C(\cdot) = (Fc(x(t)) - C_{asp}(t))/C_{asp}(t)$

$C_{asp}(t)$: aspiration level for cost at t-stage/year

WC : weighting factor of the economic membership function.

(2) Membership function for reliability criterion

$$\mu_R(x(t-1),u(t)) = \begin{cases} 1 & : \Delta R(\bullet) \ge 0 \\ e^{W_R \Delta R(x(t-1),u(t))} & : \Delta R(\bullet) < 0 \end{cases} \quad (21)$$

where,

$\mu_R(\cdot)$: membership function of reliability (supply reserve rate) fuzzy set

$\Delta R(\cdot) = (R(x(t)) - R_{asp}(t))/R_{asp}(t)$

$R_{asp}(t)$: aspiration level for reliability (supply reserve rate) at t-stage/year

W_R : weighting factor of reliability membership function .

(3) Membership function for the air pollution criterion (considering CO_2 only)

$$\mu_A(x(t-1),u(t)) = \begin{cases} 1 & : \Delta A(\bullet) \le 0 \\ e^{W_A \Delta A(x(t-1),u(t))} & : \Delta A(\bullet) > 0 \end{cases} \tag{22}$$

where,

$\mu_A(\cdot)$: membership function for CO_2 air pollution fuzzy set

$\Delta A(\cdot) = (A(x(t))-A_{asp}(t))/A_{asp}(t)$

$A_{asp}(t)$: aspiration level for air pollution at t-stage/year

W_A: weighting factor of air pollution membership function .

(4) Membership function for the forecasted peak load

$$\mu_L(x(t-1),u(t)) = \begin{cases} 1+\dfrac{1}{W_L(\Delta L(\bullet)/2\sigma_{+p.u}(t))^2} & : \Delta L(\bullet) \ge 0 \\ 1+\dfrac{1}{W_L(\Delta L(\bullet)/2\sigma_{-p.u}(t))^2} & : \Delta L(\bullet) < 0 \end{cases} \tag{23}$$

where,

$\mu_L(\cdot)$: membership function for fuzzy set of the forecasted peak load

$\Delta L(\cdot) = (L_p(x(t))-L_{pfasp}(t))/L_{pfasp}(t)$

$L_{pfasp}(t)$: aspiration level for forecasted peak load at t-stage

$\sigma_{p.u}(t) = \sigma(t)/L_{pforecasted}(t)$

$\sigma(t)$: standard deviation of $L_{pfasp}(t)$

W_L: weighting factor of the membership function of the forecasted peak load

◆ The proposed fuzzy dynamic programming based solution procedure

$$D = C \cap R \cap A \cap L \qquad (24)$$

where,
C,R,A & L are economics, reliability, air pollution and forecasted load fuzzy sets

$$\mu_D(x(t)) = \max[\min\{\mu_C(x(t-1),u(t)),\mu_A(x(t-1),u(t)),\mu_R(x(t-1),u(t)),\mu_L(x(t-1),u(t))\}]$$
$$u_{\min}(t) \le u(t) \le u_{\max}(t) \qquad (25)$$

where, $x(t)=x(t-1)+u(t)$
$\mu D(x(0)) = 1.0$

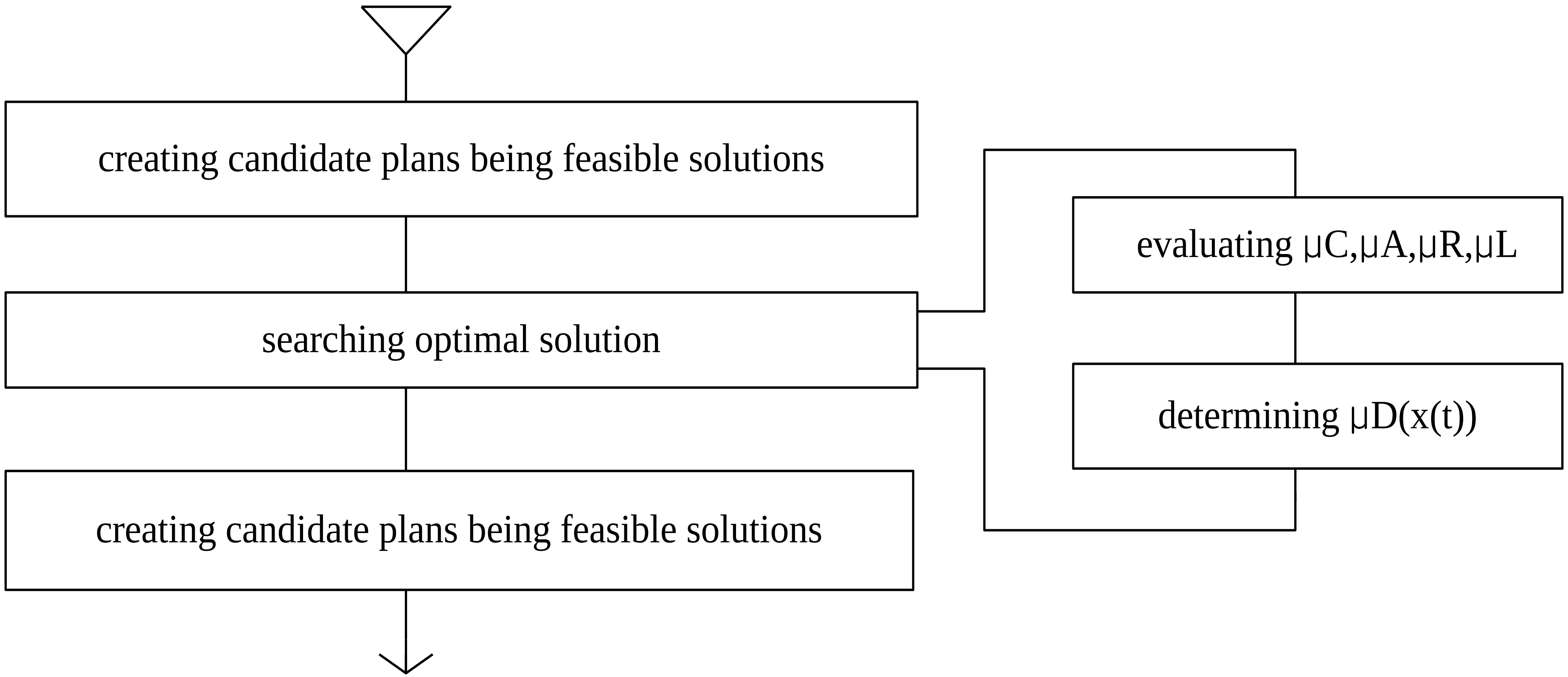
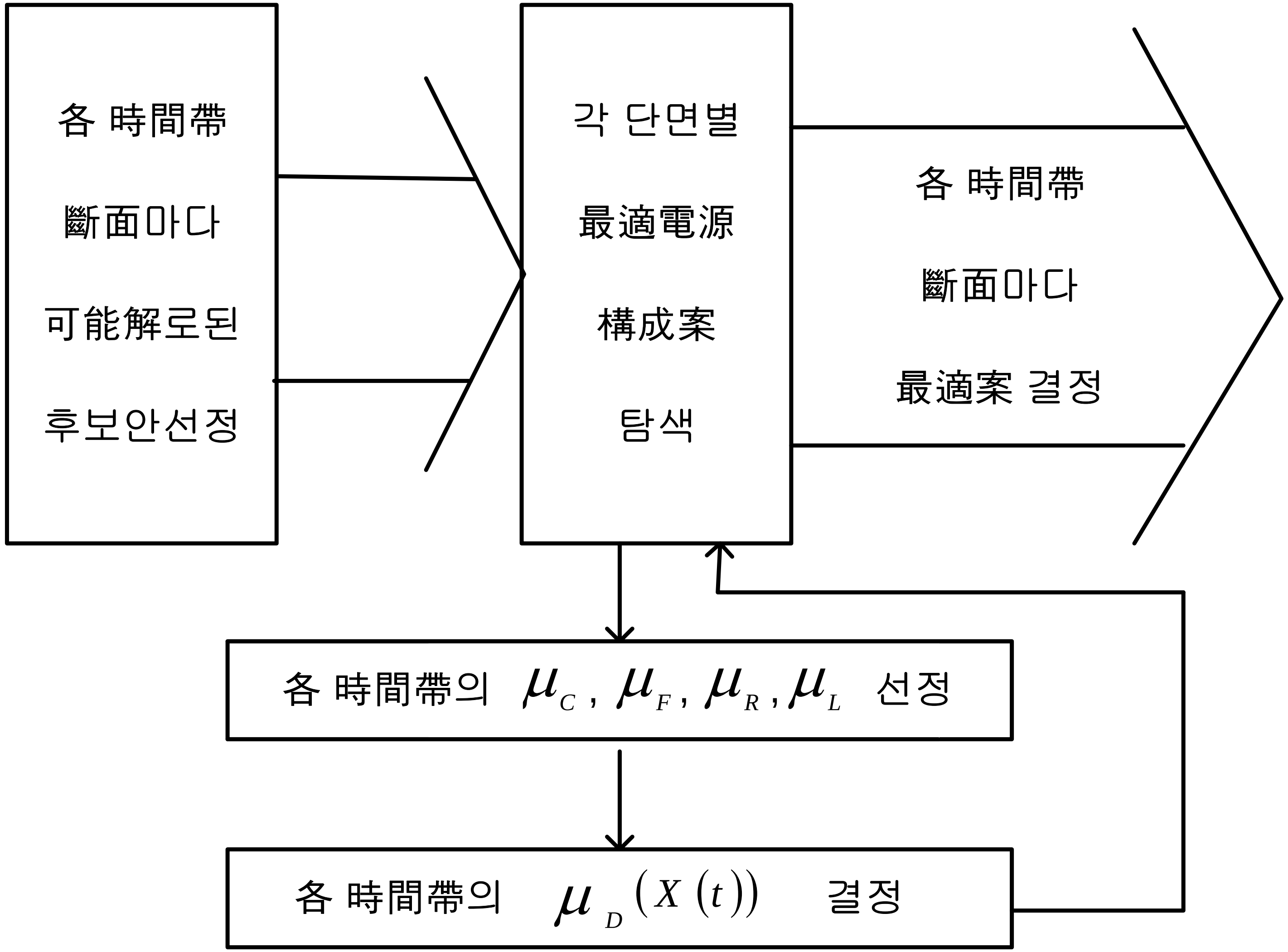
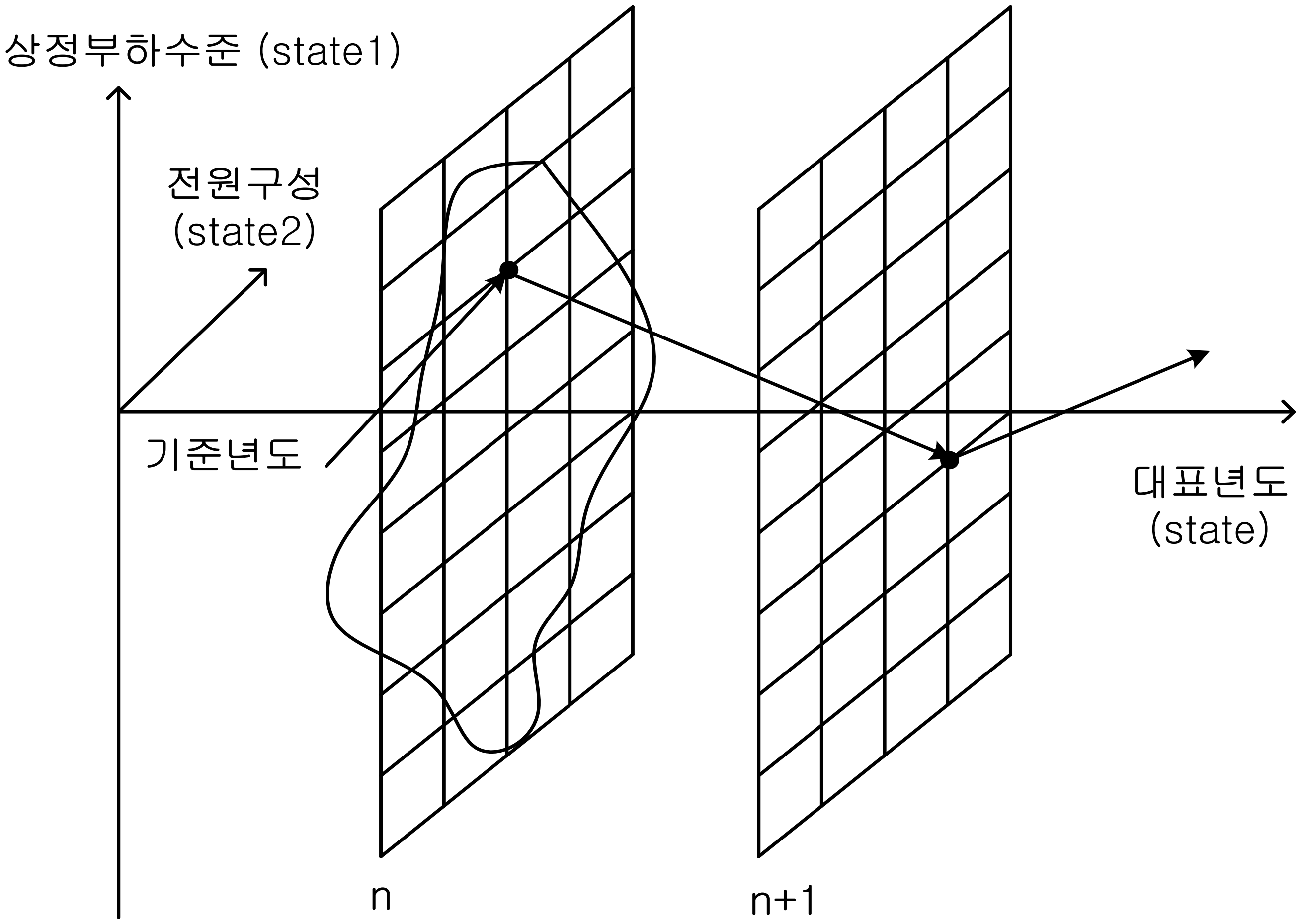


Fig 2. Procedure for analyzing the generation mix problem using fuzzy dynamic programming

※ 퍼지 동적계획법에 의한 전원구성문제의 해석과정



※ 퍼지 동적계획법에 의한 격자에서 전원구성문제의 해의 탐색과정



Case Study

Table 1. Maximum load, minimum load, and hydro plant at standard years

Year	Peak load L_P [MW]	Base load L_B [MW]	Hydro [MW]	LEP (10^3Ton)
2006	48,108	30,340	1,800	--
2011	57,340	34,200	2,000	4,500
2016	69,500	42,500	2,200	5,500
2021	78,200	47,500	2,400	6,500
2026	87,000	53,500	2,600	7,500

Table 2. The characteristics of economic input date

Gen. type	Initial year capacity [MW]	Fixed charge [10^5won/kW]	A_{ER} of fixed charge [%]	Marginal fuel cost [Won/kWh]	A_{ER} of fuel cost [%]	Annual cost rate [%]
Nucl	16,715	145.0	2	6.8	1	19
Coal	17,465	100.0	1	13.8	1	17
LNG	14,313	85.0	1	21.5	1	17
Oil	4,308	75.0	1	120.0	4	17
P-G	2,000	45.0	1	0.0	0	13

Table 3. The capacity factors and the gases emission data of plants

Gen. Type	Capacity factor [%]	Fuel consumption rate (ρ) [Ton/MWh]	Density (σ) [ppm/Ton] CO_2, SO_X, NO_X
Nucl	80	--	
Coal	70	0.4030	700 450 500
LNG	65	0.0500	450 200 300
Oil	55	0.0234	600 200 100
P-G	30	--	

Table 4. Yearly total generating capacities [MW]

Year	Generation Capacity [MW]
2006	56,601
2011	67,800
2016	88,500
2021	93,000
2026	105,000

Table 5. Generation mix and capacity in the initial year (2006)

Gen. type	Generation Mix [%]	Capacity [MW]
Nucl	29.5	16,715
Coal	30.9	17,465
LNG	25.3	14,313
Oil	7.6	4,308
P-G	3.5	2,000
Hyd	3.2	1,000
Total	100	56,601

Table 6. Maximum permissible limitation/criterion of the SO_x and NO_x emission constraints (10^3[Ton

Gases	2011	2016	2021	2026
SO_X	40	40	40	40
NO_X	40	40	40	40

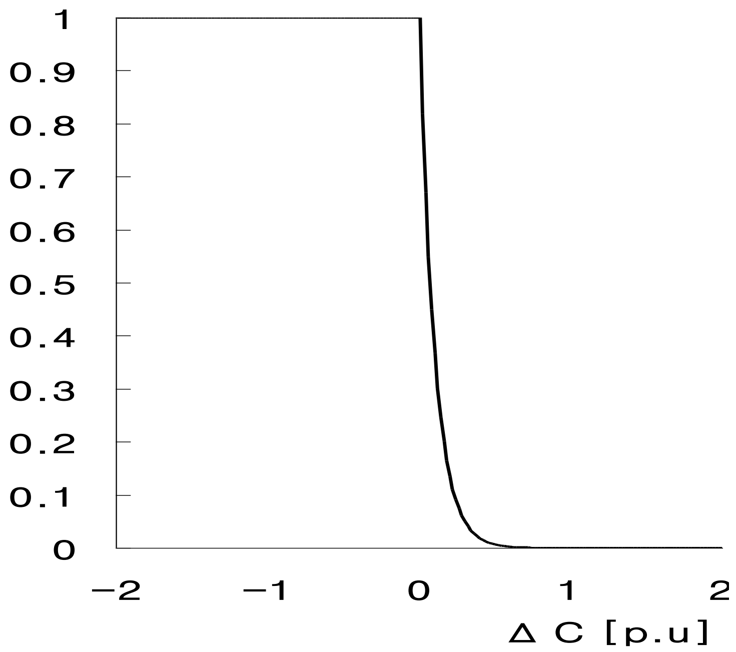
Table 7. Aspiration level of total cost, reliability and CO_2 in years/stage

Aspiration	2011	2016	2021	2026
Cost **(Z_{01})** [10^{12}won]	65	120	155	182
CO_2 **(Z_{03n})** [10^3Ton/yr]	125	140	155	170
Reliability **(Z_{02n})** [%]	10	10	10	10

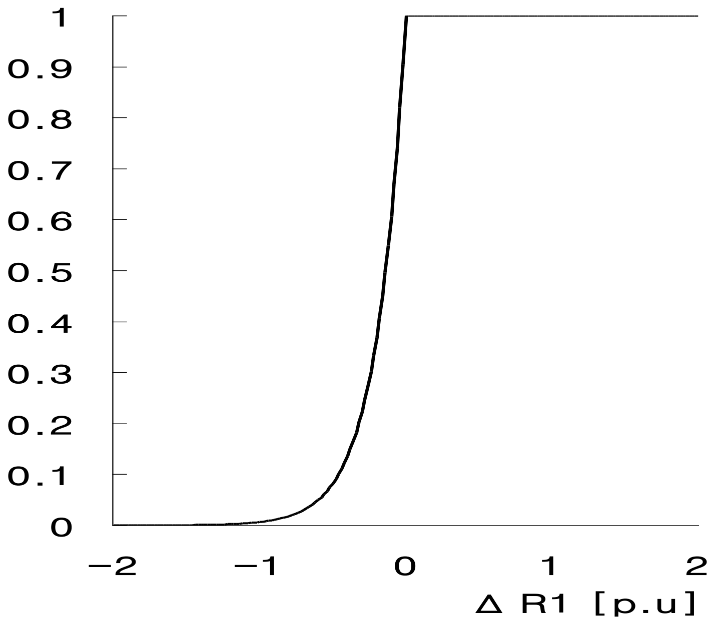
Table 8. Weighting factors of membership function

	Weighting factors of membership function
Cost	10.0
Reliability	15.0
Load	10.0
CO_2	5.0

◆ Membership functions for fuzzy sets of cost and reliability



(a) Pattern of membership functions of cost (C) and CO_2 emission (A)



(b) Pattern of membership function of reliability (R)

Fig 3. Membership functions for fuzzy sets of cost and reliability

◆ Results and discussion

(1) Case C0 : crisp and not considering emissions constraints using crisp

(2) Case F0 : fuzzy but not considering emissions constraints

(3) Case F1 : the fuzzy considering emissions constraints

(4) Case F2 : the fuzzy case considering CO_2 emission constraint with -10% deceased CO_2 aspiration level

Table 7. Best generation mix for the conventional crisp method (not considering CO_2) [%]

Gen. type	Crisp Conventional method (Case C0) (minimize total cost)			
	2011	2016	2021	2026
Nucl	28.5	23.5	23.5	22.0
Coal	39.4	48.5	48.5	47.0
LNG	14.5	17.0	18.5	19.0
Oil	10.4	3.0	2.3	2.0
P-G	3.2	4.7	4.5	7.8
Hyd	4.0	3.3	2.7	2.2

◆ Results and discussion

Table 8. Best generation mix for the conventional fuzzy method (not considering CO_2) [%]

Gen. type	Fuzzy Conventional method (Case F0) (Not considering CO_2 emission constraint)			
	2011	2016	2021	2026
Nucl	23.5	23.5	23.5	46.5
Coal	44.4	48.5	48.5	21.5
LNG	14.5	17.0	18.5	19.0
Oil	10.4	3.0	2.3	2.0
P-G	3.2	4.7	4.5	8.8
Hyd	4.0	3.3	2.7	2.2

◆ Results and discussion

Table 9. Best generation mix for the proposed fuzzy method (con sidering CO_2) [%]

Gen. type	Fuzzy Proposed method (Case F1) (CO_2 reinforcement mix)			
	2011	2016	2021	2026
Nucl	46.5	48.5	48.5	48.5
Coal	17.4	23.5	23.5	23.5
LNG	14.5	17.0	18.5	19.0
Oil	10.4	3.0	2.3	2.0
P-G	7.2	4.7	4.5	4.8
Hyd	4.0	3.3	2.7	2.2

◆ Results and discussion

Table 10 Best generation mix for the other proposed fuzzy method
(considering CO_2 with -10% deceased CO_2 aspiration level) [%]

Gen. type	Fuzzy Proposed method (Case F2) (CO_2 10% more reinforcement mix)			
	2011	2016	2021	2026
Nucl	46.5	48.5	48.5	48.5
Coal	17.4	23.5	23.5	23.5
LNG	14.5	17.0	18.5	19.0
Oil	10.4	3.0	2.3	2.0
P-G	7.2	4.7	4.5	4.8
Hyd	4.0	3.3	2.7	2.2

◆ Results and discussion

Table 11. Satisfaction levels for cases

	Constraints	Satisfaction Level
Case C0	Crisp and Minimize cost and not considering CO_2	---
Case F0	Fuzzy and not considering CO_2	1.0000
Case F1	Fuzzy and considering CO_2 emission constraint	0.8984
Case F2	Fuzzy and -10% Aasp	0.5093

Conclusions

- New approach for the long-term generation mix with multi-criteria considering air pollution constraints, which are not only SO_X and NO_X but also CO_2 emission limitations, under the uncertain circumstances is proposed using a Fuzzy Dynamic programming.
- The effectiveness of the proposed approach is demonstrated by using it to determi ne the best generation mix problem of the KEPCO-system, which contains nuclea r, coal, LNG, oil and pumped-storage hydro plant in multi-years.
- A result of the CO_2 emissions constraint is the recommendation of nuclear or LN G power plant construction shown available. This in turn increases the total cost o f the BGM.
- The proposed approach can be generalized to handle other emissions constraints s uch as those on SO_X and NO_X.
- This approach can accommodate the operation of pumped-storage generation whi ch has a relationship with operation of nuclear power plant with some strict for lo ad following.

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Thank you very much for your attention !!

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Ta Panta rhei, "everything flows"

Heraclitus – Greek philosopher

Thank for Your Attention !

Everybody Loves
Hydro Energy &
Energy Survival
DNA!

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Biography

Jaeseok Choi(S’88, M’91, SM’05) was born at Kyeongju, Korea in 1958. He obtained B.Sc., M.Sc. and Ph.D. degrees from Korea University in 1981, 1984 and 1990 respectively. His research interests include Fuzzy Applications, Probabilistic Production Cost Simulation, Reliability Evaluation and Outage Cost Assessment of Power Systems. He was a Post-Doctor at University of Saskatchewan in Canada on 1996. He was also a visiting professor at Cornell University, NY, USA in 2004 to 2007. He is an adjunct professor of Illinois Institute of Technology, IL, USA since 2008. Since 1991, he has been on the faculty of Gyeongsang National University, Jinju, where he is a professor. He was 2020 president of KIEE. And He is Fellow of KIEE.

1. 최적전원구성문제의 정식화

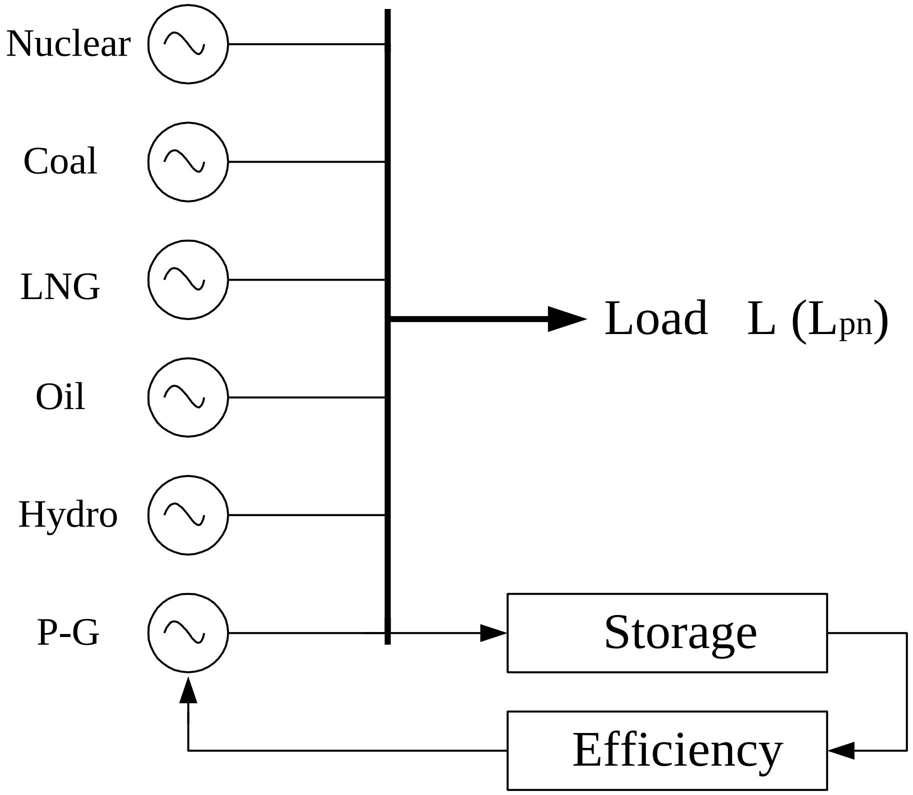


그림.1 최적전원구성모델의 개요

1.1 목적함수

$$Minimize\ \ Z = \sum_{n=1}^{N}\sum_{i=1}^{NG} K_{cin} d_{in} \alpha_i \Delta x_{in} + \sum_{n=1}^{N}\sum_{i=1}^{NG} K_{fin} f_{in} y_{in} = F(\Delta x_{in}, y_{in})$$

단,

i : 전원종별의 표시하는 번호(원자력:1, 석탄화력:2, LNG:3, 석유화력:4, 양수발전: 5)

N: 총 연구대상년도 수[년]

NG: 전원종류

K_{cin}= $((1+eci)/(1+r))^{n\,\Delta T}$

K_{fin}= $((1+efi)/(1+r))^{n\,\Delta T}$

e_{ci}: i번째 전원의 건설자재의 피상물가상승율(apparent escalation rate)

e_{fi}: i번째 전원의 연료비의 피상물가상승율(apparent escalation rate)

r: 할인율(discount rate)

ΔT: 연구대상년도의 간격[년]

d_{in}: n 년도에서 i번째 전원의 건설비 단가[won/kW]

f_{in} : n 년도에서 i번째 전원의 건설비 단가[won/kW]

α_i: i번째 전원의 년경비율

Δx_{in}: n 년도에서 i 번째 전원의 건설용량 [MW]

y_{in}: n 년도에서 i 번째 전원의 발전량 [MWh]

1.2 제약조건

1) 부하수급제약조건(*Installed capacity constraint)*

$$\sum_{i=1}^{NG}(x_{in}+\Delta x_{in}) \geq L_n^P(1+R_n)-HYD_n \qquad \mathrm{n}=1\sim \mathrm{N}$$

단,
R_n: n년도의 공급예비력기준 [p.u]
HYD_n: n년도의 수력발전기용량[MW]

2) 수급에너지제약조건(*Energy constraint of demand)*

$$\sum_{i=1}^{NG} y_{in} \geq (L_n^P + L_n^B)\times 8760/2 + V_n \ - HYD_n \times 8760 \times CF_H \quad n=1\sim N$$

단,
L^P_n: n 년도의 최대부하[MW]
L^B_n: n 년도의 최소부하[MW]
V_n: 양수발전원의 양수에 의한 증가된 부하량[MWH]
CF_H: 수력전원의 년평균설비이용율[p.u]

3) 전원별 설비이용율 제약조건 (*Production energy constraint of generation system)*

$$y_{in} \le (x_{in} + \Delta x_{in}) \times 8760 \times CF_i \quad i = 1 \sim NG,\ n = 1 \sim N$$

단, CF_i: i 전원의 년 평균설비이용율

4) 초기년도 설비용량제약조건(*Capacity constraint in initial year)*

$$x_{i1=EX_i} \quad i = 1 \sim NG$$

단, EX_i: i 전원의 초기년도 용량

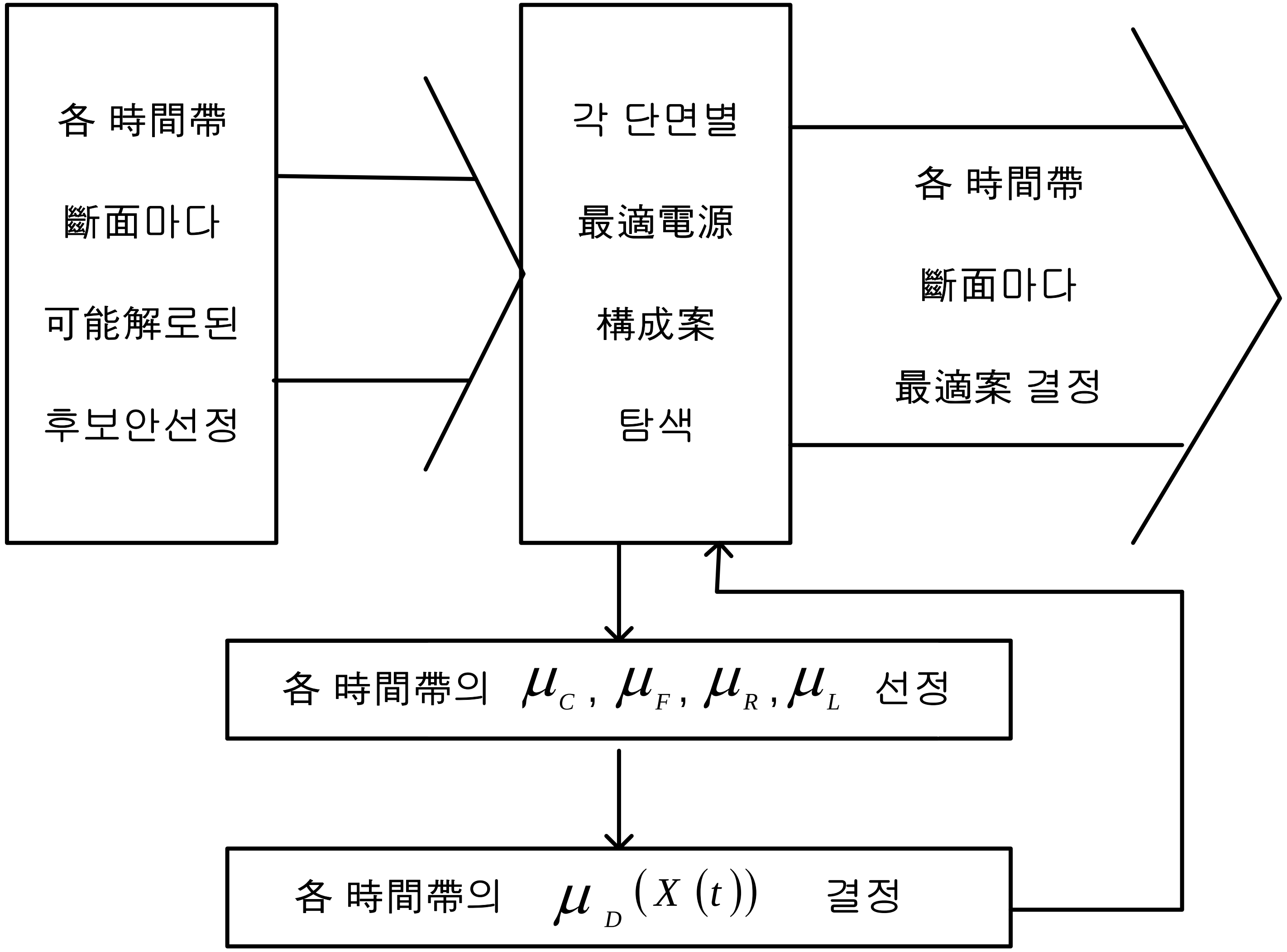
5) 전원용량 년도별 상태 제약조건 (*Constraint of mutual relationship between existing generator and new generator capacity (state equation)*

$$x_{in+1} = x_{in} + \Delta x_{in+1} \quad i = 1 \sim NG,\ n = 1 \sim N$$

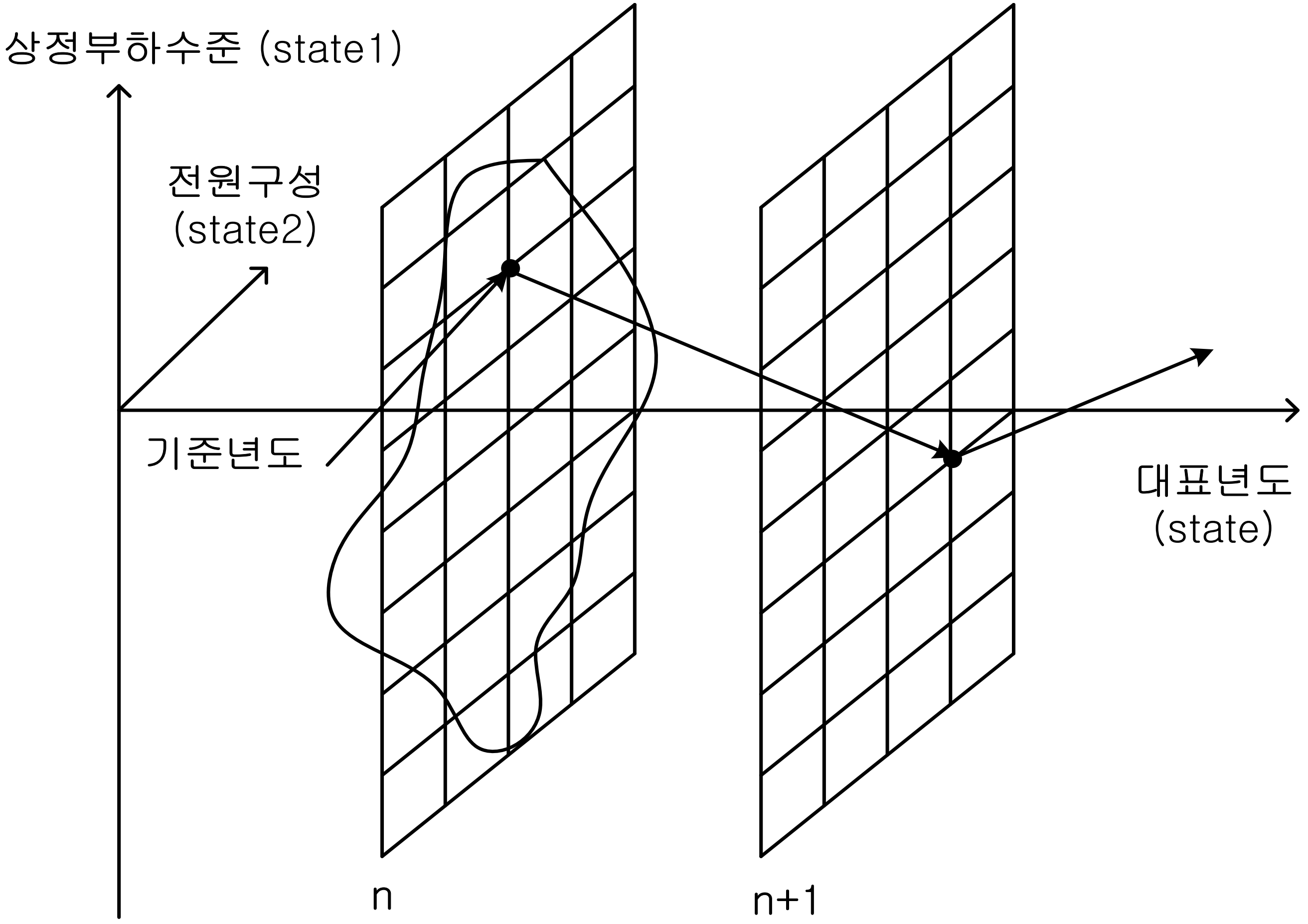
6) LNG화력발전원의 에너지 제약조건 (*Energy constraint of LNG thermal plant)*

$$y_{3n} \ge LEP_{\min} \quad i = 1 \sim N$$

※ 퍼지 동적계획법에 의한 전원구성문제의 해석과정



※ 퍼지 동적계획법에 의한 격자에서 전원구성문제의 해의 탐색과정



2. 간단한 사례연구 (환경성을 고려한 경우)

Table 1. Maximum load, minimum load, and hydro plant at standard years

Year	Peak load LP [MW]	Base load LB [MW]	Hydro [MW]	LEP (103Ton)
2006	48,108	30,340	1,800	--
2011	57,340	34,200	2,000	4500
2016	69,500	42,500	2,200	5500
2021	78,200	47,500	2,400	6500
2026	87,000	53,500	2,600	7500

Table 2. Maximum load, minimum load, and hydro plant at standard years

Gen.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Density [ppm/Ton]		
									CO_2	SO_2	NO_x
Nucl.	16,715	145.0	2	6.8	1	19	80	--	----		
Coal	17,465	100.0	1	13.8	1	17	70	0.4030	700	450	500
LNG	14,313	85.0	1	21.5	1	17	65	0.0500	450	200	300
Oil	4,308	75.0	1	120.0	4	17	55	0.0234	600	200	100
P-G	2,000	45.0	1	0.0	0	13	30	--	----		

{(1) Initial capacity [MW]; (2) Fixed charge [10^5won/kW]; (3) AER of fixed charge [%];
(4) Marginal fuel cost [Won/kW]; (5) A_{ER} of fuel cost [%]; (6) Annual cost rate [%];
(7) Capacity factor [%]; (8) Fuel consumption rate [Ton/MWh]}

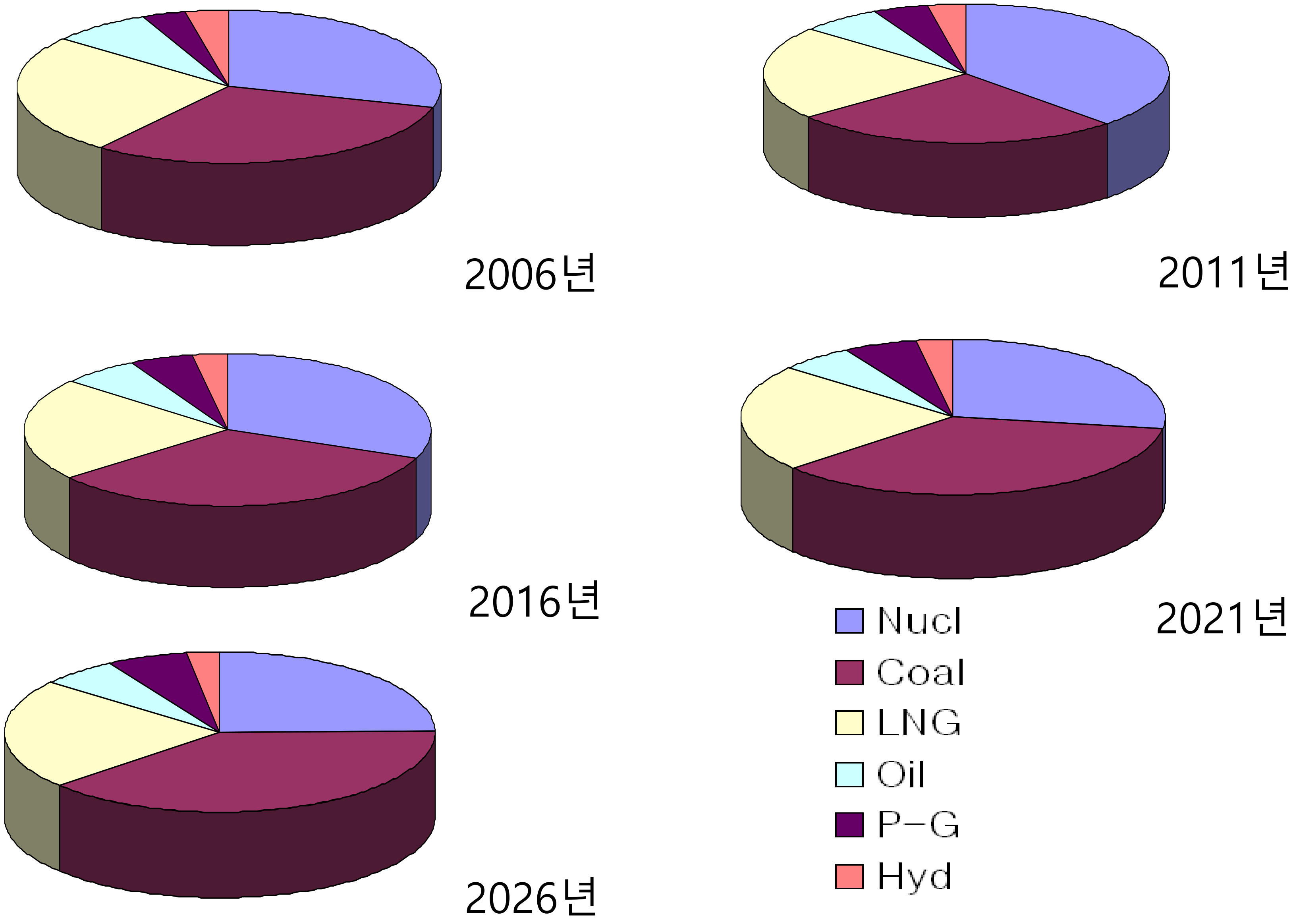
Table 3. Best generation mix for the conventional and proposed methods.[%]

Gen Type	Conventional method (Base Case: Case 0)					Proposed method (Case 1) (APC reinforcement mix)			
	2006	2011	2016	2021	2026	2011	2016	2021	2026
Nucl	29.5	37.7	31.1	27.6	24.8	37.7	43.6	38.9	34.9
Coal	30.9	26.5	33.1	35.9	38.6	26.5	21.9	24.7	22.2
LNG	25.3	21.7	22.0	22.3	22.2	21.7	20.8	22.3	28.5
Oil	7.6	6.5	6.0	5.9	5.8	6.5	6.0	5.9	5.8
P-G	3.5	4.5	5.0	5.6	6.0	4.5	5.0	5.6	6.0
Hyd	3.2	3.0	2.8	2.7	2.6	3.0	2.8	2.7	2.6

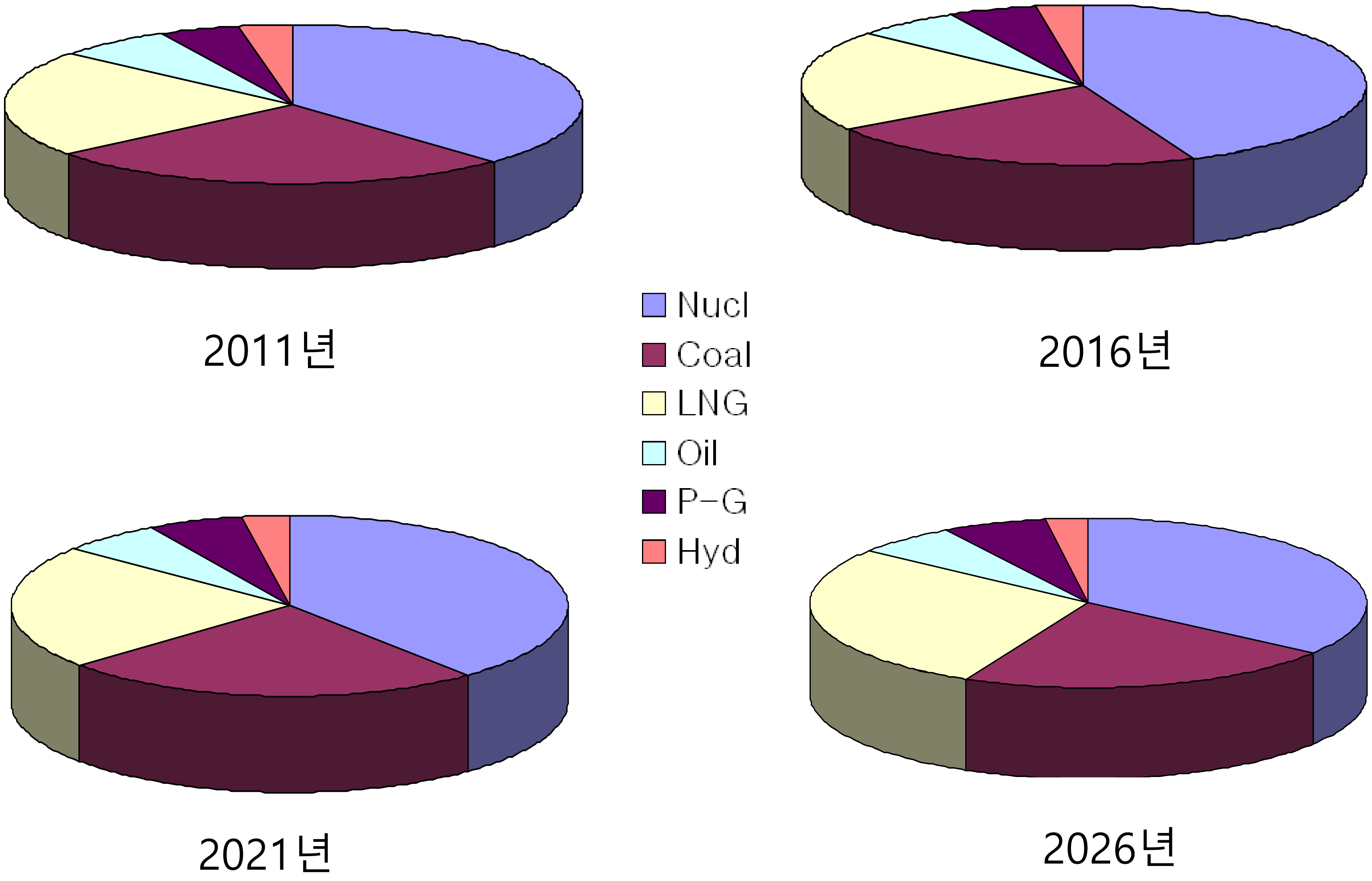
Table 4. Total cost evaluation of best generation mix in the two cases. [Billion Won]

	Construction Cost	Operation Cost	Total Cost
Conventional method	3,463.10	7,751.29	11,214.39
Mix with CO_2 APC	4,065.65	7,221.03	11,286.68
Remark(Difference)	602.55	-530.26	72.29

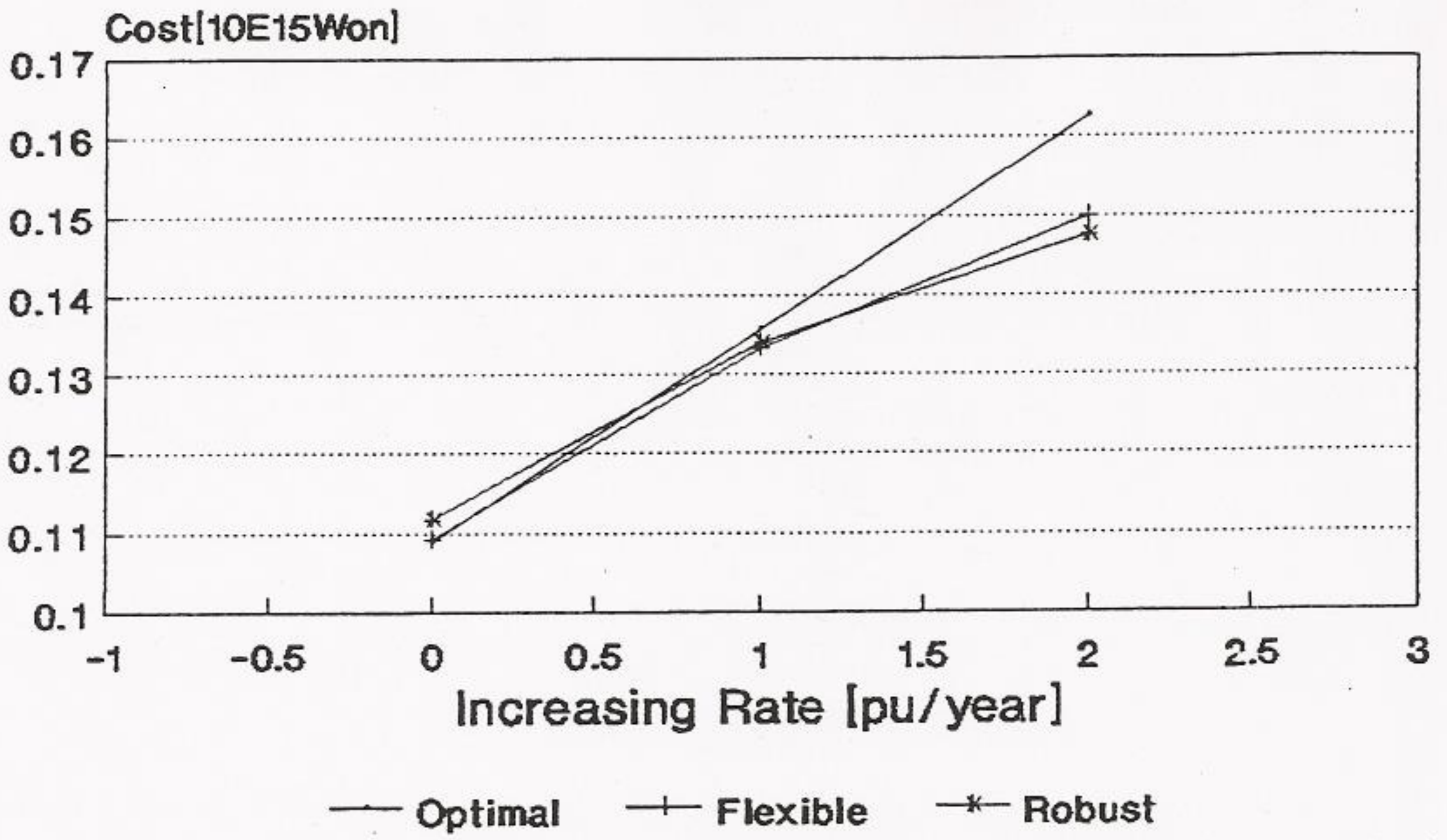
※ 기존의 방법



※ 제안 방법

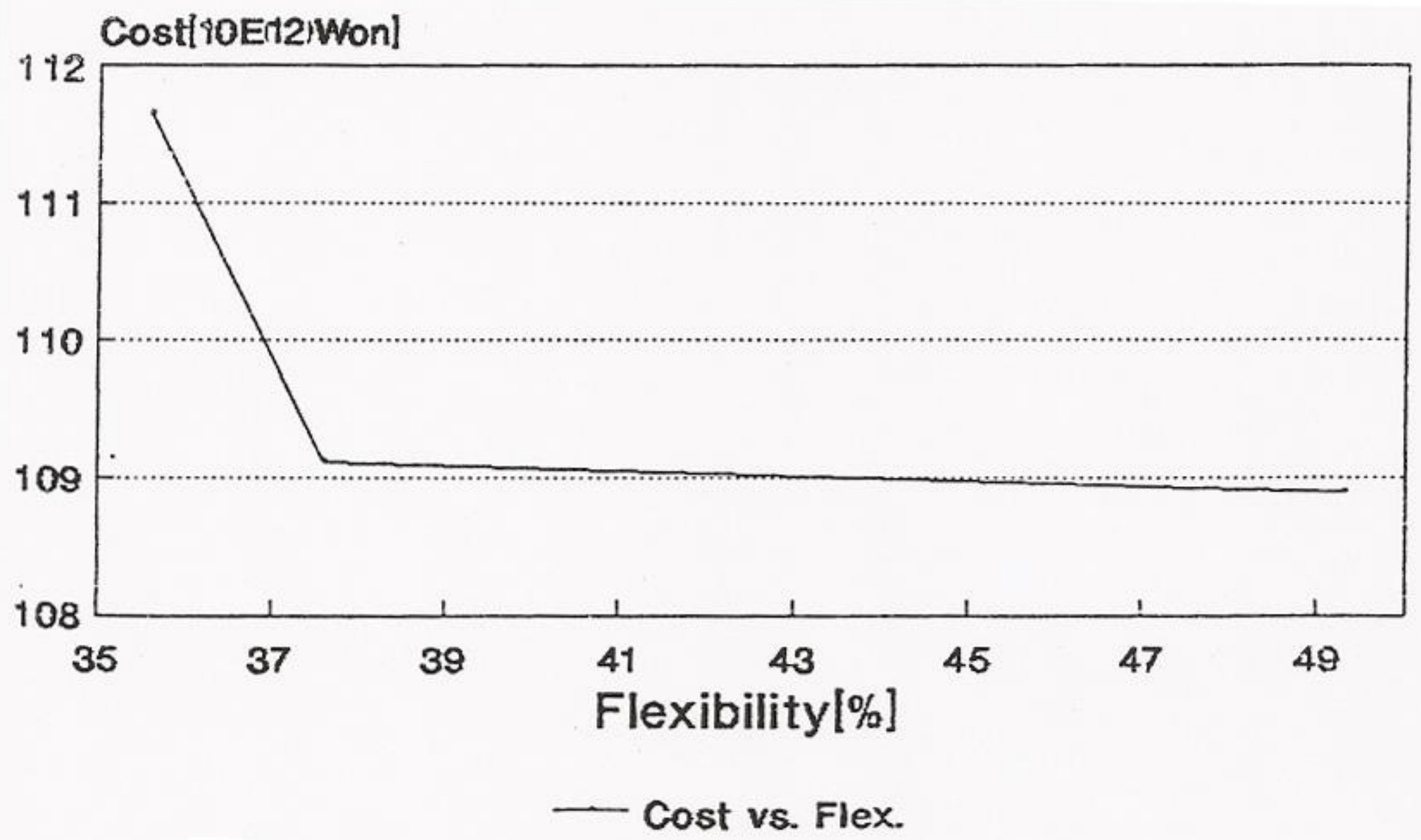


※ 최대부하에 대한 감도해석



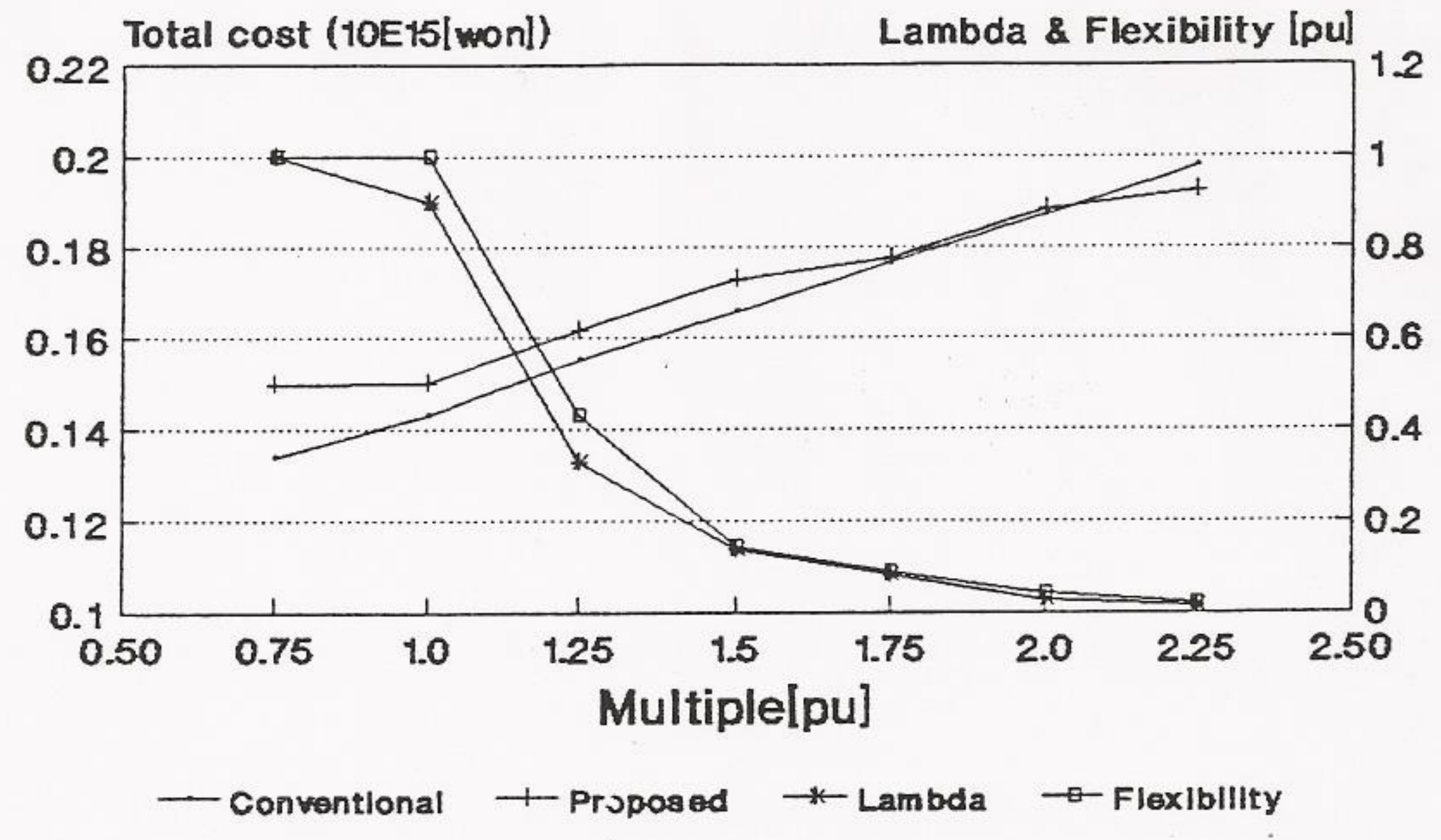
최대부하에 대한 감도해석

※ 유연성과 경제성의 관계



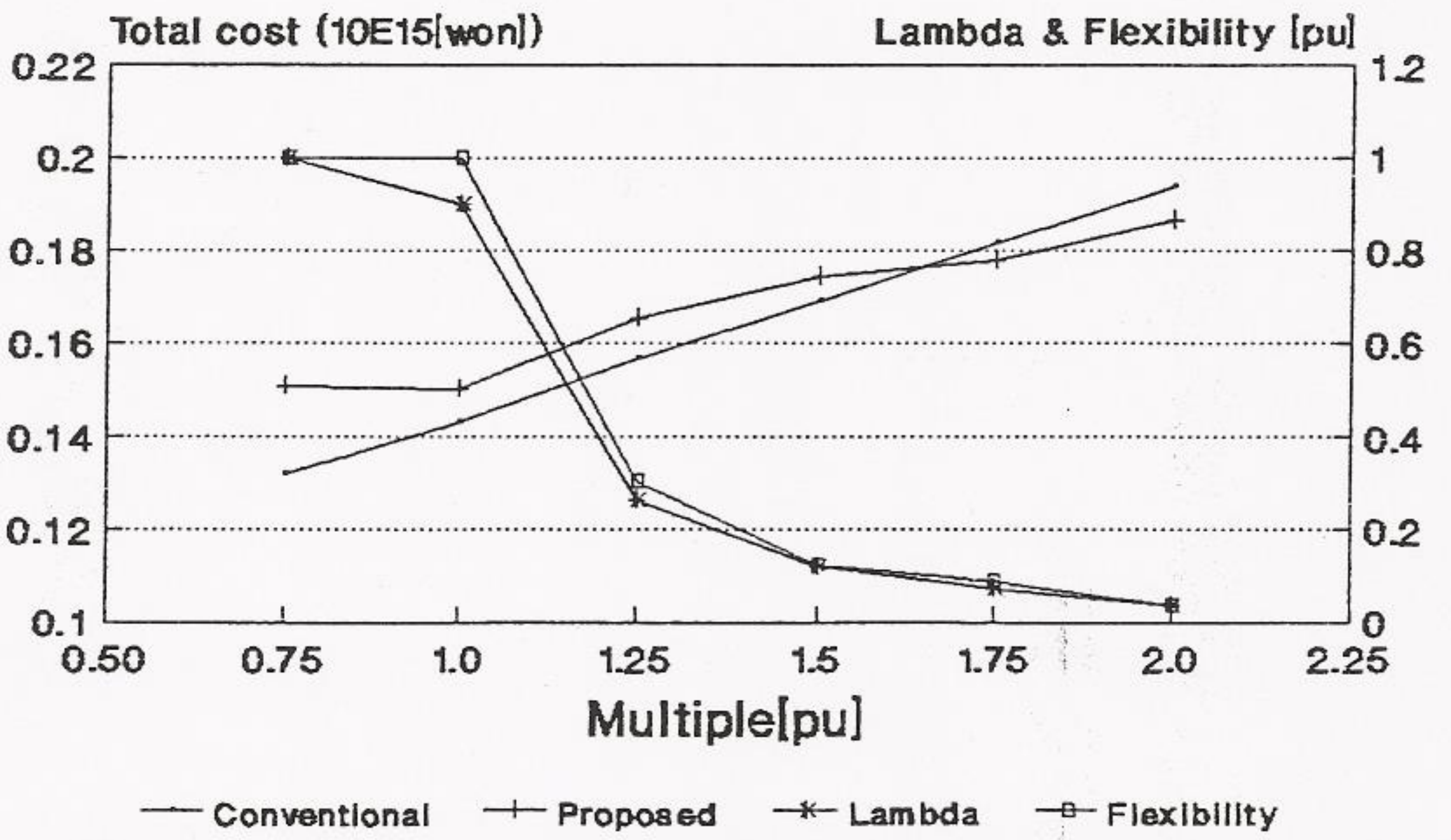
유연성과 경제성의 관계

※ 건설단가에 대한 감도해석



건설단가에대한 감도해석

※ 연료단가에 대한 감도해석



연료단가에대한 감도해석

※ 종합발전단가 및 년설비이용율의 변화