論 文
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An Expert System for Short-Term Generation Scheduling of Electric Power Systems

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Abstract - This paper presents an efficient short-term generation scheduling method using a rule-based expert/consulting system approach to assist electric energy system operators and planners. The expert system approach is applied to improve the Dynamic Programming(DP) based generation scheduling algorithm. In the selection procedure of the feasible combinations of generating units at each stage, automatic consulting on the manipulation of several constraints such as the minimum up time, the minimum down time and the maximum running time constraints of generating units will be performed by the expert/consulting system. In order to maximize the solution feasibility, the aforementioned constraints are controlled by a rule-based expert system, that is, instead of imposing penalty cost to those constraint violated combinations, which sometimes may become the very reason of no existing solutions, several constraints will be manipulated within their flexibilities using the rules and facts that are established by domain experts.

In this paper, for the purpose of implementing the consulting of several constraints during the dynamic process of generation scheduling, an expert system named STGSCS is developed. As a building tool of the expert system, C Language Integrated Production System(CLIPS) is used. The effectiveness of the proposed algorithm has been demonstrated by applying it to a model electric energy system.

Key Words : Generation Scheduling(발전계획), Expert System(전문가시스템),
Dynamic Programming(동적계획법), Rule-based System(규칙베이스시스템)

List of symbols

t : time index
T : period of hours for which the system is studied
i : index of the thermal unit
j : index of the fuel constrained/hydro unit
l : index of transmission line
R : total number of thermal units
H : total number of hydro units
L : total number of fuel constrained units
Nu : total number of units
Nl : total number of transmission lines
$f_i(\cdot)$: fuel cost function of the ith thermal unit
P_i^t : MW power generated by the ith thermal unit at time t
P_j^t : MW power generated by the jth fuel constrained/hydro unit at time t
P_D^t : MW total load demand at time t
$C(j, k)$: transfer cost from state j to state k
$C_T(j, k)$: transitional cost from state j to state k
$C_p(j, k)$: penalty cost from state j to state k
u_i^t : commitment state of ith unit at time t
u_i^{t-1} : commitment state of ith unit at time $t-1$
$P_i^{\min}$: minimum MW power of ith unit
$P_i^{\max}$: maximum MW power of ith unit
q_j^t : fuel/water consumption rate of jth unit
$q_j^{\min}$: minimum fuel/water consumption of jth unit
$q_j^{\max}$: maximum fuel/water consumption of jth unit
Q_j : total fuel/water usage amount of jth unit in the scheduling time horizon
τh_i : minimum up time of ith unit
τl_i : minimum shot down time of ith unit
τu_i : maximum operating time of ith unit
Pf_l^t : MW power flow of lth transmission line at time t
$Pf_l^{\max}$: maximum MW power flow limit of lth transmission line
w_i^{t-1} : operating duration of unit i at time $t-1$
z_i^{t-1} : shut-down duration of unit i at time $t-1$
v_i^{t-1} : accumulated operating time of unit i at time $t-1$
$Sa(Ta)$: minimum starting cost of cycling unit
$Sb(Tb)$: maximum starting cost of cycling unit
Sc : unit price of starting cost
Sd : unit price of shut-down cost

1. Introduction

Under the tremendous increasing of electric energy consumption, because of not only the rapid increase of various office automation and information communication facilities but also the inclination of delightful living environment, the electric energy system has been in fast expansion for the recent decade. In order to supply high quality electric energy to the customer in a secure and economic manner, electric utilities face many economical and technical problems in operation, planning and control of electric energy systems. Under the these circumstances, electric energy quality and reliability/security become important tasks, and for the purpose of optimal planning and operation of large scale energy systems, modern system theory and optimization techniques are being applied with the expectation of considerable cost saving and enhancement of system security level.

One of the major problems that needs to be considered in order to achieve above mentioned tasks is the determination of the most economical and secure commitment schedule for generating units, so called generation scheduling, such that a series of operating constraints are satisfied simultaneously. Various approaches were proposed for solving the generation scheduling/unit commitment problem so far[1~6]. Among those approaches, especially, the DP based algorithm has proven to be one of the most successful approach. This algorithm would systematically evaluate a large unmber of possible decisions in terms of minimizing the overall cost in a multi-stage scheduling problem. Due to the enumerative nature of the method, DP suffers from a long processing time that expands exponentially with the size of the problem, and soon reaches a level that is practically impossible to compute. In order to reduce the difficulties, several heuristic strat-

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egies have been introduced in the dynamic search procedure of the generation scheduling problem[7, 8]. Not all of these methods, however, are regarded as feasible and/or practical as the size of the system and the constraints increase. In spite of various heuristic strategies incorporated in the DP algorithm, the trade-offs would always exist between the quality of the optimal solution and speed of execution. When operating constraints are fully considered in the algorithm, a feasible/optimal solution becomes rather scarce or even does not exist. The heuristic rules are challenged by the complicated situations such as those imposed by the minimum up time, the minimum down time and the maximum running time constraints of generating units and so on. In order to preserve the solution feasibility, either very conservative values are chosen for parameters such as the window size or they are adjusted iteratively to enhance the effectiveness of heuristic strategies[9].

Recently, considering the shortcomings of the mathematical programming, it was thought to be of interest to apply the Artificial Intelligence(AI) and fuzzy theory related approaches for supplementing the present mathematical programming based algorithms in the scheduling problems of electric energy systems. As a result, several expert/consulting systems for the generation scheduling/unit commitment are proposed [10~12]. However, those methods are not concerned with the optimization of the commitment schedule but the expert system application is primarily for the preparation of the input data that would be used in the mathematical programming approach. Therefore, there are still some difficulties that would occur when all the practical operational constraints need to be considered. Expert system techniques have been successfully applying to many real world problems in industry and other fields. Recent developments in AI have demonstrated successful applications of expert systems for the specific problem solving tasks, and electric energy system also became one of the improtant application fields of expert systems[13].

This paper presents an efficient short-term generation scheduling method using a rule-based expert/consulting system approach to assist electric energy system operators and planners. The expert system approach is applied to improve the DP based generation scheduling algorithm. In the selection procedure of the feasible combinations of generating units of each stage, automatic consulting on the manipulation of several constraints such as the minimum up time, the minimum down time and the maximum running time constraints of generating units will be performed by the expert/consulting system. In order to maximize the solution feasibility, the aforementioned constraints are controlled by a rule-based expert system, that is, instead of imposing penalty cost to those constraint violated combinations, which sometimes may become the very reason of no existing solutions, several constraints will be manipulated within their flexibilities using the rule and facts that are established by domain experts. In this paper, the CLIPS is used as a building tool of the expert system. the CLIPS, which was developed by NASA at the AI section of the Johnson Space Center, is a forward chaining rule-based language that has inferencing and representation capabilities(see the reference[14] for the details). Because of its high portability, the CLIPS has been using on a wide variety of real world problem solving tasks[15].

In this paper, in summary, for the purpose of implementing the consulting of several constraints during the dynamic process of generation scheduling, an expert system named STGSCS(Short-Term Generation Scheduling Consulting System) is developed and the effectiveness of the proposed system has been demonstrated by applying it to a model electric energy system.

2. Problem Description and Definition

2.1 Problem descriptions

The objective of the generation scheduling problem is to minimize the fuel cost consumed by thermal units for the power generation and startup processes within the study period, and the general scheduling procedures are as follows.

1) Electric energy demand forecasting in hourly base.
2) Evaluation and assessment of area/bus load.
3) Power plant maintenance scheduling and generator availability assessment.
4) Unit commitment and economic load dispatch plan.

In this paper, the short-term generation scheduling problem will be solved under the following premises.

1) The study period is one day and divided into smaller time intervals of equal duration. The typical duration that is considered for each division is one hour.
2) Assessment of the area/bus load is possible, and the load is assumed to be constant within each time interval.
3) Power plant maintenance schedules, generator availability status and priority order are given.
4) Production fuel costs are represented as a second order polynomial of the output.
5) Start-up cost of cycling units are represented as a linear function of the unit down time between the minimum and the maximum boundaries.
6) Shut-down cost of units are represented as an appropriate constant value in association with each unit.
7) The loadability of a transmission line is evaluated as 30[%] of its stability margin.
8) Only the active power dispatch problem will be treated, and transmission loss is considered using the loss penalty factor of each generating unit.
9) The proposed short-term generation scheduling system will be operated by domain experts.

2.2 Problem definition

1) The objective of generation scheduling: Determination of the most economical and secure commitment pattern of generating units.
    - Derivation of optimal combination of generating units.
    - Determination of economic dispatch status.
2) Constraints : system constraints, generating units constraints, securtiy constraints, fuel constraints and environmental constraint.
    - System constraints : active power balance, spinning reserve, maintenance schedules, generating units status(must run, fixed run, cycling) and crew constraint.
    - Generating units constraints : the maximum/minimum limits of output, the minimum up time, the minimum down time and ramping rate.
    - Security constraints : the loadability of the transmission lines and the net interchange of each area.
    - Fuel constraints : LNG, coal and water usable amount.
    - Environmental constraint : the maximum running time of thermal units.

As mentioned above, the generation scheduling problem is to determine the combination of generating units and its output levels which allow the minimum total operation cost over the study period subject to a set of constraints that arise from the system requirements and restrictions on the operation of generating units.

3. Problem Formulation

The objective function is generally to minimize the total operation cost of thermal units subject to a set of inequality and equality constraints over the horizon time of 24 hours. The objective functional to be minimized is then written as

$$\text{Minimize} : \sum[\sum f_i(P_i^t) + C(j, k)] \tag{1}$$

where $C(j, k) \in \{C_T(j, k), C_P(j, k)\}$

Subject to following constraints :

1) real power balance constraint

$$\sum P_i^t + \sum P_j^t = P_D^t, \ t \in T \tag{2}$$

2) capacity limits of generating units

$$u_i^t P_i^{\min} \leq P_i^t \leq u_i^t P_i^{\max}, \ i \in \{R, H, L\}, \ t \in T \tag{3}$$

3) spinning reserve constraint

$$\sum u_i^t P_i^{\max} - \text{Mid}(u_i^t P_i^{\max}) \geq P_D^t, \ t \in T \tag{4}$$

where Mid means the middle capacity unit

4) fuel and water usage constraint

$$q_j^{\min} \le q_j^t \le q_j^{\max},\ j \in \{H, L\},\ t \in T \qquad (5)$$

where $\int q_j^t(t)dt = Q_j \rightarrow$ const.

5) the minimum up time constraint

$$(u_i^t - u_i^{t-1})(w_i^{t-1} - \tau h_i) \le 0,\ i \in R,\ t \in T \qquad (6)$$

where $w_i^t = u_i^t(w_i^{t-1} + 1)$

6) the minimum down time constraint

$$(u_i^t - u_i^{t-1})(z_i^{t-1} - \tau l_i) \ge 0,\ i \in R,\ t \in T \qquad (7)$$

where $z_i^t = (1 - u_i^t)(z_i^{t-1} + 1)$

7) the maximum operating time constraint

$$u_i^t(v_i^{t-1} - \tau u_i) \le 0,\ i \in R,\ t \in T \qquad (8)$$

where $v_i^t = u_i^t(v_i^{t-1} - 1)$

8) transmission line flow limits

$$-Pf_l^{\max} \le Pf_l^t \le Pf_l^{\max},\ l \in Nl,\ t \in T \qquad (9)$$

This formulation is a simplified representation of the operation of a real system. The crew and ramping rate constraints are not included in this study.

4. Solution Procedures and Strategies

4.1 Mathematical programming approach

In the conventional DP approach, the unit commitment problem can be modeled as follows.

$$F_t^*({}^tU^k) = \text{Min}\{\Phi_t^k({}^{t-1}U^j, {}^tU^k)\},\ t \in T \qquad (10)$$

where

$$\begin{aligned}\Phi_t^k({}^{k-1}U^j, {}^tU^k) = {} & \Sigma f_i(P_i^t) + \Sigma SC_i(z_i^{t-1}) \\ & + \Sigma DC_i + C_p(j, k) \\ & + F_{t-1}({}^{t-1}U^j) \qquad (11)\end{aligned}$$

Equation (10) is the least total operation cost to arrive at the state $({}^tU^k)$. In equation (11), the first, the second and the third terms represent the total production fuel costs, the start-up costs and the shut-down costs of generating units respectively. The fourth term represents the penalty costs, and the last term of the equation represents the minimum total accumulation cost to reach the state $({}^{t-1}U^j)$. The penalty costs will be imposed when the some kinds of constraints such as generating units constraints and environmental constraint are violated.

Various heuristics have been introduced in DP in order to reduce its execution time and memory size. The author has proposed one of the schemes named Search and Selection (S&S) technique that provides a better compromise between the speed and closeness of the solution to the optimal value. In the S&S algorithm, the execution of the program is performed stage by stage, every stage represents a time interval in the scheduling time span. In most applications, this interval is generally chosen as one hour.

The search ranges in S&S algorithm are determined by the following procedures.

1) Sort all of the thermal generating units by their priority in ascending order, so that the most costly unit which is on the top of the list would have the lowest priority.
2) Start from the bottom of the priority list and commit units temporarily until the peak load demand plus the spinning reserve requirements are satisfied.
   Assume this step results in the temporary commitment of m units, and this becomes the upper bound of the search range.
3) Form the lower bound of the search range using n units which need to be committed in order to fulfill the off-peak load demand plus spinning reserve requirements of the study period. Then $(m-n)$ will become the search range.
4) Constitute primary possible combinations that provide sufficient output to fit the load demand plus spinning reserve requirements using the generators which are within the search range. For the combinations that provide insufficient output, more units will be appended from the excess range in the order of higher priority.

Fig. 1 illustrates the basic conception of the S&S technique.

A combination that can provide the required system load demand plus the spinning reserve capacity without violating any of the operating constraints is defined as a valid-combination.

The operating constraints represented by equations (2) ~ (9) can be considered as follows. The

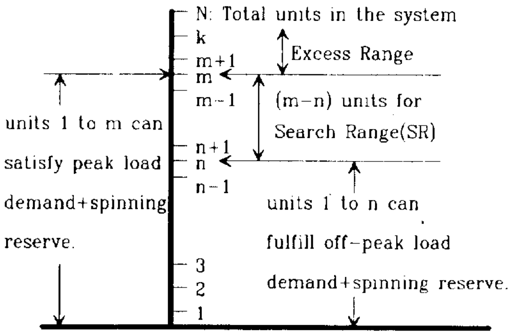

Fig. 1 Conception of Search & Selection technique

constraints 1) and 2) are handled in the economic load dispatch module and the constraint 3) is treated in the constitution procedure of the valid combinations. The constraints 5) ~ 7) are handled during the process of state transition by DP algorithm, and the constraints 4) and 8) are considered using the separate optimization modules[16].

When the operational constraints such as the minimum up and down times and the maximum running time are incorporated in the DP algorithm, serious problem may arise with a insufficient search range as there may be no valid-combinations within the search range because of the violations of the constraints. This problem would cause DP-S&S program to fail in reaching any feasible solution. When this happens at one of the later stages, a considerable amount of time and computer resource will have been wasted.

Since there are no simple rules that could guide a operator to solve the above mentioned problems, recently, the necessity of an expert system like method has been keenly emphasized.

4.2 Rule-based expert system approach

The expert system approach is applied to improve the DP based generation scheduling algorithm. In the selection procedure of the valid combinations of generating units of each stage, automatic consulting on the manipulation of several constraints such as the minimum up time, the minimum down time and the maximum running time constraints of generating units will be performed by the expert/consulting system. In order to maximize the solution feasibility, the aforementioned constraints are controlled by a rule-based expert system, that is, instead of imposing penalty costs to those constraint violated combinations, which sometimes may become the very reason of no existing solution, several constraints will be manipulated within their flexibilities using the rules and facts that are estabilished by domain experts.

In this paper, for the purpose of implementing the consulting of several constraints during the dynamic process of generation scheduling, an expert system named STGSCS is developed and the CLIPS is used as a building tool of the expert system. the CLIPS, which was developed by NASA at the AI section of the Johnson Space Center, is a forward chaining rule-based language that has inferencing and representation capabilities. Because of its high portability and the characteristics of forward chaining, the CLIPS has been using on a wide variety of real world problem solving tasks such as planning, monitoring and control problems. That's why it is selected as the expert system building tool in this study.

In order to develop the STGSCS following steps were taken.

1) Short-term generation scheduling problem identification:
 The details are described in Chapter 2.
2) Acquisition of the knowledges and experiences of domain experts/operators:
 An experienced operator was interviewed on the manipulation possibility of several constraints for the cycling units.
3) Expert system tool selection:
 CLIPS was selected as the building tool of the system.
4) Configuration design and knowledge base creation

In the previous chapters and sections, brief descriptions on the steps from 1) to 3) of the expert system developing procedures are presented. In this section, therefore, the step 4) will be discussed in detail.

Two possible configurations, the menu driven system and the closed loop system, were consid-

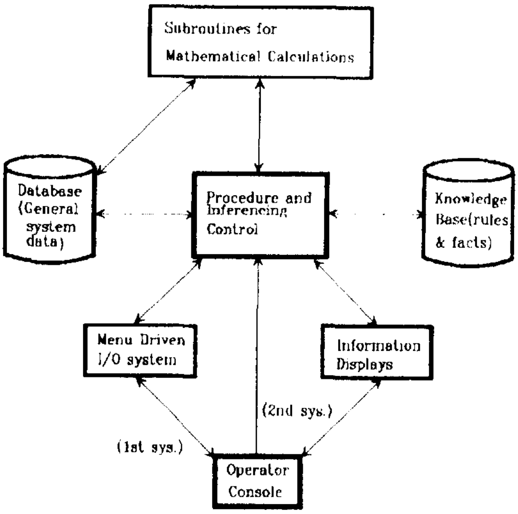

Fig. 2 The configuration of the STGSCS

ered as illustrated in Fig. 2. The major difference between the first and the second configurations is the consultation procedure on the manipulation of constraints. In the first system, domain experts will be asked to answer the question from the system via operators console/Man-Machine Interface(MMI) during the scheduling process. On the other hand, in the second closed loop system, the consulting system will be used as a subroutine of the program in order to consult on the constraints automatically without any interaction with the operators.

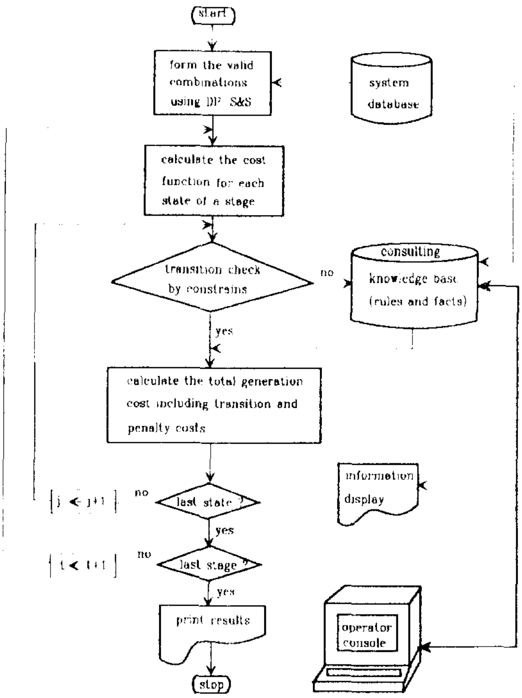

Fig. 3 Flow of the scheduling by the STGSCS

In this study, the interactive and automatic consulting on the minimum up time, the minimum down time and the maximum running time constraints of generating units were performed by the above mentioned expert system. Fig. 3 illustrates the overall flow of the short-term generation scheduling method proposed in this paper.

Table 1 Characteristic parameters of the generating units

No.	name	ea	P^{min}	P^{max}	α	β	γ	cost	p.f.
1	T UT01	1	15.0	60.0	.00510	2.20340	15.00000	11.000	1.000
2	T UT03	1	20.0	80.0	.00396	1.91610	25.00000	11.000	1.000
3	T UT05	1	23.0	118.0	.00382	1.69660	32.00000	11.000	1.000
4	T UT06	1	75.0	280.0	.00261	1.53540	72.00000	10.000	1.000
5	T UT02	1	30.0	100.0	.00393	1.58180	40.00000	10.000	1.000
6	T UT04	1	50.0	148.0	.00212	1.80150	29.00000	10.000	1.000
7	T UT07	1	120.0	320.0	.00289	1.26430	49.00000	10.000	1.000
8	T UT08	1	125.0	443.0	.00148	1.21360	82.00000	10.000	1.000
9	T UT09	1	250.0	520.0	.00127	1.19540	105.00000	10.000	1.000
10	T UT10	1	250.0	550.0	.00135	1.12850	100.00000	10.000	1.000
11	H HP11	1	15.0	60.0	.00510	2.20340	15.00000	1.000	1.000
12	H HP12	1	20.0	80.0	.00396	1.91610	25.00000	1.000	1.000
13	L LN13	1	25.0	118.0	.00382	1.69660	32.00000	1.000	1.000

5. Study Case and Results

The proposed STGSCS is tested on a hypothetical system which consists of 10-thermal units, 2-hydro units and 1-LNG unit. The characteristics

```
*DO YOU WANT TO CONSULT THE TIME CONSTRAINTS OF
 THE CYCLING UNITS ?
 PLEASE ENTER "YES" OR "NO"

 >YES

*SELECT AN OPTION NUMBER YOU WANT !!

0 : OPTION FREE
1 : CONTROL FOR 1-HOUR MAXIMUM
2 : CONTROL FOR 2-HOURS MAXIMUM
3 : CONTROL FOR 3-HOURS MAXIMUM
4 : CONTROL FOR 4-HOURS MAXIMUM
5 : CONTROL FOR 5-HOURS MAXIMUM

>1

*END CONSULTATION !!
 BECAUSE -- THERE ARE NO CYCLING UNITS SATISFYING
                 THE SELECTED CONDITION.

*DO YOU WANT TO CONSULT THE TIME CONSTRAINTS OF
 THE CYCLING UNITS ?
 PLEASE ENTER "YES" OR "NO"

>YES

*SELECT AN OPTION NUMBER YOU WANT !!

>2

*CONTINUE CONSULTATION !!

*THE TIME CONSTRAINT VIOLATION MESSAGE ON (TH)
  AS FOLLOWS

 IT=  4      MGLT=  62      MFLT=  60
 UNIT NAME : UNIT02
 INITIAL VALUE OF (TH) :   8.0
 PRESENT VALUE OF (TH) :   7.0

*MAKE YOUR DECISION NOW !!
 IF YOU WANT TO CHANGE THE INITIAL VALUE
 MAKE THE INITIAL VALUE .LE. PRESENT VALUE

*DO YOU WANT TO CHANGE THE TH(L) OF ABOVE UNIT ?
 PLEASE ENTER "YES" OR "NO"

>YES

*WHAT IS THE CHANGED VALUE ?
 PLEASE ENTER THE VALUE USING INTEGER (I3)

 007

*CONFIRM OF THE CHANGED VALUE !!
 TH(L)-NEW OF UNIT02 =   7.0

 END CONSULTATION
```

Fig. 4 A consulting example of the τh

```
FIRE   1   read-data-file:  f-0
==>   Activation 0        number-of-violation-2 :
==>   Activation 0        number-of-violation-2 :
==>   Activation 0        number-of-violation-2 :
==>   Activation 0        file-close :  f-46
FIRE   2   file-close:  f-46
FIRE   3   number-of-violation-1 :
==>   f-47   (move-goal    goto-sorting-rule)
==>   Activation 0        sorting-op-violation :
FIRE   4   sorting-op-violation :  f-47,f-26,f-27,f-28,f-29,f-30
==>   f-48   (move-goal    goto-op-flexibility)
==>   Activation 0        op- flexibility-vio :
FIRE   5   op-flexibility-vio :
==>   f-49   (move-goal    goto-main-flex)
==>   Activation 0           return-to-main-after all :  f-49,f-49
The modification of the maximum operating time is IMPOSSIBLE
The reason is the flexibility size violation
FIRE   6   return-to-main-after all :  f-49,f-49
<==   f-49   (move-goal    goto-main-flex)

*****This is the final decision*****
The violation size of constraints exceeds FLEXIBILITY
Therefore this combination must be discarded!!!
Control flag of the combination is then '888'

Control returned to MAIN!!!

FIRE   7   number-of-violation-2 :
==>   f-50   (move-goal    goto-main)
==>   Activation 0    return-to-main-directly :  f-50,f-50
FIRE   8   return-to-main-directly :  f-50,f-50
<==   f-50   (move-goal    goto-main)

*****This is the final decision*****
The violation size of constraints exceeds the limit
Therefore this combination must be discarded!!!
Control flag of the combination is then '888'

Control returned to MAIN!!!

FIRE   9   number-of-violation-2 :
==>   f-51   (move-goal    goto-main)
==>   Activation 0    return-to-main-directly :  f-51,f-51
FIRE   10   return-to-main-directly :  f-51,f-51
<==   f-51   (move-goal    goto-main)

*****This is the final decision*****
The violation size of constraints exceeds the limit
Therefore this combination must be discarded!!!
Control flag of the combination is then '888'

Control returned to MAIN!!!

10 rules fired.
```

Fig. 5 A consulting example of the τh, τl and τu

Table 2 Initial condition of the cycling units

No.	name	xo	TM	$Sa(Ta)$	$Sb(Tb)$	Sc	Sd	τl	τh	τu
1	UT01	0	−5.0	4.(2.0)	11.(4.0)	3.50	1.	−6.0	8.0	24.0
2	UT03	1	5.0	5.(2.0)	12.(5.0)	2.33	1.	−6.0	8.0	24.0
3	UT05	1	5.0	4.(2.0)	11.(5.0)	2.33	1.	−6.0	8.0	24.0
4	UT06	1	5.0	5.(2.0)	13.(5.0)	2.67	1.	−6.0	8.0	13.0
5	UT02	1	5.0	5.(2.0)	13.(5.0)	2.67	1.	−6.0	8.0	24.0
6	UT04	1	5.0	5.(2.0)	13.(5.0)	2.67	1.	−8.0	10.0	24.0

of the generating units in the system are given in Table 1.

In the Table 1, α, β and γ represent the coefficients of the quadratic fuel cost function of the generating units, and 'cost' means the unit price of the fuel. The 'p.f.' represent the loss penalty factors of the generating units and the value of 1.0 means transmission losses are not considered in this study case but the program has the handling capability.

Table 2 gives the initial condition of the cycling units. The symbols that are used throughout the paper are given in the appendix.

Fig. 4 represents a consulting procedure of the minimum up time(τh) of the cycling unit using the menu driven consulting system (the first part of the STGSCS), and Fig. 5 describes a consulting example of the τh, τl and τu using the proposed rule-based expert system (the second part of the STGSCS).

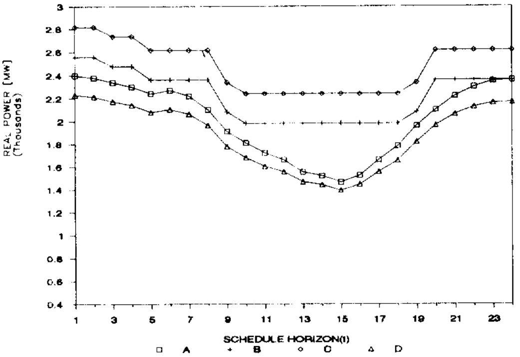

Fig. 6 System load pattern and scheduled capacity of units

The hourly load and the daily scheduling results of generating units of the sample power system are given in Table 3.

Finally, Fig. 6 shows the load pattern and the scheduled capacity of the system graphically. In Fig. 6, the legends A, B, C and D represent the system load, the scheduled capacity of thermal units, the scheduled capacity of all units and the load level that is supplied by thermal units, respectively.

6. Conclusions

In this paper, for the purpose of implementing the consulting of several constraints during the dynamic solution process of short-term generation scheduling, an expert system approach is applied to improve the defects of the DP based generation scheduling algorithm.

An expert system named STGSCS is developed using the CLIPS as a building tool of the system. In the selection procedure of the feasible combinations of generating units of each stage, automatic consulting on the manipulation of several constraints such as the minimum up time, the minimum down time and the maximum running time constraints of generating units was performed by a rule-based expert system which consist of the rules and facts those are established by domain experts.

Using the proposed algorithm, the solution feasibility is always guaranteed by its consulting proce-

Table 3 The hourly load and ELD results of units

Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
UT01	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
UT03	46.	44.	42.	40.	0	0.	0.	0	0.	0.	0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
UT05	76.	75.	72.	70.	0	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
UT06	186.	184.	180.	176.	181.	185.	179.	167.	0.	0.	0.	0.	0.	0	0.	0.	0.	0.	0.	167.	179.	188.	196.	198.
UT02	100.	100.	100.	100.	100.	100.	100.	100.	100.	0.	0.	0.	0.	0	0.	0.	0.	0.	100.	100.	100.	100.	100.	100.
UT04	148.	148.	148	148.	148.	148.	148.	143.	140.	140.	129.	121.	107.	103.	96.	104.	121.	136.	147.	143.	148.	148.	148.	148.
UT07	215.	213.	209.	206.	211.	214.	209.	198.	196.	196.	187.	182.	172.	169	163.	169.	182.	193.	200.	198.	209.	217.	224.	225.
UT08	436	433.	426.	419.	429.	434.	425.	404.	399.	399.	383.	372.	352.	346.	336.	347.	372.	394.	409.	404.	425.	440.	443.	443.
UT09	515	511.	504.	496.	507.	513.	502.	477.	473.	473.	453.	441	418.	411	398.	412.	441.	466.	483.	477.	502.	520.	520.	520.
UT10	509.	506.	499.	491.	502.	508.	497.	474.	469.	469.	451.	439	418.	411.	399.	412.	439.	463.	479.	474.	497.	514.	530.	533.
HP11	47.	46.	44.	42	45.	46.	44.	37.	36.	36.	30.	27	21.	19.	16.	19.	27.	34.	38.	37.	44.	48.	53.	54.
HP12	53.	52.	49.	47	50.	52.	49.	41.	40.	40.	34.	30.	24.	22.	20.	22.	30.	38.	43.	41.	49.	54.	60.	61.
LN13	70.	69.	67.	64	67.	69.	66.	59.	57.	57.	52.	48.	41.	39.	35.	39.	48.	55.	60.	59.	66.	71.	77.	78.
Load	2400.	2380	2340.	2300.	2240.	2270.	2200.	2100.	1910.	1810.	1720.	1660.	1553.	1519.	1463.	1524.	1660.	1780.	1690.	2100.	2220.	2300.	2350.	2360.

dures of the violations of the constraints, which is one of the improved features of the algorithm in comparison with the conventional DP based algorithm, and a satisfactory suboptimal schedule was obtained within a reasonable computation time even using 386/486 processor installed PC. The performance of the system has been examined by applying it to a hypothetical power system, and the solution was obtained within 420[s] using 386 installed PC in this case. Moreover the application possibility of the CLIPS to the power system scheduling problems is also verfied through the study case.

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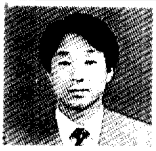

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