1. Detailed description of Eq. (51)

|  |  |
| --- | --- |
|  |  |

where *m* is the current iteration number; is the solution of the subproblem after the *lth* iteration; and is the value of the uncertain variable in the worst-case scenario obtained after the *lth* iteration.

1. System setting

1) IEEE-33 power system with a PGHI-IES



Fig.B1. IEEE-33 power system with a PGHI-IES

2) The parameters of the system

|  |  |  |  |
| --- | --- | --- | --- |
| Table b1  parameters of candidate equipment | | | |
| Equipment | Efficiency | Investment cost | Operation cost |
| ESS | - | 560 ($/kWh) | 0.031 ($/kW) |
| PV | - | 891 ($/kW) | 0.0073 ($/kW) |
| WT | - | 1320 ($/kW) | 0.0089 ($/kW) |
| TP | - | 650 ($/kW) | 0.0051 ($/kW) |
| P2G | 0.85 | 1020 ($/kW) | 0.0071 ($/kW) |
| ED | 0.6 | 1490 ($/kW) | 0.084 ($/kW) |
| HMGT | 0.85 | 2451 ($/kW) | 0.0091 ($/kW) |
| GT | 0.90 | 2067 ($/kW) | 0.0076 ($/kW) |
| IHS | 0.95 | 1250 ($/kWh) | 0.065 ($/kW) |
| H2P | 0.6 | 1050 ($/kW) | 0.051 ($/kW) |

3) The input data of the system

1. C&CG algorithm process

1) Given a set of uncertain variables ***u*** taking values as the initial worst-case scenario, set the final scheduling scheme corresponding to the operating cost of the lower bound ,the upper bound , the number of iterations *m* = 1;

2) Solving the master problem Eq. (57) based on the worst-case scenario  yields the optimal solution , where the value of the objective function of the master problem serves as the new lower bound ;

3) Substituting the obtained solution of the master problem into Eq. (61), the subproblem is solved to obtain the value of the objective function of the subproblem  and the corresponding value of the uncertainty variable ***u*** in the worst-case scenario , and to update the upper bound, .

4) Given the convergence threshold of the algorithm is , if , the iteration is stopped and the optimal solutions are returned, otherwise, add the variable  until the algorithm converges.

1. Analysis of typical scenario generation

Compared to the conventional approach of classifying scenarios based solely on seasonal divisions, the scenario generation method proposed in this paper is more detailed in its categorization and better describes the long-term supply and demand for IES. To verify that, the clustering results throughout the year are shown in Fig. D1. Different categories are distinguished by different colors and numbers. The numbers represent their scenario categories.

|  |
| --- |
|  |
| Fig.D1. Input data and corresponding scenarios categories |

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Table D1 Scenarios included in each month | | | | | | | | | | | | |
| Scenario | January | February | March | April | May | June | July | August | September | October | November | December |
| 1 |  |  | **√** | **√** | **√** | **√** | **√** | **√** | **√** | **√** | **√** |  |
| 2 |  |  |  |  | **√** | **√** | **√** | **√** |  |  |  |  |
| 3 | **√** | **√** | **√** |  |  |  |  |  | **√** | **√** | **√** | **√** |
| 4 | **√** | **√** | **√** |  |  | **√** | **√** | **√** | **√** | **√** | **√** | **√** |
| 5 |  |  | **√** | **√** | **√** | **√** | **√** | **√** | **√** |  |  |  |
| 6 | **√** | **√** | **√** | **√** | **√** | **√** | **√** | **√** | **√** | **√** | **√** | **√** |
| 7 | **√** | **√** | **√** | **√** | **√** | **√** | **√** | **√** | **√** | **√** | **√** | **√** |
| 8 | **√** | **√** | **√** |  |  |  |  |  |  | **√** | **√** | **√** |
| **√**indicates that the scenario is included in the month. | | | | | | | | | | | | |

As shown in Fig.D1 and Table D1, each month contains at least four typical scenarios and up to seven throughout the year. This indicates that the clustering method proposed in this paper provides a more refined classification of typical scenarios compared to the conventional approach of dividing the year into four seasonal scenarios. By extracting representative time periods, this method better captures different operating conditions (such as periods of high renewable energy with low load and periods of low renewable energy with high load), thereby accurately reflecting the long-term supply-demand characteristics of the integrated energy system (IES). Consequently, the proposed approach enhances the adaptability of planning schemes to various operational conditions. Moreover, the refined scenario classification contributes to the rationality and economic efficiency of planning, enabling intertemporal hydrogen energy storage (IHS) to more effectively address renewable energy fluctuations and achieve long-term optimal operation.