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Optimization method of flexible response capability of power system with limited cost constraint

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Abstract
The flexible response capability of power system varies greatly under different conditions, so the optimization method of flexible response capability of power system is designed based on the theory of finite cost constraint. The bidding function with the monthly quotation as the core is obtained, and the demand response inhibition factor is calculated by combining the single inhibition rate; Under the influence of the length waveform, the one-dimensional feature recognition vector is obtained, the feature point Credibility under different conditions is obtained, the objective function is designed with the minimum operating cost, and the power emergency demand response model is established based on the concept of limited cost constraint; The optimization algorithm of flexible response capability of power system is designed, and the optimization method of response capability is obtained. The experimental results show that the optimization method has a good effect on the flexible response capability of power system in different time periods.
Keywords: *Limitedcost constraint; power system simulation; responsiveness; optimization algorithm*.

I. Introduction

In the context of the modern energy crisis, China is facing the situation of power shortage all the time, so using renewable energy to connect to the power grid has become an acceptable solution. The demand of users for power varies periodically in time. For example, within a day, the period of maximum power consumption is from 18:00 to 22:00,andtheperiodofminimumpowerconsumptionisfrom2:00to4:00inthemorning.Theperiodofresidential electricity consumption and renewable energy supply is not always within the same time period, so it is necessarytoprovidereliabledemandresponsestrategiesfornewtechnologiesofsmartgridthroughartificialmeans,soas to solve the problem of uneven resources on the user side. According to the response mechanism of the energy system,document[1]contributes abasicmodelbasedoncostandbenefitallocationtothetradingentitythrough

The comprehensive energy transaction architecture, and completes the process of economic cost allocation under the condition of power demand response, thus obtaining a reasonable response mechanism optimization method. Document [2] completed the power demand response management between the power company and the household power network under the algorithm of the multi-layer game model, fed back the optimal amount of electricity to the household users at each time, and obtained the equilibrium unique solution in the model, but the cost control effect was poor. Document [3] designed a user response characteristic analysis method based on automatic encoder and improved fuzzy mean clustering algorithm, established data extraction models under different power consumption modes, and completed the actual management of power grid data. Document [4] proposes a source load storage coordination optimization model with flexible electro thermal load response threshold with the goal of maximizing new energy consumption and minimizing system operation cost.

The flexible response capability of previous research results varies greatly under different conditions. Based on the above document, this paper designs an optimization method of flexible response capability of power system based on limited cost constraint. Under the condition that the total power consumption in a day remains unchanged, itcanincreasethepowerconsumptioninthelowpeakperiodandsimultaneouslyreducethepowerconsumption in the peak period, thus successfully reducing the power cost, which is more practical.

II. Optimizationofflexibleresponsecapability of powersystem

The optimization method of response capability is divided into two aspects: limited cost constraint and optimization of flexible response capability, as shown in Fig.1.

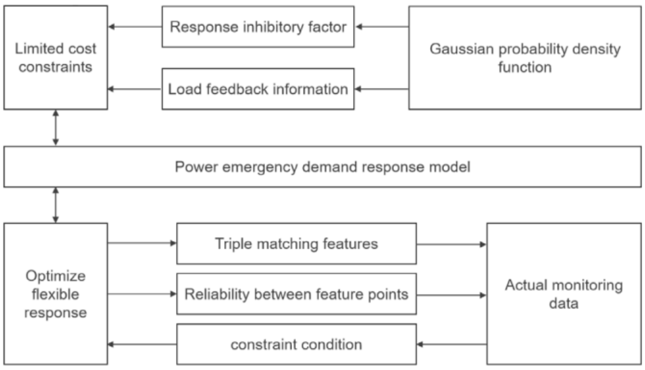

Fig.1. Optimizationframeworkofflexibleresponsecapabilityofpowersystem.

In Fig.1, the key is to calculate the difference degree between different data features and the reliability between two feature points based on the Gaussian probability density function and response suppression factor, focus on analyzing the probability of constraint conditions in the process of random variables, optimize the solution resultsofthepoweremergencydemandresponsemodel,andprovidehelpforreducingpowercostsandoptimizingflexible response capacity.

Calculatedemandresponseinhibitionfactor

Under the influence of economic philosophy, power consumption measures can be reduced in a planned way,and the basic autonomy of demand bidding can be guaranteed. In the expectation of the data center, the reported electricity price is the lowest point, and it is divided into economic type and reliable type to obtain the total amount of electricity that needs to be suppressed by different demand response mechanisms. In the Gaussian probability densityfunction,takingthemonthlyquotationofthedatacenterasthecompetitionmodel,thebiddingfunction can be obtained:

$$F_{qx} = \frac{\sum_{i=1}^{n} V_{im} + 1}{P_k} \qquad s.t. k_m > 0, p_i > 0 \tag{1}$$

where, *F (x)* represents the competition function of the monthly quotation of the data center; $k_m$represents the standard deviation of the distribution amplitude; $t_p$indicates the expected value of the power company to suppress power consumption; $u_i$represents the Gaussian probability density under the action of the demand response factor; $p_i$indicates the distribution position of peak quotation [5,6]. Under the action of this function, in order to balancethepowerlossofthe power system,it is necessaryto take thesuppressionfactoras a parameterofdemandresponse and calculate the single suppression rate of the suppression factor. The calculation formula is:

$$F\ (x) = \frac{1}{k_m \sqrt{2t_p}} r^{-\frac{(u_i - p_i)^2}{2km}} \tag{2}$$

where, V_{im}represents the execution rate of single power regulation of the data measurement center; $s_i$indicates the capacity required to implement the required benchmark measures in a unit time period; $P_m$represents the average powerofthedemandresponseofthedatacenter;$v_i$representstheminimumvalueofpowerresponsecapacitywithin thecontract.Combinedwiththesingleinhibitionrate,thedemandresponseinhibitionfactorcanbecalculated:

$$V_{im} = \frac{\sqrt{\sum_{i=1}^{n} s_i} + P_m}{\sqrt{\sum_{i=1}^{n} v_i}} \tag{3}$$

where, F_{qx}represents the demand response suppression factor of the actual power consumption under the influence of the control variable; $P_k$indicates the execution parameters of a single demand response. Through the above formula, the demand response inhibition factor can be obtained. Based on the data center and smart grid, the communication between users and power enterprises is realized.

Poweremergencydemandresponsemodelbasedontheconceptoflimitedcostconstraint

Power load is the most important control object in power emergency demand response. Traditional demand response focuses more on the overall load analysis of users, and realizes the analysis of load characteristics at differentlevels.Atthistime,itisfirstnecessarytoidentifythefeaturesoftheuser'sactualmonitoringdata[7], and complete the calculation of one-dimensional vector through the length waveform:

$$d(a_m, b_m) = \sqrt{\frac{\sum_{i=1}^{n} \left(a_m{}^2 - b_m{}^2\right)}{N_k}} \quad (4)$$

where,$d(a_m,b_m)$ represents the Euclidean distance of the feature waveform vector in different feature points, where $a_m$and$b_m$represents two adjacent feature points;$N_k$indicates the degree of difference between features measured by Euclidean distance. In this formula, the difference degree between different data features is calculated through this formula, and the $d(a_m,b_m)$ general value is [0,1]. i stands for number of samples. The closer to 1, the smallerand larger the difference between the two data, and the larger the difference between them. The reliability between thetwofeaturepointsiscalculatedatthesametime[8].Undertheunifiedloadtype,thecalculationformulacan be obtained:

$$D(a_m, b_m) = \sqrt{\frac{\sum_{i=1}^{n} [d\,(a_m, b_m)]^2}{K_p}} \quad (5)$$

where, $K_p$represents the maximum reliability of each template. Under this formula, the triple matching character- istics of load characteristics are calculated to achieve load decomposition. In combination with the uncertain factors under the real renewable energy, it is necessary to complete the constraint of a decision result in the process of solving random variables:

$$\begin{cases} min\dfrac{H\left(t_p, \xi_f\right)}{H_p} \\ s.t.D_w\left(x\right) \leq 0 \\ \Pr\left\{E_k\left(t_p, \xi_f\right)\right\} \geq \dfrac{\sqrt{d_m}}{H_p} \end{cases} \quad (6)$$

where (Ht_p, ξ_f) represents the objective function in the decision result, wherein, $t_p$represents the decision vector of the function and $\xi_f$represents the random vector of the function; $H_p$indicates the target quantity of constraint conditions;$D_w(x)$ indicates a target format that does not include random parameters; $E_k(t_p,\xi_f)$ represents the test constraint conditions of random simulation under the intelligent optimization algorithm; Prgenerally indicates the probabilitythattheconstraintconditionsaresatisfied.Inthefunctionratiooftheterminal,theobjectivefunction of the minimum operating cost can be obtained:

$$\begin{cases} \min P_r = \dfrac{\sum_{i=1}^{n}\left[f_m(t)+h_m(t)\right]^2+\sum_{i=1}^{n}\left[P_{gi}(t)+k_{fi}(t)\right]^2}{2} \\ f_m(t)=F_g{}^2K_a{}^2 \\ h_m(t)=\sqrt{F_d}-2P_a \\ P_{gi}(t)=\sum_{i=1}^{n}\dfrac{P_a+P_b}{2} \\ k_{fi}(t)=a_{acc}p_{dlc}(t) \end{cases} \tag{7}$$

where, $P_r$represents the minimum load of system operation in the power model.$f_m(t)$, $H_m(t)$, $P_{gj}(t)$ and $k_{fi}(t)$ represent values of non flexible load, interruptible load, adjustable load and transferable load in the power system respectively; $F_g$indicates the number of users actually controlled by the conventional unit within the interruptible load; $P_a$indicates the load forecasting index constrained by the model in the system [9,10]; $P_a$represents variable which is the flexible load in the interrupted state; $P_b$represents the variable of the flexible load in the continuous state; a_{acc}represents the balance value of system power;$P_{dlc}(t)$ represents the distribution function of the total power generation of the system [11–13]. Combined with the above formula, we can get the power emergency demand response model based on the concept of limited cost constraint.

Theoptimizationalgorithmofflexibleresponsecapabilityofpowersystem

In order to optimize the flexible response ability of the power system more effectively, the decision-making processisdividedintodifferentperiods[14,15].Afterscreeningtheuncertainfactors,theinitialparametersaffecting the flexible response ability of the power load are input, and the power response results of the power load are calculated, as shown in Fig.2.

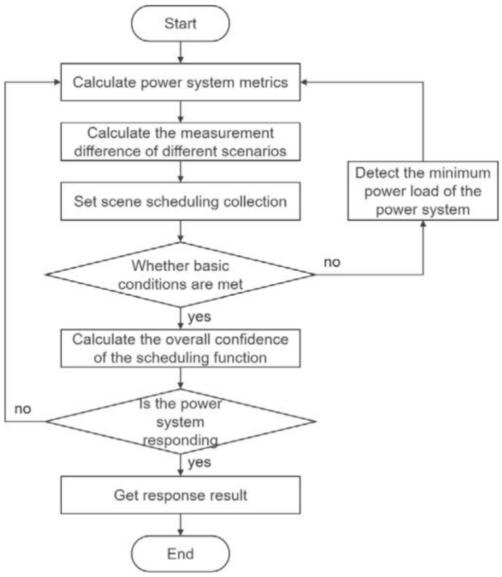

Fig.2. Algorithmprocess.

As shown in Fig.2, in the deterministic model, the function value of the dual objective is obtained by copyingthe targeted variables. The objective function of the minimum operating cost is solved as the basic condition, thatis, the overall confidence is maximized [16–18]. Through repeated iteration, the redundancy and complexity of the decision-making process are reduced, and the optimal solution of the power system response is obtained:

$$L_n = \sum_{t=1}^{n} -\lambda_i F_t \qquad (8)$$

where, $L_n$represents the function value of the flexible response of the power system; $\lambda_i$represents the power flow constraint parameter;$F_t$indicates the calling function in different time periods. According to the above methods,the optimization method of flexible response capability of power system under the constraint of limited cost can be obtained.

2. Exampleanalysis

Simulationdataandparameters

Inthispaper,aflexibleresponsecapabilityoptimizationmethodofpowersystemwithlimitedcostconstraints is designed. To test the effectiveness of this method, the following experiments are designed. The simulation datain the experiment are all from a smart grid application demonstration area. Each household in the residential areahas a smart meter. Smart meters can mainly test non flexible loads and interruptible loads. Relatively speaking, the electricity consumption in spring and autumn is relatively small. The non flexible load and interruptible load of residents in this residential area within 24 h are shown in Fig.3.

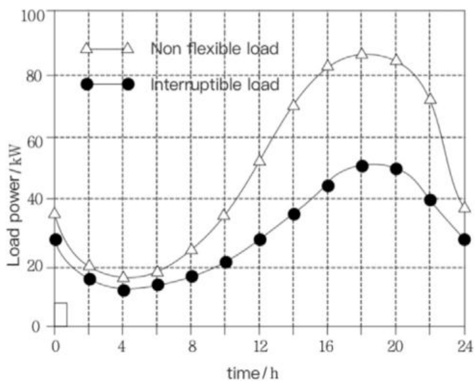

Fig.3. Residentialpowerloadcurve.

As shown in Fig.3, in the statistics of residential power load within 24 h, both the non flexible load and interruptible load of residents have certain periodicity. The power load around 4:00 is generally small, gradually increasing to the maximum value from 8:00 to 18:00, and gradually falling to the minimum value from 18:00 to 4:00.Inordertoensurethatresidentssaveelectricity,threedifferenttypesofelectricitypricesareset.Theelectricity prices are divided into three periods. The electricity price in the peak period (14:00–22:00) is 0.65 yuan/kW h, the electricity price in the low period (22:00–6:00) is 0.20 yuan/kW h, and the electricity price in the general period (6:00–14:00) is 0.45 yuan/kW h.

Flexibleresponsecapabilitytestofpowersysteminaday

In this paper, the flexible response ability of different periods of time within 24 h is tested by using the optimal scheduling model of different residential power loads [19,20]. It is compared with several existing optimization methods, namely, Cost and Benefit Allocation Method (method in Ref. [1]), Multi-layer Game Method (method in Ref.[2]),AE-MFCMMethod(methodinRef.[3]),andCostConstraintMethod(methodinRef.[4]). The total

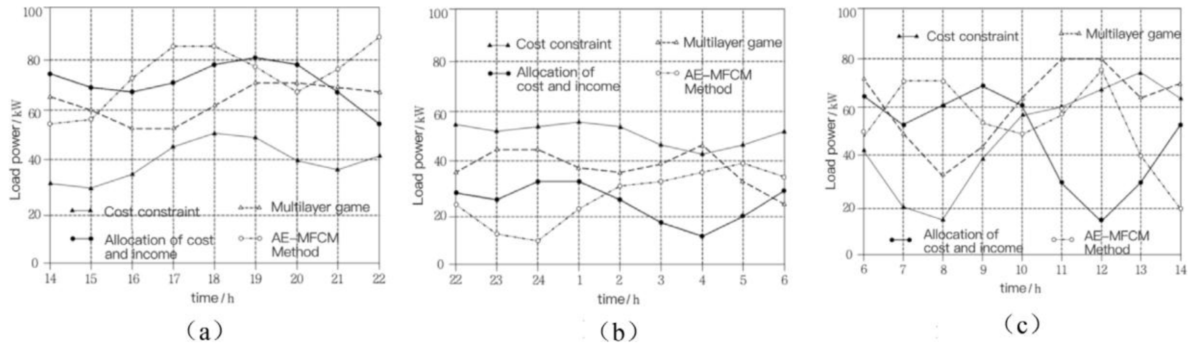

Fig.4. Simulationexamplesresults(a)Peakload(b)Lowload(c)flatload.

resident load in different power consumption periods is analyzed by simulation examples, and the results are shown in Fig.4

As shownin Fig.4,inthesimulationanalysisofdailyloadpower,thefinitecostconstraintmethoddesigned in this paper can effectively bind the power load in the peak period of power consumption and reduce the power consumption in this period. In the low power consumption period, the power load under other methods is low, but thelimitedcostconstraintmethodusesalargeamountofelectricity.Inthegeneralpowerconsumptionperiod,it is difficult to distinguish the power load capacity of the four response capacity optimization methods.

Flexibleresponsecapabilitytestofpowersystemintheyear

Indifferentseasons,theresponsecapacityofthepowersystemisquitedifferent,especiallyinsummerandwinter, most households have a large demand for large-scale power [21,22]. Using the cost constraint method, multi-layer game method, cost and benefit allocation method, and AE-MFCM technology as comparison methods, the annual powerloadpowerissimulatedandanalyzed.Withinayear,summer(JuneAugust)andwinter(DecemberFebruary) are the peak periods of power consumption, and spring (March May) and autumn (September November) are the troughperiodsofpowerconsumption.Theloadpowerin12monthsisanalyzed,andtheresultsareshowninFig.5.

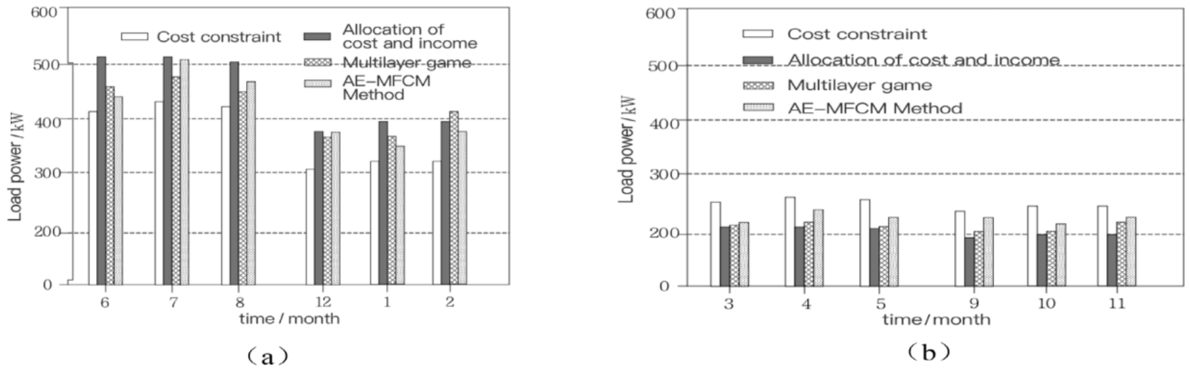

Fig.5. Responsecapabilitytestresult(a)Peakload(b)Lowload.

AsshowninFig.5,intheannualloadpowersimulationanalysis,thetotalloadpowerrequiredinsummer and winter is significantly greater than that in spring and winter, thus obtaining the peak and trough periods ofpowerconsumption.Andundertheinfluenceofthefourresponsecapacityoptimizationalgorithms,thepower consumptionofthefourseasonsalsohasgreatdifferences[23,24].Itcanbeclearlyseenthatinthepeakperiod of power consumption, the finite cost constraint algorithm designed in this paper can reduce the load power in this period, so that it uses less power than other algorithms in the same period. In the low power consumption period,thealgorithmcanalsoincreasethetotalpoweroftheloadtoincreaseitspowerconsumptioninthisperiod.

3. Concluding remarks

This paper designs an optimization method of flexible response capability of power system based on the theoryoflimitedcostconstraint.Throughthecalculationofdemandresponseinhibitionfactor,thepowerdemandrespons e model under emergency conditions is established, and the response algorithm is designed. The power system responsecapabilityinthedayandthepowersystemresponsecapabilityintheyeararetestedrespectively,and theresultsofpowerconsumptiontroughperiodTheresultsofsimulationanalysisinpeakorgeneralperiodscan be used as a reference for relevant practical applications.

Declaration of competing interest
The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Lipan Fan has patent licensed to China.

Data availability
Data will be made available onrequest.

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References

[1] YingjunWu,ChengjunLiu,ZhiweiLin,etal.Powerdemandresponsegamemodelconsideringcostandbenefitallocation.PowerConstr2021;42(06):135–44.
[2] YemingDai,Xiliansun,LuLi,etal.Realtimedemandresponsemechanismofsmartgridresidentialpowerbasedonmulti-layergame.OperResManag2021;30(10):11–7.
[3] JianfengWang,JiamingNi,XudongWang,etal.Analysismethodofpoweruserresponsecharacteristicsbasedonae-mfcmtechnology.JPowerSystAutom2021;33(04):47–54.
[4] Yuanyuan Peng, Renjun Zhou, Shaofeng Fang, et al. Source charge storage coordination optimization model with flexible electrothermalloadresponsethreshold.JPowerSystAutom2020;32(5):30–7.
[5] Haijiang Wu, Jinrong Chen. Construction of power load demand side response model of distribution network. Power Grid Clean Energy2021;37(09):77–82.
[6] YiqunSun,JiaLiu,ChaojunLiu,etal.ResearchonMPPTalgorithmofphotovoltaicpowergenerationsystembasedonenvironmentadaptation. MicrocomputAppl2020;36(5):89–91106.
[7] Houhe Chen, Zening Li, Tao Jiang, et al. Smart building energy flexibility regulation strategy based on model predictive control. AutomElectrPowerSyst2019;06(08):1–9.
[8] JiachaoChen,YongjunZhang,GuoquanHuang,etal.Optimizationmodelofpowergridfaultdiagnosisconsideringthereliabilityofprotectionandcircuitbreakeralarminformation.PowerSystProtControl2021;49(4):28–36.
[9] Day-aheadshort-termloadprobabilitydensityforecastingmethodwithadecomposition-basedquantileregressionforest.ApplEnergy2020;262(Mar.15):621–38.
[10] mingzengHuang,YahanHu,YunfengWen,etal.Powersystemtransientstabilityassessmentmethodintegratingjmimandngboost.PowerSystAutom2021;45(8):155–65.
[11] GuohuiJin, Xue Wei, Weijian Zhang. ABC-BPNN-based energy consumption prediction model for residential buildings in the grasslandsofwesternInnerMongolia.JCivilEngManag2019;36(02):48–52,60.
[12] ZhijunYang,PingpingHan,FupingZhou.Fastpredictionandsimulationofregionalbuildingpowerenergyconsumptionunderbigdataenvironment.ComputSimul2019;36(04):432–5,473.
[13] FengTian,LeiYin,BinLu,etal.Loadandcostoptimizationofdemand-sidemanagementofintelligentbuildings.JNanjingUnivPostsTelecommun(NatSciEd)2018;38(06):1–8.
[14] BingyuZhou,BoLiu,DanWang,etal.Clusteranalysisofuserinteractionelectricityconsumptionbehaviorbasedonself-organizingcenterK-meansalgorithm.ElectrPowerConstr2019;40(01):68–76.
[15] YongBai.Designofclusteranalysismodelbasedonpoweruserloadcharacteristiccurve.JChongqingUnivTechnol(NatSci)2018;32(12):181–5.
[16] RuizhiDu,JunqiYu.ApplicationofGM-WLSSVMmodelinofficebuildingpowerconsumptionprediction.ComputApplSoftw2018;35(09):44–9,55.
[17] Qing Qian, Guizhong Tang, Guangming Zhang, et al. Sub-item short-term prediction of building energy consumption based on AR-DBN.ComputEng2019;06(08):1–6.
[18] DaLiu,KunSun,HanHuang.MonthlyloadforecastingbasedonEEMDandrandomforest.SmartElectrPower2018;46(06):12–8.
[19] WeihongYang,QingpingLai,YuLan,etal.Researchontheclusteranalysisalgorithmofconsumerelectricityconsumptionbehaviorbasedonregulationpotentialindex.ElectrPowerConstr2018;39(06):96–104.
[20] ShuqingZhang,ShuangRen,RongfeiChen,etal.Short-termpowerloadforecastingbasedonbigdatareductionandPCAimprovedRBFnetwork.ActaMetrol2018;39(03):392–6.
[21] LinlinWang,ZhongjuXie,YongquanChen,etal.Machinelearningclusteringcombinationalgorithmanditsapplication.JShandongAgricUniv(NatSciEd)2018;49(03).
[22] FeiChen,MeixiaZhang.Demand-sideuserloadpatternanalysismethodbasedonmulti-layerclustering.HydropowerEnergySci2018;36(03):215–8.
[23] YiBao,FengdanLou,WanliangWang.Multi-objectiveoptimizationcontrolofsmarthomepowerconsumptionunderdemandsidemanagement.JIntellSyst2018;13(01):125–30.
[24] MingzhaoChen,JianMao,ZonglinDu,etal.Analysisandresearchofindustrialuserdemand-sidemanagement(DSM)schemebasedonclusteringmethod.PowerSystProtControl2017;45(07):84–9.