RESOURCE SCHEDULING IN MODERN POWER SYSTEM

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Certificate

This is to certify that the thesis titled **Resource Scheduling in Modern Power System** which is being submitted by **Mr. Srikanth Reddy Konda** for the fulfillment of the requirements for the award of degree of **Doctor of Philosophy**, is a record of the student's own work carried out at the Indian Institute of Technology Delhi under our supervision and guidance. The matter embodied in this thesis has not been submitted elsewhere for the award of any other degree or diploma.

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Abstract

The resource scheduling problem in modern power systems has evolved into a multi-dimensional in nature with involvement of various stakeholders with distinct objectives. Scheduling of generation is considered to be the optimal scheduling of generation in older systems with load shedding/curtailment as an inevitable procedure under system instability. However, with the advent of smart technologies such as advanced communication and cyber-physical systems, demand side resource management is taking a crucial part in power system scheduling. Therefore, appropriate scheduling of resource on both generation as well as demand side becomes an important aspect of power system operational management.

The main focus of this work is to enhance the resource scheduling problem by relating the objectives to real world information available. This study considers improving the scheduling aspects of generation side resources and demand side resources with respect to different aspects. The aspects considered for improvement in this study are economic and environmental efficiency improvement in generation side resource equipped with clean energy technologies under emission control policies. In the demand side, load profile attributes are considered in place of conventional willingness factor to improve the customer involvement and accuracy of participation.

The sustainability practices in the power system other than renewable energy generation are considered in this study through carbon capture technology (post-capture system). The application of carbon capture technology attributes to power generation is carried out by devising performance indices depending on the operation of thermal power generation units, carbon capture technology plant and generation resource characteristics. The implications of clean energy policies are also modeled for the proposed performance indices. The case studies are performed with different resource types, to verify the appropriateness of performance indices. The sensitivity analysis pertaining to resource sensitivity, test case and impact of correction factors indicate the volatility of performance indices at lower capture rates of carbon capture power plant.

Considering the importance of responsive loads and wide range of services offered by such loads, this study also analyses the impact of load profile attributes on demand response programs in different frameworks. To this end, the segregated profiles of customer baseline load and responsive loads are used to define utilization and availability factors respectively. Which are further used in generic load behavior models employed in price based demand response scheduling by aggregator. The load profile based scheduling with proposed load profile attributes is carried out for different test cases. The results are analyzed with respect to seasonal variation of response load scheduling. Also, analysis with respect to load sectors (residential, commercial, industrial, agricultural and municipal) is also carried out in this study.

The impact of load profile attributes on demand response exchange framework is also examined. The demand response exchange framework is designed to overcome the partial demand response programs involving limited stakeholders with conflicting objectives. The load profile attributes are incorporated into generic load sensitivity. Additionally, an online adaptive fuzzy inference based model is developed to unify the load profile attributes alongside the customer willingness. The performance tuning of the fuzzy system parameters is carried out with an objective of maximizing the social welfare of demand response exchange.

The study is concluded by drawing observations from each of the resource scheduling aspects examined. Utilization of resource information and load profile information can enhance the objectives of generation side and demand side resource scheduling. The potential benefits of the study are diversified over economic, environmental and social factors of power system resource scheduling.

संक्षेप

आधुनिक विद्युत प्रणालियों में संसाधन शेड्यूलिंग समस्या विभिन्न उद्देश्यों के साथ विभिन्न हितधारकों की भागीदारी के साथ प्रकृति में बहु-आयामी में विकसित हुई है। उत्पादन के निर्धारण को सिस्टम अस्थिरता के तहत एक अपरिहार्य प्रक्रिया के रूप में लोड शेडिंग / कमी के साथ पुराने सिस्टम में उत्पादन का इष्टतम शेड्यूलिंग माना जाता है। हालांकि, उन्नत संचार और साइबर-भौतिक प्रणालियों जैसे स्मार्ट प्रौद्योगिकियों के आगमन के साथ, मांग पक्ष संसाधन प्रबंधन बिजली व्यवस्था शेड्यूलिंग में एक महत्वपूर्ण भूमिका निभा रहा है। इसलिए, दोनों उत्पादन के साथ-साथ मांग पक्ष पर संसाधन का उपयुक्त शेड्यूलिंग पावर सिस्टम परिचालन प्रबंधन का एक महत्वपूर्ण पहलू बन जाता है।

इस काम का मुख्य फोकस उपलब्ध वास्तविक दुनिया की जानकारी के उद्देश्यों से संबंधित संसाधन शेड्यूलिंग समस्या को बढ़ाने के लिए है। यह अध्ययन विभिन्न पहलुओं के संबंध में उत्पादन के पक्ष संसाधनों और मांग पक्ष संसाधनों के शेड्यूलिंग पहलुओं में सुधार करने पर विचार करता है। इस अध्ययन में सुधार के लिए विचार किए गए पहलू उत्सर्जन नियंत्रण नीतियों के तहत स्वच्छ ऊर्जा प्रौद्योगिकियों से लैस उत्पादन के पक्ष संसाधन में आर्थिक और पर्यावरणीय दक्षता में सुधार हैं। मांग पक्ष में, ग्राहक भागीदारी और भागीदारी की सटीकता में सुधार के लिए पारंपरिक इच्छा कारक के स्थान पर लोड प्रोफ़ाइल विशेषताओं को माना जाता है।

नवीकरणीय ऊर्जा उत्पादन के अलावा बिजली व्यवस्था में स्थायित्व प्रथाओं को इस अध्ययन में कार्बन कैप्चर प्रौद्योगिकी (पोस्ट-कैप्चर सिस्टम) के माध्यम से माना जाता है। बिजली उत्पादन में कार्बन कैप्चर टेक्नोलॉजी के गुणों का उपयोग थर्मल पावर उत्पादन इकाइयों, कार्बन कैप्चर टेक्नोलॉजी प्लांट और उत्पादन संसाधन विशेषताओं के संचालन के आधार पर प्रदर्शन सूचकांक तैयार करके किया जाता है। प्रस्तावित प्रदर्शन सूचकांक के लिए स्वच्छ ऊर्जा नीतियों के प्रभाव भी मॉडलिंग किए जाते हैं। प्रदर्शन सूचकांक की उचितता को सत्यापित करने के लिए केस स्टडीज विभिन्न संसाधन प्रकारों के साथ किया जाता है। संसाधन संवेदनशीलता, परीक्षण मामले, और सुधार कारकों के प्रभाव से संबंधित संवेदनशीलता विश्लेषण कार्बन कैप्चर पावर प्लांट की कम कैप्चर दरों पर प्रदर्शन सूचकांक की अस्थिरता को इंगित करता है।

उत्तरदायी भार और इस तरह के भार द्वारा प्रदान की जाने वाली सेवाओं की विस्तृत श्रृंखला के महत्व को ध्यान में रखते हुए, यह अध्ययन अलग-अलग ढांचे में मांग प्रतिक्रिया कार्यक्रमों पर लोड प्रोफ़ाइल विशेषताओं के प्रभाव का भी विश्लेषण करता है। इस सन्दर्भ में, ग्राहक बेसलाइन लोड और उत्तरदायी भार की पृथक प्रोफाइल क्रमशः उपयोग और उपलब्धता कारकों को परिभाषित करने के लिए उपयोग की जाती है, जो कि एग्रीगेटर द्वारा मूल्य आधारित मांग प्रतिक्रिया शेड्यूलिंग में नियोजित जेनेरिक लोड व्यवहार मॉडल में आगे उपयोग किया गया है। प्रस्तावित लोड प्रोफाइल विशेषताओं के साथ लोड प्रोफाइल आधारित शेड्यूलिंग विभिन्न परीक्षण मामलों के लिए किया जाता है। प्रतिक्रिया लोड शेड्यूलिंग के मौसमी बदलाव के संबंध में परिणामों का विश्लेषण किया गया है। इसके अलावा, इस अध्ययन में भार क्षेत्रों (आवासीय, वाणिज्यिक, औद्योगिक, कृषि और नगर पालिका) के संबंध में विश्लेषण भी किया गया है।

मांग प्रतिक्रिया विनिमय ढांचे पर लोड प्रोफाइल विशेषताओं का प्रभाव भी जांच किया गया है। मांग प्रतिक्रिया विनिमय ढांचे को विवादित उद्देश्यों के साथ सीमित हितधारकों से जुड़े आंशिक मांग प्रतिक्रिया कार्यक्रमों को दूर करने के लिए डिज़ाइन किया गया है। लोड प्रोफ़ाइल विशेषताओं जेनेरिक लोड संवेदनशीलता में शामिल हैं। इसके अतिरिक्त, ग्राहक अनुकूलता के साथ लोड प्रोफ़ाइल विशेषताओं को एकजुट करने के लिए एक ऑनलाइन अनुकूली अस्पष्ट अनुमान आधारित मॉडल विकसित किया गया है। फ़ज़ी सिस्टम पैरामीटर का प्रदर्शन ट्यूनिंग मांग प्रतिक्रिया विनिमय के सामाजिक कल्याण को अधिकतम करने के उद्देश्य से किया गया है।

अध्ययन की जांच की गई प्रत्येक संसाधन शेड्यूलिंग पहलुओं से अवलोकनों को चित्रित करके निष्कर्ष निकाला गया है। संसाधन जानकारी और लोड प्रोफाइल जानकारी का उपयोग उत्पादन के पक्ष और मांग पक्ष संसाधन शेड्यूलिंग के उद्देश्यों को बढ़ा सकता है। अध्ययन के संभावित लाभ बिजली व्यवस्था संसाधन शेड्यूलिंग के आर्थिक, पर्यावरण और सामाजिक कारकों पर विविधतापूर्ण हैं।

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Nomenclature

Time index	t
Unit index	g
Thermal generation cost coefficients	a_g, b_g, c_g
Startup cost	SC_t^g
Hot start up	H_{SC}^g
Cold start up	C_{SC}^g
Minimum down time	M_{DT}^g
Minimum up time	M_{UT}^g
OFF time	T_{off}^g
ON time	T_{on}^g
Cold start hours	H_{CS}^g
Generator set	$\mathcal{G}$
Scheduling slot time set	$\mathcal{H}$
Number of generators	NG
Number of time slots	T
Maximum generation limit	P_{max}^g
Minimum generation limit	P_{min}^g
Spinning reserve (%)	sr
Load	L_t
Ramp up rate	R_{RU}^g
Ramp down rate	R_{RD}^g
Capture cost function	CC_g
Coefficients of capture function	a_c, b_c, c_c
Emission function	EC_g
Emission correction factor	ECF_r
Carbon content of coal rank r	C_r
Hydrogen content of coal rank r	H_r
Oxygen content of coal rank r	O_r
Sulfur content of coal rank r	S_r
Post carbon emission function	PCE_g

Capture efficiency	η_c
Emission coefficients	a_e, b_e, c_e
Performance index	PI
Revenue function with CER benefits	R_{CER}
Carbon tax function	C_{tax}
Carbon tax	Δ_c^{tax}
CER price	Δ_{CER}
Carbon tax	σ_c
Weight factors	ϕ_1, ϕ_2
DR cost function	$C_{DR}(P_d r)$
Willingness factor	θ
DR cost coefficients	$a_d r, b_d r, c_d r$
DR power schedule variable	P_{dr}
DR Schedule status variable	S_{dr}
DR availability status variable	A_{dr}
Availability factor	A
Utilization factor	U
Index for load type	l
Index for iteration	j
Iteration termination error	ϵ
Power generation variable	P_t^g
Power generation function	$GC_g(P_g)$
Unit commitment variable	C_t^g
Cost correction factor	CCF_r
Coal rank (base, relative)	b, r
Energy penalty function	EP
Generation correction factor	GCF_r
Energy penalty coefficients	$a_e p, b_e p, c_e p$
Heating value of coal	HV_r/b
Coal price	CP_r/b

Index for load number	k
Hourly load of a particular load type	$CBL_t^{l,k}$
Set of loads per type	$\mathcal{K}$
Set of load type	$\mathcal{L}$
Number of loads	K_{dr}
Number of load type	L_{dr}
Upper and lower limits of DR load	$P_{min}^{(l,k,t)}, P_{max}^{(l,k,t)}$
Energy price	P_e
Reserve price	P_r
Outage rate/contingency rate	r
DR seller cost function	$S(P_dr)$
DR buyer cost function	$B(P_dr)$
DR seller cost coefficients	$a_{dr}^s, b_{dr}^s, c_{dr}^s$
DR buyer cost coefficients	$a_{dr}^b, b_{dr}^b, c_{dr}^b$
Set of buyers	$\mathcal{B}$
Set of sellers	$\mathcal{S}$
Number of buyers	B
Number of sellers	S
Customer baseline load parameter	CBL_t
DR load maximum limit	P_{dr}
Cost factor of DR	CF_{dr}
Linear DR function coefficients	$a_{dr}^{lr}, b_{dr}^{lr}, c_{dr}^{lr},$
Exponential DR function coefficients	$a_{dr}^{ex}, b_{dr}^{ex}, c_{dr}^{ex},$
Non-linear DR function coefficients	$a_{dr}^{nl}, b_{dr}^{nl}, c_{dr}^{nl}$
Index for iteration	i