Shamol elektr stansiyasiga ega bo‘lgan avtonom tizimda agregatlar tarkibini optimallashtirish

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Dolzarblik: hozirgi elektr energiya iste’molining keskin suratlarda oshib borishi, uglevodorod yoqilg‘i zahiralarining cheklanganligi hamda energetikaning ekologik muammolarini keskinligi sharoitlarida qayta tiklanuvchan energiya resurslarida ishlovchi elektr stansiyalarini loyihalash va ishlatishning yanada takomillashgan usullarini ishlab chiqish va joriy e tish muhim sanaladi. Bunday turdagi energiya resurslaridan foydalanuvchi elektr stansiyalarini loyihalashning asosiy masalalaridan biri ulardagi jihozlarning optimal tarkibini tanlash hisoblanadi. Hozirgi davrda ushbu masalani yechish bo‘yicha bir qator ishlanma va dasturlarning mavjud bo‘lishiga qaramasdan ularni barcha cheklovchi va ta’sir etuvchi faktorlarni e’tiborga olish, optimizatsion hisoblashlarning ishonchliligi va aniqlgini oshirish hisobiga takomillashtirish dolzarb masalalaigicha qolmoqda.
Maqsad: qayta tiklanuvchan energiya resurslarida ishlovchi elektr stansiyalarini loyihalash va ishlatishning yanada takomillashgan usullarini ishlab chiqish va joriy etishdan iborat.
Usullar: tarkibida shamol elektr stansiyasi va akkumulyator batareyasi mavjud bo‘lgan avtonom tizimlar jihozlarining optimal tarkibini tanlashning samarali matematik modeli va uni chiziqli dasturlash masalasiga keltirib, simpleks usuldan foydalanish orqali yechishga asoslangan algoritm taklif etilgan.
Natijalar: matematik model va optimallash algoritmining samaradorligi berilgan sutkalik yuklama grafigi bo‘yicha ishlovchi iste’molchiga ega bo‘lgan avtonom tizimda shamol agregatlari va akkumulyator batareyasi parametrlarini optimal tanlash bilan izohlanadi.
Kalit so‘zlar: optimallashtirish, matematik model, algoritm, avtonom tizim, shamol elektr stansiyasi, shamol agregati, kapital xarajat, ishlatish xarajati.

Оптимизация состава агрегатов в автономной системе с ветроэнергетической установкой

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Актуальность: В современных условиях интенсивного повышения электропотребления, ограниченности запасов углеводородного топлива, а также обострения экологических проблем энергетики, важным является разработка и внедрение более совершенных методов проектирования и эксплуатации электростанций, работающих на возобновляемых энергоресурсах. Одной из основных задач проектирования автономных систем со станциями, использующими такие виды энергоресурсов, является выбор оптимального состава используемого оборудования. Несмотря на существование в настоящее время ряд разработок и программ по решению этой проблемы, вопросы их усовершенствования посредством учета всех ограничивающих и влияющих факторов, повышения надежности и точности оптимизационных расчетов, остается актуальной задачей.
Цель: заключается в разработке и внедрении более совершенных методов проектирования и эксплуатации электростанций, работающих на возобновляемых источниках энергии.
Методы: предложена эффективная математическая модель выбора оптимального состава оборудования автономной системы, включающую в себя ветроэнергетическую установку и аккумуляторную батарею; предлагается алгоритм решения путем применения симплексного метода в задаче линейного программирования.
Результаты: Эффективность математической модели и алгоритма оптимизации объясняется оптимальным выбором параметров ветроустановок и аккумуляторных батарей в автономной системе с потребителем, работающим по заданному суточному графику нагрузки.
Ключевые слова: оптимизация, математическая модель, алгоритм, автономная система, ветровая электростанция, ветровой агрегат, капиталовложение, эксплуатационные затраты.

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Optimizing the composition of aggregates in an autonomous system with a wind power plant

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Relevance: In modern conditions of intensive increase in electricity consumption, limited hydrocarbon fuel reserves, as well as the severity of environmental problems in the energy sector, it is important to develop and implement more advanced methods for the design and operation of power plants operating on renewable energy resources. One of the main tasks in designing autonomous systems with stations using these types of energy resources is choosing the optimal composition of the equipment used. Despite the current existence of a number of developments and programs to solve this problem, improving them by taking into account all limiting and influencing factors, increasing the reliability and accuracy of optimization calculations remains as an urgent task.
Aim: is to develop and implement more improved methods of designing and operating power plants working on renewable energy resources.
Methods: an effective mathematical model for choosing the optimal composition of autonomous system equipment, which includes a wind power plant and a storage battery, and an algorithm based on solving it by applying the simplex method to the problem of linear programming is proposed.
Results: the effectiveness of the mathematical model and optimization algorithm is explained by the optimal selection of parameters of wind units and accumulator batteries in an autonomous system with a consumer operating according to a given daily load schedule.
Keywords: optimization, mathematical model, algorithm, autonomous system, wind power plant, wind unit, capital investment, operating costs.

1. Kirish (Introduction)

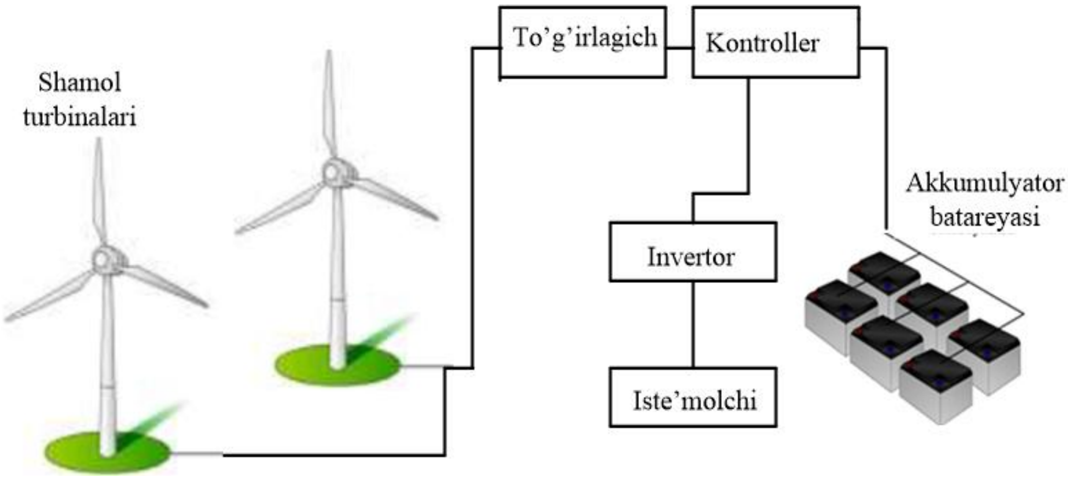
Hozirgi elektr energiya iste'molining keskin suratlarda oshib borishi, uglevodorod yoqilg'i zahiralarining cheklanganligi hamda energetikaning ekologik muammolarini keskinligi sharoitlarida qayta tiklanuvchan energiya resurslarida ishlovchi elektr stansiyalarini loyihalash va ishlatishning yanada takomillashgan usullarini ishlab chiqish va joriy etish muhim sanaladi. Bu masalani kompleks yechish, jumladan, ularni loyihalashda foydalaniluvchi jihozlarning optimal tarkibini tanlashni ko'zda tutadi. Ushbu ishda shamol elektr stansiyasi (SHES) va akkumulyator batareyasi (AB)ga ega bo'luvchi avtonom tizimni loyihalashda ularda o'rnatiluvchi agregatlarning optimal tarkibini tanlash masalalari ko'rib o'tilgan.

Mavjud adabiyotlarda ko'rilayotgan masalani yechishga bag'ishlangan bir qator [1-7] kabi ishlanmalar keltirilgan. Ular, shubhasiz, qayta tiklanuvchan energiya resurlarida ishlovchi elektr stansiyalariga ega bo'lgan tizimlarni loyihalash va ishlatish nazariyasi taraqqiyotiga ulkan hissa qo'shgan. Biroq, mavjud ishlanmalar uchun ularni ushbu ishda ko'riliyotgan masalani yechish uchun bevosita qo'llashning mumkin emasligi, ayrim cheklovchi va ta'sir etuvchi faktorlarning e'tiborga olinmaganligi, model yoki hisoblash algoritmi aniqligining nisbatan pastligi bilan bog'liq kamchiliklar xarakterlidir. Shu sababli, ularni barcha cheklovchi va ta'sir etuvchi faktorlarni hisobga olib, yanada katta aniqlikda yechish imkonini beruvchi modellar va hisoblash algoritmlarini yaratish yo'nalishida takomillashtirish dolzarb masalaligicha qolmoqda.

Ushbu maqolada qayta tiklanuvchan energiya manbalarida ishlovchi stansiyalarga ega bo'lgan tizimlarni loyihalash va ishlatish bilan bog'liq muammolarni hal etish yo'nalishida amalga oshirilgan ilmiy tadqiqot ishlari [9-11] ni davom ettirish asosida shamol elektr stansiyasi va akkumulyator batareyasi mavjud bo'lgan avtonom elektr tizimini loyihalashda jihozlarning optimal tarkibini tanlash masalasining matematik modeli va uni chiziqli dasturlash masalasiga keltirish orqali simpleks usulida yechish algoritmi taklif etilmoqda.

2. Optimallashtirish masalasining matematik modeli va uni yechish algoritmi (Materials and Methods)

Ko'rilayotgan avtonom tizimning prinsipial sxemasini 1- rasmdagi ko'rinishda ifodalash mumkin.



1-rasm. Shamol stansiyasi va akkumulyator batareyasiga ega bo‘lgan avtonom tizimning prinsipial sxemasi

Fig. 1. A schematic diagram of an autonomous system with a wind farm and a battery

Shamol stansiyasi va akkumulyator batareyasidan tashkil topgan avtonom energetika tizimida jihozlarning tarkibini optimallashtirish masalasining matametik modelini quyidagicha ifodalash mumkin:

- tizimni qurish va hisoblanayotgan davr T davomida ishlatish bilan bog‘liq bo‘lgan umumiy xarajatlardan iborat bo‘lgan maqsad funksiyasi

$$\text{З} = \text{З}_W + \text{З}_{BS} + \text{З}_{BOS} = \left(1 + k_{W.OM}\right)\cdot C_W \cdot N_W + \left(C_{BS} + C_{BS.rep.}\right)\cdot N_{BS} + \text{З}_{BOS} \rightarrow \min \quad (1)$$

quyidagi chegaraviy shartlarni hisobga olib minimallashtirilsin:
ko‘rilayotgan davr T ning har bir vaqt intervalida

- aktiv quvvat balansi bo‘yicha

$$P_W^{(t)} + P_{BS}^{dch(t)} = P_L^{(t)} + P_{BS}^{ch(t)}, \quad t = 1, 2, ..., T; \quad (2)$$

- shamol agregatlarining ruxsat etilgan minimal va maksimal quvvatlari bo‘yicha

$$P_W^{\min} \le P_W^{(t)} \le P_W^{\max}, \quad t = 1, 2, ..., T; \quad (3)$$

- akkumulyator batareyasining ruxsat etlgan minimal va maksimal zaryadlanish va razryadlanish quvvatlari bo‘yicha

$$0 \le P_{BS}^{ch(t)} \le P_{BS}^{ch.max}, \quad t = 1, 2, ..., T; \qquad 0 \le P_{BS}^{dch(t)} \le P_{BS}^{dch.max}, \quad t = 1, 2, ..., T; \quad (4)$$

- akkumulyator batareyasida jamlanuvchi ruxsat etilgan minimal va maksimal energiyalar (sig‘imi) bo‘yicha

$$W_{BS}^{(t)min} \le W_{BS}^{(t)} \le W_{BS}^{(t)max}, \quad t = 1, 2, ..., T; \quad (5)$$

bu yerda T- ko‘rilatgan davrdagi vaqt intervallari soni; З_W, З_{BS}, З_{BOS} – mos holda, shamol agregatlari, akkumulyator batareyasi va boshqa o‘zgartirish, boshqarish va qayd etish qurilmalari uchun sarflanuvchi kapital xarajatlar va ishlatish davridagi qo‘shimcha xarajatlarning yig‘indisi; C_W, C_{BS}- shamol agregatlari va akkumulyator batareyalari uchun solishtirma kapital xarajatlar; $C_{BS.rep.}$- akkumulyator baareyasini almashtirish bilan bog‘liq bo‘lgan solishtirma kapital xarajatlar; $k_{W.OM}$ – shamol agregati uchun solishtirima ishlatish xarajatlari; N_W, N_{BS}- shamol agregatlari va akkumulyator batareyalari soni; $P_W^{(t)}$, $P_{BS}^{ch(t)}$, $P_{BS}^{dch(t)}$- shamol agregatlarining umumiy, akkumulyator batareyasining t- chi vaqt intervalidagi umumiy zaryad va razryad quvvatlari; $P_{BS}^{ch.max}, P_{BS}^{dch.max}$ - akkumulyator batareyasining ruxsat etilgan maksimal zaryad va razryad quvvatlari; $W_{BS}^{(t)}, W_{BS}^{(t)min}, W_{BS}^{(t)max}$ - t- chi vaqt intervalida akkumulyator batareyasida jamlangan energiya miqdori va uning ruxsat etilgan minimal va maksimal qiymatlari; $W_{BS.\text{отд.}}^{(t)}, W_{BS.\text{пол.}}^{(t)}$ - vaqtning t- chi intervaliga kelib akkumulyator batareyasidan uning razryadlanishi hisobiga tarmoqqa berilgan va zaryadlanishi hisobiga tarmoqdan olingan energiya miqdorlari.

Qo‘yilgan masalani yechish natijasida, jumladan, shamol agregatlarining optimal soni N_W; batareyadagi akkumulyatorlarning umumiy soni N_{BS} lar topiladi. Shu sbabli masalani yuqorida keltirilgan modeldan foydalanib yechish uchun chegaraviy shartlardagi parametrlarni ushbu noma'lumlar orqali ifodalaymiz. Shamol agregatlarining t- chi vaqt intervalidagi umumiy quvvatini [6] dagi ifoda bo'yicha topish mumkin:

$$P_W^{(t)} = \left(av^{(t)3} + bv^{(t)2} + cv^{(t)} + d\right)\cdot \eta_W^{(t)} \cdot \eta_{El} \cdot N_W\,, \tag{6}$$

bu yerda $\eta_W^{(t)}$ - shamol agregatining t- chi vaqt intervalidagi foydali ish koeffitsiyenti; η_{El} - SHESni ishonchli ishlashini ta'minlash uchun xizmat qiluvchi elektronika tizmining foydal ish koeffitsiyenti bo'lib, [8] ga ko'ra η_{El} =0,98; $v^{(t)}$ - t- chi vaqt intervalida shamolning tezligi; *a, b, c, d*- shamol agregatini ishlab chiqaruvchi tomonidan beriluvchi bog'lanish $P_W(v)$ ni approksimatsiyalash natijasida hosil bo'luvchi kubik algebraik polinomning o'zgarmas koeffifitsentlari.

Davrning t- vaqt intervaliga kelib akkumulyator batareyasida jamlanuvchi energiya miqdori $W_{BS}^{(t)}$ quyidagicha aniqlanadi:

$$W_{BS}^{(t)} = W_b + \sum_{i=1}^{t} P_{BS}^{ch(i)} - \sum_{i=1}^{t} \frac{P_{BS}^{dch(i)}}{\eta_{BS}^{(i)}}\,, \tag{7}$$

bu yerda W_b – ko'rilayotgan davrning boshlanishida, ya'ni $t=0$ da akkumulyator batareyasida mavjud bo'lgan qoldiq energiya; $\eta_{BS}^{(i)}$ - akkumulyator batareyasining vaqtni i- chi intervalidagi foydali ish koeffitsiyenti.

(6) ni hisobga olib, chegaraviy shart (3) ni quyidagi ko'rinishda tasvirlash mumkin:

$$P_{1W}^{\min} \cdot N_W \le \left(av^{(t)3} + bv^{(t)2} + cv^{(t)} + d\right)\cdot N_W \le P_{1W}^{\max} \cdot N_W\,, \tag{8}$$

bu yerda $P_{1W}^{\min}$, $P_{1W}^{\max}$ - bitta shamol agregatining ruxsat etilgan minimal va maksimal quvvatlari.

Chegaraviy shart (8) ni N_W ga bo'lish natijasida shamol agregatlarining soniga bog'liq bo'lmagan chegaraviy shartni hosil qilamiz. Bu esa, chegaraviy shart (3) ko'rilayotgan masalaning yechimiga ta'sir etmasligini ko'rsatadi. Shu sababli masalaning matematik modeliga ushbu chegaraviy shartni kiritmaymiz.

Akkumulyator batareyasining ruxsat etilgan minimal va maksimal zaryad va razryad quvvatlari bo'yicha chegaraviy shart (4) ni quyidagi ko'rinishda tasvirlash mumkin:

$$0 \le P_{BS}^{ch(t)} \le P_{1BS}^{ch.max} \cdot N_{BS}, \quad t = 1, 2, ..., T\,; 0 \le P_{BS}^{dch(t)} \le P_{1BS}^{dch.max} \cdot N_{BS}, \quad t = 1, 2, ..., T\,, \tag{9}$$

bu yerda $P_{1BS}^{ch.\max}$, $P_{1BS}^{dch.\max}$ - batareyadagi bitta akkumulyatorning ruxsat etilgan maksimal zaryadlanish va razryadlanish quvvatlari.

Yuqoridagilarga o'xshash tarzda chegaraviy shart (5) ni quyidagicha ifodalash mumkin:

$$W_{1BS}^{\min} \cdot N_{BS} \le W_b + \sum_{i=1}^{t} P_{BS}^{ch(i)} - \sum_{i=1}^{t} \frac{P_{BS}^{dch(i)}}{\eta_{BS}^{(i)}} \le W_{1BS}^{\max} \cdot N_{BS}, \quad t = 1, 2, ..., T, \tag{10}$$

bu yerda $W_{1BS}^{\min}$, $W_{1BS}^{\max}$ - batareyadagi bitta akkumulyatorda jamlanishi mumkin bo'lgan ruxsat etilgan minimal va maksimal energiya miqdori.

Ko'rilayotgan davr ya'kunida, ya'ni $t=T$ bo'lganda akkumulyator batareyasidagi qoldiq energiya uning davrni boshlanishidagi qiymati W_b ga teng deb qabul qilsak, hisobga olinuvchi chegaraviy shartlar qatoriga quyidagi shart ham qo'shiladi:

$$\sum_{i=1}^{T} P_{BS}^{ch(i)} - \sum_{i=1}^{T} \frac{P_{BS}^{dch(i)}}{\eta_{BS}^{(i)}} = 0\,, \tag{11}$$

bu yerda tenglikning chap tomonidagi birinchi va ikkinchi tashkil etuvchilar, mos holda, ko'rilayotgan davr davomida akkumulyator batareyasi tomonidan uning zaryadlanishi natijasida qabul qilingan va razryadlanishi natijasida berilgan energiya miqdorlirini ifodalaydi.

Hozirgi davrda ko'plab shamol agregatlari va boshqa o'zgartirish, boshqarish, qayd etish va va bog'lash qurilmalarining meyoriy xizmat qilish muddatlari 25 yilni tashkil etadi [6, 8]. Shu bilan bir qatorda ushbu holatda foydalanish mumkin bo'lgan geliyli akkumulyatorning meyoriy xizmat ko'rsatish davri 10 yilni tashkil etadi.

Barcha xarajatlarni 25 yilga keltiramiz. Buda akkumulyatorlarni almashtirish bilan bog'liq bo'lgan xarajatlarni amaldagi naxlarga keltirish uchun quyidagi formuladan foydalanish mumkin:

$$C_{BS.rep} = k_{pr.rep} \cdot C_{BS} = \frac{1}{\left(1 + k_{dis}\right)^n} \cdot C_{BS}\,, \tag{12}$$

bu yerda $k_{pr.rep}$- solishtirma kapital xarajatlarni amaldagi naxlarga keltirish koeffitsiyenti; k_{dis}- almashtirishda solishtirma kapital xarajatlarning kamayib borish darajasini belgilovchi diskont koeffitsiyenti bo'lib, u, odatda, 5,15% qabul qilinadi; n- ishlatish boshlanganidan so'ng akkumulyator batareyasini almashtirish yilini tartib raqami. Mos holda akkumulyator batareyasi uchun solishtirma kapital xarajatlarni 25 yilga keltirish uchun uni 2 marta, ya'ni 10 va 20 yildan keyin almashtirilishi va qoldiq narxini hisobga olish zarur:

$$k_{pr.rep}=\frac{1}{1{,}0515^{10}}+0{,}5\cdot\left(\frac{1}{1{,}0515^{20}}+\frac{1}{1{,}0515^{30}}\right)=0{,}9\,.$$

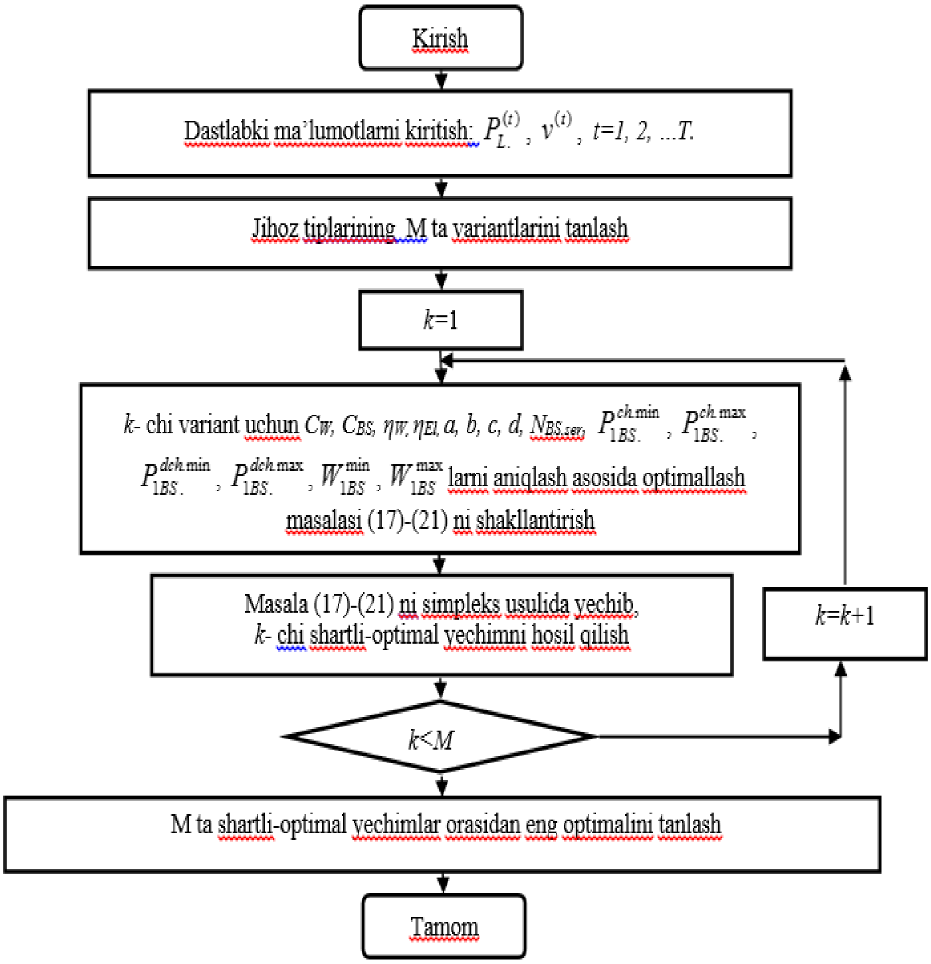
Shunday qilib, $C_{BS.rep}=0{,}9\cdot C_{BS}$. (13)

Akkumulyator batareyasining bitta shoxabchasidagi akkumulyatorlar soni tarmoqning U_{net} va bitta akkumulyatorning U_{1BS} nominal kuchlanishlariga muvofiq holda formula

$$N_{BS.ser.}=U_{net}/U_{1BS}\,, \quad (14)$$

bo'yicha, batareyadagi akkumulyatorlarning umumiy soni esa, ketma-ket ulangan akkumulyator batareyalariga ega bo'lgan parallel ulanuvchi shoxobchalar soni $N_{BS.par.}$ ni $N_{BS.ser}$ ga ko'paytirish orqali topiladi:

$$N_{BS}=N_{BS.par.}\cdot N_{BS.ser.}\,. \quad (15)$$



2-rasm. SHES va AB ga ega bo'lgan avtonom tizim jihozlarining tarkibini optimallashtirish algortmining yiriklashtirilgan blok-sxemasi
Fig. 1. Enlarged block diagram of the optimization algorithm of the composition of autonomous system equipment with SHES and AB

Hisoblashlarda shamol agregatlari uchun yillik ishlatishdagi ko'shimcha xarajatlarni kapital xarajatga nisbatan 2% [6, 8], diskont koeffitsiyentini esa 5,15% qabul qilish mumkin. Bunday holatda kelajakdagi ishlatish xarajatlarini amaldagi naxlarga keltirish uchun quyidagi formuladan foydalanamiz:

$$k_{pr.W}=\frac{(1+k_{dis})^{N}-1}{k_{dis}\cdot(1+k_{dis})^{N}}=\frac{1{,}0515^{25}-1}{0{,}0515\cdot 1{,}0515^{25}}=13{,}88 \quad (16)$$

Bunga mos holda $k_{W.OM}$ = 0,278.

Qolgan qurilmalar uchun kapital va ishlatish xarajatlari $З_{BOS}$ ularning shamol agregatlari uchun qiymatlariga bog‘liq bo‘lib, ularni [6] dagi singari $З_{BOS} = 0{,}5 \cdot З_W$ qabul qilish mumkin.

Shunday qilib, ko‘rilayotgan masala matematik jihatdan quyidagicha shakllantiriladi:

Maqsad funksiyasi

$$З = 1{,}847 \cdot C_{PV} \cdot N_{PV} + 1{,}778 \cdot C_W \cdot N_W + 1{,}9 \cdot C_{BS} \cdot N_{BS.ser.} \cdot N_{BS.par.} \to \min \quad (17)$$

chegaraviy shartlar

$$\left(av^{(t)3} + bv^{(t)2} + cv^{(t)} + d\right) \cdot \eta_W^{(t)} \cdot \eta_{El} \cdot N_W - P_{BS}^{ch(t)} + P_{BS}^{dch(t)} = P_L^{(t)}, \quad t = 1, 2, ..., T; \quad (18)$$

$$0 \le P_{BS}^{ch(t)} \le P_{1BS}^{ch.max} \cdot N_{BS.ser} \cdot N_{BS.par}, \quad t = 1, 2, ..., T; \quad (19)$$

$$0 \le P_{BS}^{dch(t)} \le P_{1BS}^{dch.max} \cdot N_{BS.ser} \cdot N_{BS.par}, \quad t = 1, 2, ..., T, \quad (19a)$$

$$W_{1BS}^{\min} \cdot N_{BS.ser} \cdot N_{BS.par} \le W_b + \sum_{i=1}^{t} P_{BS}^{ch(i)} - \sum_{i=1}^{t} \frac{P_{BS}^{dch(i)}}{\eta_{BS}^{(i)}} \le W_{1BS}^{\max} \cdot N_{BS.ser} \cdot N_{BS.par}, \quad t = 1, 2, ..., T, \quad (20)$$

$$\sum_{i=1}^{T} P_{BS}^{ch(i)} - \sum_{i=1}^{T} \frac{P_{BS}^{dch(i)}}{\eta_{BS}^{(i)}} = 0, \quad (21)$$

Shamol tezligi grafigi $v^{(t)}$ ma’lum bo‘lganda masala (17)-(21) chiziqli dasturlash masalasiga keltiriladi. Bunday holatda uni yechish uchun simpleks usuldan foydalanishimiz mumkin. Ko‘rilayotgan masalani simpleks usuli asosda yechish algoritmining blok-sxemasi 2- rasmda keltirilgan.

Masalani yechish natijasida barcha 2+2T ta noma’lum parametrlar N_W, $N_{BS.par.}$ va $P_{BS}^{ch(1)}, P_{BS}^{ch(2)}, ..., P_{BS}^{ch(T)}, P_{BS}^{dch(1)}, P_{BS}^{dch(2)}, ..., P_{BS}^{dch(T)}$ ning qiymatlari aniqlanadi. Shamol agegatlari va akkumulyator batareyasidagi parallel ulanuvchi shoxobchalar soni mos N_W, $N_{BS.par}$ larni ularga yaqin bo‘lgan butun sonlarga yaxlitlash orqali aniqlanadi.

3. Natijalar (Results)

Taklif etilgan matematik model va optimallash algoritmining samaradorligi berilgan sutkalik yuklama grafigi bo‘yicha ishlovchi iste’molchiga ega bo‘lgan avtonom tizimda shamol agregatlari va akkumulyator batareyasi parametrlarini optimal tanlash misolida tadqiq qilindi.

Sutka uchun iste’molchining yuklama, shamolning tezligi va shamol agregatining ishlab chiqaruvchi ma’lumotlari (jadval. 1) asosida aniqlangan quvvat grafiklari 2- jadvalda keltirilgan.

Misol tariqasida bittadan tipdagi shamol agregati va akkumulyator batareyasi ko‘rib chiqilgan.

Shamol agregatining parametrlari:

Model: SWG EW-1000; nominal quvvati: 1 kW; energiya ishlab chiqara boshlashda shamol tezligi: 3,5 m/s; hisobiy ishchi tezlik: 12 m/s; aylanish chastotasi: 450 ayl./min, soat strelkasi harakati yo‘nalishida; solishtirma narxi: 1000 $/dona; quvvat egri chizig‘i (beruvchi quvvatini shamolning tezligiga bog‘lanishi) 1- jadvalda keltirilgan.

Akkumulyator batareyasining parametrlari:

Ishlab chiqarish joyi: Guangdong, Xitoy; Model: GE100AH/ 12V(100); tip: Gel Lead Battery; meyoriy xizmat qilish muddati: 10 yil; akkumulyatorning parametrlari: 12 V, 100 A.soat; maksimal zaryadlanish toki: $I_1^{ch.\max}$ = 10 A; bitta akkumulyatorning narxi: 91 $/dona. Hisoblashlarda barcha vaqt intervallarida akkumulyator batareyasining foydali ish koeffitsiyenti $\eta_{BS}^{(i)}$ =0,85 qabul qilingan.

1-jadval. EW-1000 tipidagi shamol agregatining quvvat egri chizig‘i
Table 1. Power curve of EW-1000 type wind turbine

v, m/s.	3,5	4,0	5,0	6,0	7,0	8,0	9,0	10,0	11,0	12,0
P_W, kW	0,04	0,06	0,10	0,15	0,25	0,35	0,47	0,62	0,85	1,10

2-jadval. Iste'molchining yuklama, shamolning tezligi va shamol agregatining solishtirima quvvat grafiklari
Table 2. Graphs of consumer load, wind speed and relative power of the wind turbine

t, soat.	1	2	3	4	5	6	7	8	9	10	11	12
	13	14	15	16	17	18	19	20	21	22	23	24
P_L, kW	3,8	2,9	2,3	2,8	3,1	4,6	6,3	8,8	11,2	13,6	15,2	13,4
	11,6	10,2	12,2	12,6	14,3	15,6	17,5	18,0	16,2	13,3	9,3	6,2
$V^{(t)}$, m/s	5,6	5,3	5,4	4,6	4,8	4,7	4,9	5,0	5,6	3,6	3,5	2,5
	2,9	3,9	4,8	4,1	3,9	4,4	5,3	5,0	6,3	6,0	5,2	6,2

Optimallashtirish masalasining matematik modeli (17)-(21) ning mos parametrlari aniqlandi. Elektr tarmog'ining nominal kuchlanishi 220 V va bitta akkumulyatorning nominal kuchlanishi 12 V ga muvofiq holda batareya sxemasining har bir shoxobchasidagi akkumulyatorlar soni $N_{BS.ser}$ = 20 ta. Bularga mos holda

$$P_{BS}^{ch.\max} = P_{1.BS}^{ch.\max} \cdot N_{BS.ser} \cdot N_{BS.par} = 12 \cdot I_1^{ch.\max} \cdot 20 \cdot N_{BS.par} = 2{,}4 N_{BS.par}.$$

Tanlangan geliyli akkumulyator uchun maksimal razryadlanish toki $I_1^{dch.\max}$ = 100 A va mos razryadlanish quvvati $P_{BS}^{dch.\max} = 24 N_{BS.par}$.

Shu singari hisoblashlar asosida akkumulyator batareyasida jamlanishi mumkin bo'lgan maksimal energiya miqdorini aniqlaymiz: $W_{BS}^{\max} = 24 N_{BS.par}$. Unda saqlanishi zarur bo'lgan minimal ruxsat etilgan energiya miqdori razryadlanish chuqurligi 20% bo'yicha aniqlangan: $W_{BS}^{\min} = 4{,}8 N_{BS.par}$ Taklif etilgan matematik model $W_{BS}^{\min}$ va $W_{BS}^{\max}$ larning qiymatlarini ko'rilayotgan vaqt davomida o'zgarib turishini hisobga olish imkonini beradi. Ko'rib o'tilayotgan misolda, soddalik uchun, ularning qiymatlari barcha vaqt intervallarida o'zgarishsiz qoldirilgan.

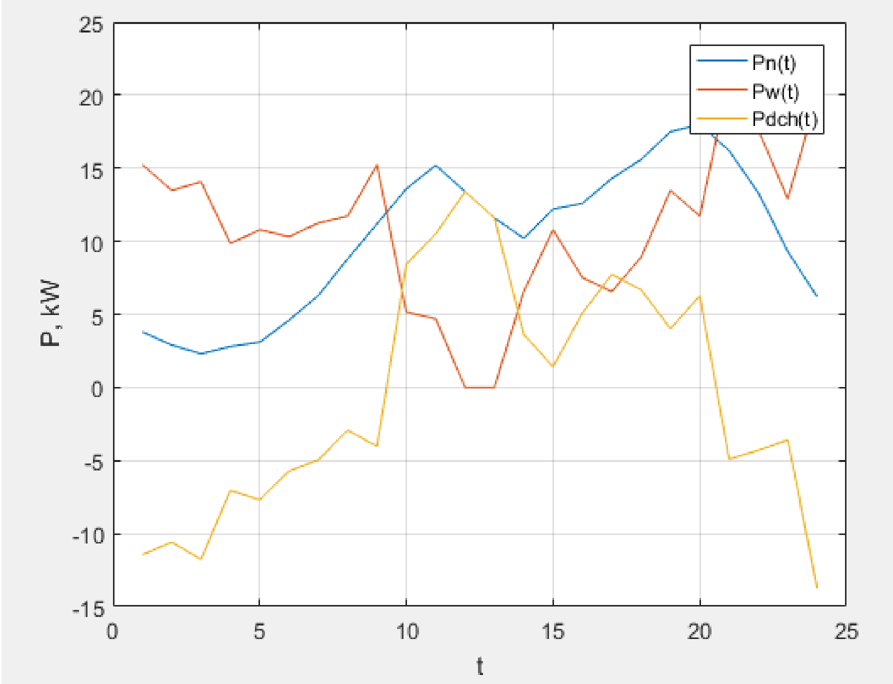
4. Munozara (Discussion)

Taklif etilgan matematik model va algoritmdan foydalanish asosida aniqlangan shamol agregatlarining optimal soni: 120 ta. Har birida 20 tadan akkumulyator mavjud bo'lgan parallel ulanuvchi shoxobchalarning optimal soni: $N_{BS.par}$= 6 ta. Mos holda batareyadagi akkumulyatorlarning umumiy soni: N_{BS} = 20x6= 120 ta. Minimal umumiy xarajatlar: $З_{min}$ = 232600 $.

3-jadval va 3- rasmda ko'rilayotgan masalani taklif etilgan matematik model va optimallashtirish algoritmi asosida yechish natijasida hosil bo'lgan shamol stansiyasining hamda akkumulyator batareyasining zaryadlanish-razryadlanish quvvatlarining optimal grafiklari keltirilgan. 3- rasmda akkumulyatorning yig'indi quvvat grafigi $P_{dch}(t)$ uning har bir vaqt intervalidagi razryadlanish va zaryadlanish quvvatlarining ayirmasi sifatida aniqlangan.

3-jadval. Iste'molchining yuklama, SHESning optimal quvvat berish va akkumulyator batareyasining zaryadlanish-razryadlanish quvvat grafiklari.
Table 3. Graphs of load of the consumer, optimal power supply of SHES and charge-discharge power of the battery

t, soat.	1	2	3	4	5	6	7	8	9	10	11	12
	13	14	15	16	17	18	19	20	21	22	23	24
PL, kW	3,8	2,9	2,3	2,8	3,1	4,6	6,3	8,8	11,2	13,6	15,2	13,4
	11,6	10,2	12,2	12,6	14,3	15,6	17,5	18,0	16,2	13,3	9,3	6,2
$P_W^{(t)}$, kW	15,24	13,48	14,07	9,85	10,79	10,32	11,26	11,73	15,24	5,16	4,69	0,00
	0,00	6,57	10,79	7,50	6,57	8,91	13,48	11,73	21,11	17,59	12,90	19,93
$P_{BS}^{ch.(t)}$, kW	11,44	10,58	11,77	7,05	7,69	5,72	4,96	2,93	4,04	0,00	0,00	0,00
	0,00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4,91	4,29	3,60	13,73
$P_{BS}^{dch.(t)}$, kW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8,44	10.51	13,40
	11,60	3,63	1,41	5,10	7,73	6,69	4,02	6,27	0,00	0.00	0.00	0.00



3-rasm. Iste'molchining yuklama, SHESning optimal quvvat berish va ABning optimal yig'indi razryadlanish-zaryadlanish quvvat grafiklari
Fig. 3. Graphs of load of the consumer, optimal power supply of SHES and optimal total discharge-discharge power of AB

Olingan natijalarning ishonchliligi ularni oddiy tanlash asosida va mos holda optimallashtirishning baholash modelidan foydalanib topilgan ruxsat etilgan yechimlar to'plami bilan solishtirish asosida aniqlandi. Taklif etilgan model va algoritm asosida olingan natijada umumiy xarajatlar baholash modeli asosida aniqlangan barcha natijalardagiga nisbatan kichik ekanligi ko'rsatildi.

5. Xulosa (Conclusions)

Shamol elektr stansiyasi va akkumulyator batareyasiga ega bo'lgan avtonom tizimda jihozlarning tarkibini optimallashtirish masalasining barcha ta'sir etuvchi va cheklovchi faktorlarni hisobga oluvchi samarali matematik modeli taklif etildi.

Shamol elektr stansiyasi va akkumulyator batareyasiga ega bo'lgan avtonom tizimda jihozlarning optimal tarkibini barcha ta'sir etuvchi faktorlarni hisobga olib optimallashtirishning simpleks usuldan foydalanishga asoslangan algoritmi ishlab chiqildi.

Hisoblash tajribalarining natijalari taklif etilgan model va algoritm yuqori samaradorlikka ega ekanligini ko'rsatdi.

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