



Quyosh fotoelektr tizimlari va energiya saqlash qurilmalari asosida taqsimlangan generatsiya samaradorligini oshirish

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Dolzarbli: taqsimlangan quyosh fotoelektr tizimlarining elektr tarmoqlaridagi ulushi ortishi bilan ularning o'zgaruvchan generatsiyasini mahalliy yuklama bilan muvofiqlashtirish masalasi dolzarb bo'lib bormoqda. Quyosh nurlanishining sutkalik va qisqa muddatli o'zgarishi tarmoqdan olinadigan hamda tarmoqqa uzatiladigan quvvatning keskin o'zgarishiga sabab bo'lishi mumkin. Batareyali energiya saqlash tizimi ortiqcha fotoelektr energiyasini vaqt bo'yicha ko'chirish va tarmoq bilan quvvat almashinuvini yumshatish imkonini beradi.

Maqsad: 10,24 kW quvvatli quyosh fotoelektr tizimi va 20 kWh sig'imli energiya saqlash tizimining turli quyosh nurlanishi va yuklama holatlaridagi energiya balansini, zaryad-razryad rejimlarini va tarmoq bilan quvvat almashinuviga ta'sirini baholash.

Usullari: fotoelektr ishlab chiqarish, invertor yo'qotishlari, mahalliy yuklama, energiya saqlash tizimining zaryad-razryad samaradorligi va zaryadlanganlik darajasi hisobga olingan soddalashtirilgan energetik model qo'llanildi. To'rtta xarakterli rejim uchun quvvat va energiya balansini hisoblandi.

Natijalar: $G = 800 \text{ W/m}^2$ sharoitida o'zgaruvchan tok tomonidagi fotoelektr quvvat 9,93 kW bo'lib, 8 kW yuklamada 1,93 kW ortiqcha quvvat hosil bo'ldi. Ushbu rejim 3 soat davom etganda 92 % zaryad samaradorligini hisobga olib batareyada 5,33 kWh energiya yig'ilishi va zaryadlanganlik darajasining 50 % dan 76,7 % gacha oshishi aniqlandi. $G = 300 \text{ W/m}^2$ sharoitida esa 4,28 kW quvvat yetishmovchiligi yuzaga kelib, energiya saqlash tizimi 2 soat davomida yuklamani tarmoqdan quvvat olmasdan ta'minlay olishi ko'rsatildi. Kechki 10 kW yuklama holatida 8 kW razryad quvvati cheklovi sababli tarmoqdan olinadigan quvvat 2 kW gacha kamaytirildi.

Kalit so'zlar: qayta tiklanuvchi energiya, taqsimlangan generatsiya, quyosh fotoelektr tizimi, batareyali energiya saqlash tizimi, energiya balans, zaryadlanganlik darajasi, o'z-o'zini iste'mol qilish, tarmoqqa quvvat uzatish.

Повышение эффективности распределенной генерации на основе солнечных фотоэлектрических систем и накопителей энергии

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Актуальность: рост доли распределенных фотоэлектрических систем требует согласования переменной солнечной генерации с локальной нагрузкой. Изменение инсоляции приводит к колебаниям обменной мощности с внешней сетью, а аккумуляторная система накопления энергии позволяет переносить избыточную энергию во времени и сглаживать эти колебания.

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Цель: оценить энергетический баланс, режимы заряда-разряда и влияние на обмен мощностью с сетью фотоэлектрической системы мощностью 10,24 кВт совместно с накопителем энергии емкостью 20 кВт·ч.

Методы: использована упрощенная энергетическая модель, учитывающая фотоэлектрическую генерацию, потери инвертора, локальную нагрузку, КПД заряда-разряда и степень заряженности батареи. Рассмотрены четыре характерных режима.

Результаты: при $G = 800 \text{ Вт/м}^2$ мощность на стороне переменного тока составила 9,93 кВт, а при нагрузке 8 кВт образовался избыток 1,93 кВт. За 3 часа, с учетом КПД заряда 92 %, в батарее накапливается около 5,33 кВт·ч, а степень заряженности возрастает с 50 до 76,7 %. При $G = 300 \text{ Вт/м}^2$ дефицит мощности составил 4,28 кВт и может быть компенсирован накопителем в течение двух часов. При вечерней нагрузке 10 кВт ограничение разрядной мощности 8 кВт снижает потребление из сети до 2 кВт.

Ключевые слова: возобновляемая энергия, распределенная генерация, фотоэлектрическая система, аккумуляторная система накопления энергии, энергетический баланс, степень заряженности, собственное потребление, обмен мощностью с сетью.

Improving distributed generation efficiency using solar photovoltaic and battery energy storage systems

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Relevance: the growing penetration of distributed photovoltaic systems increases the need to coordinate variable solar generation with local demand. Short-term irradiance variations cause rapid changes in grid import and export, while battery energy storage can shift surplus photovoltaic energy in time and smooth the power exchange with the utility grid.

Aim: to evaluate the energy balance, charging/discharging modes and grid power exchange of a 10.24 kW photovoltaic system combined with a 20 kWh battery energy storage system under different irradiance and load conditions.

Methods: a simplified energy model was applied considering photovoltaic generation, inverter losses, local load, battery charge/discharge efficiencies and state of charge. Four representative operating modes were calculated.

Results: at $G = 800 \text{ W/m}^2$ the AC-side photovoltaic power reached 9.93 kW, resulting in a 1.93 kW surplus at an 8 kW load. Over three hours, with 92% charging efficiency, approximately 5.33 kWh is stored and the battery state of charge rises from 50% to 76.7%. At $G = 300 \text{ W/m}^2$ a 4.28 kW deficit occurs and can be supplied by the battery for two hours. Under a 10 kW evening load, the 8 kW discharge-power limit reduces grid import to 2 kW while the battery is active.

Keywords: renewable energy, distributed generation, photovoltaic system, battery energy storage system, energy balance, state of charge, self-consumption, grid power exchange.

1. Kirish (Introduction)

Elektr energetika tizimlarida taqsimlangan generatsiyaning, ayniqsa iste'molchiga yaqin joylashtiriladigan quyosh fotoelektr tizimlarining ulushi oshib bormoqda. Bunday tizimlar markazlashgan tarmoqdan olinadigan energiyani kamaytirish, mahalliy qayta tiklanuvchi resurslardan foydalanish va taqsimlash tarmog'idagi ayrim quvvat oqimlarini qisqartirish imkonini beradi [6,11–13]. Shu bilan birga, fotoelektr ishlab chiqarish quyosh nurlanishi, panel harorati va tashqi muhit sharoitlariga kuchli bog'liq bo'lib, generatsiya profili iste'mol grafigi bilan doim ham mos kelmaydi [1,2].

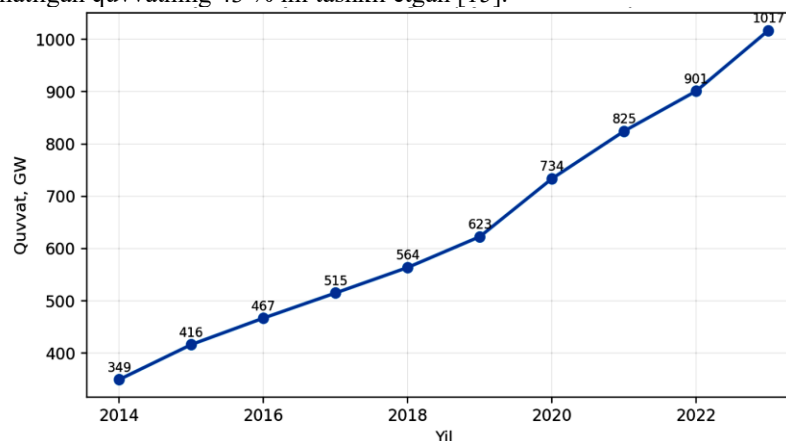
O'zbekistonda tarmoqqa ulangan fotoelektr tizimlarning rejim ko'rsatkichlariga ta'siri bo'yicha bir qator tadqiqotlar bajarilgan. 9 kW sinfidagi fotoelektr tizimning 0,4 kV lokal tarmoqqa ta'siri, kuchlanish va chastota o'zgarishlari hamda markaziy tarmoqqa integratsiyalashgan fotoelektr stansiya parametrlarining xususiyatlari [1–3,11,13] da yoritilgan. Ushbu ishlar fotoelektr generatsiyaning tarmoq bilan o'zaro ishlashini baholash uchun muhim asos yaratadi.

Fotoelektr generatsiyaning o'zgaruvchanligini kamaytirishning samarali vositalaridan biri batareyali energiya saqlash tizimidir. Energiya saqlash qurilmasi fotoelektr tizim ishlab chiqarishi

mahalliy iste'moldan yuqori bo'lgan davrda zaryadlanadi, ishlab chiqarish kamayganda esa saqlangan energiyani yuklamaga qaytaradi. Natijada tarmoqqa uzatiladigan ortiqcha quvvat va tarmoqdan olinadigan eng yuqori quvvat kamayishi mumkin [4,5,8,9]. Mahalliy tadqiqotlarda ham iste'molchi talabini energiya saqlash tizimlari orqali qoplash va batareya boshqaruv rejimlarini tarmoq talablariga moslashtirish masalalari ko'rib chiqilgan [4,5].

Xalqaro adabiyotlarda taqsimlangan energiya tizimlari texnologik tuzilishi, boshqaruv strategiyalari va energiya saqlash bilan integratsiyasi bo'yicha keng tahlil qilingan [6–9]. Fotoelektr tizim bilan birgalikda energiya saqlash qurilmasining zaryadlanish vaqtini rejalashtirish tarmoqqa ortiqcha quvvat uzatishni kamaytirishi mumkin [5,8,9], energiya saqlash esa taqsimlangan generatsiyaning moslashuvchanligini oshiradi [9]. Zamonaviy inverterlar aktiv va reaktiv quvvatni boshqarish orqali tarmoqni qo'llab-quvvatlash imkonini ham beradi [1], tezkor energiya saqlash qurilmalari esa chastota javobini yaxshilashda qo'llanishi mumkin [10].

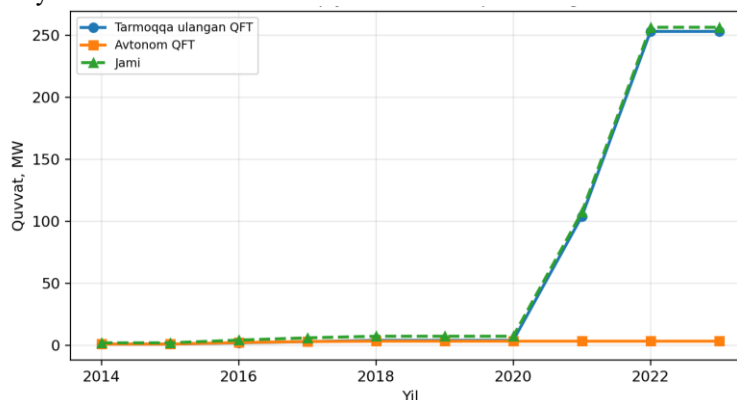
Mazkur maqolaning maqsadi 10,24 kW quvvatli quyosh fotoelektr tizimi va 20 kWh sig'imli energiya saqlash tizimidan iborat taqsimlangan generatsiya obyektining turli quyosh nurlanishi va yuklama holatlaridagi quvvat-energiya balansini baholash, batareyaning zaryad-razryad rejimlarini aniqlash hamda energiya saqlash tizimining tarmoq bilan quvvat almashinuviga ta'sirini ko'rsatishdan iborat. Yo'nalishning dolzarbligi rasmiy xalqaro statistikalarda ham yaqqol ko'rinadi. IRENA ma'lumotlariga ko'ra, jahon bo'yicha o'rnatilgan quyosh fotoelektr quvvati 2014-yildagi 349,4 GW dan 2023-yilda 1017,2 GW gacha oshgan. 2023-yilning o'zida qayta tiklanuvchi quvvatlar 473 GW ga ko'payib, shundan 346 GW quyosh energetikasi hissasiga to'g'ri kelgan, qayta tiklanuvchi manbalar esa global o'rnatilgan quvvatning 43 % ini tashkil etgan [15].



1-rasm. Jahon bo'yicha o'rnatilgan quyosh fotoelektr quvvatining o'sishi (2014–2023 yy.)

Fig.1. Growth of installed global solar photovoltaic capacity (2014–2023)

O'zbekistonda ham quyosh fotoelektr energetikasi bosqichma-bosqich rivojlanmoqda. IRENA ma'lumotlariga ko'ra, mamlakatda tarmoqqa ulangan quyosh fotoelektr quvvati 2014-yildagi 1 MW dan 2023-yilda 253 MW gacha oshgan, avtonom quyosh fotoelektr quvvati esa shu davrda 1 MW dan 3,325 MW gacha yetgan [15]. Bu esa QFT va EST integratsiyasining mahalliy tarmoqlar uchun dolzarbligini kuchaytiradi.



2-rasm. O'zbekistonda quyosh fotoelektr quvvatining o'sishi (2014–2023)

Fig 2. Growth of solar photovoltaic capacity in Uzbekistan (2014–2023)



Batareyali energiya saqlash texnologiyalarining amaliy ahamiyati ham jadal oshmoqda. Xalqaro energetika agentligi (IEA) ma'lumotiga ko'ra, 2023-yilda elektr energetikasi sektorida batareya saqlash quvvatlarining yillik joriy etilishi ikki martadan ko'proq oshib, 42 GW ga yetgan, 2023-yil yakunida esa quvvat sektorida foydalanilayotgan jami batareya saqlash quvvati 85 GW dan ortgan [16]. Shu bilan birga, litiy-ion batareyalar narxi 2010-yildagi 1400 AQSH doll./kWh darajadan 2023-yilda 140 AQSH doll./kWh dan past qiymatgacha tushgani ESTni taqsimlangan generatsiya loyihalari uchun iqtisodiy jihatdan yanada jozibador qilmoqda [16].

2. Metodlar va materiallar (Methods and materials)

Tadqiqot obyekti tarmoqqa ulangan kichik quvvatli quyosh fotoelektr tizimi, o'zgaras tokni o'zgaruvchan tokka aylantiruvchi inverter, 20 kWh sig'imli energiya saqlash tizimi, mahalliy yuklama va tashqi elektr tarmog'idan tashkil topgan. Hisoblash elektromagnit o'tkinchi jarayonlarni emas, balki aktiv quvvat va energiyaning vaqt bo'yicha balansini baholashga qaratilgan.

Fotoelektr panelning soddalashtirilgan ishlab chiqarish quvvati quyosh nurlanishi intensivligi, faol yuzasi va samaradorlik koeffitsienti orqali aniqlanadi:

$$P_{PV} = \eta_{PV} \cdot A \cdot G; \quad (1)$$

bu yerda P_{PV} — bitta panelning elektr quvvati, W; η_{PV} — fotoelektr panel samaradorligi; A — panelning faol yuzasi, m²; G — quyosh nurlanishi intensivligi, W/m²:

$$P_{PV, total} = N \cdot P_{PV}; \quad (2)$$

bu yerda N — fotoelektr panellar soni. Inverter yo'qotishlarini hisobga olganda o'zgaruvchan tok tomonidagi quvvat:

$$P_{AC} = P_{PV, total} \cdot \eta_{inv}. \quad (3)$$

Hisoblashlarda inverter samaradorligi $\eta_{inv} = 0,97$ deb qabul qilindi. Mahalliy yuklama va fotoelektr ishlab chiqarish orasidagi quvvat farqi energiya boshqaruv tizimining asosiy kirish kattaligidir:

$$\Delta P = P_{AC} - P_{load}. \quad (4)$$

Agar $\Delta P > 0$ bo'lsa, ortiqcha quvvat energiya saqlash tizimini zaryadlash yoki tarmoqqa uzatish uchun mavjud; $\Delta P < 0$ bo'lsa, quvvat yetishmovchiligi energiya saqlash tizimi yoki tashqi tarmoqdan qoplanadi:

$$E_{BESS}(t+\Delta t) = E_{BESS}(t) + \eta_{ch} \cdot P_{ch} \cdot \Delta t - (P_{dis}/\eta_{dis}) \cdot \Delta t; \quad (5)$$

bu yerda E_{BESS} — batareyada saqlangan energiya, kWh; P_{ch} va P_{dis} — mos ravishda zaryad va razryad quvvati, kW; $\eta_{ch} = 0,92$ va $\eta_{dis} = 0,90$ — zaryad va razryad samaradorligi; Δt — vaqt qadami:

$$SOC = E_{BESS} / E_{nom} \cdot 100\%. \quad (6)$$

Batareya resursini saqlash maqsadida zaryadlanganlik darajasining quyi chegarasi $SOC_{min} = 20\%$ va yuqori chegarasi $SOC_{max} = 90\%$ deb qabul qilindi. Shuning uchun 20 kWh nominal sig'imli batareyaning boshqaruv uchun foydalaniladigan energiya diapazoni 14 kWh ni tashkil etadi.

$$P_{grid} = P_{load} + P_{ch} - P_{AC} - P_{dis} \quad (7)$$

Bu ifodada $P_{grid} > 0$ bo'lsa tashqi tarmoqdan quvvat olinadi, $P_{grid} < 0$ bo'lsa tarmoqqa ortiqcha quvvat uzatiladi. Mazkur belgi qoidasi natijalarni tarmoq nuqtai nazaridan taqqoslash imkonini beradi.

1-jadval. Hisoblashda qabul qilingan asosiy parametrlar

Table 1. Key parameters adopted for the calculation

Parametr	Belgilanishi	Qiymati
Panel samaradorligi	η_{PV}	0,20
Panel faol yuzasi	A	1,6 m ²
Panellar soni	N	40
Inverter samaradorligi	η_{inv}	0,97
EST nominal sig'imi	E_{nom}	20 kWh
Boshlang'ich zaryadlanganlik darajasi	SOC_0	50 %
Zaryad samaradorligi	η_{ch}	0,92
Razryad samaradorligi	η_{dis}	0,90
Eng katta zaryad/razryad quvvati	P_{max}	8 kW
Zaryadlanganlik chegaralari	SOC_{min} / SOC_{max}	20 % / 90 %

Boshqaruv algoritmi uch holatga asoslandi: 1) $P_{AC} > P_{load}$ va $SOC < SOC_{max}$ bo'lsa, ortiqcha quvvat bilan energiya saqlash tizimi zaryadlanadi; 2) $P_{AC} < P_{load}$ va $SOC > SOC_{min}$ bo'lsa, yetishmayotgan quvvat razryad orqali qoplanadi; 3) batareya zaryadlanganlik yoki quvvat chegarasiga yetganda qolgan



nomutanosiblik tashqi tarmoq bilan almashinuv orqali muvozanatlanadi. Ushbu yondashuv o'z-o'zini iste'mol qilishni oshirish va tarmoqqa ortiqcha quvvat uzatishni kamaytirishga qaratilgan [5,9].

3. Natijalar va muhokama (Results and discussion)

Hisoblashlar to'rtta xarakterli ish rejimi uchun bajarildi. Rejimlar yuqori, o'rta va nol quyosh nurlanishi hamda turli yuklama darajalarini qamrab oladi. Natijalar 2-jadvalda keltirilgan.

2-jadval. QFT va EST majmuasining xarakterli ish rejimlari

Table 2. Characteristic operating modes of the PV and BESS complex

Rejim	G, W/m ²	P _{PV} , kW	P _{AC} , kW	P _{load} , kW	ΔP, kW	Boshqaruv holati
A	800	10,24	9,93	8,0	+1,93	ESTni zaryadlash
B	1000	12,80	12,42	6,0	+6,42	ESTni zaryadlash / eksport
C	300	3,84	3,72	8,0	-4,28	ESTni razryadlash
D	0	0	0	10,0	-10,0	EST + tarmoqdan quvvat olish

A rejimda $G = 800 \text{ W/m}^2$ bo'lganda bitta panel quvvati 256 W ni, 40 ta panelning o'zgaras tok tomonidagi quvvati 10,24 kW ni tashkil etadi. Invertor samaradorligi hisobga olinganda o'zgaruvchan tok tomonidagi quvvat 9,93 kW bo'ladi. 8 kW yuklamada 1,93 kW ortiqcha quvvat hosil bo'ladi. Ushbu holat 3 soat davom etsa, ortiqcha energiya 5,79 kWh ni, zaryad samaradorligi hisobga olinganda batareya yig'iladigan energiya 5,33 kWh ni tashkil etadi. Boshlang'ich 50 % zaryadlanganlikda batareya energiyasi 10 kWh dan 15,33 kWh gacha oshadi, ya'ni zaryadlanganlik darajasi 76,7 % ga yetadi.

B rejimda $G = 1000 \text{ W/m}^2$ va yuklama 6 kW bo'lganda 6,42 kW ortiqcha quvvat hosil bo'ladi. Agar batareya 50 % zaryadlanganlikdan ish boshlasa, $\text{SOC}_{\max} = 90 \%$ gacha 8 kWh energiya sig'imi mavjud. 92 % zaryad samaradorligi sababli ushbu 8 kWh ni saqlash uchun fotoelektr tomondan taxminan 8,70 kWh energiya kelishi kerak. 6,42 kW ortiqcha quvvat doimiy saqlansa, batareya taxminan 1,35 soatda yuqori zaryad chegarasiga yetadi, undan keyingi ortiqcha energiya tarmoqqa uzatiladi. Bu natija EST sig'imi bilan zaryadlash vaqtini birgalikda tanlash zarurligini ko'rsatadi [5,8].

C rejimda $G = 300 \text{ W/m}^2$ bo'lganda o'zgaruvchan tok tomonidagi fotoelektr quvvat 3,72 kW ni tashkil etadi. 8 kW yuklamada 4,28 kW quvvat yetishmovchiligi yuzaga keladi. EST 2 soat davomida yuklamaga 8,56 kWh energiya beradi; 90 % razryad samaradorligini hisobga olganda batareyadan 9,51 kWh energiya sarflanadi. Agar ushbu rejim A rejimdan keyin yuz bersa, batareya energiyasi 15,33 kWh dan taxminan 5,82 kWh gacha kamayadi, bu $\text{SOC} \approx 29,1 \%$ ga teng. Demak, zaryadlanganlik darajasi belgilangan 20 % quyi chegaradan yuqori bo'lib qoladi.

D rejim kechki eng yuqori yuklama holatini ifodalaydi. Fotoelektr ishlab chiqarish nolga teng bo'lganda va yuklama 10 kW bo'lsa, ESTning 8 kW razryad quvvati chegarasi sababli tarmoqdan olinadigan quvvat 2 kW gacha kamayadi. Ushbu holat energiya saqlash tizimini faqat kWh sig'imi bo'yicha emas, balki kW quvvat ko'rsatkichi bo'yicha ham tanlash zarurligini ko'rsatadi.

3-jadval. EST mavjud va mavjud bo'lmagan holatda tarmoq bilan quvvat almashinuvi

Table 3. Power exchange with the grid with and without BESS

Rejim	ESTsiz tarmoq almashinuvi	EST bilan tarmoq almashinuvi	Asosiy samara
A	1,93 kW eksport	0 kW*	ortiqcha energiyani saqlash
B	6,42 kW eksport	0 kW* → eksport	eksport cho'qqisini kechiktirish
C	4,28 kW import	0 kW*	yetishmovchilikni batareya bilan qoplash
D	10 kW import	2 kW*	tarmoqdan olinadigan cho'qqi quvvatni kamaytirish

* EST energiya va quvvat chegaralari ruxsat bergan davr uchun.

3-jadvaldan ko'rinadiki, energiya saqlash tizimi fotoelektr ishlab chiqarishni ko'paytirmaydi, biroq generatsiya va iste'mol orasidagi vaqt nomutanosibligini kamaytiradi. A va B rejimlarda ortiqcha quvvat tarmoqqa bevosita uzatilish o'rniga batareyaga yo'naltiriladi; C rejimda esa tarmoqdan olinishi kerak bo'lgan 4,28 kW quvvat EST hisobidan qoplanadi. D rejimda quvvat cheklovi tarmoq importini

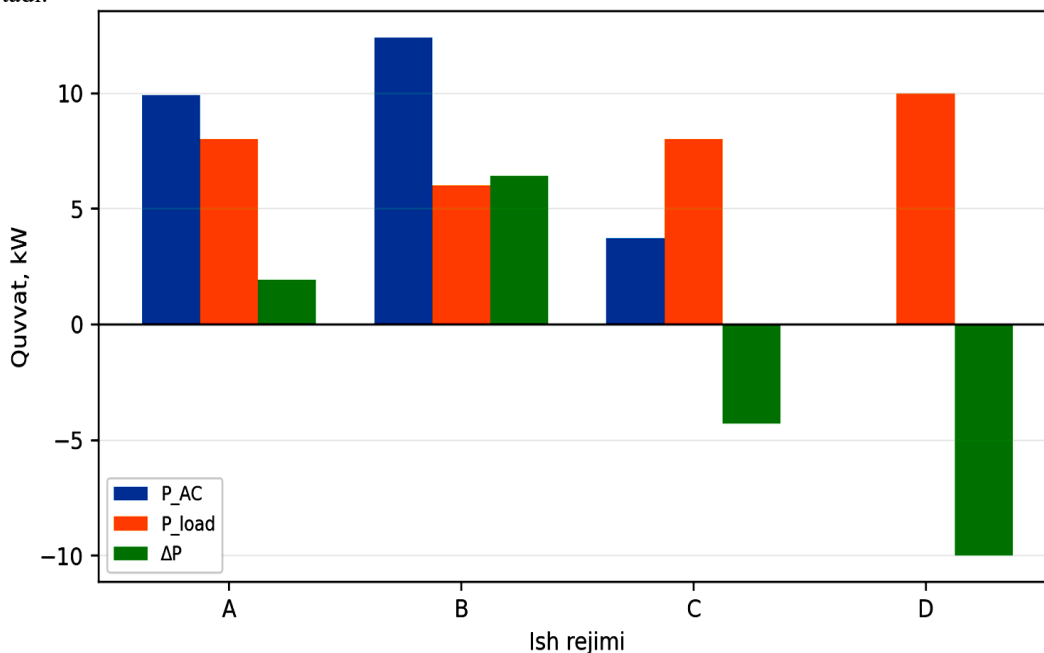
10 kW dan 2 kW gacha kamaytiradi. Shunday qilib, ESTning asosiy samarasi quvvat profilini tekislash va tarmoq bilan almashinuvning keskinligini kamaytirishdan iborat.

Energiya saqlash tizimi sig'imini ortiqcha kattalashtirish kapital xarajatlarni oshiradi, juda kichik sig'im esa kunduzgi ortiqcha fotoelektr energiyasini to'liq qabul qila olmaydi. Mazkur misolda 20 kWh ESTning 10,24 kW QFTga nisbati 1,95 kWh/kW ni tashkil etadi. Biroq bu universal optimal qiymat emas. Amaliy loyihada sig'im va quvvatni kamida bir yillik quyosh nurlanishi va yuklama grafiklari, tarmoq cheklovlari, tariflar va batareya eskirishi bilan birgalikda optimallashtirish zarur [8, 14].

O'z-o'zini iste'mol qilish boshqaruvida QFT avvalo mahalliy yuklamani ta'minlaydi, ortiqcha energiya ESTga yo'naltiriladi va batareya yuqori zaryad chegarasiga yetgandan keyingina tarmoqqa uzatiladi. Tarmoqqa ortiqcha quvvat uzatishni kamaytirish maqsadida zaryadlash vaqti oldindan rejalashtirilishi mumkin [5,9]. Eng yuqori yuklama quvvatini pasaytirish rejimida esa EST tarmoqdan olinadigan maksimal quvvatni cheklash uchun razryadlanadi.

Tadqiqotning soddalashtirilgan modeli panel haroratining vaqt bo'yicha o'zgarishi, batareya eskirishi, reaktiv quvvat, garmonikalar va tarmoq kuchlanishining dinamik o'zgarishlarini to'liq hisobga olmaydi. Mahalliy tajribalar atrof-muhit harorati fotoelektr tizim chiqish parametrlariga sezilarli ta'sir qilishini ko'rsatadi [2]. Shuning uchun keyingi bosqichda real meteorologik qatorlar asosida vaqt qadamli modellash va QFT-EST majmuasining RMS yoki EMT dinamik modeli ishlab chiqilishi maqsadga muvofiq. Zamonaviy inverterlarning aktiv va reaktiv quvvatni boshqarish imkoniyatlari [1] hamda energiya saqlash tizimining chastota javobiga ta'siri [10] bunday kengaytirilgan modelga kiritilishi mumkin.

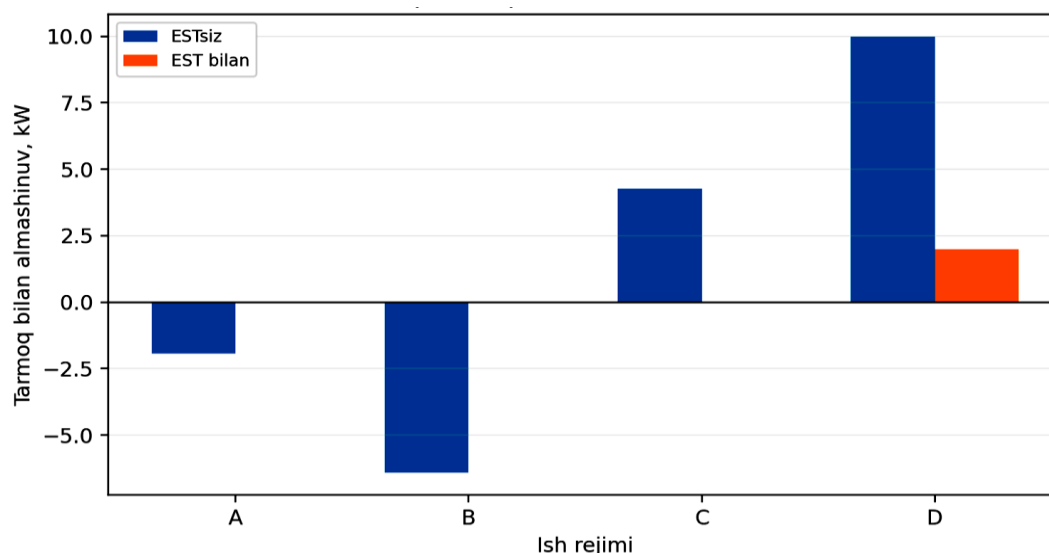
2- va 3-jadvallarda olingan hisob natijalarini grafik ko'rinishda tahlil qilish ESTning quvvat profilini tekislashdagi samaradorligini yaqqol ko'rsatadi. 3-rasmda A va B rejimlarda fotoelektr generatsiya yuklamadan yuqori, C va D rejimlarda esa yuklamadan past ekanligi ko'rsatilgan. Ayniqsa, D rejimda quyosh generatsiyasi nol bo'lib, yuklamani qoplashda EST va tashqi tarmoqning roli keskin ortadi.



3-rasm. Rejimlar bo'yicha fotoelektr quvvati, yuklama va quvvat balansi

Fig 3. Photovoltaic power, load, and power balance by mode

4-rasmdan ko'rinadiki, EST qo'llanganda A va B rejimlarda tarmoqqa eksport qilinadigan quvvat nolga yaqinlashadi, C rejimda esa 4,28 kW import to'liq qoplanadi. D rejimda ham tarmoqdan olinadigan cho'qqi quvvat 10 kW dan 2 kW gacha kamayadi. Demak, ESTning asosiy amaliy samarasini tarmoq bilan quvvat almashinuvini tekislash va import/eksportning keskin o'zgarishlarini yumshatish deb baholash mumkin.



4-rasm. EST mavjud va mavjud bo'lmagan holatda tarmoq bilan quvvat almashinuvi
Fig 4. Power exchange with the grid with and without BESS

4. Xulosa (Conclusion)

Mazkur tadqiqotda 10,24 kW quvvatli quyosh fotoelektr tizimi va 20 kWh sig'imli batareyali energiya saqlash tizimidan tashkil topgan taqsimlangan generatsiya obyektining energiya balansi baholandi. QFT, inverter, mahalliy yuklama va ESTning zaryad-razryad samaradorligi hisobga olingan soddalashtirilgan model asosida to'rtta xarakterli rejim tahlil qilindi.

$G = 800 \text{ W/m}^2$ sharoitida o'zgaruvchan tok tomonidagi quvvat 9,93 kW bo'lib, 8 kW yuklamada 1,93 kW ortiqcha quvvat hosil bo'ldi. Ushbu holat 3 soat davom etganda batareyada 5,33 kWh energiya yig'ilishi va SOCning 50 % dan 76,7 % gacha oshishi aniqlandi. $G = 300 \text{ W/m}^2$ sharoitida 4,28 kW quvvat yetishmovchiligi yuzaga kelib, EST ushbu yetishmovchilikni 2 soat davomida qoplay olishi ko'rsatildi. Kechki 10 kW yuklama holatida 8 kW razryad quvvati cheklovi sababli tarmoqdan olinadigan quvvat 2 kW gacha kamaytirildi.

Natijalar energiya saqlash tizimi fotoelektr ishlab chiqarish miqdorini oshirmasligini, ammo ortiqcha energiyani vaqt bo'yicha ko'chirish, o'z-o'zini iste'mol qilishni oshirish, tarmoqqa uzatiladigan va tarmoqdan olinadigan cho'qqi quvvatlarni kamaytirish hamda quvvat almashinuvini yumshatish imkonini berishini ko'rsatdi. ESTni amaliy tanlashda energiya sig'imi bilan bir qatorda zaryad-razryad quvvati, zaryadlanganlik chegaralari, foydali ish koeffitsienti, eskirish va real sutkalik-yillik grafiklar hisobga olinishi kerak.

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