Qayta tiklanuvchi energiya manbalarida ishlovchi elektr stansiyalar quvvatlarini kamayishida elektr energetikasi tizimining normal holatini qidirib topish algoritmi

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Dolzarbligi: bugungi kunda qayta tiklanuvchi energiya manbalari elektr energetika tizimlarining ajralmas qismiga aylangan. Shu bilan birga, ushbu manbalar ish rejimlarining o‘zgaruvchanligi energetik tizimlarning barqarorligi va ishonchliligiga jiddiy ta’sir etadi. Ish jarayonida ishlab chiqarishni keskin pasayishi - tez-tez uchraydigan va elektr energiyasini boshqarish bilan bog‘liq jiddiy muammolarga olib keladigan hodisadir.
Ishlab chiqarishning keskin pasayishi turli sabablarga ko‘ra yuzaga kelishi mumkin, masalan, iqlim omillarining o‘zgarishi, texnik nosozlik, tabiiy ofatlar va boshqalar. Ushbu holatlar nafaqat iqtisodiy yo‘qotishlarga olib keladi, balki ijtimoiy va ekologik muammolarni ham keltirib chiqaradi. Shu sababli, elektr energiyasi tizimlarini tezkor boshqarish vazifalari uchun normal ish rejimini topishning samarali algoritmlarini ishlab chiqish va qo‘llash juda muhimdir.
Quvvatning to‘satdan kamayishi texnik nosozliklar, tabiiy ofatlar, yoqilg‘i ta’minotidagi uzilishlar kabi turli sabablar tufayli yuzaga kelishi mumkin. Bu holatlar nafaqat iqtisodiy zarar keltiradi, balki ijtimoiy va ekologik muammolarni ham keltirib chiqarishi mumkin. Shu sababli, elektr energetika tizimi normal holatini tezda qidirib topish uchun samarali algoritmlarni ishlab chiqish muhim ahamiyatga ega.
Maqsad: ushbu maqolaning maqsadi qayta tiklanadigan energiya manbalariga asoslangan stansiyalar ishlab chiqarishning keskin pasayishi bilan elektr tizimining normal holatini tiklash uchun samarali algoritmni ishlab chiqishdir.
Usullari: ishlab chiqarishning keskin pasayishi bilan elektr energiyasi tizimining normal rejimini topish algoritmi va dasturi, unda quyidagilar qo‘llaniladi: barqaror rejimlarni hisoblash usullari (xususan, Nyuton-Rafson usuli); qiyosiy tahlil usullari, elektr tizimlarini modellashtirish usullari va vositalari (DIgSILENT PowerFactory 2022); ma’lumotlarni qayta ishlash usullari va vositalari (Python 3.8).
Natijalar: taqdim etilgan algoritmning asosiy natijasi - ishlab chiqarishning keskin pasayishi bilan normal holatni operativ tarzda qidirib topishidir. Algoritm 14 tugunli IEEE test sxemasida sinovdan o‘tkazildi.
Kalit so‘zlari: elektr energetikasi tizimi, qayta tiklanadigan energiya manbalari, barqarorlashgan holat, algoritm, elektr tizimlarini modellashtirish.

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Алгоритм поиска нормального режима энергосистемы при снижении мощности электростанций, работающих на возобновляемых источниках энергии

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Актуальность: в настоящее время возобновляемые источники энергии являются неотъемлемой частью электроэнергетических систем. Однако изменчивость режима работы этих источников представляют собой серьезную угрозу для стабильности и надежности энергосистем. Внезапное снижение генерации в процессе работы - явление, которое часто встречается и приводит к серьезным проблемам, связанным с управлением электроэнергетической системы.
Внезапное снижение генерации может быть вызвано различными причинами, например, такими как изменение климатических факторов, техническая неисправность, стихийные бедствия и другие. Эти ситуации не только приводят к экономическим убыткам, но также могут вызвать социальные и экологические проблемы. Поэтому разработка эффективных алгоритмов быстрого поиска нормального

режима для задач оперативного управления электроэнергетических систем является весьма актуальным.
Цель: целью данной статьи является разработка эффективного алгоритма для восстановления нормального режима электроэнергетической системы при внезапном снижении генерации станций на основе возобновляемых источников энергии.
Методы: алгоритм и программа поиска нормального режима электроэнергетической системы при внезапном снижении генерации, где использованы: методы расчёта установившихся режимов (в частности, метод Ньютона-Рафсона); методы сравнительного анализа, методы и средства моделирования электрических систем (DIgSILENT PowerFactory 2022); методы и средства обработки данных (Python 3.8).
Результаты: основным результатом работы представленного алгоритма является оперативность нахождения нормального состояния при внезапном снижении генерации. Апробация алгоритма проводилась на тестовой 14 узловой схеме IEEE.
Ключевые слова: электроэнергетическая система, возобновляемые источники энергии, установившийся режим, алгоритм, моделирование электрических систем.

Algorithm for searching the normal mode of the power system during power reduction at power plants operating on renewable energy sources

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Relevance: nowadays, renewable energy sources are an integral part of electric power systems. However, the variability of the operation mode of these sources poses a serious threat to the stability and reliability of power systems. Sudden decrease in generation during operation is a phenomenon that is common and leads to serious problems related to power system management.
Sudden reduction in generation can be caused by various reasons such as changing climatic factors, technical failure, natural disasters and others. These situations not only cause economic losses but also cause social and environmental problems. Therefore, the development of efficient algorithms for finding the normal operation regime for the tasks of operational control of electric power systems is highly relevant.
Aim: the aim of this paper is to develop an efficient algorithm to restore the normal mode of the electric power system in case of a sudden decrease in the generation of renewable energy plants.
Methods: algorithm and program for searching the normal mode of an electric power system in case of sudden generation reduction, where the following methods are used: methods of steady-state calculation (in particular, Newton-Raphson method); methods of comparative analysis, methods and means of modeling of electric systems (DIgSILENT PowerFactory 2022); methods and means of data processing (Python 3.8).
Results: the main result of the presented algorithm is the efficiency of finding the normal state in case of sudden generation decrease. Approbation of the algorithm was carried out on the test 14 node IEEE circuit.
Keywords: electric power system, renewable energy sources, steady state, algorithm, modeling of electric systems.

1. Kirish (Introduction)

Bugungi kunda qayta tiklanuvchi energiya manbalari (QTEM) elektr energetika tizimlarining ajralmas qismiga aylangan. Masalan, 2000 yilda QTEMlar umumiy elektr energiyasi ishlab chiqarilishining 19 %, 2022 yilda - 29,4 %, 2023 yilda - 30,3 % tashkil etdi [1]. Bu holat QTEM (hususan, quyosh va shamol energiyasi manba) larini butun dunyo bo‘ylab elektr energetikasi tizimlariga toboro ko‘proq qo‘llanilishini ko‘rsatadi. Bunga asosiy sabablardan bu elektr energiyasini ishlab chiqarish jarayonida QTEMlarini an’anaviy energiya manbalariga nisbatan atrof-muhitga zarar keltirmasligi, resurslarning cheksizligi va borgan sari energiya ishlab chiqarish xarajatlarining toboro pasayib borishini keltirish mumkin. Shu bilan birga, ushbu manbalar ish regimlarining o‘zgaruvchanligi va noaniqligi, ularning elektr energiyasini ishlab chiqarish ko‘rsatgichlarini prognoz qilish qiyinligi elektr energetik tizim (EET) yoki elektr ta’minoti tizim (ETT) larining barqarorligi va ishonchliligiga jiddiy ta’sir ko‘rsatadi va ularni boshqarish jarayonini murakkablashtiradi [2].

EET (yoki ETT) larda mavjud QTEMda ishlovchi stansiyalarda ishlab chiqarishni keskin pasayishi - tez-tez uchraydigan va elektr energiyasini boshqarish bilan bog‘liq jiddiy muammolarga olib keladigan hodisadir.

EET (yoki ETT) larda quvvatning keskin pasayishi turli sabablarga ko‘ra yuzaga kelishi mumkin. Bularga misol qilib quyidagilarni keltirish mumkin:

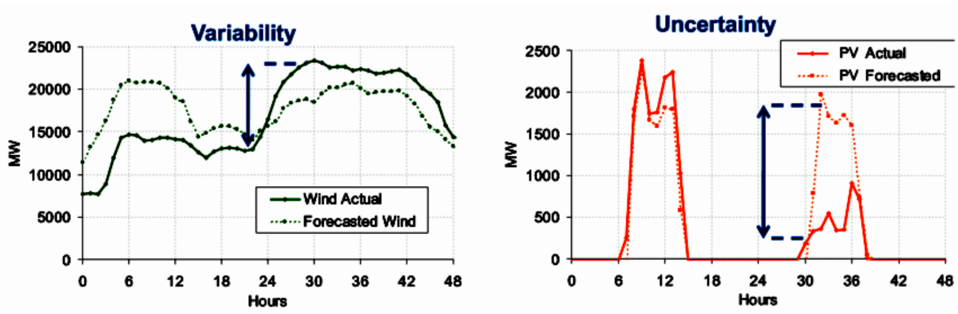
1) Tashqi iqlimiy omillar ta’sirida quyosh (Rasm 1a) va shamol (Rasm 1b) energiyasining o‘zgaruvchanligi va noaniqligi: Masalan, osmonni bulut qoplashi quyosh elektr stansiyalari (QES) tomonidan, yoki shamol tezligining kamayishi shamol elektr stansiyalari (ShES) tomonidan ishlab chiqariladigan quvvatni keskin kamayishiga sabab bo‘ladi [3]. Huddi shu sabablarga ko‘ra QES va ShES tomonidan ishlab chiqariladigan quvvat uning prognoz qilingan qiymatidan keskin farq qilishi mumkin;

2) Texnik nosozliklar: Elektr stansiya (ES) yoki elektr uzatish liniya (EUL)larida bo‘ladigan texnik nosozliklar, avariya holatlari va uskunalarning ishlamay qolishi natijasida ishlab chiqariladigan quvvatni keskin kamayishi kuzatiladi [4];

3) Tabiiy ofatlar: Zilzila, suv toshqinlari, kuchli shamollar yoki boshqa tabiiy ofatlar qayta tiklanuvchi va an’anaviy energiya manbalariga asoslangan ES va EULlariga zarar yetkazishi va bu orqali ishlab chiqariladigan quvvatni keskin kamayishiga sabab bo‘ladi [5];

4) Yoqilg‘i ta’minotidagi muammolar: An’anaviy energiya manbalariga asoslangan ES uchun zarur bo‘lgan yoqilg‘i (ko‘mir, gaz, mazut) ta’minotidagi muammolar ishlab chiqariladigan quvvatni keskin kamayishiga sabab bo‘ladi.

Ushbu sabablarning barchasi EET (yoki ETT) barqarorligiga va ishonchliligiga salbiy ta’sir ko‘rsatuvchi omillar bo‘lib xisoblanadi [6].



1-rasm. Quyosh (a) va shamol (b) ES lari quvvatining o‘zgaruvchanligi va noaniqligi
Fig.1. Variability and uncertainty of solar (a) and wind (b) power plants

Ishlab chiqariladigan quvvatni to‘satdan kamayishi nafaqat iqtisodiy zararga sabab bo‘ladi, balki ijtimoiy va ekologik muammolarni ham keltirib chiqarishi mumkin.

Turli sabablar tufayli EET (yoki ETT) normal holati buzilganda uni operativ tarzda normal holatga qaytarish bir nechta alohida usullar (yoki ulardan birgalikda foidalanish) orqali amalga oshirilishi mumkin:

1. Zaxira quvvat manbalaridan foydalanish orqali: Zaxira quvvat manbalari (masalan, zaxira generatorlar yoki akkumulyatorlar) tayyor holatda bo‘ladi va ularni tarmoqqa tezda ulash quvvat pasayishini qoplash imkonini beradi [7].
2. Avtomatik boshqaruv tizimlari yordamida: Avtomatik boshqaruv tizim (ABT)lari real vaqt rejimida tarmoqdagi quvvat talabi va taklifni muvozanatlash imkonini beradi.
3. Sun’iy intellekt texnologiyalaridan foydalanish yordamida: EETdagi quvvat o‘zgarishlarini qisqa muddatli prognozlash uchun sun’iy intellekt texnologiyalaridan foydalanish uni samarali boshqarish imkonini beradi [8,9].
4. EETni monitoring va diagnostika qilish orqali: Doimiy monitoring va diagnostika tizimlari elektr tarmoqlardagi har qanday nosozlikni o‘z vaqtida aniqlash va uni bartaraf etish imkonini beradi [10-11].
5. Elektr quvvatga bo‘lgan talabni boshqarish orqali: Masalan, quvvatga talab yuqori bo‘lgan vaqtlarda iste'molchilarni energiya tejashga undash uchun turli imtiyozlarni taklif etish quvvatni muvozanatlash imkonini beradi [12,13].

2. Usul (Materials and Methods)

EETning normal holatini hisoblash masalasi dispetcherlik boshqaruvida, loyihalashda ko‘p uchraydigan vazifalardan hisoblanadi. U qisqa va uzoq muddatli rejalashtirishda, EET asosiy uskunalarini ta'mirlashga chiqarishda, avariyaga qarshi avtomatikaning parametrlarini tanlashda va boshqa bir qator muhim masalalarni hal qilishda asos bo‘lib hisoblanadi [14-16]. Shu sababli EET normal holatini operativ tarzda aniqlashda, yuqorida keltirilgan usullardan tashqari, samarali usul va algoritmlarini ishlab chiqish ham muhim masalalardan hisoblanadi. Ushbu masalani echishda QTEMda ishlovchi ES quyidagicha modellashtiriladi:

1) Quyosh elektr stansiyasi (QES) quyosh panellari va invertorlar tomonidan ishlab chiqariladigan quvvatlarni hisobga oladi. Bunda quyosh panellari tomonidan ishlab chiqarilgan aktiv

quvvat quyidagicha ifodalanadi:

$$P_{ish.ch.} = P_{o'rn.} \times \eta \times \frac{I_{ins.}}{I_{st.}} ; \quad (1)$$

bu yerda $P_{o'rn.}$ – panellarning oʻrnatilgan quvvati, η – panellar samaradorligi, $I_{ins.}$ – joriy insolyatsiya, $I_{st.}$ – standard insolyatsiya (odatda 1000 Vt/m^2).

Invertorning reaktiv quvvati esa quyidagicha ifodalanadi:

$$Q_{ish.ch.} = P_{ish.ch.} * \tan(\phi) ; \quad (2)$$

bu yerda ϕ – fazalar oʻzgarish burchagi, quvvat koeffitsienti bilan aniqlanadi.

2) Shamol elektr stansiyasi (ShES) esa shamol generatorlari tomonidan ishlab chiqariladigan aktiv va reaktiv quvvatlarini hisobga oladi. Bunda aktiv quvvat quyidagicha hisoblanadi:

$$P_{shamol} = \frac{1}{2}\rho \times AC_p v^3 ; \quad (3)$$

bu yerda $\rho -$ havoning zichligi, $A -$ parrakning aylanishidan hosil boʻlgan maydon, C_p – quvvat koefitsienti (turbinaning samaradorligi), v – shamol tezligi.

Reaktiv quvvat esa quyidagicha hisoblanadi:

$$Q_{ish.ch.} = Q_{ish.ch.} * \tan(\phi) ; \quad (4)$$

bu yerda ϕ – fazalar oʻzgarish burchagi, quvvat koeffitsienti bilan aniqlanadi.

Ushbu ifodalardan koʻrinib turibdiki, EETning normal holatini hisoblashda, QTEMda ishlovchi ESlar xam ananaviy ESlar kabi aktiv va reaktiv quvvatlar (P_i^{gen}, Q_i^{gen}) orqali ifodalanishi mumkin [17-18].

Quyida QTEMda ishlovchi ES chiqishidagi quvvatning toʻsatdan kamayishi kuzatilganda EET normal holatini qidirib topish algoritmi keltirilgan. U oʻz ichiga quyidagi bosqichlarni oladi:

1. Dastavval QTEMda ishlovchi va boshqa turdagi ESlarga ega EET sxemasi kiritiladi va u normal holatda boʻladi.

Ushbu holatga mos boʻlgan QTEMda ishlovchi va ananaviy ESlar quvvatlari (P_i^{gen}, Q_i^{gen}), yuklamalar (P_i^{load}, Q_i^{load}), tugunlardagi kuchlanishlar (U_i), shahobchalardagi quvvat oqimlari (P_{ij}, Q_{ij}) ma’lum boʻladi. Undan tashqari har bir ES uchun maksimum ($P_i^{gen\,max}, Q_i^{gen\,max}$) va minimum ($P_i^{gen\,min}, Q_i^{gen\,min}$) quvvatlari, liniyalardagi maksimal tok oqimlari (I_{ij}^{max}) va transformatorlarning nominal quvvatlari (S_i^{nom}) ma’lum boʻladi.

2. QTEMda ishlovchi ESga yaqin turgan ESlarini ajratib olish uchun kerakli boʻlgan hududni aniqlash uchun shaxobcalar soni *N* kiritiladi. Undan tashqari, QTEMda ishlovchi ES ulangan tugun (*i*) va u ishlab chiqaradigan quvvatning pasayishi miqdorlari ($dP_{QTi}^{gen}, dQ_{QTi}^{gen}$) kiritiladi;

3. Shaxobchalar soni *(N)* va ularning uzunliklari (L_{ij}) yordamida QTEMda ishlovchi ESga yaqin hudud aniqlanadi va undagi ESlar va yuklamalar ajratib olinadi;

4. QTEMda ishlovchi ES ishlab chiqaradigan quvvati 10% qadam bilan belgilangan qiymatgacha kamaytirilib boriladi va itteratsion tarzda quyidagi amallar bajariladi:

5. EETda aktiv quvvat zaxirasi koeffitsienti quyidagi shart boʻyicha tekshiriladi:

$$k_{EES}^{P} = \frac{(\sum P_i^{gen\,max} - \sum P_i^{gen})}{dP_{QTi}^{gen}} = \frac{P_{sis}^{resve}}{dP_{QTi}^{gen}} \geq 1 \, . \quad (5)$$

6. Zaxira quvvati mavjud boʻlsa, yani (5) shart bajarilsa, QTEMda ishlovchi ES ishlab chiqaradigan quvvatning pasayishi, yaqinligidan kelib chiqib, ajratib olingan ESlar yordamida qoplanadi;

7. Zaxira quvvati mavjud boʻlmasa, yani (5) shart bajarilmasa, QTEMda ishlovchi ES ishlab chiqaradigan quvvatning pasayishi, quvvat balansini ta’minlash talabidan kelib chiqib, ajratib olingan yuklamalarni kamaytirish orqali qoplanadi.

8. ET ning holati Nyuton-Rafson usulida hisoblanadi.

9. EET ning holati normal ekanligi quyidagi shartlar asosida tekshiriladi:

a) quvvatlar balansining ta’minlanishi:

$$P_i^{gen} - P_i^{load} = \Sigma P_{ij}; \; Q_i^{gen} - Q_i^{load} = \Sigma Q_{ij} ; \quad (6)$$

b) ESlardagi quvvatlar roʻxsat etilgan chegarada boʻlishi:

$$P_i^{min} \leq P_i^{gen} \leq P_i^{max} ; \; Q_i^{min} \leq Q_i^{gen} \leq Q_i^{max} ; \quad (7)$$

c) tugun kuchlanishlari qiymatlari roʻxsat etilgan chegarada boʻlishi:

$$U_i^{min} \leq U_i^{nom} \leq U_i^{max} \; yoki \; 0.9U_i^{nom} \leq U_i^{nom} \leq 1.1U_i^{nom} ; \quad (8)$$

d) shaxobchalarning qizishsiz oʻtkazuvchanlik qobiliyatining ta’minlanishi:

$$\left|P_{ij} + jQ_{ij}\right| \leq S_{ij}^{max} ; \quad (9)$$

bu yerda S_{ij}^{max} – shaxobchaning maksimal roʻxsat etilgan quvvati va u quyidagicha hisoblanadi:

elektr uzatish liniyalari uchun: $$S_{ij}^{max} = U^{nom} \cdot I_{ij}^{max} ; \quad (10)$$

transformatorlar uchun: $$S_{ij}^{max} = S_i^{nom} ; \quad (11)$$

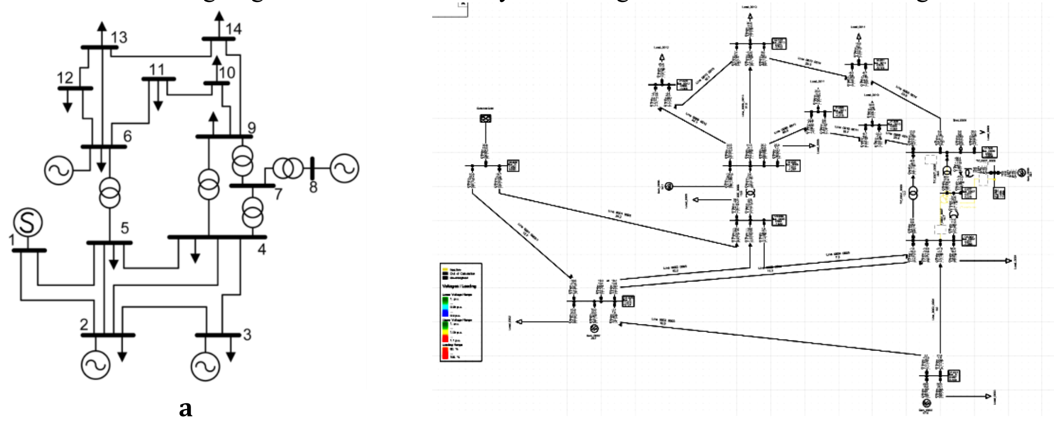
bu yerda U^{nom} - elektr uzatish liniyasining nominal kuchlanishi; I_{ij}^{max} – qizishsiz liniya boʻylab oqishi mumkin boʻlgan tok; S_i^{nom} – transformatorning nominal quvvati.

10. Ushbu shartlar bajarilganda EETning normal holati qidirib topiladi va algoritm ishlashdan to‘xtaydi.

Ushbu algoritm asosida, Python (ver.3.8) dasturlashtirish tilida dastur yozilib Digsilent PowerFactory 2022 tizimiga integratsiya qilingan.

3. Natijalar (Results)

Keltirilgan algoritmni 14 tugunli IEEE sinov sxemasiga (2a-rasm) nisbatan qo‘llaymiz. Ushbu EET sxemasida 5ta generatorli va 11ta yuklamali tugun mavjud. Undan tashqari sxemada 5ta transformator va 15ta EULdan iborat shaxobchalar mavjud. Sxemada **ES1** balanslovchi tugun bo‘lib hisoblanadi. EETning DIgSILENT PowerFactory dasturidagi modeli 2b-rasmda keltirilgan.



a b

2-rasm. 14 tugunli IEEE sinov sxemasi (a) va modeli (b)
Fig.2. 14-bus IEEE power system scheme (a) and model (b)

Tanlab olingan EETdagi generatorlar va yuklamar bo‘yicha ma’lumotlar 1 va 2 – jadvallarda, uning holatiga doir ma’lumotlar esa 2 va 3 – jadvallarda keltirilgan. Natijalardan ko’rinib turibdiki EET normal holatda, yani algoritmning 9 bosqichida keltirilgan shartlar barchasi bajariladi.

Jadval 1. Generatorlar bo‘yicha ma’lumotlar
Table 1. Information on generators

Tugun	P	Q	P_{min}	Pmax	Qmin	Qmax
	MW	MVar	MW	MW	MVar	MVar
ES-2	70	25	65	150	0	88
ES-3	80	15	50	90	0	55
ES-6	130	50	0	150	0	60
ES-8	75	22	45	75	0	50

Jadval 2. Yuklamalar bo‘yicha ma’lumotlar
Table 2. Information on loads

Tugun	P MW	Q MVar	Load -9	35	14,9
Load-2	45	20,5	Load -10	32	13,6
Load -3	55	25,1	Load -11	25	11,4
Load -4	50	16,4	Load -12	25	11,4
Load -5	39	14,2	Load -13	22	7,2
Load -6	25	7,3	Load -14	18	8,2

Jadval 3. Tugun kuchlanishlari bo‘yicha ma’lumot
Table 3. Information on bus voltages

№	Nomi	U_i, (n.b.)	$0.9 \leq U_{p.u} \leq 1$ chegaradan og‘ishi, (%)	Izoh (yuqori, quyi)
1	Bus1	1.050	0	-
2	Bus2	1.029	0	-
3	Bus3	1.008	0	-
4	Bus4	0.986	0	-
5	Bus5	0.992	0	-
6	Bus6	1.032	0	-

7	Bus7	0.984	0	-
8	Bus8	1.013	0	-
9	Bus9	0.961	0	-
10	Bus10	0.945	0	-
11	Bus11	0.963	0	-
12	Bus12	0.966	0	-
13	Bus13	0.974	0	-
14	Bus14	0.939	0	-

Jadval 4. Shaxobchalardagi quvvat oqimlari bo‘yicha ma’lumot
Table 4. Power flow data in branches

№	Turi	Boshi	Ohiri	P (MW)	Q (MVar)	S (MVA)	Smax (MVA)	Izoh
1	EUL	1	5	17.9	20.6	27.2	228	-
2	EUL	1	2	6.2	16.3	16.3	228	-
3	EUL	2	3	2.8	9.0	9.4	228	-
4	EUL	2	4	20.1	168	26.1	228	-
5	EUL	2	5	20.0	14.0	24.4	228	-
6	EUL	3	4	22.1	3.3	22.3	228	-
7	TR	4	9	7.1	10.5	12.6	100	-
8	EUL	4	5	14.4	11.9	18.7	228	-
9	TR	4	7	9.6	4.3	10.5	100	-
10	TR	5	6	3.1	13.6	13.9	100	-
11	EUL	6	11	35.1	19.7	40.2	228	-
12	EUL	6	12	22.5	12.8	25.8	228	-
13	EUL	6	13	44.4	23.5	50.2	228	-
14	TR	7	9	60.6	22.7	64.7	100	-
15	TR	7	8	75.0	11.5	75.8	100	-
16	EUL	9	14	8.9	3.5	9.6	228	-
17	EUL	9	10	23.7	9.2	25.4	228	-
18	EUL	10	11	8.6	5.3	10.0	228	-
19	EUL	12	13	3.4	0.5	3.4	228	-
20	EUL	13	14	9.4	5.4	10.8	228	-

EETda 6 tunga ulangan **ES-6** QTEMda ishlovchi ES. Uning ishlab chiqaradigan quvvati 60% ga kamaygan, yani P = 52 MW, Q = 20 MW. Generatorlar va yuklamar bo‘yicha qolgan ma’lumotlar o‘zgarmagan. **ES-6** da ishlab chiqariladigan quvvat 60% ga kamayganda EET holatiga doir ma’lumotlar 5 va 6 – jadvallarda keltirilgan.

Jadval 5. Tugun kuchlanishlari bo‘yicha ma’lumot
Table 5. Information on bus voltages

№	Nomi	U_i, (n.b.)	$0.9 \leq U_{p.u} \leq 1$ chegaradan og‘ishi, (%)	Izoh (yuqori, quyi)
1	Bus1	1.050	0	-
2	Bus2	0.990	0	-
3	Bus3	0.946	0	-
4	Bus4	0.901	0	-
5	Bus5	0.907	0	-
6	Bus6	0.853	4.7 %	quyi
7	Bus7	0.864	3.6 %	quyi
8	Bus8	0.895	0.5 %	quyi
9	Bus9	0.829	7.1 %	quyi
10	Bus10	0.801	9.9 %	quyi
11	Bus11	0.798	10.2 %	quyi
12	Bus12	0.775	12.5 %	quyi
13	Bus13	0.793	10.7 %	quyi
14	Bus14	0.780	12.0 %	quyi

Jadval 6. Shaxobchalardagi quvvat oqimlari bo‘yicha ma’lumot
Table 6. Power flow data in branches

№	Turi	Boshi	Ohiri	P (MW)	Q (MVar)	S (MVA)	S^{max} (MVA)	Izoh
1	EUL	1	5	79.2	54.0	73.1	228	-
2	EUL	1	2	32.8	40.7	52.2	228	-
3	EUL	2	3	6.9	18.3	19.5	228	-
4	EUL	2	4	41.3	35.2	54.3	228	-
5	EUL	2	5	42.4	32.4	53.3	228	-
6	EUL	3	4	31.6	11.4	33.6	228	-
7	TR	4	9	17.0	17.8	27.6	100	-
8	EUL	4	5	1.4	13.2	13.3	228	-
9	TR	4	7	1.9	25.0	25.2	100	-
10	TR	5	6	49.5	50.2	70.5	100	-
11	EUL	6	11	19.1	21.8	42.6	228	-
12	EUL	6	12	20.8	13.1	24.5	228	-
13	EUL	6	13	36.6	21.8	42.6	228	-
14	TR	7	9	76.9	21.8	79.9	100	-
15	TR	7	8	75.0	22.0	78.2	100	-
16	EUL	9	14	19.4	6.7	20.5	228	-
17	EUL	9	10	38.7	12.0	40.5	228	-
18	EUL	10	11	6.6	1.8	6.8	228	-
19	EUL	12	13	5.4	0.7	5.5	228	-
20	EUL	13	14	0.6	3.2	3.2	228	-

4. Muhokama (Discussion)

5 - jadvaldan ko’rinib turibdiki, **ES-6-**ning quvvati to‘stadan 60% ga kamayganda, Bus6 – Bus14 tugunlaridagi kuchlanishlar quyi chegaradan 12.5 % gacha og‘ib ketadi, yani algoritmdagi 9- sharti bajarilmaydi va EET normal holatdan chiqib ketadi.

EET normal holatini qidirib topish algoritmini ishga tushiramiz. Algoritm ishlashi natijasi 7 – 9 -jadvallarda keltirilgan. Bunda dasturni ishlash vaqti 3.3 sekundni tashkil etdi.

Jadval 7. Generatorlar bo‘yicha ma’lumotlar
Table 7. Information on generators

Tugun	P	Q	Pmin	Pmax	Qmin	Qmax
	MW	MVar	MW	MW	MVar	MVar
ES-2	148	87	65	150	0	88
ES-3	80	41	50	90	0	55
ES-6	52	20	0	150	0	60
ES-8	75	36	45	75	0	50

Jadval 8. Tugun kuchlanishlari bo‘yicha ma’lumot
Table 8. Information on bus voltages

№	Nomi	U_i, (n.b.)	$0.9 \leq U_{p.u} \leq 1$ chegaradan og‘ishi, (%)	Izoh (yuqori, quyi)
1	Bus1	1.050	0	-
2	Bus2	1.060	0	-
3	Bus3	1.050	0	-
4	Bus4	0.992	0	-
5	Bus5	0.988	0	-
6	Bus6	0.969	0	-
7	Bus7	0.993	0	-
8	Bus8	1.045	0	-
9	Bus9	0.958	0	-
10	Bus10	0.932	0	-
11	Bus11	0.925	0	-
12	Bus12	0.903	0	-
13	Bus13	0.918	0	-
14	Bus14	0.912	0	-

Jadval 9. Shaxobchalardagi quvvat oqimlari bo‘yicha ma’lumot
Table 9. Power flow data in branches

№	Turi	Boshi	Oxiri	P (MW)	Q (MVar)	S (MVA)	S^{max} (MVA)	Izoh
1	EUL	1	5	34.7	19.1	39.6	228	-
2	EUL	1	2	0.9	9.7	9.7	228	-
3	EUL	2	3	10.0	0.2	10.1	228	-
4	EUL	2	4	44.4	25.0	50.9	228	-
5	EUL	2	5	46.7	27.7	54.2	228	-
6	EUL	3	4	33.9	21.8	10.2	228	-
7	TR	4	9	16.9	12.9	21.3	100	-
8	EUL	4	5	7.1	7.9	10.6	228	-
9	TR	4	7	2.8	10.2	10.8	100	-
10	TR	5	6	47.2	41.0	62.5	100	-
11	EUL	6	11	18.2	12.7	22.1	228	-
12	EUL	6	12	20.3	12.3	23.7	228	-
13	EUL	6	13	35.7	20.0	40.8	228	-
14	TR	7	9	77.8	35.0	85.35	100	-
15	TR	7	8	75.0	36.0	83.2	100	-
16	EUL	9	14	19.7	7.3	21.1	228	-
17	EUL	9	10	40.0	15.2	42.8	228	-
18	EUL	10	11	7.4	0.1	7.3	228	-
19	EUL	12	13	5.5	0.8	5.6	228	-
20	EUL	13	14	1.1	2.2	2.5	228	-

Jadval 10. Shaxobchalardagi quvvat oqimlari bo‘yicha ma’lumot
Table 10. Power flow data in branches

ES nomi	Quvvat kamayishi (%)	Eng katta kuchlanish o‘g’ishi (%)	Zaxira quvvati (MW)	Yuklama kamayishi (MW)	Ishlash vaqti(s)
ES-6	10	-	97	-	-
ES-6	20	-	84	-	-
ES-6	30	0.896 (0.44%)	71	-	3.2
ES-6	40	0.863 (4.11%)	58	-	3.1
ES-6	50	0.831 (7.66%)	45	-	3.4
ES-6	60	0.775 (12.50%)	32	-	3.3
ES-6	70	0.766 (14.88%)	19	-	4.1
ES-6	80	0.743 (17.44%)	6	-	3.9
ES-6	90	0.731 (18.77%)	-7	7	4.2
ES-6	100	0.723 (19.66%)	-20	20	4.4

5. Xulosa (Conclusions)

Qayta tiklanuvchi energiya manbalari elektr energetika tizimlarining ajralmas qismiga aylangan. Biroq, ularning ish holatlarini o‘zgaruvchanligi elektr energetik tizimlarning barqarorligi va ishonchliligiga ta’sir etib iqtisodiy yo‘qotishlar, ijtimoiy va ekologik muammolarga olib kelishi mumkin. Shu sababli, elektr energetika tizimini operativ boshqarishda, uning normal ish holati qayta tiklanuvchi energiya manbalari ta’sirida buzilganda, normal holatni qidirib topishning samarali algoritmini ishlab chiqish muhimdir.

Elektr energetika tizimi normal holatini qidirib topish algoritmi 14 tugunli IEEE test sxemasida sinovdan o‘tkazildi. Hisob kitob natijalariga ko’ra, qayta tiklanuvchi energiya manbalarida ishlovchi stansiya o‘zining 80 % gacha bo‘lgan quvvatini yo‘qotganda tizimda mavjud bo‘lgan quvvat zahirasi hisobiga qoplanadi, 90 % va undan yuqori yo‘qotishlarda qo‘shimchasiga yuklamani o‘chirish talab etiladi.

Mavjud tizimda normal holat nisbatan eng og‘ir holatda 4.4 soniyada qidirib topildi. Bunda normal holatni ta’minlash uchun tizimning quvvat zahirasi etarli emas va u 20 MW yuklamani o‘chirish hisobiga ta’minlanadi.

Elektr energetika tizimi normal holatini qidirib topish vaqti tizimning murakkabligi va holatning og‘irligiga bog‘liq ravishda o‘zgaradi.

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