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Articles are published in Uzbek, Russian, and English, ensuring a wide-reaching audience and fostering cross-cultural academic exchange. As a beacon of academic excellence, the "Journal of Transport" continues to serve as a vital conduit for knowledge dissemination, collaboration, and innovation in the transport sector and related fields.

Models and trends of digitalization in the energy sector - analysis based on international experience

J.Kh. Makhmudov[1][a]
[1]Tashkent University of Information Technologies named after Muhammad al-Khwarizmi, Tashkent, Uzbekistan

Abstract: This article analyzes models of digitalization of the energy sector based on international experience. Nowadays, digitalization creates opportunities not only for effective management of energy infrastructure, but also for sustainable development, energy saving, carbon emission reduction, and rapid response to consumer needs. The application of Smart Grid, Big Data, AI, IoT, Blockchain, and Digital Twin technologies in energy is analyzed using the examples of the European Union, the United States, China, and Japan. The advantages and distinctive features of the models in each country are shown. The results of the study showed that digitalization plays an important role in increasing efficiency in energy systems, ensuring stability of supply, saving resources, and improving interactive relations with consumers. Recommendations for Uzbekistan are also substantiated - the need to form management based on integrated systems, consumer centricity, artificial intelligence, and Big Data.

Keywords: digital energy, artificial intelligence, Smart Grid, Big Data, AI, SCADA, IoT, Blockchain, international experience, energy transformation

Energetikada raqamlashtirish modellari va tendentsiyalari - xalqaro tajriba asosida tahlil

Maxmudov J.X.[1][a]
[1]Muhammad al-Xorazmiy nomidagi Toshkent axborot texnologiyalari universiteti, Toshkent, O‘zbekiston

Annotatsiya: Ushbu maqolada xalqaro tajribalar asosida energetika sohasini raqamlashtirish modellari tahlil qilingan. Hozirgi zamonda raqamlashtirish nafaqat energetik infratuzilmani samarali boshqarishga, balki barqaror rivojlanish, energiya tejash, uglerod chiqindilarini kamaytirish va iste’molchilar ehtiyojlariga tezkor javob berish imkoniyatini ham yaratadi. Yevropa Ittifoqi, AQSh, Xitoy va Yaponiya misolida Smart Grid, Big Data, AI, IoT, Blockchain va Digital Twin texnologiyalarining energetikadagi qo’llanilishi tahlil etilgan. Har bir mamlakatdagi modellarning afzalliklari va o’zgacha jihatlari ko’rsatilgan. Tadqiqot natijalari raqamlashtirishning energetik tizimlarda samaradorlikni oshirish, ta’minot barqarorligini ta’minlash, resurslarni tejash va iste’molchilar bilan interaktiv aloqalarni yaxshilashda muhim ahamiyat kasb etishini ko’rsatdi. Shuningdek, O’zbekiston uchun tavsiyalar – integratsiyalashgan tizimlar, iste’molchi markazlashuvi, sun’iy intellekt va Big Data asosida boshqaruvni shakllantirish zarurligi asoslab berilgan.

Kalit so‘zlar: raqamli energetika, sun’iy intellekt, Smart Grid, Big Data, AI, SCADA, IoT, Blockchain, xalqaro tajriba, energetika transformatsiyasi

1. Kirish

Gidrokarbon resurslariga qaramlik, global iqlim o’zgarishlari, energiya ta’minotidagi uzilishlar va energiyaning uzluksizligini ta’minlash kabi dolzarb muammolar bugungi kunda barcha rivojlangan va rivojlanayotgan davlatlarning e’tibor markazida turibdi [1]. Bu muammolarni hal etishda energetika sohasining raqamli transformatsiyasi asosiy strategik yo’nalishlardan biriga aylanib bormoqda. Ayniqsa, elektr energetika tizimlarida samaradorlik, ishonchlilik, xavfsizlik va ekologik barqarorlikni ta’minlash uchun raqamli texnologiyalar va "aqlli boshqaruv" yechimlarining joriy etilishi global tendentsiyaga aylanmoqda [2].

Global energetika bozori raqamli transformatsiyaning turli modellari va yo’nalishlarini sinab ko’rgan ilg’or tajribalarga boy. Bu modellar davlat siyosati, texnologik infratuzilma, inson kapitali va bozor sharoitiga bog’liq holda shakllangan. Masalan, ayrim mamlakatlar "aqlli tarmoqlar" (Smart Grid) modellarini joriy qilgan bo’lsa, boshqalari "energetik ekotizimlar" (Energy Ecosystems) kontseptsiyalariga asoslangan yondashuvlarni tanlagan. Bu modellar o’zaro raqobat va integratsiya sharoitida jadal rivojlanmoqda [3].

Yevropa Ittifoqi mamlakatlarida strategik yondashuv sifatida Smart Grid modellari ko’proq qo’llaniladi. Xususan, Germaniya, Frantsiya, Niderlandiya kabi davlatlar "Smart Energy Europe" strategiyasini amalga oshirmoqda [4]. Ushbu strategiyaning asosiy tarkibiy qismlari quyidagilardan iborat:

[a] https://orcid.org/0009-0002-2626-5296

1. Intellektual hisoblagichlar (Smart meters) yordamida iste'molchilar tomonidan energiya sarfini real vaqtda kuzatish va tahlil qilish;
2. Smart Grid orqali elektr ta'minotini avtomatlashtirish, tizimdagi yuklamalarni optimallashtirish va talab yuqori paytlarda intellektual qayta taqsimlashni ta'minlash;
3. Distributed Generation – detsentralizatsiyalashgan energiya manbalarini (quyosh, shamol, biomassa) tarmoqqa samarali integratsiya qilish;
4. Green Digitalization – raqamli texnologiyalarning ekologik samaradorlik bilan uyg'unlashgan holda joriy etilishi, karbon izini kamaytirishga qaratilgan tizimlar.

Germaniyada amalga oshirilayotgan "E-Energy" pilot loyihalarida mahalliy elektr tarmoqlari SCADA (Supervisory Control and Data Acquisition) va IoT (Internet of Things) platformalari bilan birlashtirilgan. Bu esa har bir tarmoq uzelining real vaqtda monitoringini va intellektual boshqaruvini ta'minlaydi [5-7]. Masalan, lokal iste'mol nuqtalarda ortiqcha sarf aniqlansa, sistema avtomatik ravishda energiya taqsimotini o'zgartirish imkoniga ega. Shuningdek, raqamli boshqaruv markazlari (Digital control centers) orqali elektr oqimi real vaqtda nazorat qilinib, prognozlash asosida qaysi tarmoq elementlari yuklamani ko'tara olmasligi yoki ishdan chiqishi mumkinligi aniqlanadi [8-9].

Bunday yondashuvlar nafaqat ishonchli ta'minotni, balki energiya tejamkorligi, iste'molchi va ishlab chiqaruvchi o'rtasidagi o'zaro ta'sirning shaffofligini ham ta'minlaydi. Raqamli texnologiyalar, sun'iy intellekt, blokcheyn va "bulutli hisoblash" kabi texnologik vositalar butun energetik tizimni inklyuziv, barqaror va raqobatbardosh qilishda muhim omil sifatida namoyon bo'lmoqda [10].

O'zbekistonda ham elektr energetika sohasida raqamli texnologiyalarni joriy qilish borasida bosqichma-bosqich islohotlar olib borilmoqda. Biroq, xorijiy tajribalarni tahlil qilish orqali mamlakatimizda qanday raqamli yechimlar eng samarali bo'lishi mumkinligini aniqlash, texnologik infratuzilma va boshqaruv mexanizmlarini takomillashtirish dolzarb vazifa hisoblanadi.

2. Tadqiqot metodologiyasi

AQSh energetika sohasini raqamlashtirishda xususiy sektor yetakchi hisoblanadi va xususiy kompaniyalar faol rolь o'ynaydi. EnerNOC, General Electric, Pacific Gas & Electric kabi korporatsiyalar intellektual tizimlar orqali elektr ta'minotini avtomatlashtirmoqda. Grid Modernization Initiative (GMI) – AQSh Energetika vazirligi tomonidan amalga oshirilayotgan islohotlar kompleksi hisoblanadi. Demand Response Systems – sun'iy intellekt va Big Data yordamida talab asosida energiya taqsimoti amalga oshiriladi. Digital Twins – energetik uskunalarning raqamli modellarini yaratish va texnogen xatarlarni prognozlash uchun qo'llaniladi. Natijada energetikadagi avariyalar soni 25% ga kamaygan, elektr ta'minotdagi uzilishlar vaqti 40% ga qisqargan.

Xitoy raqamli energetika ekotizimi va sun'iy intellekt asosida boshqaruvni amalga oshirmoqda va raqamli energetikada "State Grid Corporation" orqali markazlashgan, yirik miqyosli platforma yaratgan. Platforma yordamida Big Data markazlari har bir transformator va hisoblagichdan ma'lumot yig'adi, AI algoritmlar yordamida talabni bashorat qilish va energiya zaxiralarini boshqarish amalga oshiriladi. Shuningdek, Blockchain asosida qayta tiklanuvchi energiya almashinuvi va sertifikatlash tizimi va SuperGrid va Ultra High Voltage (UHV) tarmoqlarida raqamli boshqaruv yo'lga qo'yilgan.

Bu model Xitoyga 2023 yilga kelib 12% ga kam energiya yo'qotish va iste'molchilarga faol hisob-kitob platformalarini yaratish imkonini bergan.

3. Tadqiqot natijalari va muhokama

Yaponiya raqamlashtirish va barqarorlik uyg'unligini ta'minlash maqsadida "Society 5.0" kontseptsiyasi asosida raqamli energetika modelini joriy etmoqda. Natijada:

1. TEPCO kompaniyasi elektr tarmoqlarida intellektual hisoblagichlar, amalda real-time billing tizimini joriy etgan;
2. Smart Energy Communities – mahalliy aholi va biznes uchun integratsiyalangan energiya menejmentini yo'lga qo'ygan;
3. Seysmik xavfli hududlarda raqamli himoya tizimlari – sun'iy intellekt orqali xavfni oldindan aniqlash amalga oshiriladi.

1-jadvalda modellarni taqqoslash natijalari keltirilgan:

1-jadval

Modellarni taqqoslash natijalari

Mamlakat	Asosiy texnologiyalar	Model turi	Afzalliklari
Germaniya	Smart Grid, IoT	Tarmoq asosidagi raqamlashtirish	Barqarorlik, "yashil energetika"
AQSh	Big Data, AI, CRM	Xususiy sektor yetakchiligidagi transformatsiya	Talabga mos energiya taqsimoti
Xitoy	Big Data, Blockchain	Markazlashgan platforma	Qamrov kengligi, yuklamani bashorat qilish
Yaponiya	AI, Digital Communities	Jamoaviy raqamlashtirish	Iste'molchi-markazlashuv, xavfsizlik

Muhokama. Tahlillar O'zbekiston uchun quyidagi saboqlar va tavsiyalarni keltirib chiqardi [3]:

1. Integratsiyalashgan yondashuv: SCADA, ERP, GIS va CRM tizimlarini birlashtirish;
2. Iste'molchi markazlashuvi: mobil ilovalar va onlayn platforma orqali real vaqtda hisob-kitob;
3. Qayta tiklanuvchi energiya va raqamli monitoring: energiya manbalarini raqamli ko'rinishda kuzatish;

4. Data-Driven boshqaruv: Big Data markazlarini shakllantirish va KPI tizimini avtomatlashtirish;
5. Sun'iy intellekt va prognostik tahlillar: energiya ehtiyojlarini oldindan aniqlash va optimal taqsimot.

4. Xulosa

Xalqaro tajriba shuni ko'rsatmoqdaki, raqamli transformatsiya – bu nafaqat texnologik, balki strategik o'zgarishlar jarayonidir. Turli modellarni taqqoslash orqali O'zbekiston o'z milliy sharoitiga mos keladigan, samarali va barqaror raqamli energetika tizimini yaratishi mumkin. Bu jarayonda davlat siyosati, xususiy sektor ishtiroki va kadrlar tayyorgarligi hal qiluvchi omillar bo'lib xizmat qiladi.

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Mualliflar to'g'risida ma'lumot/ Information about the authors

Makhmudov Jakhongir Khakim ugli/ Makhmudov Jakhongir
Muhammad al-Xorazmiy nomidagi Toshkent axborot texnologiyalari universiteti Karyera markazi va talabalar amaliyoti bo'limi boshlig'i.
E-mail: jaxongir9316@icloud.com
Tel.: +99890 968 51 31
https://orcid.org/0009-0002-2626-5296

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