Nasos agregatlarini avtomatik boshqaruv modelini ishlab chiqish hisobiga suv ta’minoti korxonasining samaradorligini oshirish

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Dolzarbligi: urbanizatsiya jarayonining kuchayishi va sanoatlashuvning tezlashishi bilan dunyo bo‘yicha energiyaga bo‘lgan talab sezilarli darajada oshib bormoqda. 2021 yilda global elektr energiya iste’moli 27,000 teravatt-soatni tashkil etdi va bu ko‘rsatkich yiliga o‘rtacha 2,7% ga oshib bormoqda. Xalqaro Energetika Agentligining prognozlariga ko‘ra, 2040 yilga kelib global energiya iste’moli 40% ga o‘sishi kutilmoqda.

Respublikamiz aholisini toza va sifatli ichimlik suv bilan ta’minlash hamda oqova suv xizmatlarini yaxshilash borasida olib borilayotgan ishlarni yanada jadallashtirish, ichimlik suv ta’minoti va oqova suv xizmatlari qamrovini oshirish orqali ularning munosib turmush sharoitlarini yaratish hamda sog‘lig‘ini saqlash maqsadida Prezidentining PF-60-sonli 2022-yil 28-yanvardagi Farmoni bilan tasdiqlangan 2022-2026-yillarga mo‘ljallangan Yangi O‘zbekistonning taraqqiyot strategiyasiga asoslangan holda respublika aholisining ichimlik suv bilan ta’minlanganlik darajasini 87 foizga yetkazish, 32 ta yirik shaharlar va 155 ta tuman markazlarida oqova suv tizimlarini yangilash ko‘zda tutilgan. Odatda Respublikamizda ishlab kelayotgan aksariyat nasos stantsiylarining elektr yuritmalari o‘zgarmas ya’ni bir tezlikli elektr motorlar bilan jihozlangan. Suv ta’minoti korxonalarining nasos agregatlari asosan o‘zgaruvchan yuklamada ishlaydi. Bu esa sohada o‘zgaruvchan tezlikli yoki ko‘p tezlikli motorlarni tadbiq qilishni taqazo etadi. O‘zgaruvchan tezlikli tejamkor elektr motorlarni qo‘llash va ularni boshqarishning innovatsion usullaridan foydalanish nasos stantsiyalarning samaradorligini oshirishga xizmat qiladi.

Maqsad: suv ta’minoti korxonalarining samaradorligini oshirish uchun nasos agregatlarini avtomatik boshqarishning yangi modelini ishlab chiqish va joriy qilishdir. Nasos agregatlarini ishlash jarayonini avtomatlashtirish orqali energiya tejamkorligini oshirish, tizimning ish unumdorligini yaxshilash, va suv ta’minoti tizimining ishlash jarayonlarini optimallashtirishdan iborat.

Usullari: nasos agregatlarini avtomatik boshqaruv modelini ishlab chiqishda Fuzzy mantig‘i usuli hamda Mamdani qaror qabul qilish usullari qo‘llanilgan.

Natijalar: suv ta’minoti korxonasining samaradorligini oshirishda Fuzzy mantig‘i usuli asosida ishlab chiqilgan model nasos agregatlarini suv iste’moli talablaridan kelib chiqib turli xil tezliklarda boshqarish imkonini yaratadi.

Kalit so‘zlar: Fuzzy mantig‘i, Mamdani, PLC, vintel, smart, defuzzifikatsiya, fuzzifikatsiya, SCADA, raqamli texnologiya, suv iste’moli, birinchi tur smart boshqaruv mexanizmi, ikkinchi tur smart boshqaruv mexanizmi, qaror qabul qilish, reduktor, ma’lumotlar bazasi.

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Повышение эффективности предприятия водоснабжения за счет разработки модели автоматического управления насосными агрегатами

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Актуальность: с ростом урбанизации и ускорением индустриализации спрос на энергию во всем мире значительно возрастает. В 2021 году мировое потребление электроэнергии составило 27 000 тераватт-часов, и этот показатель увеличивается в среднем на 2,7% в год. По прогно-

зам Международного энергетического агентства, к 2040 году мировое потребление энергии вырастет на 40%. В целях дальнейшего ускорения проводимой работы по обеспечению населения нашей республики чистой и качественной питьевой водой и улучшению услуг водоотведения, созданию достойных условий жизни и сохранению их здоровья путем увеличения охвата услугами питьевого водоснабжения и водоотведения, ПФ Президента - Согласно Стратегии развития Нового Узбекистана на 2022-2026 годы, утвержденной Указом №60 от 28 января 2022 года, уровень обеспеченности питьевой водой населения республики - 87%, 32 крупных города и 155 районов В центрах планируется обновить системы водоотведения. Как правило, большинство насосных станций, действующих в нашей стране, оснащены электродвигателями с фиксированной, то есть односкоростными двигателями. Насосные агрегаты предприятий водоснабжения в основном работают с переменной нагрузкой. Это приводит к применению в полевых условиях двигателей с регулируемой или многоскоростной скоростью. Использование экономичных электродвигателей с регулируемой скоростью и применение инновационных методов их управления служат повышению эффективности насосных станций.

Цель: разработать и внедрить новую модель автоматического управления насосными агрегатами для повышения эффективности предприятий водоснабжения. Он заключается в повышении энергоэффективности, улучшении производительности системы, оптимизации работы системы водоснабжения за счет автоматизации работы насосных агрегатов.

Методы: при разработке модели автоматического управления насосными агрегатами использованы метод нечеткой логики и методы принятия решений Мамдани.

Результаты: разработанная на основе метода нечеткой логики модель повышения эффективности работы предприятия водоснабжения позволяет управлять насосными агрегатами на разных скоростях исходя из требований водопотребления.

Ключевые слова: нечеткая логика, Мамдани, PLC, винтел, смарт, дефаззификация, фаззификацция, SCADA, цифровые технологии, водопотребление, интеллектуальный механизм управления первого типа, интеллектуальный механизм управления второго типа, принятие решений, редуктор, база данных.

Improving the efficiency of a water supply enterprise through the development of an automatic control model for pump units

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Relevance: with the rise of urbanization and accelerated industrialization, global energy demand has significantly increased. In 2021, the world's electricity consumption amounted to 27,000 terawatt-hours, and this figure is growing at an average rate of 2.7% per year. According to the International Energy Agency, global energy consumption is projected to increase by 40% by 2040.

To further accelerate efforts to provide the population of our republic with clean and high-quality drinking water and improve wastewater services, as well as to create decent living conditions and preserve public health through increased coverage of drinking water and wastewater services, the President's Decree - According to the New Uzbekistan Development Strategy for 2022-2026, approved by Decree No. 60 of January 28, 2022, the level of drinking water supply coverage in the republic is 87%, with plans to upgrade the wastewater systems in 32 major cities and 155 districts. Generally, most of the pump stations operating in our country are equipped with fixed-speed, or single-speed, electric motors. Pumping units in water supply enterprises mainly operate with variable loads, leading to the use of motors with adjustable or multi-speed settings in the field. The use of energy-efficient electric motors with adjustable speed and innovative control methods serves to enhance the efficiency of pump stations.

Aim: develop and implement a new model of automatic control for pump units to enhance the efficiency of water supply enterprises. This involves improving energy efficiency, enhancing system performance, and optimizing the operation of the water supply system through the automation of pump unit operations.

Methods: the model for automatic control of pump units was developed using fuzzy logic methods and Mamdani decision-making methods.

Results: the model, developed based on fuzzy logic methods, allows for managing pump units at dif-

ferent speeds according to water consumption requirements, thereby enhancing the efficiency of water supply enterprises.
Key words: fuzzy logic, Mamdani, PLC, valve, smart, defuzzification, fuzzification, SCADA, digital technologies, water consumption, first-type intelligent control mechanism, second-type intelligent control mechanism, decision-making, reducer, database.

1. Kirish (Introduction)

Bugungi kunda raqamli texnologiyalar sanoatning turli sohalarida keng qo‘llanilib, ularning samaradorligini sezilarli darajada oshirmoqda. Suv ta’minoti va nasos agregatlarini boshqarish ham bundan mustasno emas. Suv ta’minoti tizimida avtomatik boshqaruv tizimini to‘g‘ri tashkil etish energiya samaradorligini sezilarli darajada oshirishga sabab bo‘ladi. Suv ta’minoti tizimida samarador boshqaruv tizimini joriy etish orqali, energiya sarfini kamaytirish, suv ta’minoti tizimining ishonchliligini oshirish va uzoq muddatli barqaror ishlashi ta’minlanadi [1,2,3].

Joriy holatda, suv ta’minoti korxonasida avtomatlashtirilgan nasos agregatlarini ishga tushirish va o‘chirish tizimlari, suv sarfini va bosimini o‘lchash qurilmalari mavjud. Ammo, boshqaruv tizimi suv iste’moli talabidan kelib chiqqan holda kerakli agregatlarni ishga tushirish yoki ba’zi agregatlarni o‘chirish dispetcher orqali amalga oshiriladi [4,5].

Bundan tashqari, nasos agregatlari uchun ikki tezlikli motorlarni qo‘llash, boshqarish tizimini avtomatlashtirishga ehtiyojni oshiradi. Mazkur zaruratdan kelib chiqqan holda, avtomatik boshqaruvni (keyingi o‘rinlarda smart boshqaruv) tashkil etishni matematik modelini ishlab chiqish masalasini yechishga qaratildi.

Yuqoridagi kamchiliklarni bartaraf etish maqsadida qutblari o‘zgaruvchan ko‘p tezlikli asinxron motorlar va raqamli texnologiyalardan foydalanish hisobiga suv ta’minoti korxonasini avtomatlashtirilgan boshqaruv tizimini ishlab chiqish zarur hisoblanadi.

Suv ta’minoti korxonasini avtomatlashtirilgan boshqaruv tizimini ishlab chiqish uchun turli xil dasturiy vositalar va texnologiyalardan foydalanish mumkin. Bunga quyidagilar misol bo‘la oladi.

- SCADA (Supervisory Control and Data Acқuisition),
- PLC (Programmable Logic Controller),
- HMI (Human Maчine Interface),
- Bulut xizmatlari va IoT (Internet of Things).

Respublikamizda ishlab kelayotgan suv ta’minoti korxonalari SCADA (Supervisory Control and Data Acquisition), boshqaruv tizimi asosida ishlab kelmoqda, ammo yuqoridagi kamchiliklar hozirgi vaqtgacha ham uchrab turibdi.

Suv ta’minoti korxonasining boshqaruv tizimini takomillashtirish va kamchiliklarni bartaraf etish maqsadida PLC (Programmable Logic Controller), raqamli texnologiyasidan foydalanish jarayonlarini avtomatlashtirish, real vaqt rejimida ma’lumotlarni qayta ishlash va tizimni samarali boshqarish imkonini beradi.

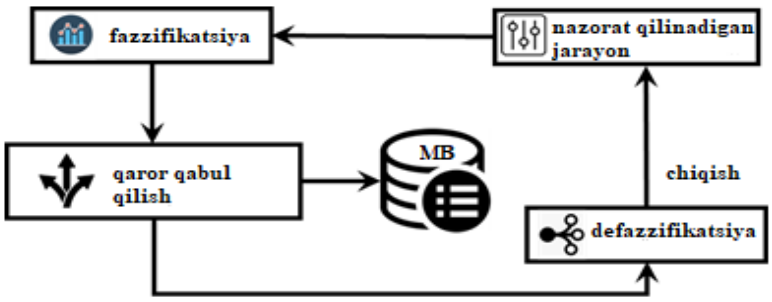
2. .Методы и материалы (Methods and materials)

Korxonaning ishlash strukturasi murakkabligi va dinamik o‘zgaruvchilarning mavjudligini inobatga olgan holda Fuzzy mantig‘idan foydalanish maqsadga muvofiq hisoblanadi.

Fuzzy mantig‘i asosida smart boshqaruv mexanizmi ikkiga bo‘linadi.

1. Birinchi tur smart boshqaruv mexanizmi
2. Ikkinchi tur smart boshqaruv mexanizmi

Birinchi va ikkinchi tur smart boshqaruv mexanizmlari o‘rtasidagi asosiy farq ularning fazzifikatsiyalari va a’zolik funksiyalarining murakkabligidadir. Birinchi tur Fuzzy smart boshqaruv mexanizmlari an’anaviy Fuzzy mantig‘ining shakli bo‘lib, unda har bir elementning biror to‘plamdagi a’zolik darajasi 0 va 1 o‘rtasida bo‘lgan yagona a’zolik qiymati bilan ifodalanadi (1-rasm).



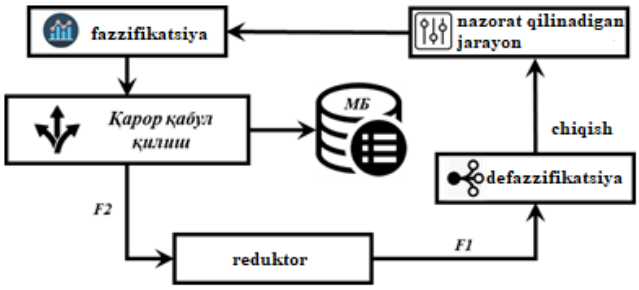
1-rasm. Birinchi tur smart boshqaruv mexanizmlari
Fig.1. The first type is smart control mechanisms

Unda D_A ma'lumotlar to'plami oralig'ida $\mu_x(x)$-qiymatning bog'liqlik darajasini e'tiborga olib, differensiallash asosida qaror qabul qilinadi [12,13]:

$$A = \int_{D_X} \mu_A(x)/x \quad (1)$$

Birinchi tur Fuzzy mantig'ida a'zolik funksiyasi aniq va muayyan bo'lib, har bir kirish qiymati ma'lum bir Fuzzy to'plamga ma'lum darajada tegishli ekanligini anglatadi.

Ikkinchi tur smart boshqaruv mexanizmlari birinchi tur Fuzzy boshqaruv mexanizmlarini kengaytirilgan ko'rinishi bo'lib, a'zolik darajasi uchun bir qiymat o'rniga sodir bo'lishi mumkin bo'lgan qiymatlar oralig'i joriy qilinadi (2-rasm).



2-rasm. Ikkinchi tur smart boshqaruv mexanizmlari
Fig.2. The second type is smart control mechanisms

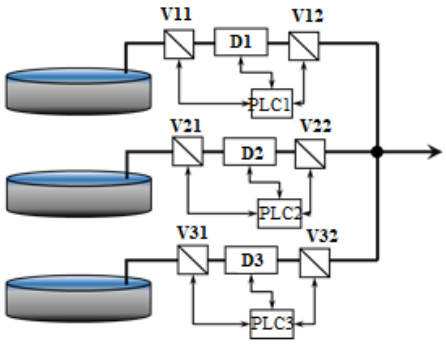
Bu yondashuv tizimning dinamik xususiyatlari sababli a'zolik funksiyasini aniqlash qiyin bo'lgan jarayonlarda qo'llaniladi. Bunda kiruvchi qiymat x ning D_x to'plamdagi qiymatini, $u \in [0,1]$ qiymatning J_x ikkilamchi to'plamdagi mos qiymatlariga umumlashtirish orqali yakuniy qaror qabul qilinadi [14,15,16]:

$$\tilde{A} = \{((x,u), \mu_{\tilde{A}}(x,u)) | \forall_x \in X; \forall_u \in J_x \subseteq [0,1]\} \quad (2)$$

Keltirilgan (4.2) formulada $\tilde{A}$ ma'lumotlar to'plami quyidagicha aniqlanadi:

$$\tilde{A} = \iint\limits_{x \in D_x \; u \in J_x \subseteq [0,1]} \frac{\mu_{\tilde{A}}(x,u)}{(x,u)} = \iint\limits_{x \in D_x \; u \in J_x \subseteq [0,1]} \frac{1}{(x,u)} =$$
$$= \int_{x \in D_x} \left[\int_{u \in J_x \subseteq [0,1]} \frac{1}{u} \right] 1/x \quad (3)$$

Birinchi va ikkinchi tur smart boshqaruv mexanizmlari qo'yilayotgan masalaning talablariga, uning noaniqlik darajasiga va mavjud hisoblash natijalariga bog'liq. Ushbu maqolada qo'yilgan asosiy masala suv ta'minoti korxonasida *smart* boshqaruv tizimida boshqarish bir nechta o'zgaruvchan kirish parametrlar oralig'ini e'tiborga olgan holda chiqish parametrlarini tanlashdan iborat.



3-rasm. Tadqiqot ob'ektining umumiy sxemasi: D – nasos dvigatellari, PLC – dasturlashtirilgan mantiqiy kontrollerlar, V – vintellar
Fig.3. General scheme of the research object: D - pump motors, PLC - programmed logical controllers, V - propellers

Xususan, uchta suv havzasidan suvni olib berish uchun nasoslarga ikki tezlikli uchta dvigatel o'rnatilgan bo'lib, ular tomondan tortilgan suvlar umumlashgan holda bir yo'nalish tomon hara-katlanadi (3-rasm). Smart boshqaruv tizimini amalga oshirish maqsadida vintellar (B) va dvigatellar dasturlashtirilgan mantiqiy kontroller orqali boshqariladi (PLC) [17,18,19]. Ushbu holda nafaqat na-

soslarning suv sarflari balki quvurdagi bosimning qiymatini ham e'tiborga olish zarur. Shuning uchun ushbu masalada ikkinchi tur mexanizmidan foydalanish maqsadga muvofiqdir.

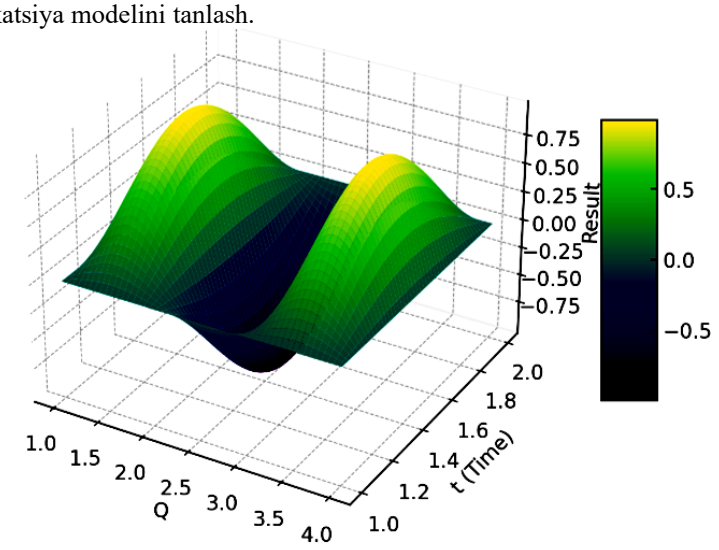
Qo'yilgan masalaning mohiyati va ikkinchi tur Fuzzy mantig'ini tanlangani sababli smart boshqaruvning matematik modelini ishlab chiqish quyidagi bosqichlar asosida amalga oshiriladi (3-rasm):

1. Suvga bo'lgan talabni tahlil qilish va suv sarfining chegaraviy qiymatlarini belgilash;
2. Suvga bo'lgan talabdan kelib chiqqan holda suv quvurlaridagi kerakli bosim, nasosning elektr energiya iste'moli va shu kabi ikkalamchi parametrlarni hisoblash;
3. Hisoblangan qiymatlarga ko'ra Fuzzy boshqaruv mantig'ini ishlab chiqish;
4. Ishlab chiqilgan Fuzzy boshqaruv mantig'idan kelib chiqqan holda yillik elektr energiya iste'molini baholash.

3. Tadqiqot natijalari (Results)

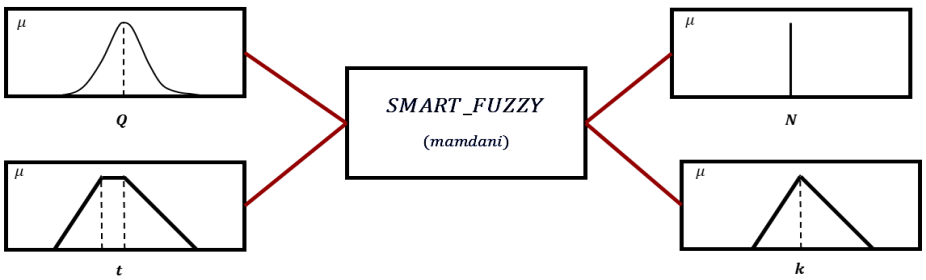
V Ma'lumki har qanday ikkinchi tur Fuzzy mantig'iga asoslangan boshqaruv tizimini ishlab chiqish quyidagi 5 ta bosqich asosida amalga oshiriladi:

1. Kirish va chiqish o'zgaruvchilarini aniqlash,
2. Fuzzy to'plamlarni va ularning a'zolik funksiyalarini ishlab chiqish,
3. Fuzzy qoidalarini qurish,
4. Boshqaruv usulini tanlash,
5. Defuzzifikatsiya modelini tanlash.



4-rasm. Smart boshqaruvning Fuzzy qoidalari to'plami grafigi
Fig.4. Fuzzy rule set graph of smart control

Tadqiqot ishida qo'yilgan masaladagi murakkab ikki xil a'zolik funksiyasiga ega bo'lgan kirish va yana boshqa o'zgarish qonuniga ega bo'lgan chiqish funksiyalari shuni ko'rsatadiki, ushbu murakkab bog'lanishni faqatgina Mamdani usuli yordamida modellashtirish mumkin.



5-rasm. Smart boshqaruv tizimining ishlash diagrammasi
Fig.5. Functional diagram of the smart control system

1-jadval. Smart boshqaruvi tizimi Fuzzy ikkinchi tur modelining xatoligini hisoblash jadvali
Table 1. Smart control system Fuzzy second type model error calculation table

Vaqt oralig‘i	Q (минг. м^3)		APE	MAPE
	yoz	model	%	%
24-1	4,17	4,35	4,3%	
1-2	4,08	3,95	3,2%	
2-3	4,17	4,35	4,3%	
3-4	4,83	4,7	2,7%	
4-5	4,50	4,575	1,7%	
5-6	5,30	5,2	1,9%	
6-7	5,20	5,2	0,0%	
7-8	5,40	5,325	1,4%	
8-9	5,10	5,2	2,0%	
9-10	5,50	5,95	8,2%	
10-11	5,95	5,95	0,0%	
11-12	6,00	5,95	0,8%	1,7
12-13	6,00	5,95	0,8%	
13-14	5,95	5,95	0,0%	
14-15	5,90	5,95	0,8%	
15-16	5,90	5,95	0,8%	
16-17	5,95	5,95	0,0%	
17-18	5,89	5,95	1,0%	
18-19	5,88	5,95	1,2%	
19-20	5,97	5,95	0,3%	
20-21	6,00	5,95	0,8%	
21-22	5,95	5,95	0,0%	
22-23	5,10	5,2	2,0%	
23-24	4,50	4,575	1,7%	

4. Xulosa (Conclusion)

Ishlab chiqilgan modelning 1,7% xatoligi ruxsat etilgan oraliqda bo‘lganligi, ushbu boshqaruv tizimini joriy etish mumkinligini bildiradi.

Mavjud smart boshqaruv algoritmlarining tahlili shuni ko‘rsatadiki, murakkab boshqaruv mantig‘iga ega bo‘lgan suv ta’minoti korxonalarining avtomatik boshqaruv tizimini tashkil etishda Fuzzy mantig‘i asosida smart boshqaruv 2-tur mexanizmi boshqa Bayez tarmoqlari, markov modellari kabi ehtimoliy usullariga nisbatan samarali ekanligi ilmiy asoslandi.

Mamdani metodiga asoslangan Fuzzy smart boshqaruv mexanizmi ishlab chiqildi, natijada murakkab suv ta’minoti tizimlarini 98,3% aniqlilikda avtomatik boshqarish imkoniyati yaratildi.

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