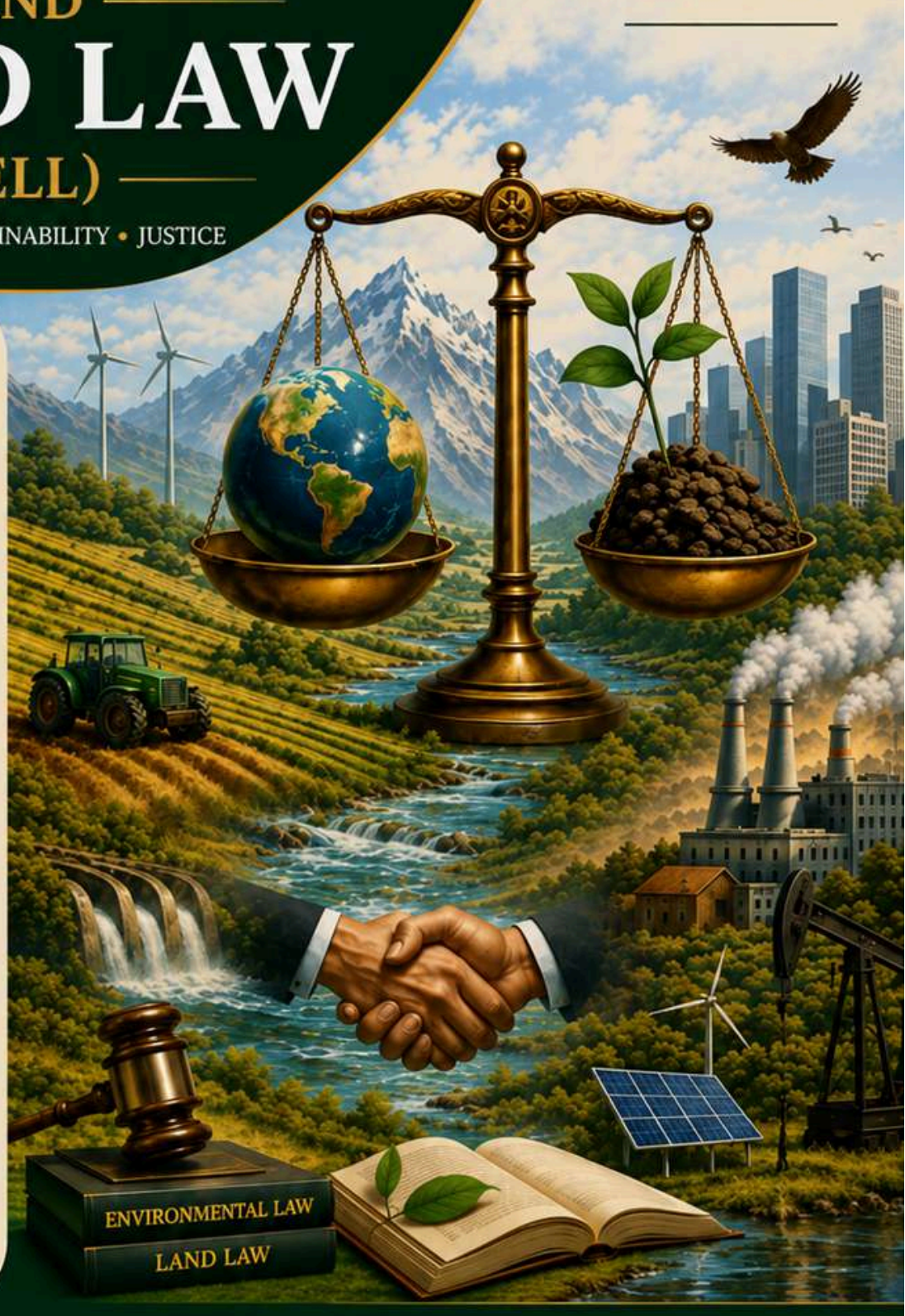
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QUYOSH PANELLARI SIRTINING IFLOSLANISH DARAJASINI INTELLEKTUAL NAZORAT QILUVCHI ELEKTRON QURILMANI ISHLAB CHIQISH

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Texnika fanlari nomzodi, PhD, dotsent

TEZIS MA'LUMOTI

Kalit so'zlar:
quyosh panellari,
fotoelektrik modul,
sirt ifloslanishi,
etalon fotoelement,
ifloslanish koeffitsiyenti,
intellektual monitoring,
ESP32, ADS1115,
tozalash algoritmi,
energiya yo'qotilishi.

A N N O T A T S I Y A

Tezisda quyosh panellari sirtining ifloslanish darajasini real vaqt rejimida baholash uchun avtonom elektron qurilma va ma'lumotlarni intellektual qayta ishlash algoritmi taklif etilgan. Ifloslanish darajasi toza va ifloslangan etalon fotoelementlarning haroratga tuzatilgan qisqa tutashuv toklari nisbati orqali aniqlanadi. Qurilma tuzilmasida ADS1115 analog-raqamli o'zgartirgichi, ESP32 mikrokontrolleri va atrof-muhit sensorlaridan foydalanish ko'zda tutilgan. Algoritm o'lchash signallarini filtrlash, ifloslanish tezligini regressiya asosida baholash hamda energiya yo'qotilishi va tozalash xarajatlarini hisobga olib qaror shakllantirishni qamrab oladi. Taklif etilgan yechim panellarni holatiga qarab tozalash va masofaviy monitoringni tashkil etishga qaratilgan. Qurilmaning aniqligi va samaradorligini tajriba sinovlari orqali baholash rejalashtirilgan.

DEVELOPMENT OF AN ELECTRONIC DEVICE FOR INTELLIGENT MONITORING OF SURFACE POLLUTION LEVELS OF SOLAR PANELS

THESIS INFO

Keywords:
solar panels,
photovoltaic module,
surface soiling,
reference photovoltaic cell,
soiling ratio,
intelligent monitoring,
ESP32,

A B S T R A C T

This conference paper proposes an autonomous electronic device and an intelligent data processing algorithm for assessing solar panel surface soiling in real time. The degree of soiling is determined from the ratio of the temperature-corrected short-circuit currents of soiled and clean reference photovoltaic cells. The proposed device incorporates an ADS1115 analog-to-digital converter, an ESP32 microcontroller, and environmental sensors. The algorithm includes measurement signal filtering, regression-based estimation of the

ADS1115,
cleaning algorithm,
energy losses.

soiling rate, and decision-making that accounts for energy losses and cleaning costs. The proposed solution is intended to support condition-based panel cleaning and remote monitoring. The accuracy and effectiveness of the device are planned to be evaluated through experimental testing.

ПРОГРАММНАЯ СИСТЕМА АВТОМАТИЗИРОВАННОГО ИНТЕЛЛЕКТУАЛЬНОГО МОНИТОРИНГА И УПРАВЛЕНИЯ СОЛНЕЧНЫМИ ПАНЕЛЯМИ

ИНФОРМАЦИЯ ТЕЗИС

Ключевые слова:
солнечные панели,
фотоэлектрический модуль,
загрязнение поверхности,
эталонный фотоэлемент,
коэффициент загрязнения,
интеллектуальный мониторинг,
ESP32, ADS1115,
алгоритм очистки,
потери энергии..

А Н Н О Т А Т С И Я

В тезисах предложены автономное электронное устройство и алгоритм интеллектуальной обработки данных для оценки степени загрязнения поверхности солнечных панелей в режиме реального времени. Степень загрязнения определяется по отношению токов короткого замыкания загрязнённого и чистого эталонных фотоэлементов с температурной коррекцией. В структуре устройства предусмотрено использование аналого-цифрового преобразователя ADS1115, микроконтроллера ESP32 и датчиков параметров окружающей среды. Алгоритм включает фильтрацию измерительных сигналов, оценку скорости загрязнения на основе регрессии и принятие решения с учётом потерь энергии и затрат на очистку. Предлагаемое решение направлено на организацию очистки панелей по их фактическому состоянию и дистанционного мониторинга. Оценку точности и эффективности устройства планируется провести в ходе экспериментальных испытаний.

KIRISH

O‘zbekiston Respublikasida fotoelektrik stansiyalar (FES) quvvatining tez o‘sishi sharoitida ularning ishlash samaradorligini saqlash dolzarb vazifaga aylandi. Markaziy Osiyo iqlimi uchun xos bo‘lgan yuqori changlanish, kam yog‘ingarchilik va yuqori harorat fotoelektrik modul (FEM) yuzasida zarralar yig‘ilishiga (soiling) olib keladi. Natijada modulga tushadigan nurlanish oqimi kamayadi, qisqa tutashuv toki va chiqish quvvati pasayadi; mahalliy tadqiqotlarda yuza uzoq muddat tozalanmaganda ishlab chiqarilgan energiya 10–30 % gacha kamayishi qayd etilgan. Amaldagi tozalash tartibi odatda qat’iy jadvalga asoslangan bo‘lib, ortiqcha suv va mehnat sarfiga yoki aksincha, tozalashning kechikishi hisobiga energiya yo‘qotilishiga olib keladi.

Muammoning holati va mavjud usullar tahlili

Ifloslanish darajasiga chang zarralarining granulometrik va kimyoviy tarkibi, havo namligi va kondensatsiya (shudring), shamol tezligi va yo‘nalishi, modulning qiyalik burchagi, shuningdek biologik ifloslantiruvchilar (qush axlati, o‘simlik changi) ta’sir ko‘rsatadi. Namlik ta’sirida chang qatlami sirtga mustahkam yopishib, oddiy yog‘ingarchilik bilan ketmaydigan qatlam (cementation) hosil qiladi. Ifloslanishni baholashning mavjud usullari quyidagi jadvalda keltirilgan.

1-jadval. *FEM ifloslanishini baholash usullarining qiyosiy tahlili*

Usul	Afzalligi	Kamchiligi
Vizual ko‘rik va jadvalli tozalash	Qo‘shimcha uskuna talab qilmaydi	Subyektiv; tozalash vaqti noaniq; sarf ortiqcha
Ishlab chiqarilgan energiya bo‘yicha (Performance Ratio)	Stansiya ma’lumotlaridan foydalaniladi	Ob-havo va nosozliklardan ajratish qiyin; kechikkan natija
Optik (lazer, infraqizil) sensorlar	Chang qalinligini bevosita o‘lchaydi	Qimmat; kalibrovka murakkab
Etalon (toza va ifloslangan) element usuli	Oddiy, arzon, aniq; real vaqt rejimi	Etalon elementni toza saqlash va kalibrlash zarur

Tahlil shuni ko‘rsatadiki, arzon, aniq va avtonom ishlay oladigan, ma’lumotni intellektual qayta ishlaydigan vosita eng maqbul yechim hisoblanadi. Shu sababli etalon element usuli asos sifatida tanlandi.

Tadqiqot maqsadi

FEM yuzasining ifloslanish darajasini real vaqt rejimida bevosita o‘lchaydigan, o‘lchash natijalarini intellektual qayta ishlaydigan va tozalash zaruriyati to‘g‘risida qaror shakllantiradigan kam quvvat iste’mol qiluvchi avtonom elektron qurilmani ishlab chiqish.

Qurilma tuzilishi va o‘lchash usuli

Qurilma bir xil turdagi ikkita kalibrlangan etalon fotoelementdan iborat: biri (ishchi) tashqi muhit ta’siriga ochiq, ikkinchisi (nazorat) davriy ravishda avtomatik tozalanadi yoki himoya qoplamasi ostida saqlanadi. Qurilma tarkibiga shuningdek quyidagilar kiradi: modul haroratini o‘lchovchi sensor, global nurlanish (piranometr yoki yoritilganlik sensori), havo namligi va changlanish omilini hisobga oluvchi atrof-muhit sensorlari, aniq tok o‘lchash uchun yuqori razryadli ARO (ADS1115) va ma’lumotlarni qayta ishlash hamda simsiz uzatish uchun ESP32 mikrokontrolleri. Ta’minot — mustaqil mini-panel va akkumulyator. Mahalliy

olimlar tomonidan irrigatsiya obyektlari uchun ishlab chiqilgan kam quvvatli intellektual o‘lchash tizimlari tajribasi [3, 6, 7, 9], o‘lchash o‘zgartirgichlarining statik va dinamik xarakteristikalarini tahlil qilish [1] hamda tajriba natijalariga statistik ishlov berish usullari [2] qurilma strukturasini tanlashda asos qilib olindi.

2-jadval. *Qurilmaning asosiy tarkibiy qismlari*

Blok	Element (taklif)	Vazifasi
O‘lchash bloki	Ikkita etalon fotoelement, shunt rezistor	Toza va ifloslangan elementlar tokini o‘lchash
Analog-raqamli o‘zgartirgich	ADS1115 (16 razryad)	Kichik signallarni yuqori aniqlikda raqamlashtirish
Atrof-muhit sensorlari	Harorat (DS18B20), namlik, yoritilganlik sensori	Haroratga va nurlanishga tuzatma kiritish
Boshqaruv va aloqa	ESP32 mikrokontrolleri (Wi-Fi/MQTT)	Qayta ishlash, qaror qabul qilish, ma’lumot uzatish
Ta’minot	Mini-panel, akkumulyator, zaryad kontrolleri	Qurilmaning avtonom ishlashi
Ijro qismi	Rele chiqishi, signalizatsiya	Tozalash tizimini yoqish, operatorni ogohlantirish

Etalon element qisqa tutashuv toki nurlanish va haroratga bog‘liq holda quyidagicha ifodalanadi:

$$I_{qt} = I_{qt,0} \cdot (G / G_0) \cdot [1 + \alpha(T - T_0)] \qquad (1)$$

bu yerda G — nurlanish zichligi, T — element harorati, α — qisqa tutashuv tokining harorat koeffitsiyenti, $G_0 = 1000$ Vt/m^2, $T_0 = 25$ °C (standart sinov sharoitlari — STC).

Ifloslanish darajasi haroratga keltirilgan toklar nisbati — ifloslanish koeffitsiyenti (Soiling Ratio, SR) — orqali baholanadi:

$$SR = I_{if}^* / I_t^*, \quad SL = (1 - SR) \cdot 100\ \% \qquad (2)$$

bu yerda I_{if}^*, I_t^* — mos ravishda ifloslangan va toza elementlarning (1) ifoda bo‘yicha T_0 haroratga keltirilgan toklari, SL — ifloslanish tufayli yo‘qotish (Soiling Loss).

Ifloslanish koeffitsiyenti bo‘yicha qurilma holatni uch darajaga ajratadi (chegaralar tajriba asosida aniqlashtiriladi):

3-jadval. *Ifloslanish darajalari va qurilma reaksiyasi*

SR qiymati	Holat	Qurilma harakati
≥ 0,97	Toza	Faqat monitoring
0,90 – 0,97	O‘rtacha ifloslangan	Ifloslanish tezligini bashorat qilish, iqtisodiy mezonni tekshirish
< 0,90	Tozalash zarur	Operatorga signal yuborish yoki tozalash tizimini yoqish

O‘lchash natijasining ishonchliligi kalibrovka va xatolikni baholash orqali ta’minlanadi. Tokni o‘lchashning nisbiy xatoliklari o‘zaro bog‘liq bo‘lmagani uchun *SR* ning nisbiy xatoligi quyidagicha baholanadi [6–8]:

$$\delta_{SR} = \sqrt{(\delta_{if}^2 + \delta_t^2 + \delta_T^2)} \qquad (3)$$

bu yerda δ_{if}, δ_t — ifloslangan va toza element toklarini o‘lchash xatoliklari, δ_T — haroratni o‘lchash va keltirish xatoligi. Ikkala etalon elementning xarakteristikalari dastlab bir xil sharoitda (ikkalasi ham toza holatda) solishtirilib, $SR = 1$ dan farq qilgan hollarda tuzatuvchi koeffitsiyent kiritiladi.

Intellektual qayta ishlash algoritmi

Mikrokontroller dasturi to‘rt bosqichdan iborat: (i) o‘lchash signallarini yuqori chastotali shovqindan tozalash (harakatlanuvchi o‘rtacha va medianali filtr, kalibrovka tuzatmalari); (ii) faqat nurlanish zichligi belgilangan chegaradan yuqori bo‘lgan barqaror sharoitlarda *SR* ni hisoblash; (iii) so‘nggi *N* kun ma’lumotlari bo‘yicha chiziqli regressiya yordamida ifloslanish tezligi $k = dSR/dt$ ni baholash; (iv) tozalash to‘g‘risida qaror qabul qilish. Energiya tejamkor ish rejimini ta’minlash algoritmlari bo‘yicha mahalliy tajriba [4, 5] hisobga olinib, qaror iqtisodiy mezonga asoslanadi:

$$\Delta W = P_{nom} \cdot (1 - SR) \cdot t_e \cdot c \geq C_t \qquad (4)$$

bu yerda P_{nom} — stansiyaning nominal quvvati, t_e — samarali quyoshli soatlar soni, c — elektr energiya tarifi, C_t — bir martalik tozalash xarajati. (4) shart bajarilganda yoki *SR* ning bashorat qilingan qiymati kritik chegaraga (masalan, 0,90) yetganda qurilma operatorga xabar yuboradi yoki avtomatik tozalash tizimini ishga tushiradi. Ma’lumotlar MQTT protokoli orqali masofaviy monitoring tizimiga uzatiladi.

KUTILAYOTGAN NATIJALAR

Taklif etilayotgan qurilma: tozalashni jadval bo‘yicha emas, modul holatiga qarab o‘tkazish imkonini beradi; suv, mehnat va energiya sarfini kamaytiradi; ifloslanishning

mavsumiy dinamikasi bo‘yicha ma’lumotlar bazasini shakllantiradi; narxi bo‘yicha import analoglaridan arzon bo‘lib, mahalliy sharoitga moslashtirilgan. Ilmiy-amaliy jihatdan ish ifloslanishni miqdoriy baholashning arzon va takrorlanuvchan metodikasini, ifloslanish tezligini bashorat qilish algoritmini hamda tozalash vaqtini asoslash uchun iqtisodiy mezonni taklif etadi. Qurilmaning aniqligi tajriba orqali etalon o‘lchash vositalariga nisbatan nisbiy xatolik bo‘yicha baholanadi.

XULOSA

FEM sirti ifloslanishini ikki etalon element toklari nisbati bo‘yicha o‘lchash va natijalarni intellektual qayta ishlash FESlarni texnik xizmat ko‘rsatishda jadvalli yondashuvdan holatga asoslangan boshqaruvga o‘tish imkonini beradi, bu esa stansiya samaradorligi va iqtisodiy ko‘rsatkichlarini oshiradi.

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