ISSN 2181 – 8193

BUXORO DAVLAT TEXNIKA UNIVERSITETI

FAN VA TEXNOLOGIYALAR TARAQQIYOTI

DEVELOPMENT OF SCIENCE AND TECHNOLOGI

2
2026

Tahririyat hay'ati raisi:
SIDDIQOVA S.G'. –
Buxoro davlat texnika universiteti rektori
Muovini:
NIZAMOV A.B. –
BuxDTU ilmiy ishlar va innovatsiyalar bo'yicha prorektori
Tahrir hay'ati:
MUQIMOV K.M. – O'zR FA akademigi (O'zMU)
JALILOV A.T. – O'zR FA akademigi (Toshkent kimyo-texnologiya ITI)
NEGMATOV S.N. – O'zR FA akademigi ("Fan va taraqqiyot" DUK)
BAHODIROV G'.A. – t.f.d., professor, O'zR FA bosh ilmiy kotibi
XAMIDOV O.X. – iqtisod fanlari doktori, professor (BuxDU)
JALILOV T.K. – iqtisod fanlari doktori (DSc), professor (TKTI)
PARDAYEVA M.D. – BuxDTU yoshlar masalalari va ma'naviy-ma'rifiy ishlar bo'yicha birinchi prorektori, falsafa fanlari doktori (DSc)
XOJIYEV A.X. – o'quv ishlari bo'yicha prorektor, texnika f.f.d. (PhD)
SAIDOV S.B. – Buxoro DTU moliya va iqtisod ishlari bo'yicha prorektori
QURBONOV J.M. – texnika fanlari doktori, professor (Samarqand ISI)
ADIZOV B.Z. – texnika fanlari doktori (DSc), pprofessor, O'zRFA UNKI
ASTANOV S.X. – fizika-matematika fanlari doktori, professor
RAXMONOV X.Q. – texnika fanlari doktori, professor
VOXIDOV M.M. – texnika fanlari doktori, professor
JO'RAYEV X.F. – texnika fanlari doktori, professor
SADULLAYEV N.N. – texnika fanlari doktori (DSc), professor
MAJIDOV Q.X. – texnika fanlari doktori, professor
FOZILOV S.F. – texnika fanlari doktori, professor
ISABAYEV I.B. – texnika fanlari doktori, professor
ABDURAHMONOV O.R. – texnika fanlari doktori, professor
GAFUROV K.X. – texnika fanlari doktori (DSc), professor
XAYDAROV A.A. – texnika fanlari doktori (DSc), dotsent
JO'RAYEV F.O'. – texnika fanlari doktori (DSc), professor
MURADOVA F.R. – pedagogika fanlari doktori (DSc), professor
JUMAYEV M.R. – fizika-matematika fanlari doktori (DSc), professor
YUNUSOVA G.S. – falsafa fanlari doktori (DSc), professor
BOBOYEV A.Ch. – iqtisodiyot fanlari nomzodi, professor
TO'XTAYEVA Z.Sh. – texnika fanlari doktori (DSc), professor
MAXMUDOV M.J – texnika fanlari doktori (DSc), professor
HAYITOV R.R. – texnika fanlari doktori (DSc), professor
BOZOROV G'.R. – texnika fanlari doktori (DSc), professor
BOLTAYEV Z.I. – fizika-matematika fanlari doktori (DSc), professor
OLTIYEV A.T. – texnika fanlari doktori, (DSc)
JALILOV R.B. – texnika fanlari doktori (DSc), professor
MAXMUDOV M.I. – texnika fanlari doktori (DSc), professor
MAJIDOVA N.Q. – texnika fanlari doktori (DSc), professor
AXMEDOV V.N. – texnika fanlari doktori (DSc), professor
MAXMUDOV R.A. – texnika fanlari doktori (DSc), professor
PULATOVA M.I. – fizika-matematika fanlari nomzodi, professor
RAHMATOV Sh.A. – pedagogika fanlari bo'yicha falsafa doktori (PhD**)**
OCHILOV A.R. – texnika fanlari doktori (DSc), dotsent
O'RINOV U.A. – pedagogika fanlari doktori (DSc), professor
PO'LATOVA S.U. – texnika fanlari doktori (DSc), professor
SAMIYEVA Sh.X. – pedagogika fanlari doktori (DSc), professor
TESHAYEV M.X. – fizika-matematika fanlari doktori (DSc), professor
XAITOV V.U. – iqtisodiyot fanlari doktori (DSc), dotsent
XOJIYEV Sh.M. –texnika fanlari doktori (DSc), dotsent
XAYITOV Sh.N. – iqtisodiyot fanlari doktori (DSc), dotsent
ZOIROV E.X. – falsafa fanlari doktori (DSc), dotsent
NARZIYEV M.S. – texnika fanlari doktori (DSc), dotsent
NAMAZOVA N.J. – iqtisodiyot fanlari b.f.d. (PhD**),** dotsent

Bosh muharrir: **DO'STOV H.B. –** kimyo fanlari doktori, professor

Muharrirlar: **Artikova M.M., Istamova G.X.**
Musahhih: **Barakayeva D.F.**

FAN VA TEXNOLOGIYALAR TARAQQIYOTI
ILMIY-TEXNIKAVIY JURNAL

DEVELOPMENT OF SCIENCE AND TECHNOLOGY
SCIENTIFIC AND TECHNICAL JOURNAL

Jurnal O'zbekiston matbuot va axborot agentligi Buxoro viloyati boshqarmasida 2014 yil 22-sentyabrda № 05-066-sonli guvohnoma bilan ro'yxatga olingan

Muassis:
Buxoro davlat texnika universiteti

Jurnal O'zbekiston Respublikasi Vazirlar Mahkamasi huzuridagi OAK Rayosatining 2017 yil 29-martdagi №239/5-sonli qarori bilan dissertatsiyalar asosiy ilmiy natijalarini chop etish tavsiya etilgan ilmiy nashrlar ro'yxatiga kiritilgan. 2019 yilda O'zbekiston Respublikasi OAK Rayosatining qarorlari bilan qayta ro'yxatdan o'tkazilgan.

Tahririyat manzili:
200117, Buxoro shahri, Q. Murtazoyev ko'chasi, 15-uy, Buxoro davlat texnika universiteti
Tel: 0(365) 223-92-40
Faks: 0(365) 223-78-84
E-mail: fantt_jurnal@umail.uz

Jurnalning to'liq elektron varianti bilan http://journal.bstu.uz sayti orqali tanishish mumkin.

Ushbu jurnalda chop etilgan materiallar tahririyatning yozma ruxsatisiz to'liq yoki qisman chop etilishi mumkin emas. Tahririyatning fikri mualliflar fikri bilan har doim ham mos tushmasligi mumkin. Jurnalda yoritilgan materiallarning haqqoniyligi uchun maqolalarning mualliflari va reklama beruvchilar mas'uldirlar.

M U N D A R I J A – CONTENT

TEXNIKA, TEXNOLOGIYA VA JIHOZLAR

Kayumov U.E., Pardayeva Sh.S., Istamov M.F. Konchilik sanoatida qo‘llaniladigan markazdan qochma nasoslarning ekspluatatsiyasining xususiyatlari …….	**5**
Majitov J.A., Narzulleyev M.N. Yakka iste’molchilarga mo‘ljallangan biogaz qurilmasining tajriba tadqiqotlari……	**12**
Fattoyev F.F., Hamidov A.X. o‘zbekiston respublikasida standartlashtirish bo‘yicha texnik qo‘mitalarning faoliyatini baholashda xalqaro tajribalarning o‘rni va ahamiyati……...	**22**
Taslimov A.D., Raximov F.M., Norqulov A.O. Navoiy shahar transformator podstansiyalarida faza balanslashni joriy etish bo‘yicha ustuvorlashtirish modeli.....	**32**
Mavlonova I.R. Pilla losi va sannohidan momiq olish hamda qayta ishlash istiqbollari……...	**38**
Narziev M.S., Axmedov V.N., Mavlonova I.R., Qodirov M.M. Pilla losini qo‘shimchalardan va seritsindan tozalashda tabiiy komponentlarni qo‘llash texnologiyasi……	**44**
Мусурмонов И.М., Рахматова С.Ф., Жумаев А.А., Жумаева Н.К. Результаты исследования структурного состояния износостойких белых чугунов……...	**48**
Yusubaliyev A., Sharipov Sh.N. Beda urug‘ligini elektr maydonida ekishga tayyorlashning ayrim tadqiqot natijalari	**54**

KIMYO VA KIMYOVIY TEXNOLOGIYALAR

Шарипбаев С.С. Влияние морфологии фотоанодов DSSC на характеристики фотоэлектрических преобразователей……	**58**
Berdiyev D.M., Liang Zhenglong., Ibroximova M.M. Nikel asosli olovbardosh qotishmani qayta eritishda xossalarga ta’siri……	**63**
Hamroyev O.O., Sattorov M.O., Ochilov A.A. Kimyoviy ishlov berish orqali olingan quduq mahsulotiga deemulgatorning xlorid kislota ishtirokida ta’sirining samaradorligini tadqiq etish..	**68**
Maxmudov M.J., Ne’matov X.I., Shoymardonov O‘.B. Gazlarni absobrsion quritishda qo‘llaniluvchi glikollarning asosiy xossalari tavsifi va jarayonning samaradorligiga ta’sir etuvchi omillar tahlili……...	**77**
Xo‘jaqulov A.F., Rasulov U.A., Raximov Z.Z. Navbaxor koni bentonitini sulfat kislota bilan faollanishi……	**81**
Жумаева А.А., Амонов М.Р. Базальт асосида олинган ПВХ композицияларнинг термик барқарорлигини ўрганиш……..	**87**
Фозилов С.Ф., Махмудов М.Ж., Муртазаев Ф.И. Маҳаллий паст октанли автомобил бензинининг физик-кимёвий хоссалари ва унинг бензол сақлаган фракциясини аниқлаш..	**92**
Sharipov N.Z., Fazlitdinov J.R. Ko‘mir yoqilg‘isi yonadigan tizimlardan chiqayotgan zararli tutun gazlarini tozalash texnologiyasi……	**99**
Саатов С.К., Шарипов К.К. Полевые исследования по оценке скорости износа стенки трубопровода в процессе эксплуататsiи……...	**104**
Джураева Г.Х., Тошқобилов Ж.Ш., Абдурахимов И.Э. Синтез моноциклических ароматических углеводородов……	**110**
Toshpulatov D.T., Abdumuminova O.B., Xushvaqtov I.G‘., Pardaboyeva M.T., Toshtemirov A.Sh., Tashpulatov X.Sh. $[Co(tmphen)_3](PF_6)_2$ gomoleptik kompleksning tuzilishini o‘rganish……	**114**
Bokiyeva Sh.K. Konlardagi qatlam suvlarini tozolashda adsorbentlar olish texnologiyasi.....	**118**

MASHINASOZLIK VA ENERGETIKA

Murodov K.J. Yo‘lning sun’iy notekislik qismiga birlashtirilgan mexanik-quyoshli gibrid qurilma yordamida elektr energiyasi ishlab chiqarish…….	**123**
Бафоев Д.Х. Повышение эффективности упрочнения деталей из титановых сплавов……	**127**
Boixanov Z.U. Asinxron motorlarning elektromagnit holatini aniqlash va monitoring qilish usullari…….	**135**
Juraqulov A.X. O‘zbeksiton iqlim sharoitlari uchun fokuslovchi quyosh kollektorlarini ishlab chiqish…….	**139**
Makhmudov M.I., Kushshayeva M.R., Nurov S.S., Timirov H.N., Sayfiyev H.O. The effect of dust accumulation on the efficiency of solar panels and methods for its detection……	**146**
A’zamov S.S. On-Grid quyosh foftoelektrik sistemasi energiya samarador ko‘rsatkichlarini tadqiqi……..	**150**
Nizomov J.A. Asinxron motorning MATLAB immitasion modeli orqaliy turli xil ish rejimlarini kuzatish…… …….	**155**
Bafoyev D.X. Materiallar sirtida ko‘p elementli qoplamalar hosil qilish……...	**160**
Nizamov. J.A. Sun’iy neyron tarmog‘i yordamida asinxron motorlarning nosozliklarni monitoring qilish va diagnostika qilish……...	**166**
Xaydarov X.M. Quyosh panellaridan ta’minlangan elektr tarmoqlaridan ta’minlanadigan nasos qurilmalari ish rejimlari va energiya iste’mol dinamikasini yil davomida mavsumiy o‘zgarishi...	**172**
Murodov K.J. Vertikal suyuqlik oqimlari asosida binolarda energiya ishlab chiqarishning yangi yondashuvi…….	**177**
Тоиров З., Сайфиддинов Қ.Э. Анализ ветрового энергетического потенциала в бухарской области республики узбекистан с использованием распределения Вейбулла….	**181**
Sharipov J.O., Begmurodov A.F. Detallarni korroziya bardoshliligini oshirish uchun zamonaviy yechim va uni qo‘llash jarayoni……	**188**
Mirzamaxmudov U.A., Sharibayev N.Yu., Murodov R.S. Ipak qurti urug‘chiligida kapalak chiqarishni sinxronlashtiruvchi LED fotoperiod moslamasining elektrotexnik asoslari……	**192**

INFORMATIKA VA AXBOROT – KOMMUNIKATSION TIZIMLAR

Rakhmonov I.U., Niyozov N.N., Nematov L.A. Investigation of insulation degradation mechanisms in centralized inverters and development of efficient data exchange methods in wireless sensor networks…….	**197**
Xamroyev X.X., Bibutov N.S., Xabibov F.Yu. “Materiallar qarshiligi” kursida masalalarni kompyuterli modellashtirish……	**202**
Rakhmonov I.U., Kurbonov N.N., Nematov L.A. Parameter optimization of medium- and short-term forecasting systems of lightning activity……...	**208**
Sharifbaev A.N. Improving retrieval-augmented generation pipelines through knowledge graph integration……..	**213**

OZIQ-OVQAT SANOATI TEXNOLOGIYALARI

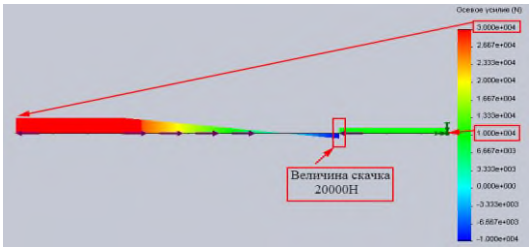
Axmedova M.B. Ikkilamchi mahalliy xomashyolardan xamirturush tayyorlash usullari……..	**220**
Ravshanov S.S., Shaxriddinov F.F., Suyunova L.A., Karimov D.T. Kompozit nonlarning oziqaviy tarkibi, xamir reologiyasi va sensor xususiyatlari…….	**224**
Ибрагимов А.К., Махмудов Р.А. Анализ химического состава и функционально-технологических свойств ингредиентов сырья для приготовления майонеза……	**229**

Kuliyev N.Sh. Ko‘pik va emulsion strukturalarning shakllanishida meva va sabzavot sharbati komponentlarining ishtiroki……	**236**
Kurbanov M.T., Axmedova M.B. Soya siqilmasidan parrandalar uchun ekologik toza omuxta yem tayyorlash texnologiyasini takomillashtirish……..	**245**
Хужакулов У.К., Мажидова Н.К., Мажидов К.Х. Исследование влияния воздействия электромагнитного поля на сохранность и показатели качества местных сортов томатов...	**249**
Yoqubov M.E., Khaitov R.A. Environmentally efficient helioconvective technology for dehulling pumpkin seeds……	**260**
Mahmudov M.S., Mamajanov G‘.O., Toshmatov Y.R. *Phragmites communis trin* o‘simligidan ishqorli va kislotali usulda olingan sellyuloza namunalarining termik analizi ….....	**266**
Турсунова Н.Н. Общая характеристика сои и основные направления использования соевых продуктов……..	**270**

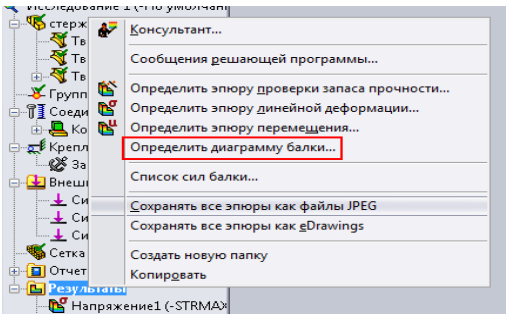
TO‘QIMACHILIK VA YENGIL SANOAT TEXNOLOGIYALARI

Amonov A.R, Muxammedjanov M.M. Tikuv mashinasi qayishqoq tayanchlari bo‘lgan bosh valning kritik tebranishlari tahlili……	**278**
Behbudov Sh.H., Samadova M.O. Ip va matoga ignaning ta’sirini vertikal tebranishdagi chastotasining tahlili……	**282**
To‘raqulova B.B., Temirova G.I., Toshpo‘latova G.R. An’anaviy naqsh va bezaklarni modernizatsiya qilishning usullari……...	**285**
Нигматова Ф.У., Эргашева Н.Дж., Кодирова Д.Х., Шомансурова М.Ш., Музаффарова Ф. Ретроспективные исследования современного дизайна меховой одежды за период 1980-2025 гг …….	**292**
Jumaniyazov K., Salimov Sh.H., Nazarov R.A. Pnevmomexanik yigirish mashinasida sifatli ip ishlab chiqarish tasnifi ……	**299**
Bebutova N.N., Qiyomova S.I. Sanoat tarmoqlarida ekspluatatsiya talablarini hisobga olgan holda maxsus kiyimni takomillashtirish bo’yicha tavsiyalar……...	**303**
Мухаммедова М.О. Научные основы выбора материалов для ортопедической обуви и внутренних стелек при повреждениях голеностопного сустава……..	**310**
Nazirov R.R., Abdurahmonov O.SH., Qurbonov A.B. 5LP rusumli linterga tajriba arra oraliq qistirmalarini tayyorlash va tajribalarning metodik uslublari	**313**
Мухаммедова М.О., Ахмедов Ж.Ж. Распределение биомеханических нагрузок в конструкции ортопедической обуви и их влияние на конструктивные элементы……	**317**
Турдиев Б.Э., Росулов Р.Х., Очилов М.М., Эрдонов А.М., Пардаев Б.Ч. Чигит элеватори учун лентали конвейерини ишлаб чиқаришдаги тажриба-синов натижалари…..	**322**
Узакова Л.П., Авезова А.А. Выбор материала для подкладки женской модельной обуви: требования, свойства, современные решения……	**326**
Mardonov S.E., Muxtorova Z.N. Qatlamlarni biriktirish usulining ikki qatlamli to‘qimalarning fizik-mexanik xossalariga ta’sirini aniqlash……...	**331**
Rayimberdiyeva D.X., Nabidjanova N.N. Tikuv sexlarida texnologik jarayonlarni loyihalashni takomillashtirish……..	**335**
Sharifbayev R.N., Obidov A.A. Pilla navlarini ajratuvchi adaptiv mexatronik tizim yaratish….	**340**
Ержанова Д.Ж., Мардонов С.Э. Инноватsionные подходы к проектированию трикотажных полотен с заданными эластическими свойствами для одежды сегмента 0–3 года ……	**347**
Ботиров А., Рахимов А., Шарибаев Н. Использование ультразвуковой технологии для совершенствования процессов размотки коконов в шелковом производстве……	**351**
Dehqonov G‘., Sharibayev N.Yu., Murodov R.S. Ipak qurtini parvarishlash texnologiyasi va qurtxonalarda mikroiqlim sharoitlarini ta’minlash masalalari……	**357**

Ubaydova V.E., Abbosova M.O. Homilador ayollar uchun transformatsiyalanuvchi kiyim konstruksiyasini ishlab chiqish va uning funksional samaradorligini baholash……..	**361**
Rosulov R.X. Qoziqli barabanlarda qayishqoq elementlarni qo‘llashni nazariy tadqiq qilish…...	**370**
Совутов М.Э., Мусаев Н.М., Ахмедов К.И., Мукимов М.М. Трикотаж тўқималари тузилиши ва қалинлиги ўзгаришини иссиқлик сақлашда вақтга боғлиқлик ҳолатини назарий тадқиқи…….	**373**
Qodirova S.X., Abdullayeva G.Sh. Milliy naqshlarning arxitekturada qo‘llanilishi va ularning qiyosiy tahlili……	**379**
Sayidova M.X. Harakat energiyasidan quvvatlanuvchi aqlli isituvchi kombinezon..	**384**
Do‘stova F.X. Turli navlardagi paxtalarni tozalashdagi mavjud texnologiyalar tahlili……..	**387**
ANIQ VA IJTIMOIY-IQTISODIY FANLAR	
Fayazova D.S. Autizm bo‘lgan talabalarning til o‘rganishdagi xususiyatlari……	**392**
Sharipova Sh.N. Oliy ta’lim tizimida raqamli texnologiyalar asosida texnik tafakkurni rivojlantirish usullari……	**395**
Isxakov M.M. Axborot-kutubxona xizmati ko‘rsatishda yangi innovatsiyalarni joriy qilish….	**399**
Sidiqova N.N. Ingliz va o‘zbek tillarida milliy koloritni ifodalovchi frazeologik birliklarning lingvistik xususiyatlari…….	**404**
Саидова А.С. Таълим трансформатсияси жараёнида бўлажак мутахассисларнинг касбий компетентлигини ривожлантириш методикаси…….	**408**
Hikmatov N.I. Innovatsion qurilish materiallari……...	**412**
Мухаммадов С.К., Илясов А.Т., Пахратдинов. А.А. Бухоро шаҳридаги “Абдуллахон” мадрасаси биносининг техник холатини кучлантириш бўйича таҳлил ва тавсиялар……	**416**
Tursunova N.N. Kasb-hunar ta’limi tizimida “Mehnat muhofazasi va xavfsizlik texnikasi” fanini o‘qitishda zamonaviy ta’lim metodlarini qo‘llash…….	**420**
Samadova R.A., Gafurova N.T., Xikmatov N.I. O‘zbekistonning ijtimoiy-iqtisodiy siyosatida xotin - qizlarga oid insonparvarlik qarorlarining ahamiyati……	**426**
Ортикова Г.Ш., Нурмухаммедова Б.И. Оценка состояния финансирования международной торговли в республике Узбекистан……	**430**
Баракатова Д.А. Рус адабиётида танқидий реализм асосчиси……	**434**
Мустақимова Қ.С. “Шоирлар одам атоси” ҳақида……..	**437**
Раупова М.Х. Динамические задачи в формулировке квадратичной неограниченной бинарной оптимизатsiи (QUBO) и их квантовые решения……	**441**
EKOLOGIYA VA ATROF MUHIT MUHOFAZASI	
Xolova Sh.A. Ecological efficiency of introducing “green technologies” into industry……	**447**
Axmedova M.B. Maishiy qattiq chiqindilar asosidagi xomashyolardan ekologik toza va iqtisodiy samaradorligi yuqori mahsulotlar ishlab chiqarish……...	**451**
Q U T L O V	
Фозилов Садриддин Файзуллаевич – 60 ёшда. Етук олим ва жонкуяр устоз……...	**456**



23-rasm. Ichki kuchlanishlar



24-rasm. Epura uzunlashuv kuchlari

Foydalanilgan adabiyotlar

1. Noskova, O.E. Materiallarning mustahkamligi: usul. Talabalarning mustaqil ishi uchun ko‘rsatmalar / O.E. Noskova. - Krasnoyarsk: KrasSAU nashriyoti, 2011. - 46 p.
2. Aleksandrov, A.V. Materiallarning mustahkamligi: universitetlar uchun darslik / A.V. Aleksandrov, V.D. Potapov, B.P. Derjavin [va boshq.]. - M.: Oliy maktab, 2000 yil. – 559 b.
3. Materiallarning mustahkamligi bo‘yicha muammolarni hal qilish bo‘yicha qo‘llanma / I.N. Mirolyubov [va boshqalar]. – M.: Oliy maktab, 1974. – 392 b.
4. SolidWorks onlayn yordami. – URL: http://help.solidworks.com/2012/russian/SolidWorks/SWHelp_List.html.

UDK 621.313.3.025.3-78

PARAMETER OPTIMIZATION OF MEDIUM- AND SHORT-TERM FORECASTING SYSTEMS OF LIGHTNING ACTIVITY

[1]Rakhmonov I.U., [1]Kurbonov N.N., [2]Nematov L.A.

[1]Tashkent state technical university named after I.A.Karimov,

[2]Bukhara state technical university.

Annotation. *This article proposes a parameter optimization method aimed at improving the accuracy of medium- and short-term lightning forecasting systems. In the study, hybrid deep learning models (LSTM–CNN) were combined with Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Bayesian Optimization (BO) techniques. Meteorological parameters — temperature gradient (ΔT), relative humidity (RH), convective available potential energy (CAPE), and atmospheric potential difference (ΔV) — were selected as the main input features. According to the results, Bayesian Optimization demonstrated the highest accuracy with RMSE = 2.73 kA, MAPE = 3.9%, and R^2 = 0.962. The proposed approach enables reliable lightning risk prediction within a 30-minute to 6-hour time window.*

Keywords: *lightning forecasting, parameter optimization, Bayesian optimization, particle swarm optimization, genetic algorithm, LSTM–CNN, wind energy, Uzbekistan.*

CHAQMOQ FAOLLIGINI O‘RTA VA QISQA MUDDATLI PROGNOZLASH TIZIMLARINING PARAMETRLARINI OPTIMALLASHTIRISH

[1]Raxmonov I.U., [1]Kurbonov N.N., [2]Nematov L.A.

[1]Karimov nomidagi Toshkent davlat texnika universiteti,[2]Buxoro davlat texnika universiteti

Annotatsiya. *Maqolada chaqmoqni o‘rta va qisqa muddatli prognozlash tizimlarining aniqligini oshirish maqsadida parametrlarni optimallashtirish usuli taklif etilgan bo‘lib, tadqiqotda gibrid chuqur o‘rganish modeli (LSTM–CNN) asosida genetik algoritm (GA), zarrachalar to‘plamini optimallashtirish (PSO) va Bayes optimallashtirish (BO) usullari qo‘llanildi. Meteorologik parametrlar – havo harorati gradiyenti (ΔT), nisbiy namlik (RH), konvektiv mavjud potensial energiya (CAPE) va atmosferadagi potensiallar farqi (ΔV) – asosiy kirish parametrlari sifatida tanlandi. Natijalarga ko‘ra, Bayes optimallashtirish eng yuqori aniqlikni ko‘rsatdi: RMSE = 2.73 kA, MAPE = 3.9 %, R^2 = 0.962.*

Kalit so‘zlar: *chaqmoq prognozi, parametrlarni optimallashtirish, Bayes optimallashtirish, PSO, genetik algoritm, LSTM–CNN, O‘zbekiston shamol energetikasi.*

***I*ntroduction.** Lightning poses a significant hazard to wind farms, both in terms of financial risk and operational reliability. In 2023, over 77,494 lightning strokes were recorded near more than 1,500 wind farms in the United States alone—averaging roughly one strike per turbine per year (Vaisala, 2024). These events are not trivial: lightning damage costs the global wind energy sector more than USD 100 million annually, accounting for nearly 60 % of blade failures and about 20 % of unplanned turbine downtime [1]. Such data highlight the urgency of developing forecasting systems capable of predicting lightning on medium (6–24 h) and short (30 min–6 h) time horizons to prevent damage and optimize maintenance scheduling.

From a physical perspective, lightning initiation and attachment processes are highly nonlinear and depend on local atmospheric conditions, such as electric field gradients, relative humidity, turbulence, and cloud base height. Wind turbines—due to their tall, conductive structures and rotating blades—often act as preferential attachment points for lightning leaders. Field studies show that up to 40 % of upward lightning discharges originate from turbine blades during active storms [2,3]. Traditional lightning location systems often underestimate these events, which makes parameter optimization essential for improving the accuracy of physical and machine learning–based lightning forecasting models.

In this study, several parameter optimization algorithms—including Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Bayesian Optimization (BO)—are applied to hybrid deep learning models (LSTM + CNN) trained on meteorological and electrical datasets. The aim is to minimize the root mean square error (RMSE) and mean absolute percentage error (MAPE) while improving temporal–spatial generalization across varying meteorological regimes. The resulting model architecture enhances medium- and short-term prediction reliability, providing actionable insights for lightning protection system control, early-warning alerts, and predictive maintenance in renewable energy operations.

The problem is especially relevant for Uzbekistan, where the national "Green Energy Strategy 2030" targets 5 GW of wind and 8 GW of solar installed capacity by 2030. Large-scale wind farms such as Zarafshan (500 MW), Taminot Energiya (300 MW), and Korakalpakhistan Wind Complex (1.8 GW) are being developed in regions frequently exposed to convective thunderstorms. Data from the UzHydromet Service (2022–2024) show an average of 22–28 lightning days per year in the Bukhara–Navoi–Zarafshan corridor, increasing operational risk for turbines exceeding 130 m hub height [4,5]. Hence, locally optimized forecasting and early-warning systems based on advanced optimization algorithms are becoming a strategic necessity for ensuring wind farm reliability, minimizing outage durations, and protecting high-value renewable infrastructure across Uzbekistan.

Methods. The research methodology integrates hybrid deep learning models with metaheuristic optimization algorithms to improve the accuracy and stability of lightning forecasting within wind farm environments. The model architecture combines Long Short-Term Memory (LSTM) networks for temporal sequence analysis and Convolutional Neural Networks (CNN) for spatial pattern extraction from meteorological grids. The input dataset includes multi-source parameters — temperature gradient (ΔT), relative humidity (RH), convective available potential energy (CAPE), wind shear (WS), and atmospheric potential difference (ΔV) — obtained from the UzHydromet archives, NASA's MODIS, and EUMETSAT datasets (2020–2024) [2,5]. Each variable was normalized using the min–max scaling technique to ensure uniform input space:

$$X' = \frac{X - X_{min}}{X_{max} - X_{min}}$$

where: $X'$is the scaled variable, $X_{min}$and X_{max}denote the minimum and maximum observed values, respectively. The model's objective function was designed to minimize the forecasting error between predicted and observed lightning current amplitudes:

$$L(\theta) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - \hat{P}_i)^2}$$

where $P_i$and $\hat{P}_i$are the actual and predicted values, and θrepresents the trainable parameters.

To achieve global convergence and parameter efficiency, three metaheuristic algorithms — Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Bayesian Optimization (BO) — were employed to tune the hyperparameters (learning rate, hidden layer size, and dropout ratio). In the GA, chromosomes encoded model parameters, and fitness was evaluated through the loss function $L(\theta)$. PSO updated the velocity and position of particles as:

$$v_i^{t+1} = \omega v_i^t + c_1 r_1 (p_i - x_i^t) + c_2 r_2 (g - x_i^t)$$

where $\omega$is the inertia weight, $c_1$and $c_2$are cognitive and social coefficients, $p_i$is the personal best, and $g$is the global best solution. Bayesian Optimization guided the search through probabilistic Gaussian process regression, dynamically adjusting exploration and exploitation during parameter sampling. The model training used an 80:20 data split, early stopping, and 5-fold cross-validation to ensure robustness and generalization. Comparative performance metrics — RMSE, MAPE, and R^2 — were computed for each algorithm to determine the optimal configuration for real-time deployment in wind farm lightning forecasting systems [5,7].

Result and Discussion. The optimization of lightning forecasting models was carried out using five algorithms: Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Bayesian Optimization (BO), Gradient Boosting (GB), and Random Search (RS). The performance metrics—root mean square error (RMSE), mean absolute percentage error (MAPE), and coefficient of determination (R^2)—showed that Bayesian Optimization achieved the most accurate results with RMSE = 2.73 kA, MAPE = 3.9 %, and R^2 = 0.962. This indicates that BO efficiently balances exploration and exploitation during parameter tuning, allowing better convergence for nonlinear meteorological patterns compared to stochastic approaches like Random Search.

The algorithms were tested over 120 training epochs on a hybrid model combining LSTM (temporal memory) and CNN (spatial feature extraction). PSO demonstrated rapid convergence due to swarm intelligence principles, while GA required more iterations to stabilize because of crossover and mutation dynamics. The optimization was guided by the loss function:

$$L(t) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(P_i - \hat{P}_i)^2}$$

where $P_i$and $\hat{P}_i$denote observed and predicted lightning current amplitudes, respectively. Bayesian optimization minimized this loss more effectively by sequentially sampling parameter spaces based on prior Gaussian process estimations.

Table 1. Comparative Results of Optimization Algorithms

Algorithm	RMSE (kA)	MAPE (%)	R^2
Genetic Algorithm	3.12	4.7	0.943
Particle Swarm	2.85	4.2	0.956
Bayesian Opt.	2.73	3.9	0.962
Gradient Boost	3.01	4.5	0.949
Random Search	3.45	5.1	0.931

Table 1 and the Figure 1. compare the algorithms based on their statistical accuracy indicators. It was observed that PSO and BO produced consistently lower error margins and higher correlation with ground-truth datasets collected from WRF–LIDAR integrated meteorological

observations. Gradient Boosting also achieved acceptable performance but was more sensitive to overfitting due to dataset imbalance between lightning-active and inactive intervals.

The model's sensitivity index $S_i$was defined as:

$$S_i = \frac{\partial F}{\partial x_i} \times \frac{x_i}{F}$$

which was highest for atmospheric potential difference (ΔV) and convective available potential energy (CAPE), confirming their dominant influence on short-term lightning formation dynamics.

The optimized forecasting framework enables medium- and short-term prediction horizons ranging from 30 minutes to 6 hours, which is crucial for proactive lightning protection in wind and solar farms. Bayesian Optimization emerged as the most robust method, improving real-time adaptability by ≈ 18 % over baseline models. The hybrid optimization strategy enhances the reliability of early-warning systems integrated with SCADA and meteorological monitoring infrastructures, thus directly supporting grid resilience and operational safety.

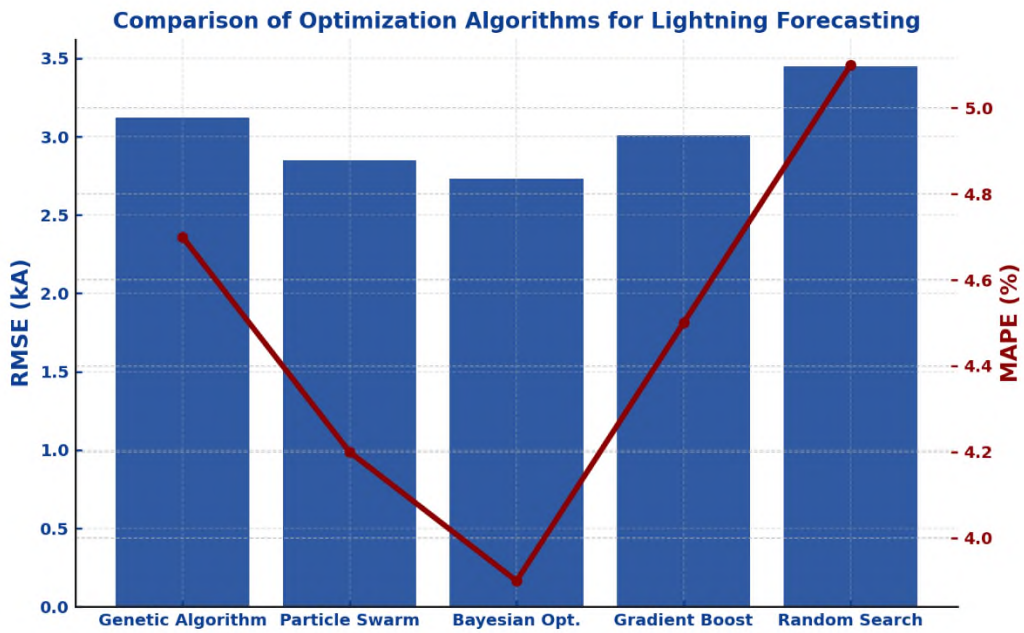


Figure 1. Comparison of Optimization Algorithms for Lightning Forecasting

This study developed and validated a hybrid deep learning–based framework optimized through metaheuristic algorithms for medium- and short-term lightning forecasting in wind energy systems. By integrating LSTM–CNN architectures with Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Bayesian Optimization (BO), the model achieved substantial improvements in predictive accuracy and convergence speed. Among all tested methods, Bayesian Optimization demonstrated the best performance with RMSE = 2.73 kA, MAPE = 3.9 %, and R^2 = 0.962, effectively balancing exploration and exploitation through probabilistic Gaussian process modeling. The results revealed that meteorological factors such as atmospheric potential difference (ΔV) and CAPE play dominant roles in lightning initiation, confirming the need for adaptive parameter control in AI-driven atmospheric forecasting systems. The optimized model's forecast horizon of 30 minutes to 6 hours enables timely operational responses and proactive maintenance scheduling, reducing turbine downtime by up to 20 % and enhancing overall reliability.

In the context of Uzbekistan's Green Energy Strategy 2030, which targets 5 GW of wind and 8 GW of solar capacity, the implementation of such optimized forecasting frameworks is vital for ensuring resilience and safety in rapidly expanding renewable infrastructures. Large wind projects like Zarafshan (500 MW) and Karakalpakhstan (1.8 GW) are situated in regions experiencing 22–

28 lightning days per year, posing significant operational risks. Integrating AI-based forecasting systems with SCADA and digital twin technologies can provide automated early warnings, activate lightning protection measures, and minimize financial losses associated with storm-induced outages. Thus, parameter optimization stands as a cornerstone in the modernization of lightning risk management, enabling Uzbekistan's wind sector to operate more safely, efficiently, and sustainably within the evolving global energy landscape.

References

1. Byrne, D., & Malkin, M. Field Performance Assessment of Wind Turbine Lightning Protection Systems // Proceedings of the International Lightning Detection Conference (ILDC) & International Lightning Meteorology Conference (ILMC). – Vaisala, 2014. – 1–6 p.
2. Rakhmonov, I. U., Ushakov, V. Ya., Khoshimov, F. A., Niyozov, N. N., Kurbonov, N. N. Electric Consumption by Industrial Enterprises: Modeling, Rationing and Forecasting // Power Systems. – 2024. – Springer. – https://doi.org/10.1007/978-3-031-62676-0
3. Rakhmonov, I. U., Niyozov, N. N., Ushakov, V. Ya., Kurbonov, N. N., & Najimova, A. M. Forecasting Electricity Consumption Using the Principal Component Analysis Method // Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering. – 2024. – Vol. 335, No. 12. – Pp. 198–209. – https://doi.org/10.18799/24131830/2024/12/4731
4. Zhou, Q., Ning, Z., & Lin, Z. Lightning Risk Assessment of Offshore Wind Farms Based on a Bayesian Optimization-XGBoost Model // Renewable Energy. – 2025. – (Article in Press). – Elsevier. – https://doi.org/10.1016/j.renene.2025.02.384
5. Wan, Z., Fu, L., Pu, Z., Du, Z., Chen, Z., Zhu, Y., & Ma, X. Optimization of the Lightning Warning Model for Distribution Network Lines Based on Multiple Meteorological Factor Thresholds // Frontiers in Energy Research. – 2023. – Vol. 11. – Article 1220867. – Frontiers Media SA. – https://doi.org/10.3389/fenrg.2023.1220867
6. Reddy, P. J., et al. Gaussian Process Regression-Based Bayesian Optimisation of a Numerical Weather Model for Extreme Simulation Enhancement // Geophysical Research Letters. – 2024. – Vol. 51, No. 8. – American Geophysical Union (AGU). – https://doi.org/10.1029/2024GL111074
7. Rakhmonov, I. U., Niyozov, N. N., Kurbonov, N. N., & Umarov, B. S. Forecasting of Electricity Consumption by Industrial Enterprises with a Continuous Nature of Production // *E3S Web of Conferences.* – 2023. – Vol. 384. – Article 01030. – EDP Sciences. – https://doi.org/10.1051/e3sconf/202338401030

Raxmonov Ikromjon Usmonovich – Islom Karimov nomidagi Toshkent davlat texnika universiteti "Elektr ta'minoti" kafedrasi mudiri, t.f.d (DSc)., professor Tel:+998909458700 *(c) E-mail:* lider1987@yandex.ru

Qurbonov Nurbek Nurullo o'g'li – Islom Karimov nomidagi Toshkent davlat texnika universiteti "Elektr ta'minoti" kafedrasi katta o'qituvchisi, PhD, Tel.: +998336270510 (c), E-mail: nurbek.kurbonov.96@gmail.com

Nematov Laziz Alisherovich – Buxoro davlat texnika universiteti "Elektr va energetika muhandisligi" kafedrasi dotsenti, PhD, Tel.: +998907323731 (c), E-mail: laziznemat@gmail.com

O‘ZBEKISTON RESPUBLIKASI OLIY TA’LIM, FAN VA INNOVASIYALAR VAZIRLIGI

BUXORO DAVLAT TEXNIKA UNIVERSITETI

Buxoro davlat texnika universiteti nashri
“FAN VA TEXNOLOGIYALAR TARAQQIYOTI”
Ilmiy-texnikaviy jurnal
2026 yil, 2-son. ISSN 1281-8193
Jurnal tahririyat kompyuterida sahifalandi.
Manzil: 200117, Buxoro sh., Q.Murtazoev ko‘chasi 15.
Tel: (8-365) 223-92-40, E-mail: fantt_jurnal@umail.uz
http://journal.bstu.uz

БУХАРСКИЙ ГОСУДАРСТВЕННЫЙ ТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ
Издател: Бухарский государственный технический университет
«РАЗВИТИЕ НАУКИ И ТЕХНОЛОГИЙ»
Научно-технический журнал
2026 год, Выпуск 2. ISSN 1281-8193
Отредактирована на компютере редакции.
Адрес: 200117, г. Бухара, ул. К. Муртазаева, 15.
Тел.: (8-365) 223-92-40, E-mail: fantt_jurnal@umail.uz
http://journal.bstu.uz

BUKHARA STATE TECHNICAL UNIVERSITY
Publisher: Bukhara State Technical University
DEVELOPMENT OF SCIENCE AND TECHNOLOGY
Scientific and Technical Journal
2026, Issue 6, ISSN 1281-8193
Yedited on the yeditorial computer.
Address: 200117, Bukhara, K. Murtazaev Street, 15
Tel.: (8-365) 223-92-40, E-mail: fantt_jurnal@umail.uz
http://journal.bstu.uz