



Elektromobillarda quvvat topologiyalari va kuchlanish arxitekturalari tahlili

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Dolzarbli: yurtimizda va dunyoda Elektromobillar (EV) sonining ortib borishi ushbu sohada foydalanilayotgan quvvat topologiyalari va kuchlanish arxitekturalarini o‘rganishni talab etadi. Haydovchilar yoki elektromobillar egalariga qulaylikni ta‘minlash maqsadida energiya samaradorligi va quvvatlash tezligini oshirish turli kuchlanish platformalarini qo‘llashni talab etmoqda. Biroq, har bir kuchlanish darajasining texnik va iqtisodiy chegaralarini aniq belgilash hamda ularning optimal qo‘llanilish sohaslarini asoslash muhim masalalardan biri bo‘lib qolmoqda. Ushbu ilmiy maqolada aynan hozirda keng qo‘llanilayotgan tizim arxitekturalari tahlil qilingan.

Maqsad: ushbu tadqiqotning maqsadi elektromobillarda foydalaniladigan kuchlanish turlarini qiyosiy tahlil qilish, hozirda energiya tizimlarida qo‘llanilayotgan tok va kuchlanish turlarini o‘rganish, 400V va 800V kuchlanishli arxitekturalarning ko‘rsatkichlarini qiyosiy tahlil qilish hamda turli segmentdagi elektromobillar uchun keng tarqalgan optimal kuchlanish platformasining mezonlarini aniqlashdan iborat.

Usullar: tadqiqot natijalarini olish uchun elektr yurtimoli avtotransport vositalari sohasidagi 2021-2026 yillardagi adabiyotlarni Bul operatorlaridan foydalangan holda aniqlash, tanlab olingan maqolalarni tahlil qilish, solishtirish va o‘rganish.

Natijalar: elektromobillarda akkumulyator batareyasi turidan qat’iy nazar undagi jihozlar va yordamchi qurilmalar, haydovchilar uchun qulaylik yaratish kabi xususiyatlardan kelib chiqib turli o‘zgaruvchan va o‘zgarmas tok, yuqori kuchlanish turlari iste’molchilariga ega bo‘lgan murakkab energetik tizim sifatida qarash mumkin.

Kalit so‘zlar: elektromobil, akkumulyator batareyasi, quvvat, tok, kuchlanish, zaryadlash, standartlar.

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Анализ топологий питания и архитектуры напряжения в электромобилях

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Актуальность: рост числа электромобилей (EV) в нашей стране и в мире требует изучения силовых топологий и архитектур напряжения, используемых в данной сфере. В целях обеспечения удобства водителей и владельцев электромобилей повышение энергоэффективности и скорости зарядки требует применения платформ с различным уровнем напряжения. Однако одним из важных вопросов остается точное определение технических и экономических границ каждого уровня напряжения, а также обоснование оптимальных сфер их применения. В данной научной статье проанализированы именно те системные архитектуры, которые широко применяются в настоящее время.

Цель: целью данного исследования является проведение сравнительного анализа типов напряжений, используемых в электромобилях, изучение типов тока и напряжения, используемых в настоящее время в энергосистемах, проведение сравнительного анализа показателей работы архитектур напряжений 400 и 800 В, а также определение критериев наиболее распространенной оптимальной напряженной платформы для электромобилей в различных сегментах.

Методы: для получения результатов исследования были выявлены литературы в области электромобилей за 2021-2026 годы с использованием Булевых операторов, а также проанализированы, сопоставлены и изучены полученные статьи.



Результаты: независимо от типа аккумуляторной батареи в электромобилях, ее можно рассматривать как сложную энергетическую систему с различными типами потребителей, как переменного, так и постоянного тока, высокого напряжения, исходя из особенностей оборудования и вспомогательных устройств, удобства для водителей.

Ключевые слова: электромобиль, аккумулятор, мощность, ток, напряжение, зарядка, стандарты.

Analysis of power topologies and voltage architectures in electric vehicles

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Relevance: the growing number of electric vehicles (EVs) in our country and around the world necessitates the study of the power topologies and voltage architectures used in this field. To ensure the convenience of drivers and electric vehicle owners, improving energy efficiency and increasing charging speeds require the use of various voltage platforms. However, accurately defining the technical and economic limits of each voltage level and justifying their optimal areas of application remains a crucial issue. This research paper analyzes the system architectures that are currently widely used.

Aim: the aim of this study is to conduct a comparative analysis of the voltage types used in electric vehicles, study the current and voltage types currently used in power systems, conduct a comparative analysis of the performance indicators of 400V and 800V voltage architectures, and determine the criteria for the most common optimal voltage platform for electric vehicles in various segments.

Methods: to obtain the research results, the literature in the field of electric vehicles for 2021-2026 was identified using Boolean operators, and the obtained articles were analyzed, compared, and studied.

Results: regardless of the type of battery in electric vehicles, it can be considered as a complex energy system with various types of consumers, both alternating and direct current, high voltage, based on the features of equipment and auxiliary devices, convenience for drivers.

Keywords: electric car, battery, power, current, voltage, charging, standards.

1. Kirish (Introduction)

Dunyoda ichki yonuv dvigatelli avtomobillar bilan bir qatorda elektr yuritmalı avtotransport vositalariga bo'lgan talab ham tobora ortib bormoqda. Ma'lumotlarga ko'ra 2020–2030-yillarda elektr yuritmalı avtotransport vositalariga bo'lgan talabning oshishi, ayniqsa elektromobillar ishlab chiqarishga e'tibor berilishi natijasida ko'plab davlatlarda ulardan foydalanuvchilarning soni jadallik bilan ommalashmoqda [1]. Jumaladan, O'zbekiston Respublikasi Milliy statistika qo'mitasining ma'lumotlariga ko'ra yurtimizda 2026-yilning 1-aprel holatiga ko'ra 109,2 mingta elektromobil ro'yxatga olingan [2]. Hozirgi kunda elektr yuritmalı avtomobillarning to'rtta asosiy, ya'ni boshqalarga nisbatan keng tarqalgan guruhi mavjud bo'lib, ularga quyidagilar kiradi: akkumulyatorli elektromobillar (BEV), tarmoqdan quvvatlanuvchi gibrid elektromobillar (PHEV), an'anaviy gibrid elektromobillar (HEV) va yonilg'i elementli elektromobillar (FCEV) [3]. Ushbu maqolada biz eng muhim energetik qismlardan biri bo'lgan akkumulyator batareyalari bloki tuzilishi bir-biriga o'xshash bo'lgan akkumulyatorli va gibrid elektromobillarda quvvat va tok shakllari hamda kuchlanish sohalarining tahlilini amalga oshiramiz.

1. Akkumulyatorli elektromobil: an'anaviy IYoD bilan jihozlanmagan bo'lib, u to'liq akkumulyator batareyasi va elektr uzatma orqali harakatlanadi. Batareyalarni quvvatlantirish uchun elektr manbaiga ulash talab etiladi. Avtomobil to'liq batareyalardan quvvat oluvchi elektr motorlariga tayanadi.

2. Elektr tarmog'idan quvvatlanuvchi gibrid elektromobillar: IYoD va elektr tarmog'iga ulanish orqali quvvatlanadigan batareyalar bilan jihozlanadi. Batareya quvvati pasayganda va ko'proq quvvat talab qilinganda, bu dvigatel batareyani quvvatlashi yoki elektr uzatmaning o'rnini to'liq bosishi mumkin. PHEVlarni umumiy stansiyalarda quvvatlash imkoniyati ulardan foydalanishni an'anaviy gibridlarga nisbatan arzonroq bo'lish ehtimolini oshiradi [4].



Yuqoridagi elektromobillarning asosiy energetik qismlariga quyidagilar kiradi: akkumulyator batareyalari, elektr dvigateli, transmissiya, bortli zaryadlovchi qurilma, DC/AC inverteri, DC/DC konvertori va elektron boshqaruv tizimi. Asosiy jihat shundaki, bunda akkumulyator batareyasi quvvati elektr dvigatelining quvvatiga mos kelishi kerak va bu qismni shunday tanlash kerakki, elektromobilni nafaqat harakatlanishini, balki yetarlicha masofa bosib o'tishini ham ta'minlashi kerak [5].

2. Materiallar va usullar (Methods and materials)

Ushbu maqola eksperimental tadqiqotlarga emas, balki tizimli tahlil prinsiplariga asoslanadi. Elektromobillar (BEV) va gibrid avtomobillar (HEV) elektr arxitekturasiga oid xalqaro ilmiy adabiyotlarni tanlashda qat'iy mezonlar qo'llanildi. Asosiy maqsad turli kuchlanish standartlari (400V, 800V va 800+V) hamda AC/DC topologiyalarini o'rganish bo'lgani uchun, qidiruv va filtrlash jarayoni bevosita muhandislik yechimlari tahliliga yo'naltirildi.

Ma'lumot manbalari va qidiruv strategiyasi:

Tahlil bazasi sifatida Scopus, Web of Science va ScienceDirect ilmiy platformalarini tanlandi. Ma'lumotlarni saralashda mantiqiy qidiruv operatorlaridan (Boolean search) foydalanildi. Qidiruvni sarlavha, annotatsiya va kalit so'zlar (TITLE-ABS-KEY) orqali amalga oshirib, bunda "EV" "Battery architecture", "Voltage", "Standards", "Topology", "400V OR 800V", hamda "AC/DC topologies" kabi texnik atamalar kiritildi, "AND", "OR" kabi operatorlardan foydalanildi. Tahlil obyekti doimiy rivojlanib boruvchi soha bo'lgani sababli, qidiruv asosan so'nggi yillarda chop etilgan dolzarb nashrlar bilan cheklanildi.

Saralash va filtrlash mezonlari:

Maqolaning ilmiy qiymati va ishonchliligini ta'minlash uchun yig'ilgan materiallar qat'iy filtrdan o'tkazildi. Tahlilga faqat Scopus va Web of Science bazalaridagi Q1, Q2 va Q3 kvartilga kiruvchi, yuqori impakt-faktorli jurnallarda chop etilgan taqrizlanadigan (peer-reviewed) maqolalar kiritildi. BEV va HEV akkumulyator bloklari tuzilishi, quvvat va tok shakllari hamda kuchlanish standartlari o'zgarishini bevosita yorituvchi ishlar asosiy manba sifatida olindi. O'rganish obyektidan tashqarida bo'lgan materiallarni, xususan, faqat mikrotarmoqlar, data-markazlar yoki transportning ichki energetik arxitekturasiga bevosita aloqasi bo'lmagan ishlar ro'yxatdan chiqarib tashlandi.

Ma'lumotlarni guruhlash va qiyosiy tahlil:

Saralab olingan maqolalar uchta asosiy texnik yo'nalish bo'yicha guruhlandi. Birinchi bosqichda BEV va HEV akkumulyator batareyalari blokining tizimli o'xshashliklari va tarmoqdagi AC/DC komponentlar taqsimoti ajratib olindi. Ikkinchi bosqichda 400V, 800V va 800+V kuchlanishlaridan foydalanishning texnik zarurati va muhandislik sabablari qiyoslandi. Uchinchi bosqichda har bir kuchlanish standartining quvvat o'tkazuvchanligi, xavfsizlik talablari va iqtisodiy omillarga ta'siri o'zaro solishtirildi. Yakunda yig'ilgan barcha dalillar mantiqiy zanjirga birlashtirib, zamonaviy elektromobillar arxitekturasining yagona tahliliy manzarasi shakllantirildi.

3. Natijalar (Results)

Elektromobillarda energiya manbasi sifatida akkumulyator batareyalaridan foydalaniladi. Akkumulyator batareyasining energiya zaxirasi uning uzoq masofada harakatlanishda muhim parametrlardan biri hisoblanadi. Bundan tashqari batareya blokining geometrik parametrlari va quvvat manbaini mutanosibligi elektromobilning massasi o'zgarishi, natijada harakatlanishi uchun sarf qilinadigan energiyaning istiqbolli bo'lishni ta'minlab beradi. Bunda harakatlanish masofasi o'rtasidagi bog'lanish inobatga olinib elektromobil ishlab chiqariladi. Ushbu masalani yechishda nafaqat batareya turi, balki batareyalarni ishlatish, ya'ni qanday turdagi kuchlanishdan foydalanishga nisbatan e'tibor berish ham muhim ahamiyat kasb etadi. Bundan tashqari elektromobillarning qulaylik va funksional vazifalarini amalga oshiruvchi jihozlar ham ma'lum miqdorda energiya iste'mol qiladi. Demak, ushbu iste'molchilarning qanday turdagi tok va kuchlanishda ishlashini bilish orqali yuklamani tog'ri taqsimlash, o'zgartirgichlar va jihozlar o'rnatish taqozo etiladi. Quyida elektromobillarda o'rnatilgan qulaylik va yordamchi jihozlarga ko'ra foydalaniladigan o'zgarma va o'zgaruvchan tok turlari. 1-jadvalda keltirib o'tilgan [10 - 13].

1-nci jadvaldan ma'lum bo'ladiki, elektromobil nafaqat o'zgaruvchan, balki o'zgarma tokdan ham barqaror foydalanish mumkinligini ko'rsatadi. Demak, jihozlar, ya'ni iste'molchilar ko'paygani sari ular uchun ham energiya zaxirasini hisoblashda to'g'ri yondashuvni qo'llash talab etiladi.

Elektromobillarning akkumulyator batareyasi blokida mavjud energiya zaxirasini hisoblash eng muhim vazifalardan biri hisoblanadi. Chunki energiya saqlash tizimini loyihalashda batareya blokining kuchlanishi, sig'imi hamda umumiy energiyasini aniq hisoblash keyingi muhim



parametrlarni aniqlashda amaliy asoslardan biri sifatida qaraladi. Yakka element yoki yacheykalardan batareya blokini shakllantirish ketma-ket N_s va parallel N_p ulanishlar orqali amalga oshiriladi [14-16].

Batareya blokining umumiy strukturaviy topologiyasi quyidagi ko'rinishga ega:

$$Topology = N_s * N_p. \quad (1)$$

1-jadval. Elektromobillarda o'zgaras va o'zgaruvchan tok turlari

Table 1. Types of direct and alternating current in electric vehicles

№	Asosiy ta'minot shakli	Odatiy kuchlanish diapazoni	Tizim
1	O'zgaras tok (DC)	Odatda 300-400 V, ba'zi avtomobillarda 870 V gacha	Yuqori kuchlanishli (HV) batareya
2	Invertordan keluvchi o'zgaruvchan tok (AC)	Harakatlantiruvchi (Traction) kuchlanishi taxminan 350-1000 V	Harakatlantiruvchi (Traction) elektr motori
3	O'zgaras tokka (DC) o'zgartiriladigan (AC) kirish toki	Quvvatlash qurilmasiga bog'liq	Tarmoqdan batareyani borta quvvatlash (OBC)
4	O'zgaras tok (DC)	Yuqori kuchlanishli batareyalarni quvvatlash sohasi	O'zgaras tokda (DC) tez quvvatlash
5	O'zgaras tok (DC)	Odatda 12 V yoki 48 V past kuchlanishli (LV) tizim	Yoritish tizimi
6	O'zgaras tok (DC)	Past kuchlanishli (LV) tizim	Displeylar / axborot-ko'ngilochar tizimlar
7	O'zgaras tok (DC)	Past kuchlanishli (LV) tizim	Oynalar / oyna boshqaruv tizimlari
8	O'zgaras tok (DC)	Misol uchun: 24 V	Oyna tozalagichlar
9	O'zgaras tok (DC)	Past kuchlanishli (LV) tizim	Datchiklar / elektron boshqaruv bloklari (ECU)
10	LV arxitekturasidagi o'zgaras tok (DC) ta'minoti	Past kuchlanishli (LV) tizim	Ventilyatorlar / nasoslar
11	LV tomonidagi DC; yirik energiya iste'molchisi	Masalan: LV tizimda 14.4 V li konditsioner yuklamasi	Iqlim nazorati (HVAC) yordamchi yuklamalari

• Batareya blokining nominal kuchlanishi V_{pack} ketma-ket ulangan yacheykalar soni va bitta yacheykaning nominal kuchlanishi V_{cell} ko'paytmasiga teng:

$$V_{pack} = N_s * V_{cell} [V]. \quad (2)$$

• Batareya blokining umumiy elektr sig'imi C_{pack} parallel ulangan tarmoqlar soni hamda bitta yacheykaning sig'imi C_{cell} orqali aniqlanadi:

$$C_{pack} = N_p * C_{cell} [Ah]. \quad (3)$$

• Batareya blokida saqlanadigan to'liq energiya hajmi E_{pack} nominal kuchlanish va umumiy sig'im ko'paytmasi bilan belgilanadi:

$$E_{pack} = V_{pack} * C_{pack} [Wh]. \quad (4)$$

• Xalqaro tadqiqotlar va muhandislik amaliyotida energiya sig'imini kilovatt-soat birligiga o'tkazish uchun quyidagi umumiy matematik model qo'llaniladi:

$$E_{kWh} = \frac{N_s * V_{cell} * N_p * C_{cell}}{1000} [kWh]. \quad (5)$$

Bu yerda: N_s – ketma-ket ulangan yacheykalar soni;

N_p – parallel ulangan yacheykalar soni;

V_{cell} – bitta yacheykaning nominal kuchlanishi [V];

C_{cell} – bitta yacheykaning nominal sig'imi [Ah];

V_{pack} – batareya blokining umumiy nominal kuchlanishi [V];

C_{pack} – batareya blokining umumiy elektr sig'imi [Ah];

E_{kWh} – batareya blokining to'liq energiya sig'imi [kWh].

Akkumulyator batareyalari blokidagi mavjud energiya sig'imi ushbu formulalar yordamida aniqlanadi. Elektromobil harakatlanishi davomida elektrotermal ko'rsatkichlari o'zgaruvchan bo'ladi, haqiqiy real vaqtdagi elektrotermal ko'rsatkichlar ko'plab formulalar yordamida aniqlanadi. Biroq bizning maqolamiz ushbu maqsad uchun mo'ljallanmagani tufayli boshqa adabiyotlarni o'rganish tavsiya etiladi.

Kuchlanish qiymati arxitekturasida asosan 400V bo'lgan ommaviy foydalaniladigan yengil elektromobillarda keng tarqalgan bo'lib, yo'lovchilar uchun mo'ljallangan elektromobillarda odatiy quvvat topologiyasi va kuchlanish turi hisoblanadi.

Kuchlanish qiymati 800V bo'lgan tizimlar asosan yangi va yuqori unumdorlikka ega elektromobillarda qo'llaniladi. Bunday tizim ko'proq yuqori dinamikli (high-performance) elektromobillarda uchraydi. Bu tizim qo'llanilishining eng muhim afzalligi akkumulyator batareyalari sig'imini o'zgartirmasdan uning kuchlanish qiymatini oshirish va tok kuchini kamaytirish orqali bir



xil quvvat darajasini ta'minlay olish imkoniyati mavjudidir. Natijada elektromobillarning turli qismlari masalan: kabel o'lehamini, qarshilik yo'qotishlarini hamda qizishni kamaytiradi va yuqori quvvatli tezkor quvvatlashni osonlashtiradi. Buning evaziga esa tizimning narxi oshadi, izolyatsiya va tarkibiy qismlarga nisbatan talablar qat'iyilashadi hamda 400V zaryadlash infratuzilmasi bilan doimiy muvofiqlikni ta'minlash zarurati yuzaga keladi [17][18][19][20][21][22]. 2-jadvalda elektromobillarda qo'llaniladigan 400 va 800 V tizimlar solishtirma jadvali keltirilgan.

1-jadval. Elektromobillar energiya tizimlarida kuchlanish turlarining solishtirma tahlil

Table 1. Comparative analysis of voltage types in electric vehicle power systems

Turi	Asosiy xulosa	Transport vositasi guruhi	Tizim
400 V	Ommaviy yengil elektromobillar uchun asosiy yechim	Yengil elektromobillar (Passenger EVs)	U quvvat imkoniyatlari, boshqariladigan tok kuchi, tayyor komponentlar va 800V tizimlarga qaraganda kamroq murakkablik darajasidagi muvozanatni ta'minlaydi
800 V	Asosan yuqori quvvat va tezroq quvvatlash uchun qo'llaniladi	Premium/yuqori dinamikli (performance) elektromobillar, tezkor quvvatlashga yo'naltirilgan platformalar	Yuqori kuchlanish bir xil quvvat uchun tok kuchini kamaytiradi, bu esa kabel yo'qotishlari va qizishni pasaytiradi hamda yuqoriroq quvvatlash quvvatini ta'minlaydi. Salbiy tomonlari: yuqoriroq xarajat hamda izolyatsiya va komponentlarga qo'yiladigan qat'iyroq talablar
800 + V	Rivojlanish va o'rganish davom etmoqda	Yangi avlod elektromobillari	Tezkor zaryadlash imkoniyati juda yuqori

Demak, elektromobillarda asosan 2 xil turdagi kuchlanish turlaridan foydalanish hozirda ommalashgan ekan. Akkumulyator batareyalari va zaryadalash turlari sohasida bo'layotgan rivojlanish tendensiyalari asosida ishlab chiqaruvchilar boshqa kuchlanish turlaridan foydalanish imkoniyatlarini amalga oshirishi va sohada keng qo'llashi ehtimoldan yiroq emas.

4. Xulosa (Conclusion)

O'rganilgan maqolalar va ma'lumotlar asosida elektromobillarning quvvat topologiyalari va kuchlanish arxitekturalari muhim xulosalarni beradi:

1. Elektromobillarda akkumulyator batareyasi turidan qa'tiy nazar o'rnatilgan jihozlar va yordamchi qurilmalarga ko'ra ham o'zgaruvchan, ham o'zgarmas tok iste'molchilariga ega bo'lgan murakkab energetik tizim sifatida qarash mumkin.
2. Elektromobillarda nafaqat past kuchlanish, balki yuqori kuchlanish doimiy ravishda sarflanadi.
3. Energiya zaxirasini hisoblashda to'g'ri yondashuv qo'llashni talab etadi.
4. Zamonaviy elektromobillarda 400, 800, 800+ V turdagi kuchlanishdan keng foydalanilmoqda, demak kuchlanish standartlari sifatida 3 ta kategoriya asosida o'rganish va tatbiq etishni taklif etishimiz mumkin.

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