Zamonaviy elektr tarmoqlarini shakllantirishda kuchlanish boshqaruvining ishonchliligini oshirish

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Dolzarblik: ishonchli kuchlanish nazoratini ta'minlash zamonaviy elektr tarmoqlarida asosiy muammo hisoblanadi. Qayta tiklanadigan energiya manbalarining o'zgarishi, elektrlashtirishning kuchayishi va infratuzilmaning qarishi kuchlanishning o'zgarishiga olib kelishi mumkin. Kuchlanishni tartibga solishni yaxshilash uchun aqlli tarmoq texnologiyalari, moslashuvchan AC uzatish tizimlari va taqsimlangan energiya resurslarini muvofiqlashtirilgan boshqarish kabi ilg'or texnikalar qo'llanilmoqda. Ishonchli kuchlanish nazorati quvvat sifati, uskunani himoya qilish va tarmoq barqarorligini ta'minlash uchun zarurdir. Voltaj boshqaruvi yechimlariga investitsiyalarni jalb qilish uchun me'yoriy-huquqiy bazalar va bozor imtiyozlari ishlab chiqilmoqda. Ishonchli kuchlanish nazoratini ta'minlash qayta tiklanadigan energiya manbalarini integratsiyalash va barqaror va bardoshli energiya tizimini ta'minlash uchun juda muhimdir.

Maqsad: zamonaviy energetika tizimlarida barqaror va ishonchli kuchlanish darajasini saqlab qolish va energiya tizimlari ko'proq taqsimlangan ishlab chiqarish manbalari va yangi elektrlashtirilgan yuklarni o'z ichiga olishi yoki texnika va strategiyalarga e'tibor qaratgan holda rivojlanib borayotganligi sababli kuchlanishni nazorat qilishning ortib borayotgan muammolarini hal qilishning muhim ahamiyatiga taalluqlidir.

Usullar: kuchlanishni nazorat qilishni yaxshilash uchun regressiya tahlili, taqqoslash usuli, matematik statistika, modellashtirish va ma'lumotlarni qayta ishlashning zamonaviy usullari qo'llanildi.

Natijalar: bu zamonaviy dasturlar yordamida olingan ma'lumotlar, natijalar va ularning muvofiqligi, shuningdek, nazariy va eksperimental natijalarning muvofiqligi asosida taqsimlangan ishlab chiqarish manbalari va elektr tarmoqlarini modellashtirish bilan izohlanadi.

Kalit so‘zlar: taqsimlangan generatsiya, zamonaviy elektr tarmoqlari, kuchlanish boshqaruvi, reaktiv quvvat, invertor boshqaruv tizimi.

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Повышение надежности управления напряжением при формировании современных электрических сетей

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Актуальность: обеспечение надежного контроля напряжения является серьезной проблемой в современных энергетических сетях. Нестационарность режимов возобновляемых источников энергии, развитие электрификации и старение инфраструктуры могут вызывать значительные колебания напряжения. Для улучшения регулирования напряжения используются передовые методы, такие как технологии интеллектуальных сетей, гибкие системы передачи переменного тока и координация управления распределенными энергоресурсами. Надежный контроль напряжения необходим для обеспечения качества электроэнергии, защиты оборудования и устойчивости сети. Для привлечения инвестиций в решение задач управления напряжением разрабатывается нормативно-правовая база и используются рыночные стимулы. Обеспечение надежности управления напряжением имеет решающее значение для интеграции возобновляемых источников энергии и обеспечения стабильности и отказоустойчивости энергосистемы.

Цель: учитывать критическую важность поддержания стабильных уровней напряжения в современных энергосистемах для решения растущих проблем контроля напряжения с учетом того, что энергосистемы развиваются и включают в себя все больше распределенных источников генерации и новых электрических нагрузок, уделять особое внимание методам и стратегиям.

Методы: для улучшения управления напряжением использовались регрессионный анализ, метод сравнения, математическая статистика, моделирование и современные методы обработки данных.

Результаты: моделирование источников распределенной генерации и электросетей на основе данных, полученных с помощью современных программ, результатов и их совместимости, а также соответствие теоретических и экспериментальных результатов.

Ключевые слова: распределенная генерация, современные электрические сети, регулирование напряжения, реактивная мощность, инверторная система управления.

Increasing the reliability of voltage control in the formation of modern electrical networks

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Relevance: providing reliable voltage control is a major challenge in modern power grids. Fluctuations in renewable energy sources, increasing electrification and aging infrastructure can cause voltage fluctuations. Advanced techniques such as smart grid technologies, flexible AC transmission systems, and coordinated management of distributed energy resources are being used to improve voltage regulation. Reliable voltage control is essential to ensure power quality, equipment protection, and grid stability. Regulatory frameworks and market incentives are being developed to attract investment in voltage management solutions. Ensuring reliable voltage control is critical to integrating renewable energy sources and ensuring a stable and resilient power system.

Aim: applies to the critical importance of maintaining stable and reliable voltage levels in modern power systems and to address the growing challenges of voltage control as power systems evolve to include more distributed generation sources and new electrified loads, or with a focus on techniques and strategies.

Methods: regression analysis, comparison method, mathematical statistics, modeling and modern data processing methods were used to improve stress control.

Results: this is explained by the modeling of distributed generation sources and power grids based on data obtained using modern programs, results and their compatibility, as well as the correspondence of theoretical and experimental results.

Keywords: distributed generation, modern power grids, voltage control, reactive power, inverter control system.

1. Kirish (Introduction)

Ushbu maqolada taqsimlangan generatsiyalar, xususan, kichik oʻlchamdagi quyosh fotoelektr stansiyalari va energiya saqlash batareyalari zamonaviy elektr tarmoqlarida kuchlanishni boshqarish ishonchliligini oshirishga qanday hissa qoʻshishi koʻrib chiqiladi. Ushbu markazlashtirilmagan energiya ishlab chiqarish bloklarining ish rejimlari va boshqaruv tizimini tahlil qilish orqali tadqiqot kuchlanishni boshqarishni yaxshilash imkoniyatlarini oʻrganadi. Natijalar kuchlanishni boshqarish ishonchliligi yuqori boʻlishini talab etgan zamonaviy elektr tarmoqlarini shakllantirishda taqsimlangan generatsining muhimligini taʼkidlaydi.

2. Usul (Materials and Methods)

Zamonaviy elektr energetika tizimlarida kuchlanishni boshqarishni takomillashtirish elektr tarmogʻida barqaror va ishonchli kuchlanish darajasini saqlab qolish uchun amalga oshirilgan usullar va texnologiyalarni nazarda tutadi [1]. Kuchlanishni nazorat qilish juda muhim, chunki oʻta yoki yetarli bo‘lmagan kuchlanish uskunaning shikastlanishiga, quvvat sifati muammolariga va hatto avariyaviy uchishlarga olib kelishi mumkin.

Ilgari kuchlanishni nazorat qilish, birinchi navbatda, qo‘lda sozlash va transformatorlardagi kran almashtirgichlar kabi an’anaviy boshqaruv asboblari orqali bajarilar edi. Biroq, texnologiyaning rivojlanishi bilan zamonaviy elektr energetika tizimlari yanada murakkab va avtomatlashtirilgan kuchlanishni boshqarish usullarini o‘z ichiga oladi. Zamonaviy elektr tarmoqlarida kuchlanishni boshqarishni yaxshilashning ba’zi asosiy jihatlari quyidagilardan iborat [2; 14]:

Kuchlanishni avtomatik rostlash (AVR- automatic voltage regulator): AVRlar kuchlanish darajasini tartibga solish va barqarorlashtirish uchun generator terminallari yoki tarmoq podstansiyalarida o‘rnatiladigan qurilmalardir. Ular kuchlanishni doimiy ravishda kuzatib boradilar va kuchlanishni maqbul chegaralarda ushlab turish uchun qo‘zg‘alish darajasini moslashtiradilar [3].

Statik Var kompensatorlari (SVS- Static Var Compensators): SVSlar reaktiv quvvatni boshqarish uchun ishlatiladigan o‘zgaruvchan tok oqimi tizimining bir turi. Ular kuchlanish darajasini tartibga solish va kuchlanish barqarorligini yaxshilash uchun tizimga reaktiv quvvatni kiritadilar yoki qabul qilib oladilar [4].

Kuchlanish nazoratiga asoslangan statkomlar: STATCOM (STATCOM-Static Synchronous Compensator) kabi quvvat elektron qurilmalari reaktiv quvvatni kiritish yoki qabul qilish orqali kuchlanishni qo‘llab-quvvatlaydi. Ushbu qurilmalar kuchlanish barqarorligini oshirib, tezkor javob vaqtlari va aniq nazoratni taklif qiladi [5].

Ilg‘or monitoring va nazorat qilish tizimlari: Zamonaviy elektr tarmoqlarida kuchlanish darajasi, yuk sharoitlari va tizimning ishlashi haqida real vaqtda ma’lumotlarni to‘plash uchun ilg‘or monitoring va nazorat qilish texnologiyalaridan foydalanadi. Ushbu ma’lumot operatorlarga kuchlanish bilan bog‘liq muammolarni aniqlashga va tezda tuzatish choralarini ko‘rishga yordam beradi [10].

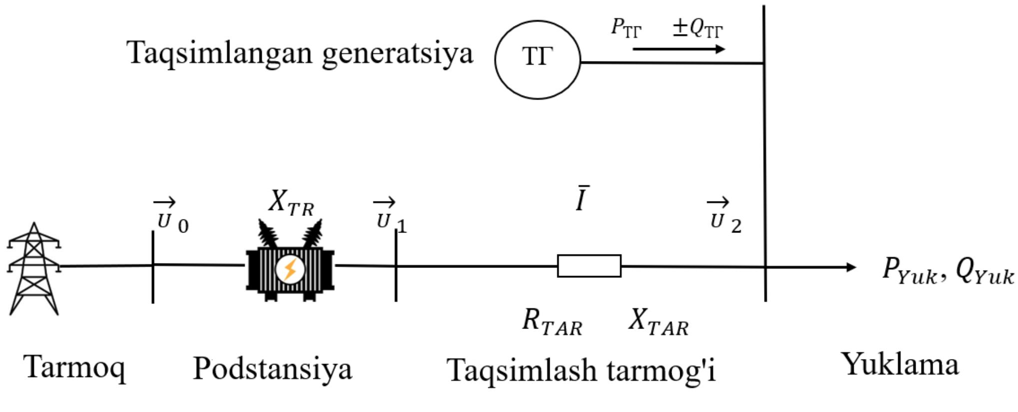
Integratsiyalashgan Volt/VAR boshqaruvi: kuchlanish va reaktiv quvvatni boshqarishni optimallashtiradigan muvofiqlashtirilgan yondashuvdir. Kuchlanish sozlamalari va reaktiv quvvat manbalarini dinamik ravishda sozlash orqali tizim yo‘qotishlarini kamaytiradi, kuchlanish barqarorligini oshiradi va umumiy tarmoq samaradorligini oshiradi [6; 15].

Taqsimlangan generatsiyalar (TG): Qayta tiklanadigan energiya manbalari va taqsimlangan generatsiyalarning ortib borayotgan integratsiyasi bilan ushbu resurslarning o‘zgaruvchanligini qondirish uchun kuchlanishni boshqarish strategiyalari ishlab chiqildi. Aqlli invertorlar va boshqarish algoritmlari TGlarga kerak bo‘lganda reaktiv quvvatni kiritish yoki so‘rish orqali kuchlanish nazoratini faol ravishda qo‘llab-quvvatlash imkonini beradi [7; 13].

Kuchlanishni boshqarish texnikasidagi ushbu yutuqlar tarmoq barqarorligini oshiradi, kuchlanish o‘zgarishini minimallashtiradi, quvvat sifatini yaxshilaydi va qayta tiklanadigan energiya manbalarini samarali integratsiyalashuviga imkon beradi. Ular yanada ishonchli va bardoshli zamonaviy tarmoqlariga hissa qo‘sha oladi hissa qo‘shadi.

TG to‘g‘ridan to‘g‘ri sinxron yoki quvvat o‘zgartiruvchi elektron qurilmalar orqali tarmoqqa ulanadi. Sinxron generatorlar yoki invertorlar TG reaktiv quvvatning turli rejimlarida ishlay oladi. TG reaktiv quvvatni ishlab chiqaradi yoki iste’mol qiladi yoki TG taqsimlash tarmog‘i bilan reaktiv quvvat almashmaydi. Sinxron generatorlar yokiinvertorga asoslangan TG tataqsimlash tarmog‘ining kuchlanishini boshqarishda ham ishtirok etishi mumkin, ya’ni TG reaktiv quvvat chiqishini o‘zgartirish orqali doimiy kuchlanishda ishlaganda. Boshqa tomondan, induksion generatorga asoslangan TG har doim reaktiv quvvatni o‘zlashtiradi [8].

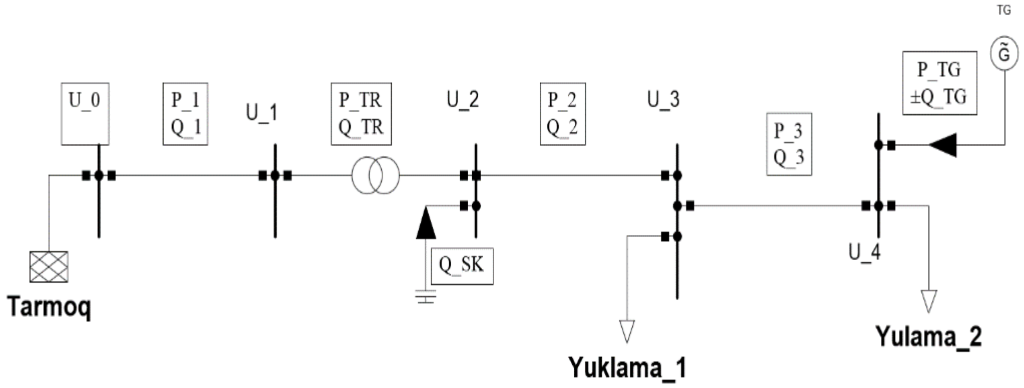
Yuklamasi va taqsimlangan generatsiyasi mavjud taqsimlash tarmog‘idagi (1-rasm) kuchlanish tushuvini quyidagicha aniqladik.



1-rasm. Taqsimlangan generatsiyasi mavjud taqsimlash tarmog‘i
Fig. 1, A distribution network with distributed generation

$$\Delta U = U_1 - U_2 = \frac{R_{Tarmoq}(P_{yuklama} - P_{TG}) + X_{Tarmoq}(Q_{yuklama} - (\pm Q_{TG}))}{U_2} \quad (1)$$

bu yerda, P_{TG} taqsimlangan generatsiya uzatadigan aktiv quvvat, Q_{TG} taqsimlangan generatsiya uzatadigan yoki iste'mol qiladigan reaktiv quvvat.



2-rasm. Taqsimlangan generatsiyasining kuchlanish nazoratiga ta'siri
Fig. 2. Effects of distributed generation on voltage control

Taqsimlangan generatsiyaning kuchlanishga ta'sirini aniqlash uchun 2-rasmda keltirilgan yuklamani oshiramiz, natijada shu yuklama ulangan tugunda kuchlanish tushuvi ko'zatiladi. Quyidagi ifoda orqali quyidagicha aniqlanadi.

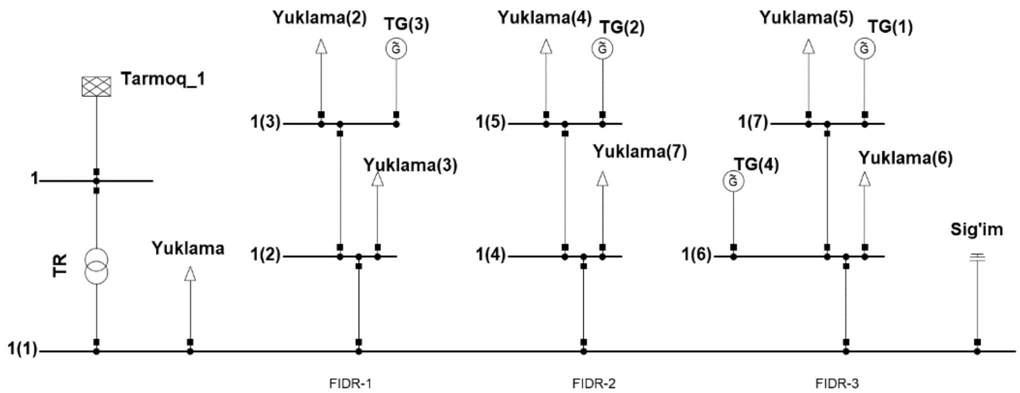
$$U_{2.1} - U_{2.2} = \frac{R_{Tarmoq}\left(P_{yuklama.2} - P_{TG}\right) + X_{Tarmoq}\left(Q_{yuklama.2} - (\pm Q_{TG})\right)}{U_{2.2}} - \frac{R_{Tarmoq}(P_{yuklama.1} - P_{TG}) + X_{Tarmoq}\left(Q_{yuklama.1} - (\pm Q_{TG})\right)}{U_{2.1}} \quad (2)$$

Taqsimlangan generatsiya konstant kuchlanish rejimida o'zining chiqish reaktiv quvvatini o'zgartirgan holda ishlaydi (2-rasm). Taqsimlangan generatsiya qo'zg'atish tizimidagi td_{TG} sig'im kondensatorlarnikidan td_{CK} ancha tez hisoblanadi. Shu bilan birga transformator yuklama ostida kuchlanish nazoratidan td_{TP} ham ancha kam vaqtni talab etadi, ularning o'zaro bog'liqligi quyidagicha:

$$td_{TG} < td_{\text{CK}} < td_{\text{TP}} \quad (3)$$

Taqsimlangan generatsiya o'zining reaktiv quvvat imkoniyati darajasida kuchlanishni belgilangan qiymatlarda ushlab turishi zarur. Bunda taqsimlangan generatsiya quyidagi oraliqda ishlaydi [9; 11; 12].

$$Q_{TG}min \le Q_{TG} \le Q_{\text{TG}}max \quad (4)$$



3-rasm. Taqsimlangan generatsiya taklif etilgan obyekt
Fig. 3. Distributed generation is a proposed facility

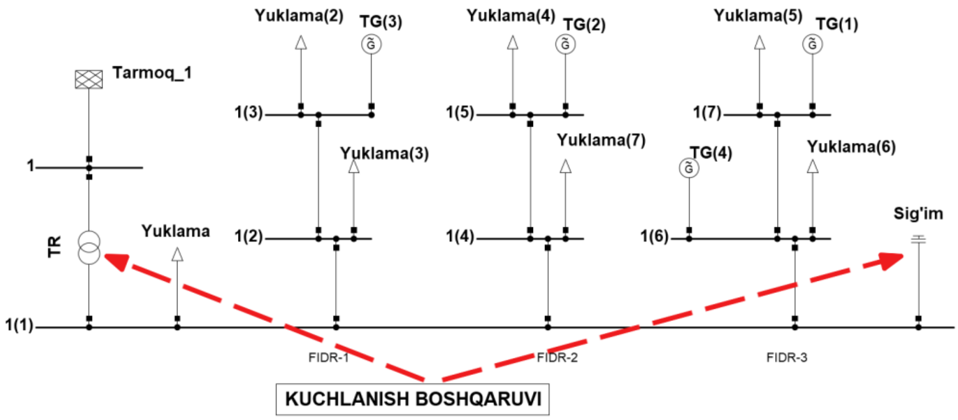
3. Natijalar (Results)

O'rganilgan hudud uchun to'rta 300 kVA ga teng bo'lgan taqsimlangan generaqiya taklif etildi. 1- va 2- fidrlarning har biriga 300 kVA, 3-fidrga 600 kVA quvvatli taqsimlangan generatsiya o'rnatildi (3-rasm). Quvvat oqimlari va kuchlanish qiymatlari 1-jadvalda keltirilgan. O'nga ko'ra taqsimlangan generatsiyaning kuchlanishni bashqarishdagi ijobiy ta’sirlarini sezilarli darajada. Bundan tashqari taqsimlash tarmog‘i va transformatorlarning yuklanishlari ham sezilarli darajada kamaygan.

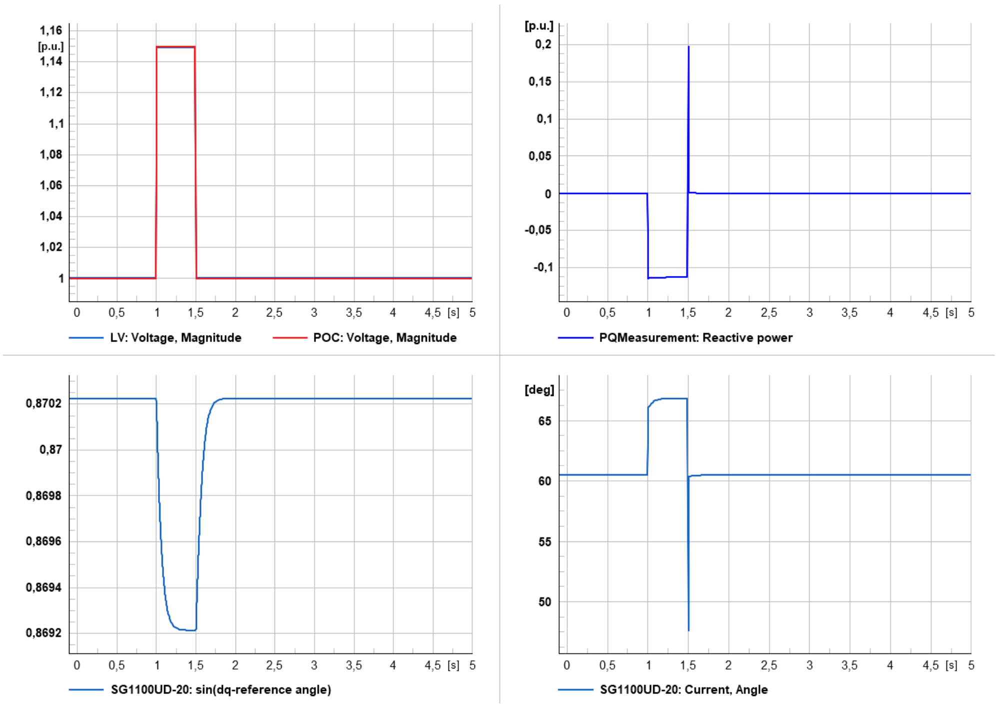
Jadval 1, Dizel generatorining “PSS” tizimida taklif etilgan qiymatlari
Table 1, Proposed values of the diesel generator in the “PSS” system

	Trans YUOKR			Sig‘im kon-1		Tarmoq	
	U_min	U_max	ΔU	Umax	Usk	Umax	Ut
TG yuq	0,97	1,02	0,05	1,05	0,05	1,04	0,04
Quvvat koef	0,98	1,02	0,04	1,03	0,03	1,02	0,02
Kons kuchlanish	0,995	1,005	0,01	1,005	0,005	1,005	0,005

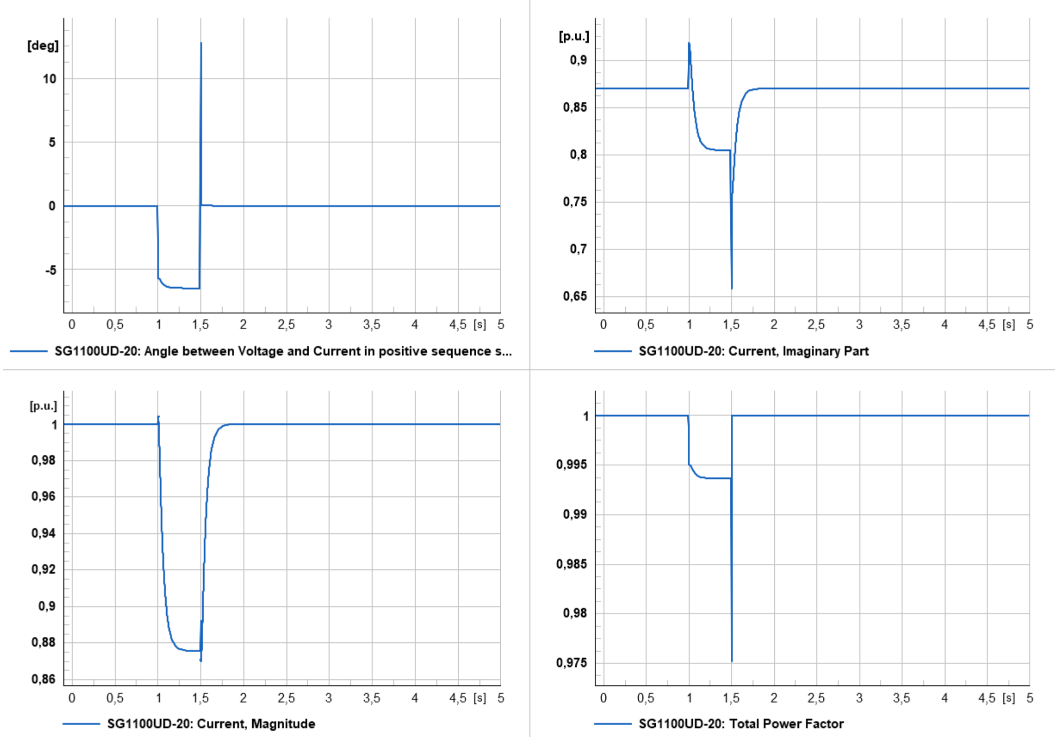
Taqsimlangan generatsiyalar ishtirokisiz kuchlanish boshqaruvi transformatorlarning yuklama ostida kuchlanish nazorati va sig‘im kondensatorlari orqali amalga oshiriladi. 4-rasmda ko‘rilayotgan hududda kuchlanish nazorati uchun podstansiya transformatori va sig‘im mavjudligi ko‘rsatilgan.



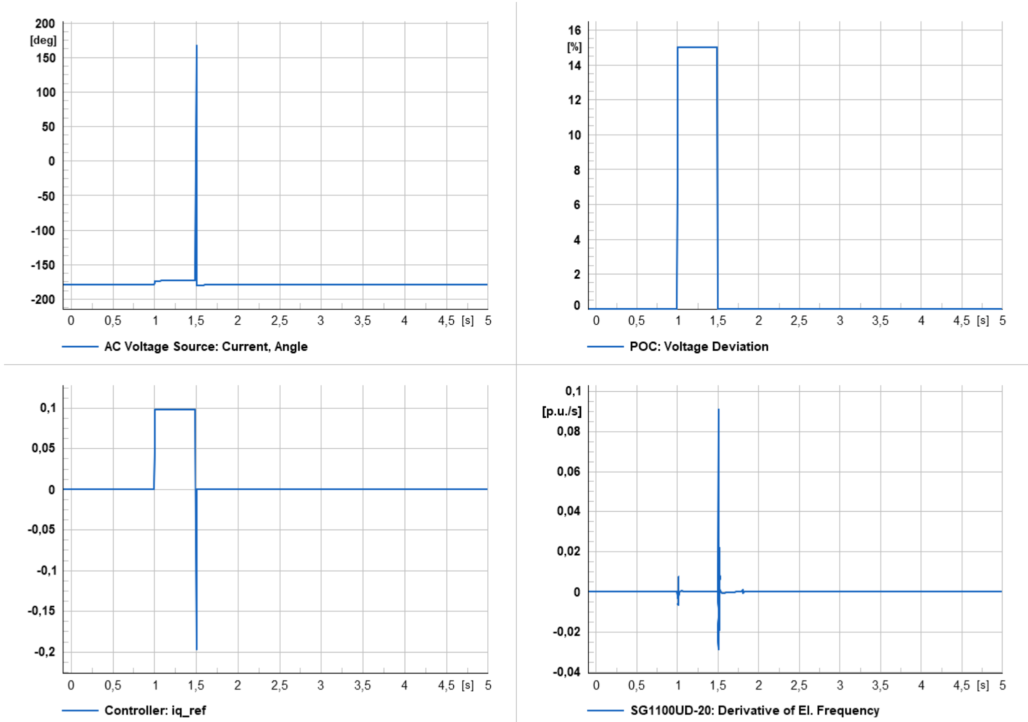
4-rasm. Taqsimlangan generatsiya taklif etilgan obyekt
Fig. 4. Distributed generation is a proposed facility



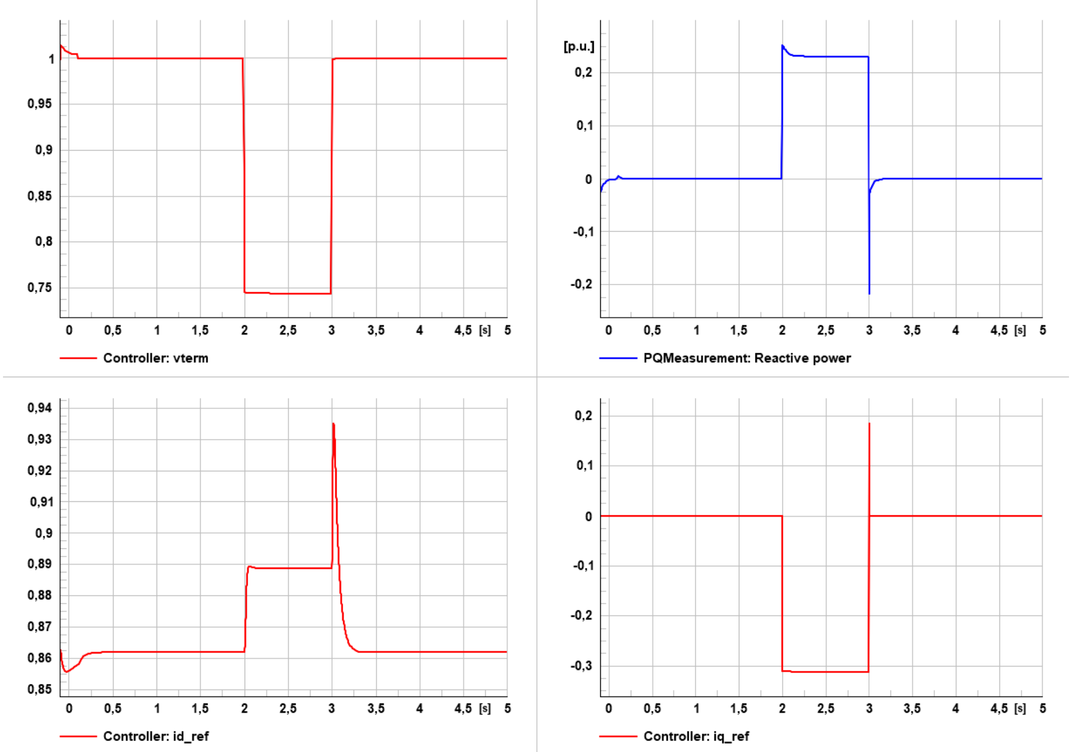
5-rasm. Kuchlanish o‘zgarishiga SG1100UD-20 invertorining javobi
Fig. 5. The response of the SG1100UD-20 inverter to voltage changes



6-rasm. Invertor chiqish tokining o‘zgarishi
Fig. 6. Variation of inverter output current



7-rasm. Boshqaruv tizimi va ulanish nuqtasidagi holat
Fig. 7. Control system and connection point status



8-rasm. Boshqaruv tizimi signallarining reaktiv quvvatni o'zgartirishi
Fig. 8. Reactive power conversion of control system signals

4. Xulosa (Conclusions)

Xulosa qilib aytganda, kuchlanishni nazorat qilish taqsimlangan generatsiyalar bilan taqsimlash tarmoqlarining hal qiluvchi jihati hisoblanadi. Ushbu usullarni qo'llash orqali elektr tarmoqlarida barqaror kuchlanish darajasini saqlab turish imkoniyati mavjud. Biroq, kuchlanishni boshqarishning samarali sxemalarini ishlab chiqish va amalga oshirish uchun taqsimlangan generatsiya manbalarining xususiyatlari, yuklama o'zgaruvchanligi va mahalliy normativlar kabi omillarni hisobga olish muhimdir.

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