Asinxron generatordagi o‘tkinchi jarayonlarda chiqish kuchlanishini barqarorlashtirilishiga doir tadqiqot natijalari

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Dolzarbligi: qayta tiklanadigan energiya manbalari tomonidan ishlab chiqariladigan elektr energiyasining ulushi tobora ortib bormoqda, shu munosabat bilan shamol va gidrogeneratorlar asosidagi elektr manbalarini tatbiq qilish va ularning avtomatik boshqarish tizimlarini rivojlantirish dolzarb ahamiyatga ega bo‘lib bormoqda. Bunday o‘zgaruvchan tok generator qurilmalari tarkibida sinxron elektr mashinalar, fazali va qisqa tutashtirilgan rotorli asinxron mashinalar qo‘llaniladi. Asinxron mashinalarning stator va rotor zanjirlariga o‘rnatiladigan chastota o‘zgartkichlari ularni qo‘zg‘atish jarayonlarini boshqarish imkonini beradi, biroq generatsiyani boshlash uchun qo‘shimcha tashqi ta’minot manbalaridan foydalanish talab etiladi. Magnit o‘tkazgichdagi qoldiq magnitlanish tufayli qisqa tutashgan rotorli asinxron mashinaning stator chulg‘amlariga kondensator batareyalarini ulash orqali uning o‘z-o‘zidan uyg‘onish jarayonini, hamda chiqish kuchlanishining barqarorligi kabi talablarni ta’minlash mumkin. Taklif etilgan kondensatorli qo‘zg‘atish usuli markazlashmagan, ya’ni avtonom elektr ta’minoti sharoitida generator qurilmasining ish rejimlarini o‘zgartirishga moslashishini ta’minlash imkonini beradi. Mazkur maqolada, o‘tkazilgan tajriba natijalari asosida quvvati 4 kW bo‘lgan qisqa tutashgan rotorli asinxron generator (AG) o‘tkinchi jarayonlaridagi chiqish kuchlanish qiymatini aks ettirgan ossillogrammalar olindi va tahlil qilindi.
Maqsad: avtonom holatda ishlayotgan AG ning yuklamasini o‘zgartirish jarayonidagi o‘tkinchi jarayonlarda chiqish kuchlanishini barqarorlashtirish va natijalarini tahlil qilish.
Usullari: tajriba asosida elektr energetikasi tizimlarining barqarorlashgan va o‘tkinchi jarayonlarini tahlil qilish usullardan foydalanildi.
Natijalar: avtonom tizimlarning quvvat manbalari konstruksiyasining soddaligi, texnik xizmat ko‘rsatishning qulayligi, nisbatan kichik massa (kVA/kg) va hajmga ega bo‘lishi, chiqish holat parametrlarining barqarorligi kabi talablarga javob berishi lozim. Tahlil asosida AG ni qayta tiklanuvchi energiya manbalarida foydalanish bo‘yicha tegishli takliflar kiritiladi.
Kalit so'zlar: qisqa tutashgan rotorli o‘z-o‘zidan qo‘zg‘atishli AG, reaktiv quvvatni avtomatik rostlash qurilmasi.

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Результаты исследований по стабилизации выходного напряжения при переходных процессах в асинхронном генераторе

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Актуальность: доля электроэнергии, производимой из возобновляемых источников, неуклонно растет, в связи с чем применение ветровых и гидрогенераторов, а также развитие их систем автоматического управления приобретают особую актуальность. В составе таких генераторов переменного тока используются синхронные электрические машины, а также асинхронные машины с фазным и короткозамкнутым ротором. Частотные преобразователи, устанавливаемые в цепи статора и ротора асинхронных машин, позволяют управлять процессами их возбуждения, однако для запуска генерации требуется использование дополнительных внешних источников питания. Благодаря остаточной намагниченности в магнитопроводе, путем подключения конденсаторных батарей к обмоткам статора асинхронной машины с короткозамкнутым ротором, можно обеспечить процесс самовозбуждения, а также

такие требования, как стабильность выходного напряжения. Предлагаемый метод конденсаторного возбуждения позволяет адаптировать генераторную установку к изменению режимов работы в условиях децентрализованного, то есть автономного электроснабжения. В данной статье, на основе результатов проведенных экспериментов, были получены и проанализированы осциллограммы, отражающие значение выходного напряжения в переходных процессах асинхронного генератора (АГ) с короткозамкнутым ротором мощностью 4 кВт.
Цель: стабилизация выходного напряжения в переходных процессах при изменении нагрузки АГ, работающего в автономном режиме, и анализ полученных результатов.
Методы: использовались методы анализа установившихся и переходных процессов в системах электроэнергетики на основе экспериментов.
Результаты: автономные системы должны отвечать таким требованиям, как простота конструкции источника питания, удобство технического обслуживания, относительно малая масса (кВА/кг) и объем, а также стабильность выходных параметров. На основе анализа будут внесены соответствующие предложения по использованию АГ в возобновляемых источниках энергии.
Ключевые слова: самовозбуждающийся АГ с короткозамкнутым ротором, устройство автоматической регулировки реактивной мощности.

Results of research on stabilizing the output voltage during transient processes in an asynchronous generator

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Relevance: the share of electricity generated from renewable sources is steadily increasing, therefore, the use of wind and hydrogenerators, as well as the development of their automatic control systems, is gaining particular relevance. In the composition of such alternating current generators, synchronous electric machines, as well as as asynchronous machines with a phase and short-circuited rotor, are used. Frequency converters installed in the stator and rotor circuits of asynchronous machines allow for controlling their excitation processes, but for starting the generation, it is necessary to use additional external power sources. Due to the residual magnetization in the magnetic core, by connecting capacitor banks to the stator windings of an asynchronous machine with a short-circuited rotor, it is possible to ensure the self-excitation process, as well as such requirements as the stability of the output voltage. The proposed method of capacitor excitation allows for the adaptation of the generator unit to changes in operating modes under decentralized, i.e., autonomous power supply conditions. In this article, based on the results of the conducted experiments, oscillograms reflecting the value of the output voltage in the transient processes of an asynchronous generator (AG) with a 4 kW short-circuited rotor were obtained and analyzed.
Aim: stabilization of the output voltage in transient processes when the load of the autonomously operating AG changes, and analysis of the obtained results.
Methods: methods for analyzing established and transient processes in electric power systems based on experiments were used.
Results: autonomous systems must meet requirements such as the simplicity of power supply design, ease of maintenance, relatively small mass (kVA/kg), and volume, as well as the stability of output parameters. Based on the analysis, appropriate proposals will be submitted for the use of AG in renewable energy sources.
Keywords: self-exciting short-circuited rotor AG, a device for automatic regulation of reactive power.

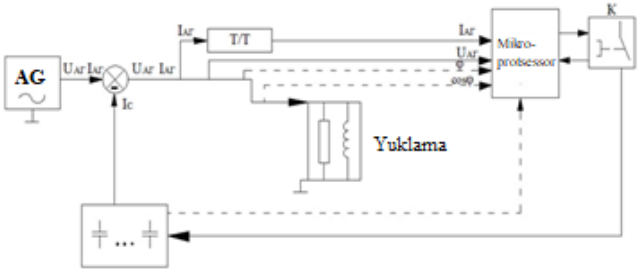
1. Kirish (Introduction)

Jahonda elektr energiyasiga bo‘lgan talabning ortib borishi munosabati bilan qayta tiklanuvchi energiya manbalaridan foydalanish kengayib bormoqda. 2024-yilda qayta tiklanuvchi energiya manbalari dunyoda ishlab chiqarilgan elektr energiyasining 33,5 foizini tashkil etdi, shundan 8,6 foizi shamol elektr stansiyalariga to‘g‘ri keladi. Markazlashgan elektr ta’minotidan uzoqda joylashgan kichik quvvatli avtonom iste’molchilarni ta’minlash birinchi navbatda shamol energiyasi manbalaridan foydalanishga bog‘liq. Agentlik ma’lumotlariga ko‘ra, 2023-yilda qayta tiklanuvchi energiya manbalarining o‘rnatilgan umumiy quvvati 3870 gigavattni tashkil etib, yangi rekordga erishdi. 2024-yilda ishga tushirilgan yangi energetika quvvatlarining 86 foizi qayta tiklanuvchi energiya manbalariga to‘g‘ri keladi. Shamol elektr stansiyalari (SHES) va gidro elektr stansiyalar (GES) dan foydalanishni kengaytirilishi maqsadga muvofiq hisoblanadi. O‘tkazilgan nazariy va amaliy tadqiqotlardan, mazkur

stansiyalarda o‘z–o‘zidan qo‘zg‘atishli, qisqa tutashgan rotorli asinxron generatorlardan foydalanish boshqa turdagi generatorlarga qaraganda texnik va iqtisodiy, hamda xizmat ko‘rsatilishi bo‘yicha qator afzalliklarga ega ekanligi ma’lum bo‘ldi [1].

2. Usullar va natijalar (Methods and materials)

AG chiqish kuchlanishini rostlovchi mikroprotsessorli reaktiv quvvatni avtomatik rostlash qurilmasi (RQARQ) ning strukturaviy sxemasi 1 - rasmda ko‘rsatilgan.



1-rasm. Mikroprotsessorli RQARQ strukturaviy sxemasi
Fig.1. Structural diagram of the microprocessor ARPRD

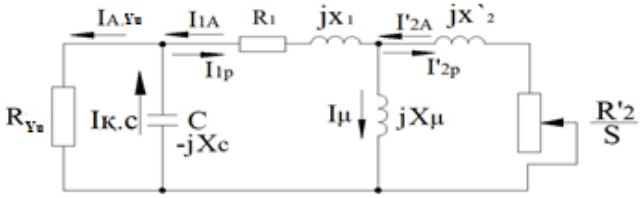
1-rasmdagi sxema bo‘yicha AG, yuklamani 380 V sinusoidal kuchlanish bilan ta’minlaydi. Taqqoslash elementining kirishiga generatordan chiqqan $U_{AГ}$, $I_{AГ}$ signallari beriladi. Bunday holda, taqqoslash elementi yuklama tokini generator salt ishlash toki bilan solishtiradi, ya’ni joriy toklar vektorlari yig‘indisini yaratadi. Yuklama toki signalning parametrlarini $I_{AГ} = I_{ю} + I_c$ ga o‘zgartiradi, bunda kondensator toki yuklamaning induktiv tashkil etuvchisini kompensatsiyalashi nazarda tutiladi. Natijada, dastlab, mikroprotsessorga, generatorga ulangan yuklamaga mos $U_{AГ}$ va $I_{AГ}$ signallari uzatiladi. Biroq, mikroprotsessorga, ushbu signallardan tashqari yana faza siljish burchagi, quvvat koeffitsiyenti kabi signallar uzatilishi mumkinligidan, mikroprotsessorli RQARQ dan ushbu qayd qilingan signallar bo‘yicha ham rostlashni amalga oshirish mumkinligi ma’lum bo‘ladi. Amaliyotda RQARQ dan, asosan iste’molchilar reaktiv quvvatlarining kompensatsiyasi uchun foydalanilganligi sababli, qurilmaning faqat quvvat koeffitsiyenti kanali qo‘llangan [2].

Qaralayotgan, AG bilan bog‘liq mazkur ilmiy tadqiqotda, AG ning yuklanish holatlaridagi chiqish kuchlanishining o‘zgarishlarini RQARQ tatbiq qilgan holda rostlanishiga erishildi, ya’ni RQARQ ning kuchlanish kanali qo‘llanildi.

AG ga ulangan yuklama miqdoriga qarab, mikroprotsessor tezlik bilan AG kuchlanishini nominal qiymatlarda barqaror saqlab turilishini ta’minlovchi zaruriy kondensator sig‘imini aniqlaydi va kondensator batareyalaridan tegishli bittasini avtomatik ulash uchun ishga tushirgich (kontaktor)ga komanda beradi. Har qanday ortib boruvchi yuklama uchun, shunga o‘xshash tarzda kondensator batareyalarini avtomatik ravishda ketma-ket ishga tushirilishi ta’minlanadi [3].

AG ni qo‘zg‘atishda, miqdor va xarakter jihatidan turli yuklamalarni qo‘shish vaqtidagi o‘tkinchi kuchlanish qiymatining o‘zgarishini qayd etish jarayonlari “UTD1000L” rusumidagi ossillografdan foydalanildi.

AG ning chiqish kuchlanishi va chastotasi o‘zgarishlari generator asosiy magnit oqimi Φ o‘zgarishiga bog‘liq bo‘lib, rostlash qurilmasiga ega bo‘lmagan AG ning chiqish kuchlanishi va chastotasi qaysi yuklamagacha o‘zining nominal qiymatlarida o‘zgarishsiz qolishini quyida keltirilgan 2-rasmdagi T-simon almashtirish sxemasi asosida tahlil qilindi [4].



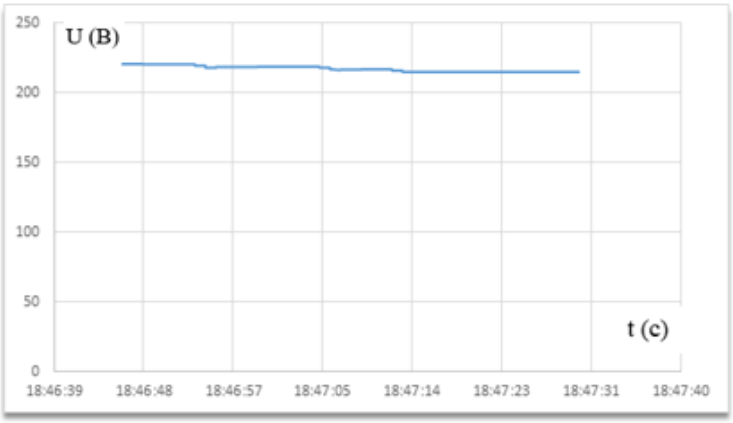
2-rasm. Nominal kuchlanishda qo‘zg‘atilgan AG almashtirish sxemasi
Fig.2. Nominal voltage induced AG replacement circuit

Ushbu sxemadan, AG aktiv yuklamasining oshishi sirpanish S ning ortishini, natijada rotor aktiv qarshiligi R_2 ni kamayib, rotor aktiv toki I'_{2A} ning oshishini, natijada stator aktiv toki I_{1A} ni oshishini keltirib chiqaradi. I_{1A} ning oshishi esa stator chulg‘amining aktiv va induktiv qarshiliklaridagi kuchlanish tushuvining oshishi hisobiga, aktiv yuklama va kondensator uchlaridagi kuchlanish U ni kamayishini keltirib chiqarib kondensator toki I_C ($I_C = \frac{U}{X_C}$) ni kamayishiga sababchi bo‘ladi. AG

yuklamasining nominal quvvatdan oshishiga almashtirish sxemasidagi barcha aktiv va induktiv qarshiliklar, jumladan stator aktiv va induktiv qarshiliklarining kamayishi mos keladi. AG ning almashtirish sxemasidan generatorga ulangan yuklamaga mos ravishda kondensatorlar sig‘imining avtomatik o‘zgarishi hisobiga yuklama uchidagi kuchlanishning barqaror saqlanishi ta’minlanadi [5].

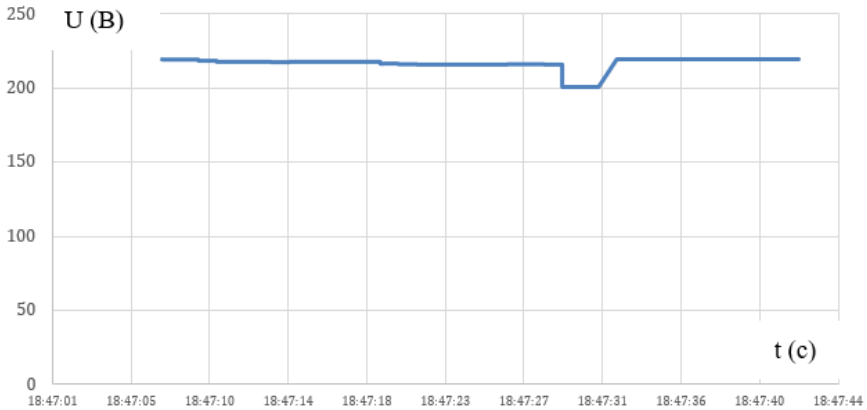
2- rasmda, dastlab 4 kW li, AG ni salt ishlash holatida ishga tushirilgandan so‘ng, AG ning chiqishiga hisoblash yo‘li bilan aniqlangan fazaviy sig‘im $C_{qo‘zg‘}$ =17 mkF ni ulash orqali chiquvchi fazaviy kuchlanishi U=220 V ga teng bo‘lgan holatda salt ishlayotgan AG ga 1,2 kW quvvatli aktiv yuklamalar ulanganda ham chiqish kuchlanishining deyarli o‘zgarmasdan qolishi ma’lum bo‘ldi.

3- rasmda, AG chiqishiga 4 kW gacha ortib boruvchi uch fazali aktiv yuklama ulanganda, chiqish kuchlanishi kontaktorlar va mikroprotsessordan iborat avtomatik rostlovchi qurilma hisobiga, o‘zining nominal qiymati darajasida barqaror qolishi ma’lum bo‘ldi. Ossillogrammadan, AG chiqishiga 3 kW yuklama ulanganda o‘sha faza kuchlanishining 3 sek davomida 200 V gacha tushib, kontaktorlar va mikroprotsessordan iborat avtomatik rostlovchi qurilma hisobiga qayta tiklanganligini ko‘rish mumkin [6].



2-rasm. C=17 mkF=const holatida qo‘zg‘atilgan AG ga quvvati 1,2 kW gacha bo‘lgan uch fazali aktiv yuklamalar ulangandagi chiqish kuchlanishining ossillogrammasi

Fig2. Oscillogram of the output voltage when connecting three-phase active loads with a power of up to 1,2 kW to an AG excited at C=17 μF=const.



3-rasm. RQARQ dan iborat avtomatik rostlovchi qurilmaga ega bo‘lgan AG ga 0,45 kW 0,9 kW va 3 kW aktiv quvvatli yuklamalar ketma-ket ulanganida chiqish kuchlanishining o‘zgarishi ossillogrammasi

Fig. 3. oscillogram of the change in output voltage when loads with an active power of 0.45 kW, 0.9 kW, and 3 kW are connected in series to an AG with an automatic regulation device consisting of an ARPRD.

Yuqoridagilardan, AG ning chiqishiga aktiv yuklama va turli yuklamali AD ulanganda ham chiquvchi kuchlanishning barqaror qolishining sababi, ular tomonidan talab etiladigan reaktiv quvvatning AG dan emas, balki ishchi kondensatordan uzatilishini ko‘rsatadi [7].

3. Natijalar va muhokama (Results and discussion)

Sanoatda ishlab chiqarilishi keng yo‘lga qo‘yilgan, kichik o‘lchamlardagi turli sig‘imli, arzon kondensatorlar batareyalaridan foydalanilgan holda, Qoraqalpoq davlat universiteti “Energetika

muhandisligi" kafedrasida, yig'ilgan reaktiv quvvatni avtomatik rostlash qurilmasi (RQARQ) dan AG chiqish kuchlanish rostlagichi sifatida tatbiq qilinishi, kontaktorlar va mikroprotsessordan iborat avtomatik rostlovchi qurilma yordamida qisqa tutashgan an'anaviy rotorli AG ning har qanday yuklamasida ham chiqish kuchlanishini nominal kuchlanish miqdorida o'zgarishsiz qolishi ta'minlandi [8].

4. Xulosa (Conclusion)

Xulosa shuki, sig'imi avtomatik rostlanuvchi kondensatorlar majmuasidan iborat RQARQ hisobiga AG yuklamasi miqdorlari har qanday o'zgarganida ham AG chiqishidagi kuchlanish miqdorining barqaror, nominal miqdorlarda o'zgarmasdan qolishi ta'minlanadi.

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